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Mathematical Modelling of Solid Waste Management in a Higher Educational Institution

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Abstract

In the present day scenario, in developing countries, solid waste management is declared as a dangerous issue. Population explosion, high standard of living, urbanization, lack of knowledge about management of waste etc. are the main cause of waste generation. An educational institution can play an important role in terms of waste management. It is observed that environmental studies is being introduced in all programs as a subject from lower primary up to higher level with the objectives to make concern everyone about their nature from childhood but it could not fulfill the objectives in deed. In this paper we propose a mathematical model using linear programming to manage the solid waste of an educational institution with minimum cost within the limited facilities there in.

Key words: Linear programming, Solid waste,Sensitivity analysis.

AMS CLASSIFICATION: 90C05, 90C31.

1. Introduction:

Waste is an unusable or unwanted product of different activities of human being. Due to growing population, rapid urbanization, changing life style etc. leads to increase of waste generation[13]. India, being the world's second most populous country, the level of urbanization in India has increased from 27.81% in 2001 to 31.16% in 2011 [15]. India is a developing country, where most people are aware of the negative impact of mismanaged wastes on the environment; their negative attitude along with lack of environmental knowledge among individuals usually leads to poor practices towards maintaining good environmental condition[9]. Also the people should be educated to realize the importance of source segregationat generation point as biodegradable, inert and recyclable material for proper waste management[8].

Institutions such as universities, colleges, hospitals etc. can play an important role in waste management. Environmental education should be included in the basic curriculum or certain course work of college students, to expand their knowledge and attitude towards improved practices on solid waste management[5]. Higher educational institution can be considered as small cities since they imitate city characteristics and their activities can produce similar environmental influences[3]. Educational institutions represent environmental degradation sources with a small direct influence on its quality[6]. To keep a healthy environment of an educational institute it is essential to manage of waste generated in the institute. Generally, the waste generated from different sources of an institute viz. laboratory waste, foodstuffs, plastic bottles etc are dumped in the premises of the institute. The dumped waste are then burned due to which various toxic gases containing carbon monoxide, nitrogen oxides are released in the atmosphere which are responsible for acid rain and contribute to global warming and ozone layer depletion. This leads to serious threats to human health and environment. Thus it becomes a major challenge in the educational institutes to find an optimal solution for management of waste. In solid waste management system, one main objective is to manage the waste with minimum cost. Our study aimed at developing a mathematical model to solve the problem of solid waste management in an educational institute.

2. *Literature Review :*

Anderson[1] was the first to propose a mathematical model to optimize the waste management system.Since then, several researchers have developed SWM models as decision support tools for technology selection, sitting and sizing of waste processing facilities. Alidi[2] had developed an integer goal programming model that takes into consideration the multiple goals and needs of many groups involved in managing and planning hazardous waste systems. The model can easily be implemented and can be used to address many of the issues related to facility location, recycling, treatment and disposal of hazardous wastes. Rawel *et al*.[12] proposed a VRP method that first minimized MSW collection vehicle routes. They compared two models—one integer-linear programming program where variables were the number of trucks and the other, mixed integer linear program where variables are the amount of waste actually transported. Daskapopoulos *et al*.[7] had proposed a linear programming model considering both economic and environmental costs. In this model, the optimal MSW flows to different types of treatment alternatives are determined by minimizing a linear cost function. Lyeme *et al*.[10] had proposed a multi objective optimization model in which objective function focused on minimizing the cost, environmental impact and final disposal to the landfill. The model follows a mixed integer programming formulation tested by data from selected wards in Dares Salaam city. In this paper the lexicographic goal programming technique is used to solve the formulated multi objective optimization model. To formulate location and routing problem for industrial hazardous waste, a multi objective mixed integer programming is proposed by Boyer *et al.*[4] considering two objectives, first objective is minimizing total cost and second objective is minimizing transportation cost. Shirazi *et al*.[14] had presented a novel linear programming model to determine the optimal status of the available system for Tehran's Solid Waste Management System. By using their model, they were able to optimize the transferring and processing units of solid waste in Tehran. Rathi[13] had developed a linear programming model to design an integrated waste management plan in Mumbai. She considered different economic and environmental cost associated with solid waste management while developing the model. In the model, community compost plants, mechanical aerobic compost plants and sanitary landfills were considered as waste processing or disposal options. Paul *et al*.[11] had developed a mathematical model for a municipal integrated SWM system. Their model serves as decision support tool to evaluate various waste management alternatives and obtain the least cost combination of technologies for handling, treatment and disposal of solid waste.

3. *Area of Study:*

During our literature survey it was observed that most of all higher educational institutions produced same types of solid waste. Therefore, this research work is carried out for solid waste management on the campus of a higher educational institution through mathematical model.We consider the campus of Jorhat Institute of Science and Technology, Assam, INDIA as the area of our study for the proposed model by managing the storage, collection, transportation, processing and waste disposal thereof.

The institution has tremendous potential to develop infrastructure in this respect to provide adequate facilities to the students as well as the faculty members to be an ideal institution through proper waste management in the campus.

4. *Data Collection :*

The purpose of this research articleis to design a waste management model for an educational institution with the help of linear programming for which wedefined anobjectivefunction subject to relevant constraints framed on the basis of collected data to develop our proposed mathematical model to manage solid waste with possible minimum costwhich will be discussed in section 5.

Type of solid waste generated at different sources of the Institute

Sl. No.	Source	Type of Waste
1	Physics Department	Plastic , Paper
2	Chemistry Department	Plastic , Paper, glass, ceramics
3	Mathematics Department	Plastic , Paper
4	InformationTechnology Department	Plastic , Paper
5	Electronic and Telecommunication Department	Plastic , Paper
6	Power Electronic and Instrumentation	Plastic , Paper
7	Civil Department	Plastic , Paper
8	Mechanical Department	Plastic , Paper,
9	Library	Plastic , Paper
10	Office	Plastic , Paper
11	Examination Cell	Plastic , Paper
12	Canteen	Food stuff, vegetables, paper, plastic, tin cans
13	Hostel	Food stuff, vegetables, paper, plastic
14	Staff Quarter	Food stuff, vegetables, paper, plastics, metals
15	Dispensary	Plastic, paper

The amount of waste generated in the institute is shown in the Fig. 4.1.

Fig. 4.1

5. *Formulation of Mathematical Model for Solid Waste Management :*

In this model we first identify the different sources and the different waste generated at these sources. We place two different bins at each source to categories them into biodegradable and non biodegradable waste .In our institution the major components of biodegradable waste consist of food waste and papers and that of non-biodegradable waste consist of plastics, tin, metals and ceramics. The biodegradable waste and the non biodegradable waste are then transported to composting plant and separation unit respectively. In the separation unit the non biodegradable waste are then classified into plastics, tin/metals and glass/ceramics. The plastic, tin/metals and glass/ceramics are then sold to scrap buyers for recycling. The remaining non recyclable waste are transported to the landfill for dumping. The compost formed in the composting unit are sold in the market and the waste remains in the composting plant are also transported to the landfill for dumping. The design of this solid waste management model is as follows:

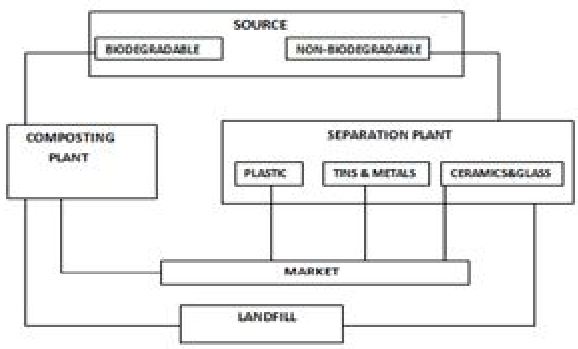

Fig. 5.1: Solid waste management model

Formulation of Mathematical Model :
Decision Variables :

WAB_{ip}: Amount of biodegradable waste per day transported from Source i to the composting plant p.

$WANB_{is}$: Amount of non- biodegradable waste per day transported from Source i to the separation unit s.

WCO_{p}: Amount of waste used for composting per day in the composting plant p.

$WCOM_p$: Amount of waste produced per day in the composting plant.

WPA_s : Amount of plastics separated per day in the separation unit.

WGL_s: Amount of glass/ceramics separated per day in the separation unit.

WME_s: Amount of tin/metals separated per day in the separation unit.

$WCOL_{pl}$: Amount of waste transported per day from composting plant *p* to landfill *l*.

$WSEL_{sl}$: Amount of waste transported per day from separation unit s to landfill *l*.

Parameters:

B_i **:** Amount of biodegradable wasteproduced per day in source i.

NB_i **:** Amount of non-biodegradable wasteproduced per day in source i.

$TWAB_{ip}$: Transportation cost of biodegradable waste per unit weight transported from Source i to the composting plant p.

$TWANB_{is}$: Transportation cost of non- biodegradable waste per unit weight transported from Source i to the separation unit s.

$TWCOL_{pl}$: Transportation cost of biodegradable waste per unit weight transported from composting plant p to landfill l.

$TWSEL_{sl}$: Transportation cost of non biodegradable waste per unit weight transported from separation unit s to the landfill l.

$PWCO_p$: Processing cost of biodegradable waste per unit weight in the composting plant p.

$PWSE_s$: Separation cost of non biodegradable waste per unit weight in the separation unit s.

$CCOP_p$: Capacity the composting plant per day.

CSE_s : Capacity of separation unit per day.

α = Fraction of biodegradable waste used for composting.

μ = Fraction of compost waste produced in composting.

β = Fraction of plastic waste present in non biodegradable waste.

$\gamma =$ Fraction of glass/ceramics waste present in non biodegradable waste.

δ = Fraction of tin/metals waste present in non biodegradable waste.

R_c: cost per unit weight of compost produced in the composting plant.

R_p: cost per unit weight of plastic collected in the Separation unit.

R_g: cost per unit weight of glass/ceramics collected in the separation unit.

R_m: cost per unit weight of tin/metals produced in the separation unit.

Objective Function :

To minimize cost of solid waste management system in the institute we define the objective function as follows:

$$Z = minimize(TC - TL)$$

Where

TC is the total cost incurred for waste

TL is the total revenue generated from the waste

Total cost is defined as:

$TC = Transportation\ cost + Composting\ \ Cost + Separation\ Cost$

Now for generalization of the problem let us consider that there are m sources, n composting plant, t separation units and k landfills in the area of study then we have

Transportation cost

$$= \sum_{i=1}^{m}\sum_{p=1}^{n} TWAB_{ip} \times WAB_{ip} + \sum_{i=1}^{m}\sum_{s=1}^{t} TWANB_{is} \times WANB_{is}$$

$$+ \sum_{p=1}^{n}\sum_{l=1}^{k} TWCOL_{pl} \times WCOL_{pl} + \sum_{s=1}^{t}\sum_{l=1}^{k} TWSEL_{sl} \times WSEL_{sl}$$

$$\textbf{Composting cost} = PWCO_p \times \sum_{p=1}^{n} WCO_p$$

$$\textbf{Separation Cost} = PWSE_s \times \sum_{i=1}^{m}\sum_{s=1}^{t} WANB_{is}$$

Also, the total revenue generated from the waste is given by

$$TL = R_c \times \sum_{p=1}^{n} WCOM_p + R_p \times \sum_{s=1}^{t} WPA_s + R_g \times \sum_{s=1}^{t} WGL_s + R_m \times \sum_{s=1}^{t} WME_s$$

Constraints :

$$\sum_{p=1}^{n} WAB_{ip} = B_i\ , \quad i = 1,2,3 \ldots\ldots..m \tag{1}$$

$$\sum_{s=1}^{t} WANB_{is} = NB_i, \quad i = 1,2,3 \ldots\ldots..m \tag{2}$$

$$\sum_{i=1}^{m} WAB_{ip} \leq COP_p, \qquad p = 1,2,3 \ldots \ldots .. \text{n} \tag{3}$$

$$\sum_{i=1}^{m} WANB_{is} \leq CSE_s, \qquad \text{s} = 1,2,3 \ldots \ldots .. \text{t} \tag{4}$$

$$\sum_{p=1}^{n} WCO_p = \alpha \sum_{p=1}^{n} \sum_{i=1}^{m} WAB_{ip} \tag{5}$$

$$\sum_{p=1}^{n} WCOMP_p = \mu * \sum_{p=1}^{n} WCO_p \tag{6}$$

$$\sum_{p=1}^{n} \sum_{l=1}^{k} WCOL_{pl} = (1-\alpha) \sum_{p=1}^{n} \sum_{i=1}^{m} WAB_{ip} \tag{7}$$

$$\sum_{s=1}^{t} WPA_s = \beta \sum_{i=1}^{m} \sum_{s=1}^{t} WANB_{is} \tag{8}$$

$$\sum_{s=1}^{t} WGL_s = \gamma \sum_{i=1}^{m} \sum_{s=1}^{t} WANB_{is} \tag{9}$$

$$\sum_{s=1}^{t} WME_s = \delta \sum_{i=1}^{m} \sum_{s=1}^{t} WANB_{is} \tag{10}$$

$$\sum_{s=1}^{t} \sum_{l=1}^{m} WSEL_{sl} = (1-\beta-\gamma-\delta) \sum_{i=1}^{i} \sum_{s=1}^{t} WANB_{is} \tag{11}$$

$$WAB_{ip}, WANB_{is}, WCO_p, WCOM_p, WPL_s, WGL_s, WME_s, WCOL_{pl}, WSEL_{sl} \geq 0 \tag{12}$$

Where, Equations (1),(2),(5)-(11) represent mass balanced constraints.
Equations (3) and (4) represent capacity limitations constraints.
Equations (12) represent non negativity restrictions.

Result and Discussions

Using a numerical example, we will illustrate how the model works in the proposed framework. We assume the following values of the parameters required for the model number of source m=11, number of composting plant n=1, numberof separating unit t=1 and number of landfill k=1

Table 6.1: Transportation cost of biodegradable waste per unit weight (per kg) transported from Source i to the composting plant p($\boldsymbol{TWAB_{ip}}$) and transportation cost of non- biodegradable waste from source i to separation unit s($\boldsymbol{TWANB_{is}}$)

SOURCE	$\boldsymbol{TWAB_{ip}}$ (in Rs)	$\boldsymbol{TWANB_{is}}$ (in Rs)
Departments	2	2
Library	2	2
Office	2	2
Examination cell	2	2
Canteen	2	2
Hostel 1	3	3
Hostel 2	3	3
Hostel 3	3	3
Hostel 4	3	3
Staff quarters	3	3
Dispensary	2	2

Table 6.2: Amount of biodegradable and non biodegradable waste produced in sourcei

Source	1	2	3	4	5	6	7	8	9	10	11	**Total waste**(in Kg)
$\boldsymbol{B_i}$ (in Kg)	2	2	5	3	20	16	15	17	20	16	4	120
$\boldsymbol{NB_i}$ (in Kg)	6	2	2	1	12	10	11	15	10	10	1	80

Value of Parameters :

$TWCOL_{pl}$ = Rs 2 per Kg, $TWSEL_{sl}$ = Rs 2 per Kg, $PWCO_p$ = Rs 3 per Kg, $PWSE_s$ = Rs 2 per Kg, $CCOP_p$ = 200 Kg per Day, CSE_s = 200 Kg per Day

α=3/4 , β=1/2 , γ=1/8 , δ=1/8 , μ=1/3

R_c = Rs 20 per kg , R_p = Rs 2 per kg, R_g = Rs 2 per kg , R_m = Rs 4 per kg

Using Lingo 18.0 Software we solve the above linear programming problem and the least total cost for managing the waste of the Institute is obtained as Rs 420 per day.

7. Sensitivity Analysis :

Analysis of transportation cost, separation cost and processing cost in composting plant:

Percentage change	20% decrease	10% decrease	10% increase	20% increase
Total cost (in Rs) due to % change in transportation cost	292	356	484	548
Total cost (in Rs) due to % change in Composting cost.	348	384	456	492
Total cost (in Rs) due to % change in separation cost.	388	404	436	452

We perform the sensitivity analysis by increasing and decreasing the transportation cost. If we increase the transportation cost by 10% and 20% then the total cost of managing waste is increase by 15.23% and 30.48% respectively. Again if we decrease the transportation cost by 10% and 20% then the total cost of managing waste decrease by 15.23% and 30.48% respectively. The sensitivity analysis is done by increasing and decreasing the processing cost in composting plant. If we increase the processing cost by 10% and 20% then the total cost of managing waste is increase by 8.57% and17.14 % respectively. Again if we decrease the processing cost by 10% and 20% then the total cost of managing waste decrease by 8.57% and 17.14% respectively. Again we perform the sensitivity analysis by increasing and decreasing the separation cost. If we increase the separation cost by 10% and 20% then the total cost of managing waste is increase by 3.8% and 7.62% respectively. if we decrease the separation cost by 10% and 20% then the total cost of managing waste decrease by 3.8% and 7.62% respectively.

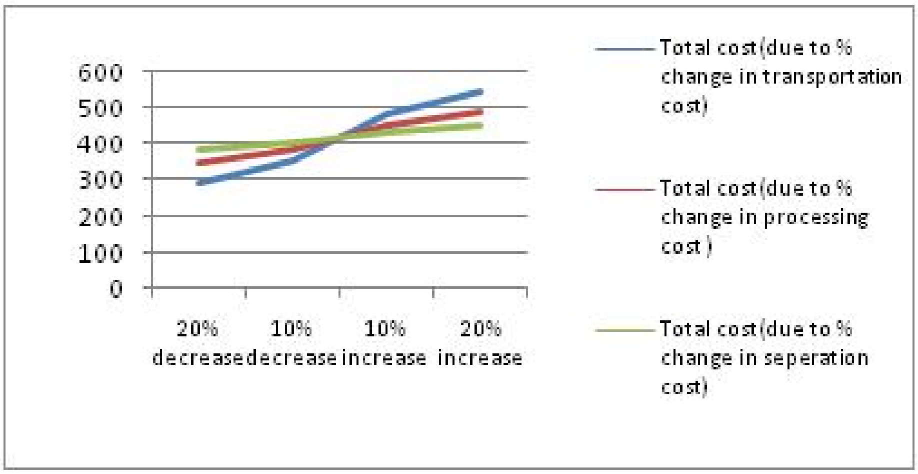

Fig.7.1: Analysis of total cost

8. Conclusion

In this paper, we discussed a model to minimize the total cost for managing waste in an educational institution with the help of linear programming techniques andwe also discussed different scenarios which affect the total cost. Finally it was proved that every institution can manage their waste with minimum cost and limited facilities therein using this model.

Scope of Future Research and Applications :

During our study it was observed that various researches had been carried out in this field which implies the importance and potential of the subject. There is tremendous scope of research in this area for the interest of this civilization. This model may be applied each institution to manage their solid waste products with minimum cost and limited facilities in the institute as stated above.

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