Optimization model for Solid Waste Management at Ilala Municipal

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Abstract—The existing solid waste management system at Ilala Municipal suffers from the lack of a real plan for collection centre locations and vehicle routes. In this study, a proposed mathematical model for municipal solid waste management process for Ilala municipality is presented. It includes the use of the concept of collection centres. Operational research methodology particularly Mixed Integer Programming is used to model the problem. The problem is solved to optimality which provides the best distribution of collection centres and their capacities. The solution shows a least-cost transportation plan with a cost saving of 38.3% per day compared to the current system.

Keywords— Solid Waste Management, Mathematical programming, Combinatorial Optimization.

I. INTRODUCTION

Solid waste collection is one of the most difficult operational problems faced by most cities in the world. In Tanzanian cities, solid waste collection plans are decided from personal experience without any optimization tools, which is prone to inefficiencies and high consumption of municipal revenues.

This study aims at formulating a mathematical model for municipal solid waste management process for Ilala municipality. The model will be used to propose the best collection centre locations for solid waste in Ilala in order to minimize the transportation cost of the municipal solid waste management process. Collection and transportation of solid waste often accounts for a substantial percentage of the total waste management budget (including labour costs). The figure can reach over 70%, depending on geographical location and fuel price [1,2].

Various mathematical models with different objectives for Solid Waste Management (SWM) systems have been proposed. Hsieh and Ho [3] presented a linear programming model to analyze a Solid Waste Management system. The objective function was to minimize the present value of collection, recycling, treatment and disposal costs. They included mass flow and capacity constraints. The model analyzes very simplified SWM systems with a small amount of management options.

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Movassaghi [4] asserts an LP model for a regionally based Refuse-To-Energy (RTE) facility consisting of incineration with steam recovery. The objective function was to minimize collection, transfer, RTE treatment and disposal costs. Mass flow and capacity constraints were included to exclusively drive waste flows based on end-user demands of the generated steam.

Cordeau et al [5] and Simonetto and Borenstein [6] investigated route optimization. They use operational research methodologies to develop computer tools for vehicle routing optimization.

In the study done by Rathi [7], a linear programming method was used to develop an optimization model for municipal solid waste management in Mumbai and further considered various economic and environmental costs associated with municipal solid waste management.

Daskalopoulos et al [8] presented a mixed integer linear programming model for the management of MSW streams, taking into account their rates and compositions, as well as their adverse environmental impacts. Using this model, they identify the optimal combination of technologies for handling, treatment and disposal of MSW in a better economical and more environmentally sustainable way. The model has been applied to the management of MSW in the UK. The findings have revealed that the current costs favour the landfill option of managing the MSW.

Fiorucci et al [9] developed a mixed integer nonlinear programming decision support model for assisting planners in decisions regarding the overall management of solid waste at a municipal level. By using that model, an optimal number of landfills and treatment plants, optimal quantities and the characteristics of refuse that have to be sent to treatment plants, to landfills and to recycling can be determined. Various classes of constraints are considered in the problem formulation, considering the regulations about the minimum requirements for recycling, incineration process requirements, sanitary landfill conservation, and mass balance. The objective function is composed of recycling, transportation and maintenance costs.

Costi et al [10] in their study done in the municipality of Genova, Italy, proposed a mixed integer nonlinear programming decision support model to help decision makers of a municipality in the development of incineration, disposal, treatment, and recycling integrated programs. In that model several treatment plants and facilities have been considered: separators, plants for producing Refuse Derived Fuel (RDF), incinerators with energy recovery, plants for treatment of

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organic material, and sanitary landfills. The main objective of that model is to plan the municipal solid waste management, define the refuse flow that has to be sent to recycling or to different treatment or disposal landfills, and to determine the optimal number, the kinds, and the localization of the plants that are to be active. Some of the decision variables in the model are binary while others are continuous. The objective consists of all possible economic costs and subjected to technical, regulatory (normative), and environmental constraints. In particular, pollution and impacts induced by the overall solid waste management system are considered through the formalization of constraints on incineration, emissions and on negative effects produced by disposal or other forms of treatments like RDF chemical composition.

Badran and El-Haggar [11] studied Optimization of solid waste management systems using operational research methodologies. They proposed a model for a municipal solid waste management system in Port Said - Egypt which includes the use of the concept of collection stations. Mixed integer programming is used to model the proposed system and its solution is performed using MPL software V4.2. The results show that the best model would include 27 collection stations of 15-ton daily capacity and 2 collection stations of 10 ton daily capacity.

Gizem et al [12], conducted research which involved the design of the supply chain network for industrial waste collection. The problem was to transport metal waste from factories to containers and from containers to Disposal Centre (DC) at an organized region of automobile parts suppliers. They applied the classic Mixed-Integer Programming (MIP) model for the two- stage supply chain to the solution of their problem.

Nganda [13] developed two mathematical models as tools for solid waste planners in decisions concerning the overall management of solid waste in a municipality. The models have respectively been formulated as integer and mixed integer linear programming problems. The choice between the two models from the practical point of view depends on the user and the technology used. One user may prefer to measure the transportation costs in terms of costs per trip made from the waste source, in which case the first model is more appropriate. In this case, the coefficients of the decision variables in the objective function are replaced with the total cost per trip from the waste collection point. At the same time, instead of measuring the amount of waste using the number of trucks used multiplied by their capacities, continuous variables are introduced to measure directly the amount of waste that goes to the plants and landfills. The integer linear problem is then transformed into a mixed integer problem that gives better total cost estimates and more precise waste amount measurements, but measuring transportation costs in terms of costs per trip. Many variants of the MSW management problem exist. For instance, Hasit and Warner [14] applied both linear programming (LP) and Mixed Integer Programming (MIP) techniques to the Waste Resource Allocation Program (WRAP) model which is a variant of MSW.

These models were both developed for specific problems which vary between municipals of different countries. This paper focuses on the MSW management problem for Ilala Municipal Council in the commercial city of Dar es salaam. The council is faced with unique challenges which mostly stem from limited resource availability, limited solid waste disposal techniques and challenges associated with city plans.

II. Solid Waste Collection Situation In Dar Es Salaam

Dar es Salaam is the commercial capital city of Tanzania, situated along the Indian Ocean. It covers an area of 1,393 km^2 and has a population of more than 3.4 million people or 25% of the total urban population in Tanzania [15]. Politically and administratively, the city is divided into three districts of Kinondoni, Ilala and Temeke. The City Council and the three Municipalities have for many years been confronted by growing volumes of solid waste and the inadequate provisions for its removal and disposal.

In principle, waste management is the responsibility of Local Authorities. Solid waste collection and disposal is administered through city cleansing section, which is a subsection of the City Health Department in the three municipalities of Ilala, Kinondoni and Temeke and private contractors [16]. The franchise type of privatization was adopted according to the experiences gained in the past in the city. Under this arrangement a private contractor is given a finite-term zonal monopoly for delivery of solid waste management service, after a competitive pre-qualification process. The private contractor recovers its cost through Direct User Charge (DUC) levied on the service beneficiaries according to rates set by the city council and the three municipalities [16].

The system of collecting waste is mainly door-to-door in high income areas. In low-income areas, where most settlements are not planned, the main collection system used is communal; in this regard households dispose waste in enclosures located along roadside [15]. Door to-door collection is partly practiced whereby handcarts are used to dispose the waste either at the contractor's collection points or at the municipal collection points [15]. Ilala municipality collects 97.1 ton/day of solid waste which is 4% of the total waste generated in the city, while Kinondoni and Temeke collect 3.9% and 1.6%, respectively [15]. Thus the solid waste collection by the three city municipalities is less than 10% of the total waste generated, while solid collection by solid waste collection private contractors is 24.4% and collection through recycling is approximated to 5.5% of the total waste generated in the city [15]. Therefore, about 60% remain uncollected.

TABLE I:
SOURCE OF SOLID WASTE IN TON PER DAY IN ILALA MUNICIPALITY

Sources	Generation(ton/ day)
Household	725
Street Sweeping	10
Commercial	190
Institutional	9
Hospitals	90
Others	64
Total	1088

Source: Ilala Municipal Health and Cleansing Department, 2009

The city of Dar es Salaam is currently using only one dump site at an area known as Pugu Kinyamwezi. This site is projected to serve the city for ten years and all wastes from Ilala municipality are collected and deposited at this site. The amount of solid waste generated in Ilala municipality is given in TABLE I. The distance of this dump site is about 26 km from the city centre [17].

Furthermore, Ilala municipality has only two collection centres to accommodate all generated wastes. This is presumed to increase transportation cost. One of the challenges is to determine the number of collection centres which would minimize overall costs.

III. PROPOSED MODEL FOR ILALA SOLID WASTE MOVEMENT

The proposed model is formulated by taking into consideration the waste flow in Ilala municipality. A schematic diagram of the waste flow through the different facilities of the proposed MSW management in Ilala municipality is as shown in figure 1. The residential, commercial and municipal service sources will dispose their waste in the collection bins located in front of their premises. Collection wagons are responsible for transferring the waste from the waste bins to the collection centres. A transfer vehicle will be responsible for waste transfer from the collection centres to the landfill. Landfill can also be used for direct delivery of waste from residential premises when they are closer to the landfill. Since the effect of recycling is very minimal, this paper only considers the relationships between

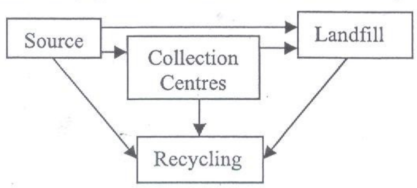

Fig. 1 Schematic diagram of solid waste flow

collection centres and landfill.

A. Objective function

The study revealed that in Ilala municipality all solid waste are either buried or burnt at the landfill, unlike other municipalities in which some waste are decomposed or recycled. Hence we need to minimize the cost of transporting waste from their sources to landfill through collection centres. Consequently, the objective of the model is to select between the different potential sites for collection centres in order to minimize the transportation cost of the municipal solid waste. The transportation costs and fixed costs of the facilities is minimized by the mixed integer model.

B. Decision Variables

There are several decision variables considered in this study and are defined as follows;

x_{ji} = amount (in ton) of daily solid waste to be removed from source i to collection centre j *(i= 1,...., I and j=1,...,J).*

y_{jk} = amount (in ton) of daily solid waste to be removed from collection centre j to landfill k *(j= 1,.....,J and k=1,...,K).*

q_j = a variable which can take a value of one or zero. It takes the value one if a collection centre is to be set up at the location j and zero otherwise *(j= 1,...., J).*

C. Parameters

The developed model uses the following parameters.

C_j = daily capacity of the collection centre j.

L_k = daily capacity of the landfill k.

W_i = amount of daily waste generated at source i.

F_j = fixed cost of the collection centre represented as daily fixed cost.

T_{jk}= transportation cost of one ton of waste from the collection centre j to the landfill k *(j=1,...,J: k=1,....,K)*

T_{ij} = transportation cost of one ton of waste from the source i to the collection centre j *(i=1,...,I: j=1,....,J)*

N = the maximum number of collection centres.

Note that, landfill is included in the list of collection centres whose distance to itself zero. This takes care of the fact that, landfill can also be used for direct delivery.

D. Mathematical Formulation

The formulated model is as follows;

$$Min\ Z(q,x,y) = \sum_{j=1}^{J} F_j q_j + \sum_{i=1}^{I}\sum_{j=1}^{J} T_{ij} x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} T_{jk} y_{jk} \quad (4)$$

Subject to the constraints

$$\sum_{j=1}^{J} x_{ij} = w_i, \quad i = 1,...I \quad (5)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} = \sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk} \quad (6)$$

$$\sum_{j=1}^{J} x_{ij} \le C_j, \quad j = 1,...J \quad (7)$$

$$\sum_{j=1}^{J} y_{jk} \le L_k, \quad k = 1,...K \quad (8)$$

$$\sum_{j=1}^{J} Q_j \le N \quad (9)$$

$$\sum_{j=1}^{J} C_j q_j \ge \sum_{i=1}^{I} W_i \quad (10)$$

And non-negativity constraints

$$x_{ij} \ge 0, y_{jk} \ge 0, \quad i = 1,...I; j = 1,...J \quad (11)$$

$$k = 1,...K$$

Equation (4) is the cost objective function, which is the sum of daily fixed cost of running the selected collection centres, transportation cost from streets to the collection centres, and transportation cost from the collection centres to landfills, respectively. Equation (5) ensures that all solid waste from each street are collected. Equation (6) guarantees that no solid waste remains at any collection centre. Inequality (7) ensures that the total waste sent to a collection centre does not exceed the centre capacity. Similarly, inequality (8) guarantees that waste sent to a landfill does not exceed the capacity of the landfill. Inequality (9) makes sure that the total number of selected collection centres does not exceed the maximum number of collection centres required. Inequality (10) ensures that the selected collection centres are big enough to take all solid waste generated from all streets.

TABLE II
RESULTS FOR DIFFERENT CASES WHEN CAPACITY IS FIXED

Case	Capacity in Tons	Collection Centres Required	Transportation Cost in Tsh
a1	100	12	11,484,816
a2	150	10	10,604,389
a3	200	7	10,012,342
a4	250	7	9,632,471
a5	300	7	9,374,165
a6	350	7	9,167,221

IV. SUMMARY OF RESULTS

The developed model was solved using GNU Linear Programming Kit (GLPK). The GNU Linear Programming Kit (GLPK) is a software package intended for solving large-scale linear programming (LP), Mixed Integer Programming (MIP), and other related problems [18].

TABLE III
RESULTS FOR DIFFERENT CASES WHEN COLLECTION CENTRES ARE FIXED

Case	Collection Centres Required	Transportation Cost in Tsh
b1	2	8,797,477
b2	4	8,703,577
b3	5	8,649,154
b4	6	8,627,669
b5	8	8,627,669
b6	11	8,627,669

In generating the results we considered two cases; A (when capacity is fixed) and B (when number of collection centres is fixed), where the maximum capacity of collection centres are 100, 150, 200, 250, 300 and 350 tons. The criterion for choosing the collection centre is minimum transportation cost. The solution of the model takes 0.1 seconds. The model consists 205 rows, 924 columns, 7150 non-zeros and 22 binary. Table II: and TABLE III summarises the results obtained for fixed capacity and fixed collection centres respectively.

The values of the objective function of the two cases A and B are as shown in Figure 2 and Figure 3 respectively. As it can be seen, the best solution is case b4 where the amount of

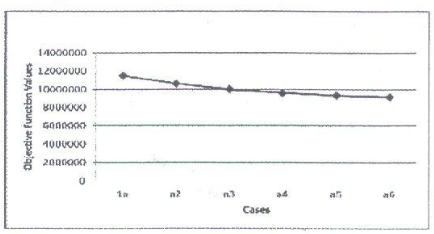

Fig. 2 Objective Function Value for Various Capacities

waste flow from each source to the proposed collection centres is as shown in TABLE IV: The objective function of the best solution has a total value of Tsh. 8,627,669 per day. The total number of collection centres is 6, where 1 of them have 343 tons per day capacity, 1 of them has 341 tons per day capacity, 1 of them has 301 tons per day capacity, another

TABLE IV
WASTE FLOW AMOUNT FROM EACH SOURCE TO THE PROPOSED COLLECTION CENTRE FOR CASE B4

Street	Collection Centres	Tons	Street	Collection Centres	Tons	Street
Malapa	P/Kinyamwezi	30	Mnyamani	P/Kinyamwezi	25	Malapa
Amana	P/Kinyamwezi	26	Bungoni	P/Kinyamwezi	24	Amana
Mchikichini	Pugu	25	Chanika	Pugu	27	Mchikichin
Kinyerezi	Kinyerezi	26	Airport	P/Kinyamwezi	30	Kinyerezi
Sitakishari	Pugu	29	Kipunguni	Pugu	26	Sitakishari
Yangeyange	P/Kinyamwezi	25	P\kajiungeni	P/Kinyamwezi	25	Yangeyang
Segerea	P/Kinyamwezi	26	Chang'ombe	P/Kinyamwezi	31	Segerea
Kimanga	Ukonga	30	Bima	Kiwalani	28	Kimanga
Madafu	P/Kinyamwezi	28	G\lamboto	Pugu	28	Madafu
Kichangani	Ukonga	27	Mtakuja	Kinyerezi	32	Kichangani
Miembeni	Ukonga	27	Lindi	Kinyerezi	14	Miembeni
Lindi	Ukonga	16	Cleist	Chanika	29	Lindi
Nkuruma	Pugu	30	Mafia	Pugu	23	Nkuruma
Swahili	Pugu	28	Uhuru	Pugu	30	Swahili
Kisutu	Pugu	28	I\Ghandi	Pugu	27	Kisutu
Kivukoni	P/Kinyamwezi	24	S\Robert	P/Kinyamwezi	23	Kivukoni
Samora	Ukonga	27	Kigilagila	Ukonga	28	Samora
Yombo	Ukonga	30	Aggrey	Ukonga	25	Yombo
Mshihiri	Ukonga	30	PPF Tower	Ukonga	25	Mshihiri
Arnautoglo	Ukonga	25	Muhimbili	Ukonga	27	Arnautoglo
Allykhani	Ukonga	25				Allykhani
				Total	1088	

1 of them has 46 tons per day capacity and 2 of them has 29 and 28 tons per day capacity respectively. Furthermore, the study shows that any additional increase of the collection centres above 6 will not improve anything since the objective function remains constant (TABLE III). The results were verified by back substitution of the result into the constraints to check if any constraint had been violated.

A review of validity of solution of the model shows that the study results minimize transportation cost. Clearly, the solution of the developed model can be applied in other municipalities in Tanzania, subject to addressing challenges of unplanned settlements which differs from one municipal to another.

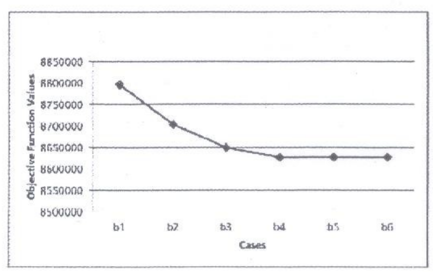

Fig. 3 Objective Function Value for Various Values of N.

V. CONCLUSION

In this paper, municipal solid waste management in Ilala municipality is modelled with the concept of having collection centres. The model is solved using GNU Linear Programming Kit (GLPK) software for Linux. The developed model provides a least transportation cost of Tsh. 8,627,669 per day compared with the one given by Ilala municipality of Tsh.

14,000,000 per day, a cost saving of 38.3%. Furthermore, the study shows that any additional increase in collection centres above 6 will be counter-productive as the objective function remains constant (see TABLE III and Figure 3).

VI. FUTURE RESEARCH DIRECTIONS

An important area for future research is to include the environmental impacts such as air pollution or noise pollution as well as recycling and composting plant in formulation of the model. Since the whole city of Dar es salaam uses the same landfill, extension of the model to cover the city will give better picture of possible further cost saving. The extension may result into a large problem which may require heuristic techniques for their solutions. Looking at the vast number of variables, parameters and variants of the problem, development of a Decision Support System (DSS) is another area of further research.

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