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Optimal Planning for Aurangabad Municipal Solid Waste through Mixed Integer Linear Programming

K. N. Chinchodkar[1] and Omprakash S. Jadhav[2]

[1]Research Scholar, Department of Statistics, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, India.

[2]Assistant Professor, Department of Statistics, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, India.

Abstract

Improper management of municipal solid waste causes hazards to inhabitants. Various studies reveal that about 90% of municipal solid waste is disposed of unscientifically in open dumps and landfills which creating problems to human being and the environment. A mixed integer linear programming method is used for treatment / disposal facility for a municipal solid waste. This paper reports on our findings in applying mixed integer linear programming approach for solving solid waste management problem in Aurangabad city with numerical illustration.

Keywords: Municipal solid waste, Treatment / disposal facility, Mixed integer linear programming, Optimization, LINGO 14.0 software.

INTRODUCTION

The rapid generation of solid waste due to economic development and population growth forces the management of municipal solid waste (MSW). It is one of the most critical environmental issues of India as well as all over the world. According to Central Pollution Control Board 144,165 TPD (Tons per day) of MSW was generated in India during 2013-14. Of the total waste generated, approximately 115,742 TPD (80%) of MSW was collected and only 32,871 TPD (22.8%) was treated. MSW generation rates are influenced by economic development, the degree of industrialization, public habits and local climate. In general a major fraction of urban MSW in India is organic matter (51%). Recyclables are 18% of the MSW and the rest 31% is inert waste [1].

Land filling is the simplest technique to handle waste in large quantity. Nevertheless, the degradation of valuable land resources and the creation of long-term environmental and human health problems arise as a result of ineffective management of waste. Sustainable and more capable waste treatment solutions are needed to reduce or replace the reliance on landfill. Among the various types of waste treatment methods biodegradable , material recycling and waste-to-energy (WTE) facilities are recognized as a promising alternative to overcome the waste generation problem as well as a potential source for reduce, revenue, reuse and renewable energy (RE) [2,3,4,5]. All these facilities are considered as an important and crucial factor for successful waste management as the concept includes all three factors for sustainable development: economy, environment and social [6].

In solid waste management (SWM) system, the problems are often arises like how to effectively determine which facilities should be developed, when they should be developed and at what capacity in order to achieve minimum system costs. These problems have been tackled using mixed integer linear programming (MILP). For example, Gordon Guo-He Huang (1997) [7] developed a MILP and simulation techniques for effective MSW capacity planning problem. S. T. Tan (2013) [8] discussed optimal planning of WTE using a combinatorial simulation and optimization model through MILP approach. Optimization results the selection and choice for power generation technology is driven by the cost efficiency factor and energy conversion of a technology. Steffen Wolfer et al. (2011) [9] proposed a MILP formulation for determining the physical configuration of a reverse logistics system for waste electric and electronic equipment (WEEE) in Chinese contexts. A different approach is adopted by S. Cheng et al. (2003) [10] who applied an integration of multi-criteria decision analysis (MCDA) and inexact MILP methods to support selection of an optimal landfill site and a waste-flow-allocation pattern such that the total system cost can be minimized. Erhan Erkut et al. (2006) [11] also presented a new multi-criteria MILP model to solve the location–allocation problem for MSW management at the regional level. Su Jing et al. (2009) [12] provide an interval-parameter two-stage chance-constraint MILP model is provided for supporting long-term planning of SWM in the city of Foshan, China. B. D. Xi et al. (2010) [13] formulated by integrating interval-parameter, mixed-integer and chance-constrained programming methods into a general framework and effectively dealing with multiple uncertainties associated with model parameters and constraints. Q. Tan et al. (2010) [14] presents a new attempt to address problems with dual uncertainties in both the objective function and constraints with the help of inexact fuzzy two-stage MILP.

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 or how the to overcome this situation [10].

Operations research (OR) is a mathematical or scientific analysis. Its application or its methods and techniques used in making decisions. OR is also used to optimize the utility of limited resources. The objective is to select the best alternative; that is, the one leading to the best result [15]. OR includes using mathematical programming models, linear programming models, integer programming models and binary integer programming model (bi-integer programming models) to optimize the solution.

Optimization approach for waste management have been developed since late 1960s with the overall objective to assist the decision making process in waste management for selection of the most cost efficient and environmentally sound approach under a specific scenario [16]. On the other hand, the optimization models can also be categorized based on the objectives of the optimization including transportation of waste, waste generation, modeling and selection of waste treatment technology [10]. A MILP method was developed for a MSW capacity planning problem, where a related optimization analysis will typically require the use of integer variables to indicate whether or not particular facility development or expansion options are to be undertaken. MILP is especially useful for this purpose. Thus, the objectives of this paper are

1) Formulate a MILP for the given MSW management system.
2) Optimize the present total system cost of considered time horizon.
3) To obtain the relevant flow allocation and facility development schemes.

OVERVIEW OF THE PROBLEM

The problem of waste collection and disposal are very challenging elements in waste management for most cities in the world. It leads to health problems and therefore calling upon all stakeholders in MSWM system to use appropriate strategies in curbing down the problem. The number of studies has been conducted to highlight the problem on SWM system [17]. The SWM system and description of mathematical models which have most inspired the development of models will be presented. These mathematical models include LP, mixed integer programming [18] and Heuristic method logistics, multiple regression analysis, multivariate statistical analysis (PCA, PLS-R, PLS-DA), reverse supply chain [19] etc. [20]. Generally, municipality is depends on an external landfill to satisfy waste disposal needs. Recently, an effective transportation method is suggest by [21] by using transportation problem approach. The city authorities, researchers wish to develop an integrated waste management system, which will potentially require the development of a centralized biodegradable facility, material recycling facility and WTE i.e. refused derived fuel (RDF) etc.

The biodegradable facility is for reducing organic wastes into a material suitable for use as soil fertilizer. The materials recycling facility will help to get recyclable materials from the generation points back to a production facility, where the recyclable materials are either used in the manufacturing of the same type of product, or a range of different products. It includes newspapers, fine paper, glass containers, steel cans and aluminum cans etc. WTE (RDF) has been used to reduce the bulk of solid waste and extract energy (by producing steam and / or electricity). In this facility unprocessed waste is burned. Generally, with very little front end removal of incombustible items (i.e. from recycling as well as biodegradable facility in some cases). However, there is problem of air pollutant emissions and ash disposal with WTE facility, which have caused significant technical and public-health concerns. But in the context of zero wastage we considered WTE facility with little beat capacity. Although, the materials not handled by all these mentioned facilities will routed to an external landfill with residue from WTE facility. External landfill is assumed to have no capacity constraints [7].

Three time periods are considered, with each of them having a time interval of five years. All facilities will be operated 365 days per year and per capita waste generation rate at year zero is 0.10-0.60 kg/capita/day in 2016 [8]. The capital budget expenditure on waste management facilities are limited by restrictions to INR $20*10^7$ (for 15 year) in any period [Aurangabad Municipal Corporation, Budget, (2017), Times of India April 30, 2017]. It is demonstrated that the MSW generation rates for this problem vary between different time periods, and the costs of operation and transportation also vary between different facilities and different time periods (Table 1 and 2). Therefore, the problem under consideration is how to effectively determine which facilities should be developed, when they should be developed and at what capacity in order to achieve minimum system costs. Taking RDF, Biodegradable and Recycling facilities considering residues from facilities [7].

METHODOLOGY

Data collection and method

The required data and different costs for different facility developments are taken from article of Gordon Guo-He Huang [7] and compares with daily waste generation of Aurangabad city. The different characterization and compositions of MSW are taken from report of Government of Maharashtra [1, 21].

A MILP method is considered to be a feasible approach for dealing with this problem and achieving optimal solutions.

Assumptions

1) Three facilities are considered for the present study viz. biodegradable facility, a material recycling facility and WTE with assuming the all facilities will either not developed or developed at some capacity level.
2) Three time periods are considered, with each of them having time interval of five years.
3) All facilities are operated 365 days per year.
4) Due to changes in MSW generation rates in different time periods, it is demonstrated that waste generation and different costs are increasing order.

Notations

i = 1, 2, 3, 4 for WTE, biodegradable, recycling and landfill facility respectively;

k = 1, 2, 3 for time periods 1, 2 and 3 respectively;

m = 1, 2 for development option for 1 and 2 respectively;

C_{ik} = is costs of waste transportation and operation for facility i in period k;

FC_{imk} = is capital costs for development capacity m at facility i in period k(INR);

ΔTC_{imk} = is development capacity m for facility i at the start of time period $k(t/d)$;

WG_k = is average waste generation rate during time period $k(t/d)$;

X_{ik} = is waste flow to facility i during time period $k(t/d)$;

Z_{imk} = is binary decision variable for development option m for facility i in time period k

Table 1: Facility development (FD) options for RDF/WTE, biodegradable & recycling facility (t/d) and their capital costs

Time periods		1	2	3
25% wastes are inert materials	ΔT_{11k}	50	50	50
	ΔT_{12k}	100	100	100
40% wastes are biodegradable	ΔT_{21k}	100	100	100
	ΔT_{22k}	200	200	200
20% wastes are recyclable	ΔT_{31k}	75	75	75
	ΔT_{32k}	150	150	150
Capital costs of RDF/WTE FD (10^7 Rs. Present value)	FC_{11k}	10	10	10
	FC_{12k}	19	19	19
Capital costs of biodegradable FD (10^7 Rs. Present value)	FC_{21k}	1.5	1.75	2
	FC_{22k}	3.75	4.4	5
Capital costs of Recycling FD (10^7 Rs. Present value)	FC_{31k}	6	7	8
	FC_{32k}	11.3	13.1	15

Table 2: Waste generation rates, transportation & operation costs

Time periods	1	2	3
Waste generation rate (t/d) WG_k	400	450	500
C_{1k}	50	55	60
C_{2k}	40	45	50
C_{3k}	35	40	45
C_{4k}	60	90	120

Where C_{ik} is the costs of transportation and operation for the RDF / WTE, biodegradable, recyclable and landfill facility (Rs/t); i = 1, 2, 3, 4 respectively.

Model application

An MILP model can be given in the following standard form,

$$Min\ f = C^T X \tag{1}$$

Subject to,

$$AX \le B, \tag{2}$$

$$x_j = binary\ variable, x_j \in X, j = 1,2,\dots,p(p < n) \tag{3}$$

$$x_j = continuous\ variable, x_j \in X, j = p+1, p+2,\dots,n \tag{4}$$

$$x_j \ge 0, j = 1,2,\dots,n \tag{5}$$

Where,

f is the objective function

$C^T = [c_1, c_2, \dots, c_n]$ is the transpose of set of objective coefficients,

$X^T = [x_1, x_2, \dots, x_n]$ is the transpose of set of decision variables,

$B^T = [b_1, b_2, \dots, b_m]$, is the set of requirement or availability of the i^{th} constraint,

$A = \{a_{ij}\}, \forall i = 1,2,\dots,m, j = 1,2,\dots,n$ is the set of $m \times n$ real matrix of coefficients

The decision variables in the MSW management system include two categories: continuous and binary variables. The continuous variables represent the flows of the MSW to the treatment and disposal facilities over the time horizon; and the binary solutions represent the treatment facility development decisions. The objective is to achieve the minimum system cost, and the relevant flow allocation and facility development schemes. The constraints include all of the relations between the decision variables and the waste generation-treatment restrictions. The detailed MILP model for the given problem is as follows,

$$Min\ f = \sum_{i=1}^{3}\sum_{m=1}^{2}\sum_{k=1}^{3} FC_{imk}Z_{imk} + 1825\left(\sum_{i=1}^{4}\sum_{k=1}^{3} C_{ik}X_{ik}\right) \qquad (6)$$

Subject to

$$\sum_{i=1}^{3}\sum_{m=1}^{2} FC_{imk}Z_{imk} \leq 20 \times 10^{6} \qquad \forall k \qquad (7)$$

(Budget expenditure constraints)

$$\sum_{i=1}^{4} X_{ik} = WG_k \qquad (8)$$

(Waste treatment / disposal demand constraints)

$$X_{ik} \leq \sum_{m=1}^{2}\sum_{k=1}^{3} \Delta TC_{imk}Z_{imk} \qquad i = 1,2,3;\ \ k = 1,2,3 \qquad (9)$$

(Facility capacity constraints)

$$X_{1k} \leq 0.25WG_k \qquad \forall k \qquad (10)$$

$$X_{2k} \leq 0.40WG_k \qquad \forall k \qquad (11)$$

$$X_{3k} \leq 0.20WG_k \qquad \forall k \qquad (12)$$

$$X_{4k} \leq 0.15WG_k \qquad \forall k \qquad (13)$$

(Inert, recyclable and biodegradable constraints)

$$X_{ik} \geq 0 \qquad \forall i,k \qquad (14)$$

(Non negativity constraints)

$$Z_{imk} = \begin{cases} \leq 1 \\ \geq 0 \end{cases} i = 1,2,3;\ \forall\, m,k \text{ and integer} \qquad (15)$$

(Non negativity and binary constraints)

$$\sum_{k=1}^{3} Z_{imk} \leq 1 \quad i = 1,2,3;\ \forall m \qquad (16)$$

(Each facility development may only be considered once)

RESULTS

Table 3 gives the optimal solutions obtained from the MILP model.

Table 3: Optimal solutions obtained through MILP model

Notations	Facility (*i*)	Capacity	Period (*k*)	Solutions
Z_{111}	WTE	1	1	0
Z_{112}	WTE	1	2	0
Z_{113}	WTE	1	3	0
Z_{121}	WTE	2	1	0
Z_{122}	WTE	2	2	0
Z_{123}	WTE	2	3	0
Z_{211}	Biodegradable	1	1	0
Z_{212}	Biodegradable	1	2	0
Z_{213}	Biodegradable	1	3	0
Z_{221}	Biodegradable	2	1	1
Z_{222}	Biodegradable	2	2	0
Z_{223}	Biodegradable	2	3	0
Z_{311}	Recycling	1	1	0
Z_{312}	Recycling	1	2	0
Z_{313}	Recycling	1	3	0
Z_{321}	Recycling	2	1	0
Z_{322}	Recycling	2	2	0
Z_{323}	Recycling	2	3	0
X_{11}	WTE		1	100
X_{12}	WTE		2	112.5
X_{13}	WTE		3	125
X_{21}	Biodegradable		1	160
X_{22}	Biodegradable		2	180
X_{23}	Biodegradable		3	200
X_{31}	Recycling		1	80
X_{32}	Recycling		2	90
X_{33}	Recycling		3	100
X_{41}	Landfill		1	60
X_{42}	Landfill		2	67.5
X_{43}	Landfill		3	75
System cost *f* (INR 10^7)				13.279

The optimal solution obtained through LINGO software. Where *f* is the objective function value. The result shows that all facilities should be developed at the start of period 1. The biodegradable facility should be developed by a capacity of 200 t/d, and the recycling facility should be developed by a capacity of 100 t/d whereas for WTE facility it should be developed by a capacity of 130 t/d. Though it costs higher and generates residues.

CONCLUSION

The results indicate that the developed biodegradable, recycling and WTE facilities are better choices of waste treatment than the only external landfill facility. A MILP method has been developed for the given MSW capacity planning problem. Three time periods are considered for present study, with each of them having a time interval of five years. The resulted MILP model then solved by LINGO software. Generally, for all periods, 40% of the generated waste flow should be routed to biodegradable facility, 20 % should be to the recycling facility, remaining 25 and 15% to the WTE and landfill facility respectively.

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