Use of Mathematical Modelling for Planning Municipal Solid Waste Collection

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Abstract

When people hear the term "Solid waste management" they immediately think of recycling. But it is not the aspect that requires the greatest expenditure, or has the greatest impact on the urban environment and public health. It is the "collection" of municipal solid waste that has a significant impact on both municipal expenditure and public health.

The decisions pertaining to solid waste collection and transportation are basically based on the perception and experience of drivers and other minor staff working at the municipalities. The optimum utilization of available resources within the municipalities for day to day collection of waste is essential as it makes the biggest demand on the Municipal budget.

Therefore the main objective of this research is to develop a mathematical model as a tool for decision making in municipal solid waste collection. This research has utilized two mathematical models known as "Network Analysis" and "Transportation problem method" to achieve the aforementioned objective.

The case study of this research is based on the proposed project of implementing three Integrated Resource Recovery Centres (IRRC) in the Matale Municipal Council (MC) to manage the solid waste by means of producing compost and recycling. By applying the two mathematical models, the research has shown the possibility of reducing the daily solid waste collection cost within the Matale MC Area.

Keywords: Solid Waste Collection, Network Analysis, Transportation Problem Method

1.0. Introduction

Cost analyzed by Ludwig and Black (1968) reveal that 85% of the solid waste system cost is due to collection, and only 15% to disposal. Therefore there is an increasing demand for greater efficiency, so as to minimize the solid waste collection costs, while providing an adequate and regular service to all of the target area.

This research is based on a proposed project of establishing three Integrated Resource Recovery Centres (IRRCs) at Matale Municipal Council (MC) for the purpose of Municipal Solid Waste (MSW) Management. IRRC is the place where the collected solid waste is further managed to produce compost and recycled. Therefore applying mathematical models to solid waste collection can lead to a significant saving in the overall cost, once the project is implemented. The collection system proposed through this research is based on solid waste collection points, road network, location of Integrated Resources Recovery Centres (IRRCs), capacity of the tractors and the population in the area under study.

First, the theoretical and methodological aspect of Municipal Solid Waste Collection, mathematical models and several past case studies of application of mathematical models in planning municipal solid waste collection, were reviewed. Thereafter two mathematical models were introduced and applied for Matale MC Area to plan activities pertaining to solid waste collection in a cost effective manner.

2.0 Case Study

The case study of this research is based on the proposed project of implementing three Integrated Resource Recovery Centres (IRRC) in Matale Municipal Council (MC), to manage the solid waste by means of producing compost and recycling. The Matale MC Area, generates 21 tons of waste from its residential and non-residential establishments daily. At present, there are four major waste management partners in the city i.e. Matale Municipal Council (17 tons per day), Matale Enrich Compost (MEC) Pvt. Ltd (01 ton per day), Informal Sector collectors (02 ton per day) and individual households (01 ton per day).
However, the Matale Municipality dumps 17 tons of waste into an open land fill daily, which has created serious environmental and social issues to the entire Matala City. By contrast, MEC Pvt. Ltd. manages 1 ton of waste daily, in an Integrated Resource Recovery Centre (IRRC), through composting and processing & selling recyclables. In this context, the Matale Municipality has identified IRRC as a suitable option to manage all the generated waste in its municipal council area through Cleaner Development Mechanisms (CDMs) and Private Public Partnership engagement. This will include capacity improvement of existing two IRRCs up to 15 tons per day (Dola Road IRRC – 5 tons, MC Road IRRC – 10 tons) and building up a new IRRC (Parawaththa IRRC) with 03 tons per day capacity with a Resources Centre.
The above improvement will enable Matale Municipal Council to manage 18 tons of waste daily under the Resource Recovery in Matale city project, which would be sufficient to handle the waste collection, transportation and disposal of the city for the next decade.

3.0 Problem Statement

Most of the time in Sri Lanka, solid waste collection is handled by the public sector especially through Municipal or Urban Councils, rather than through the private sector. Compared to the private sector, decisions taken by the public sector is more vague and difficult to express formally as most of the decisions are political and social in nature. As they do not seek to minimize the cost of operation subject to explicit constraints, it is hard to measure the effectiveness of such decisions. In this circumstance, this research is focusing on applying mathematical models as a tool for decision making in solid waste collection, in order to achieve the desired level of service at minimum cost.

Currently the Matale MC collects solid waste by means of tractors, compactors and handcarts that go from house to house. People use handcarts to collect solid waste from houses which are located adjacent to narrow roads, as solid waste collection vehicles cannot travel. The solid waste collecting route is decided by the drivers based on their perception and experience.

According to the data shown in Table 1, Matale MC annually incurs nearly 90% of its solid waste management expenditure on collection and transportation of solid waste. Currently, solid waste is collected from three out of thirteen the wards that belong to Matale MC Area as shown in Table 3.

Table 1: Municipal annual budget on solid waste management

Stage	Annual Expenditure Breakdown (in Rupees)					
	2008	%	2009	%	2010	%
Collection	8,872,066	53	14,936,860	50	15,338,815	50
Transport	5,979,436	36	12,715,314	42	13,057,486	42
Recycling	70,852	0	63,312	0	65,016	0
Disposal	951,937	6	1,526,528	5	1,567,608	5
Miscellaneous	872,769	5	679,782	2	698,075	2
Total Expenditure	**16,747,061**		**29,921,797**		**30,727,000**	

Source: Feasibility Study on Resource Recovery Options for Matale MC Area, 2010

Table 2 shows the cost structure for make 1 kg of compost at the feasible break-even point. Accordingly to produce 1 kg of compost, nearly 18% is incurred for fuel cost on collection of solid waste.

Table 2: Cost structure at feasible break-even point

Expenses	Electricity (Rs.)	Water Charges (Rs.)	Telephone charges (Rs.)	Salaries & Allowances (Rs.)	Others (Rs.)	Fuel Cost (Rs.)	Office Expenses (Rs.)	**Total Expenses (Rs.)**
Avg. Cost (Rs) per collect, transport and make 1kg compost	0.17	2.00	0.41	8.85	1.17	3.00	1.17	**16.77**

Source: Business plan for Resource recovery in Matale city project 2011 – 2015

Hence, applying mathematical models to solid waste collection, where there is a possibility to reduce the overall expenditure in solid waste collection in a meaningful way, is critical.

4.0 Objectives

The objectives of this research are to identify the most cost effective plan to collect solid waste by;

- Finding the best locations to collect solid waste generated in each zone
- Finding the shortest route from solid waste collection location to IRR center
- Finding the optimum allocation of solid waste to IRR centers considering the supply of the solid waste collection location and demand of the IRR center.

5.0. Literature Review

5.1.Solid Waste Management

There has been a rapid increase in the volume of MSW, due to continuous economic growth, urbanization and industrialization. It is becoming a burning problem for national and local governments to ensure effective and sustainable waste management. It is estimated that in 2006 the total amount of MSW generated globally reached 2.02 billion tones. This problem is aggravated in Sri Lanka as well, due to the absence of a proper solid waste management system in the country.

Solid Waste Management (SWM) is an integral part of the urban environment, and planning of the urban infrastructure in a way that ensures a safe and healthy human environment while considering the promotion of sustainable economic growth. The main aim of SWM system is to ensure human health and safety, as well as to be environmentally effective, economically affordable and socially acceptable. Municipal solid waste management (MSWM) is a complex task which depends as much upon organization and cooperation between households, communities, private enterprises and municipal authorities as it does upon the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal (Schubeler, 1996). Municipal solid waste management (MSWM) encompasses planning, engineering, organization, administration, financial and legal aspects of activities associated with generation, storage, collection, transfer and transport, processing and disposal of municipal solid wastes (household garbage and rubbish, street sweepings, construction debris, sanitation residues etc.) in an environmentally compatible manner adopting principles of economy, aesthetics, energy and conservation (Tchobanoglous et al, 1993). This study will focus on the planning aspect of activities associated with waste collection and transportation in a cost effective manner.

5.2.Waste Collection & Transportation

Waste collection is the act of picking up wastes from homes, businesses, institutions, commercial and industrial plants and other locations and loading waste into a collection vehicle and hauling them to a facility for further processing or transfer to a disposal site (Technical Guidelines on Solid Waste Management in Sri Lanka, Central Environmental Authority).Waste collection depends on the amount of waste generated in each area. Shaida, M.N.(2011)has identified that waste generation differs from place to place to a great extent, since its production and composition are influenced by the consumption pattern, climate, season, cultural practice, population density, lifestyle of the people, technological development, etc.

Korner, et. al.(2009) has identified significant criteria which should be encompassed with municipal solid waste transportation. Some of these criteria include, heavily travelled roads should not be served or used during rush hours, collection paths should not overlap and the availability of fully covered collection of vehicles during transportation.

Klundert, A. and Anschutz, J.(1999) have shown suitable criteria which should be taken in to account when planning for a solid waste collection mechanism, they include:

- Using any one of the methods, or combination of several methods on house to house collection, communal bin collection and curbside collection of municipal solid wastes
- The availability, notification and well functioning waste collection schedule
- That if there is any evidence of infectious waste or hazardous waste that it not be accepted into the normal waste collection vehicles
- Adequate collection frequency
- Evidence of daily collection in public places

- Evidence of regular clearance of public streets and drainage removal of building debris and tree cuttings
- Evidence that bins or containers wherever they are placed, are cleaned when they start overflowing

5.3. Factors that Affect Solid Waste Collection

Ghiani,G., Guerriero,F. Improta, G. and Musmannod, R. (2005) pointed out several factors that need to be considered when selecting a location for waste collection points. They are:

- *Proximity*: Locate as close as possible to where solid waste is being generated to minimize waste handling and reduce transport cost. Furthermore, locate away from water supply (Suggested minimum 500 feet)
- *Access*: Should have adequate width with minimum traffic congestion.
- *Geology / Hydrogeology*: Avoid areas with earth quakes, flood, landslides, faulty, underlying mines, sinkholes and solution cavities.
- *Soils*: Should have natural clay liner or clay available for liner and final cover material available.
- *Ground Water*: No contact with ground water. Base of fill must be above high ground water table.
- *Air*: Locate to minimize fugitive emissions and odour impacts.
- *Noise* : Minimize truck traffic and equipment operation noise
- *Land Use* : Avoid populated areas and areas of conflicting land use such as parks and scenic areas
- *Cultural resources* : Avoid areas of unique archaeological historical and paleontogical interest
- *Legal / Regulatory*: Consider local requirements for permits.
- *Public / Potential*: Gain local acceptance from elected officials and local interest groups.

5.4. Applications of Mathematical Model for Solid Waste Collection

The available literature indicate that many methods and algorithms have been used for planning municipal solid waste collection by applying mathematical models. Maniezzo,V. (2004), Amponsah ,S. KandSalhi,S. (2004) have modeled the optimization problem of urban waste collection and transport as various versions of the Arc Routing Problem.

Nevertheless, the particular problem has been also modeled by Ghiani, G., Guerriero, F., Improta, G, and Musmannod, R. (2005) as a Vehicle Routing Problem (VRP), in which a set of waste trucks have to serve a set of waste bins minimizing the cost function by applying minimal spanning tree.

Sahoo, S. Kim and Kim, B.I. (2005).and Donati, A.V., Montemanni, Casagrande,. Rizzoli, A.E and Gambardella L.M. (2003) have applied a mathematical model considering the characteristics of the vehicles and the Dijkstra's Algorithm for Municipal Solid Waste Collection and Routing Optimization 225 constraints determine the various types of VRPs.

Hsieh and Ho, (1993), Lund and Tchobanoglous, (1994) have applied the transportation problem model and LPM for optimizing sitting and routing aspects of solid waste collection networks. However, uncertainty frequently plays an important role in handling solid waste management problems. The random character of solid waste generation, the estimation errors in parameter values, and the vagueness in planning objectives and constraints, are possible sources of uncertainty.

Koo et al.(1991) applied a mathematical model for the hypothetical solid waste management problem in Canada, and for an integrated solid waste management system in Taiwan. Katkar.A.A. (2012) has developed a methodology based on Floyd's Algorithm and LPM for effectively solving the network analysis in the field of solid waste routing system in large cities.

Past practices emphasize the application of mathematical models such as Network Analysis which are based on Dijkstra's Algorithms. However, the Transportation Problem Method is more suitable to cope with non-linear optimization problems, such as deciding on efficient routing for solid waste collection and transport.

5.5 Network Analysis

A network consists of a set of nodes (vertices) and a set of arcs (edges). Each node represents a location and each arc represents the connection (road link) between two different locations. There are three types of network analysis techniques:

(a) Shortest-path model
(b) Minimum spanning tree
(c) Maximal flow model

The objective of this research is to reduce the overall solid waste collection cost. This can be achieved by finding the shortest path between solid waste collection locations and the IRR centres. To achieve this, "Shortest Path model"; one of the models which comes under the Network Analysis technique was applied.

Several methods are there to find the shortest path to a particular node from any of the other nodes in a road network. They are;

(a) Systematic method
(b) Dijkstra's Algorithm
(c) Floyd's Algorithm

In this research, Dijkstra's Algorithm was applied to find the shortest path between solid waste collection locations to IRR centres.

5.5.1Dijkstra's Algorithm

Dijkstra's algorithm was discovered by the Dutch computer scientist Edsger Dijkstra in 1956 and published in 1959. It is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree. It turns out that one can find the shortest paths from a given source to all points in a graph at the same time; hence this problem is sometimes called the single-source shortest paths problem.

To find a shortest path from starting location ***s*** to destination location ***d***, Dijkstra's algorithm maintains a set of junctions, ***S***, whose final shortest path from ***s*** has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions ***S***, and updates the shortest-path estimates of all neighbours of this junction that are not in ***S***. The algorithm continues until the destination junction is added to ***S***.

5.6 Transportation Problem Method

"Transportation Problem Method" was applied to find the optimum allocation of solid waste from solid waste collection locations to IRR centres considering the supply and demand.

"Transportation Problem Method" is a special kind of linear programming problem in which goods are transported from a set of sources, to a set off destinations, subject to the supply and demand of the source and destination respectively, such that the total cost of transportation is minimized.

Let, m be the number of sources
n be the number of destinations
a_i be the supply at source i
b_j be the demand at destination j
c_{ij} be the cost of transportation per unit from source i to destination j
X_{ij} be the number of units to be transported from the source i to the destination j

The linear programming model for the transportation problem is presented as:

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} X_{ij}$$

Subject to,

$$\sum_{i=1}^{m} X_{ij} = a_i \qquad for\ i = 1, 2, \ldots\ n$$

$$\sum_{i=1} X_{ij} = b_j \qquad for\ i = 1, 2, \ldots\ m$$

$$X_{ij} \geq 0 \qquad for\ all\ i\ and\ j$$

5.6.1 Types of Transportation Problem

The transportation problem can be classified into "balanced transportation problem" and "unbalanced transportation problem". If the sum of the supplies of all the sources is equal to the sum of the demands of all the destinations then the problem is termed as "balanced transportation problem". This may be represented by the relation:

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$$

If the sum of the supplies of all the sources is not equal to the sum of the demands of all the destinations, then the problem is termed as "unbalanced transportation problem". That means, for any unbalanced transportation problem, we have

$$\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} b_j$$

In this research the problem was considered as a "balanced transportation problem".

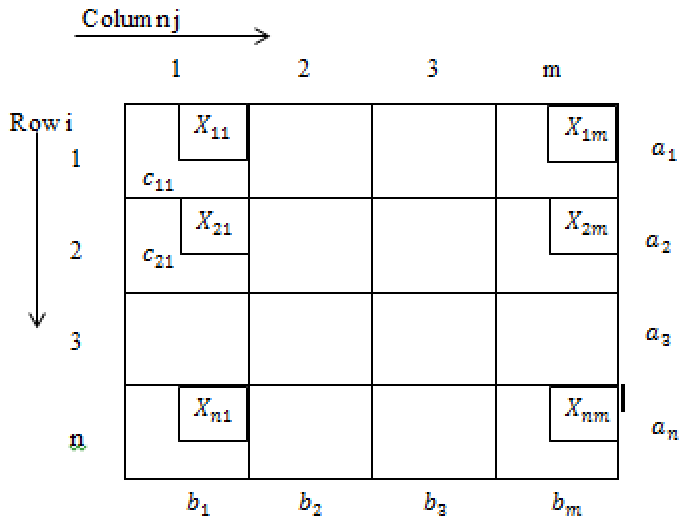
5.6.2 Methods to Solve Transportation Problem

The solution procedures for the transportation problem consist of two phases:

(a) Finding the initial basic feasible solution.
    There are three types of techniques to find the initial basic feasible solution. The solution using these techniques may not be optimal.
    (i) Least cost cell method
    (ii) Northwest corner cell method
    (iii) Vogel's approximation method (VAM)/ penalty method

This research has used Northwest corner cell method to find the initial basic feasible solution. The steps of the Northwest Corner cell method are explained below:

Consider a transportation problem with 'm' number of supply points and 'n' number of demand points. Each unit produced at supply point i and transported to demand point j incurs a variable cost of c_{ij}. The relevant data can be formulated in a transportation tableau as given below:



- Begin in the upper left (or northwest) corner of the transportation table.
- Set X_{11} as large as possible. Clearly X_{11}= min {a_1, b_1}.
- If $X_{11} = a_1$, cross out row 1 of the transportation tableau. Also set $b_1 = b_1 - a_1$.
- If $X_{11} = b_1$, cross out the column 1 of the transportation table. Also set $a_1 = a_1 - b_1$.
- If $X_{11} = a_1 = b_1$, cross out either row 1 or column 1 (but NOT both).
- If you cross out row 1, set $b_1 = 0$.
- If you cross out column 1, set $a_1 = 0$.
- Continue applying this procedure to the most northwest corner cell in the tableau that does not lie in a crossed-out row or column. Eventually, it will come to a point where there is only one cell that can be assigned a value.
- Assign this cell a value equal to its row or column demand, and cross out both the cell's row and column.

(b) Optimization of the initial basic feasible solution

U-V method is the most commonly used method to optimize the initial basic feasible solution obtained from one of the above methods.
The steps of the U-V method are explained below:

- Use the initial basic feasible solution obtained from the Northwest corner cell method.
- Use the fact that $u_1 = 0$ and $u_i + v_j = c_{ij}$ for all basic variables to find $[u_1 u_2 \ldots u_m v_1 v_2 \ldots v_n]$ for the current basic feasible solution.
- If $u_i + v_j - c_{ij} \leq 0$ for all non-basic variables, then the current basic feasible solution is optimal. If this is not the case, then we enter the variable with the most positive $u_i + v_j - c_{ij}$ into the basis using the pivoting procedure. This yields a new basic feasible solution.
- Using the new basic feasible solution, return to steps 2 and 3.
- If $u_i + v_j - c_{ij} \geq 0$ for all non-basic variables, then the current basic feasible solution is optimal. Otherwise, enter the variable with the most negative $u_i + v_j - c_{ij}$ into the basis using the pivoting procedure. This yields a new basic feasible solution.

6.0 Analysis & Results

6.1 Finding the Optimum Locations to Collect Solid Waste Generated in Each Zone

Under the above project, the MC area has been divided into seven zones (Figure 1) and it has been proposed to assign one tractor, one driver and two labourers for each zone to collect solid waste from house to house in handcarts and then to transport the collected waste to IRR centres by tractor. The seven zones were demarcated based on the ward boundary of the MC area. Table 3 shows the wards that come under each waste collection zone.

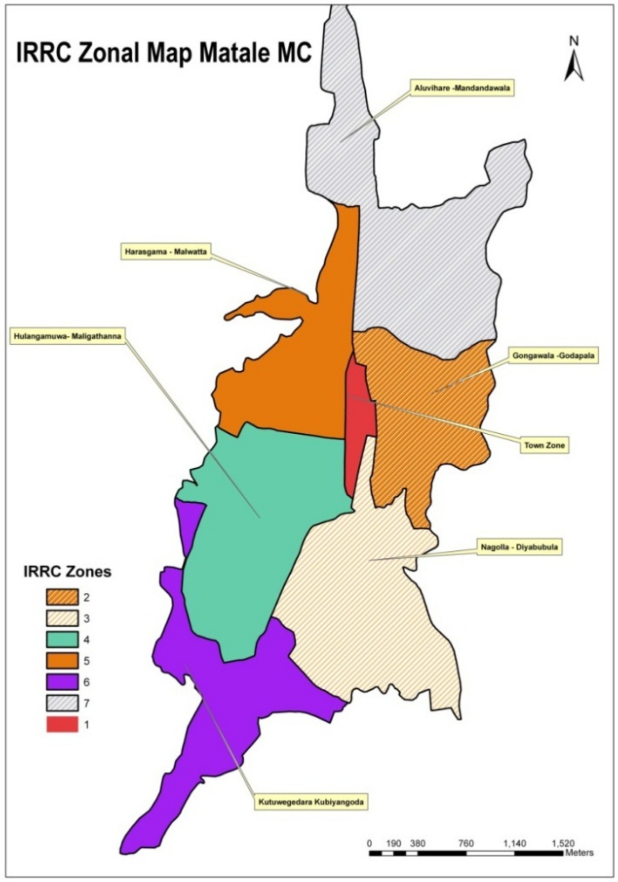


Figure 1: Solid waste collection zones of IRR Project
Source: SEVANATHA Urban Resource Centre

Table 3: Wards come under each waste collection zone

Waste Collection Zone	Wards
Zone 1	Town
Zone 2	Godapola, Gongawala
Zone 3	Diyabubula, Nagolla
Zone 4	Maligathenna, Hulangamuwa
Zone 5	Malwatta, Harasgama
Zone 6	Kumbiyangoda, Kotuwegedara
Zone 7	Mandandawela, Aluvihare

The first objective of this research is to identify suitable waste collection locations of each zone by considering the criteria identified through the literature review. The Model Builder tool in Arc GIS, was applied to spot the suitable waste collection points which fulfil the requirements such as: shortest distance from transfer stations (IRRCs), high accessibility from all houses in the zone, suitable geological condition, soil and hydrological condition, compatibility with surrounding land use activities and minimum required service area. Figure 2 shows the waste collection locations identified in this manner.

Bottles, Brown for Metals / Coconut shells and Orange for Plastic & Polythene. Each zone will have two labourers to collect and transport waste from house to house to the waste collection location using hand carts each with a capacity of 250kg, on a daily basis. Then, using tractors the collected waste at each waste collection location will be transported to IRR centre. This mechanism will facilitate a reduction in transport cost by a considerable level. It is hoped that this cost will be reduced further by finding the shortest route for the distribution of collected solid waste from each zone to IRR centre.

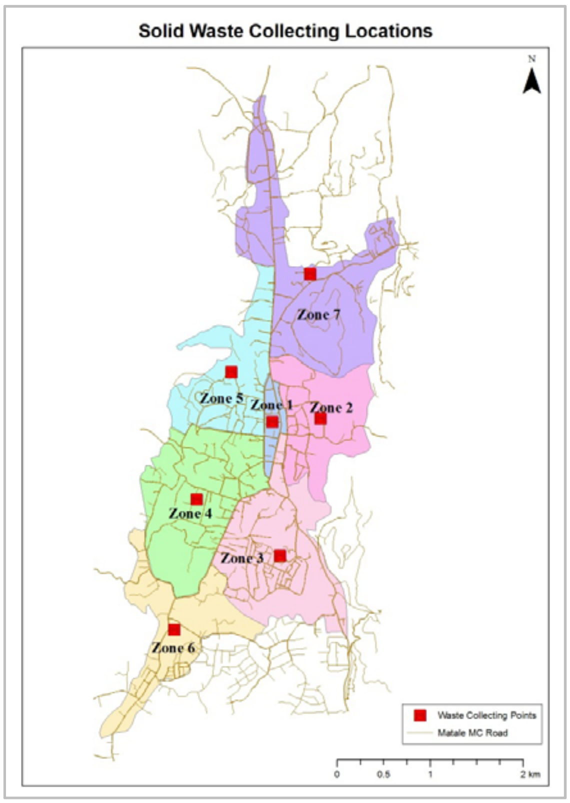


Figure 2: Optimum locations SW collection *Source*: Compiled by the Authors

Five waste collecting bins, each with a capacity of 500 kg are located in the above identified waste collection locations of all seven zones, in order to separate waste into bio-degradable and non-bio-degradable materials. The recommended colour codes for waste collection bins are Green for Organic Waste, Blue for Paper, Red for Glass

6.2 Optimizing the Routing of Municipal Solid Waste Collection

The second objective of this research is to optimize the routing process of solid waste collection by minimizing the total collection distances travelled by vehicles.

The optimum routing of Municipal solid waste collection can be examined under two aspects:

1. Optimum routing for collection of solid waste from house to house
2. Optimum routing for transportation of collected solid waste from zone to IRR center

Under this study, the scope of route optimization was restricted to find the optimum route for distribution of collected solid waste from zone to IRR centre by tractors. Therefore the waste collection location was considered as the origin point and the IRR centre was considered as the destination point.

The following assumptions were considered in applying the network analysis for optimizing the routing of Municipal Solid Waste Collection.

(a) On a given day, the first trip starts from the IRR Center and ends up at the IRR Center as well.

(b) The cost of transportation is totally based on the cost of fuel of travelled distances.

(c) The traffic condition and the physical condition of the road were considered as uniform.

(d) The slope of the MC area does not significantly influence fuel consumption or wastage. As shown in Figure 3, the slope of the Matale MC area is comparatively low when compared to its surrounding area. Hence it was considered that the slope does not significantly influence fuel consumption or wastage.

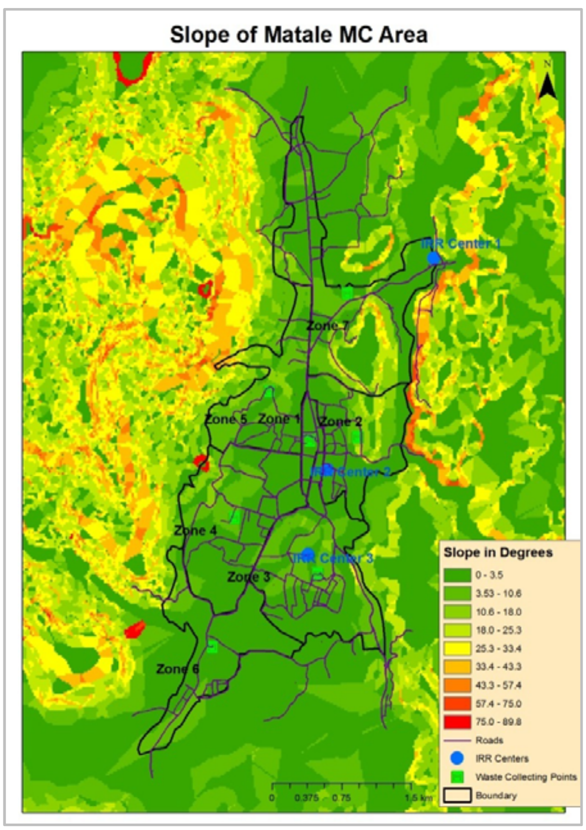


Figure 3: Slope of Matale MC Area *Source*: Compiled by the Authors

To find the shortest path between the solid waste collection points and the IRR center, Dijkstra's Algorithm was applied. Network Analysis Route tool in the ArcGIS software, which was developed based on the Dijkstra's Algorithm, was used to find the shortest path between the waste collection locations and the IRR centre. For this study, only the routes in which the solid waste collecting tractors could travel were considered. Figure 4 shows the shortest routes identified from each waste collection location to each IRR centre and Table 4 shows the shortest distance, in kilometres, between each location and IRR centre.

Table 4: Shortest Distance obtained from the Dijkstra's Algorithm

Shortest Distance from waste collecting zone to IRR Centre (in km)$(\boldsymbol{d_{ij}})$			
Waste Collection location	Centre 1	Centre 2	Centre 3
1	2.839	0.534	1.876
2	3.190	0.774	2.289
3	4.581	1.602	0.882
4	4.225	1.546	1.497
5	3.170	1.457	2.667
6	5.539	2.863	1.839
7	1.213	2.254	3.600

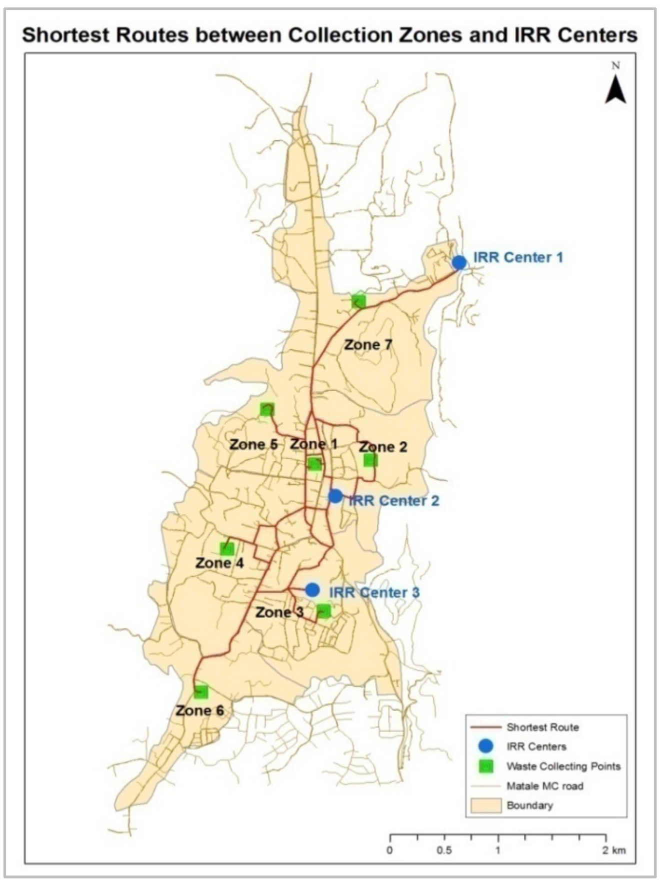


Figure 4: Shortest path between collection zones and IRR Centres
Source: Compiled by the Authors

6.3 Optimizing the Allocation of Collected Solid Waste to IRR Centres

Under the IRR project, several catchment areas were identified based on the location of the MC wards in order to collect the required amount of solid waste to IRR centres as shown Figure 5. But such catchment areas were decided on without considering the solid waste transportation cost, demand of the IRR centres and the supply of each catchment area.
As shown in Figure 6, at some IRR centres, demand is greater than the supply and at some other IRR centres demand is less than the supply. Therefore it is essential to plan an optimum strategy to allocate the collected solid waste among IRR plants considering the transportation cost, supply of solid waste collection points and demand of IRR centres. Therefore to achieve the third objective of finding the optimum allocation of solid waste from waste collection locations to IRR centres, the Transportation Problem method was applied.

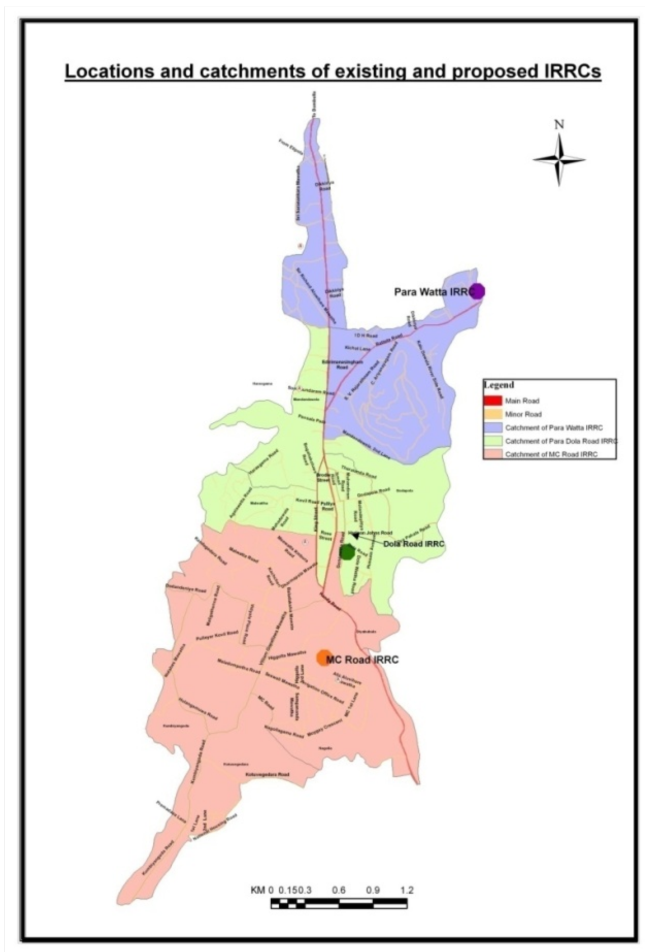


Figure 5: Locations and catchments of existing & proposed IRRCs
Source: SEVANATHA Urban Resource Centre

The following assumptions were considered when applying the Transportation problem method:

(a) Under Transportation costs only fuel costs were considered

(b) The research has obtained the relevant data and information from the feasibility study carried out by the SEVANATHA Urban Resource Center for the Matale MC area in 2010. Therefore when calculating the fuel cost, the authors have used the fuel prices in year 2010. Hence, 1 ton 1km fuel cost for solid waste transportation was considered as Rs. 180.

(c) The assignment of solid waste was considered as a "Balanced Transportation Problem"

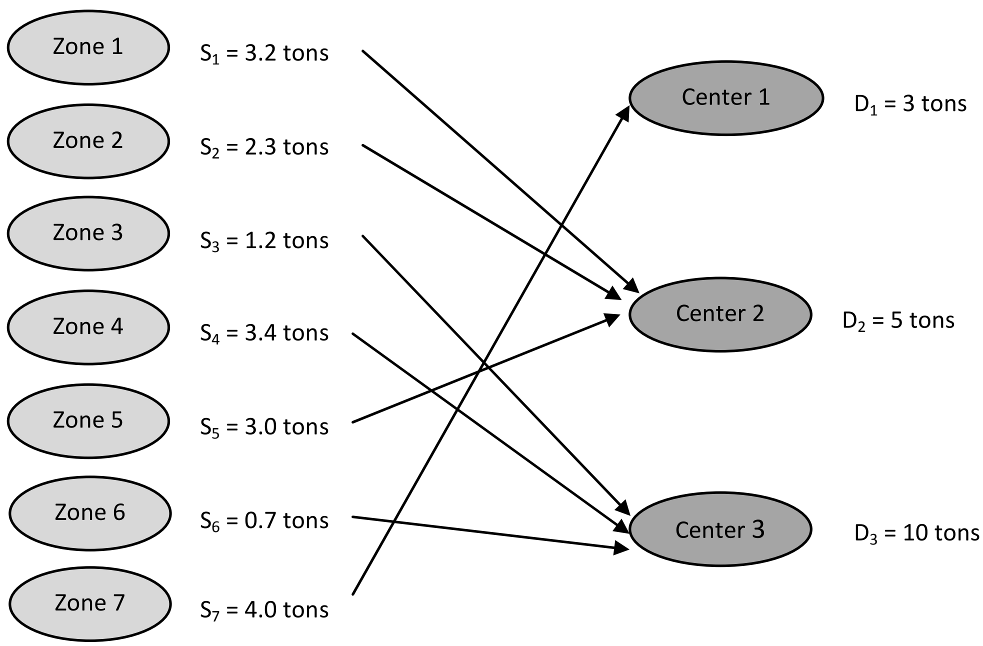


Figure 6: Proposed solid waste distribution plan under the IRR Project

To calculate the c_{ij} values, first, the cost of transportation of 1 ton of solid waste (c_{ij}) from solid waste collection zone to IRR center was calculated.

$$c_{ij} = d_{ij} \times w$$

Where,

c_{ij} = the cost of transportation per unit from source i to destination j
d_{ij} = shortest distance between source i to destination j
w = Fuel cost of transporting1 ton of solid waste for 1km distance (Rs. 180)

Table 5: One ton daily transportation cost - c_{ij}

One ton daily transportation cost (in Rupees)(c_{ij})			
Waste Collection Location	Centre 1	Centre 2	Centre 3
1	511	96	338
2	574	139	412
3	825	288	159
4	761	278	269
5	571	262	480
6	997	515	331
7	218	406	648

Thereafter, the initial basic feasible solution was obtained by using the Northwest corner cell method. Table 6 shows the initial solution obtained from the Northwest corner cell method.

Table 6: Initial Basic Feasible solution of the Northwest corner cell method

Zone	**Plant 1**	**Plant 2**	**Plant 3**	**Supply**
1	511 [3.0]	96 [0.2]	338	**3.2**
2	574	139 [2.3]	412	**2.3**
3	825	288 [1.2]	159	**1.2**
4	761	278 [1.2]	269 [2.3]	**3.4**
5	571	262	480 [3.0]	**3.0**
6	997	515	331 [0.7]	**0.7**
7	218	406	648 [4.0]	**4.0**
Demand	**3.0**	**4.9**	**9.9**	

The initial basic feasible solution obtained from the Northwest corner cell method was optimized using the U-V method.

Table 7: Optimum solution of the U-V Method

Zone	**Center 1**	**Center 2**	**Center 3**	**Supply**
1	511	96 1.6	338 1.6	**3.2**
2	574	139 2.3	412	**2.3**
3	825	288	159 1.2	**1.2**
4	761	278	269 3.4	**3.4**
5	571	262	480 3.0	**3.0**
6	997	515	331 0.7	**0.7**
7	218 3.0	406 1.0	648	**4.0**
Demand	**3.0**	**4.9**	**9.9**	

According the U-V method, the total daily solid waste collection cost is:

= Rs. (96×1.6) + (338×1.6) + (139×2.3)+(159×1.2) + (269×3.4)+(480×3)+(331×0.7) + (218×3) + (406×1)

= Rs. 4851

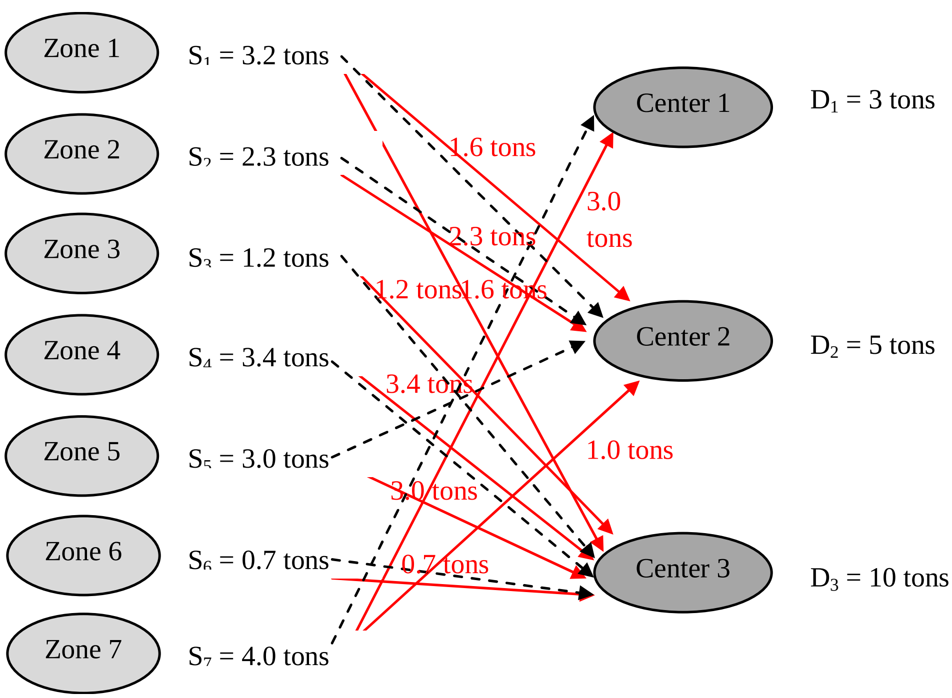


Figure 7: Solid waste distribution plan obtained from the Mathematical Model

Expected daily solid waste collection under the project	= 18 tons
Percentage of bio-degradable waste	= 85%
Quantity of daily bio-degradable waste	= 15.3tons

The compost is produced in the IRR plant with an input/output ratio of 15%.

Hence, expected daily compost production	= 15.3 ×15% tons
	= 2295 kg
Solid waste collection cost for produce 2295kg of compost	= Rs. 4851

Solid waste collection cost for produce 1kg of compost = Rs. 4851 / 2295
= Rs. 2.10

Therefore, by applying mathematical models in solid waste collection, there is a possibility to reduce the fuel cost incurred in producing 1kg of compost, by up to Rs. 2.10. Daily fuel cost to produce 2295 kg of compost, before and after applying the mathematical models, are Rs. 6885 and Rs. 4819.50 respectively. Hence there is a possibility to save Rs. 2065.50 per day with the new solid waste collection plan developed from mathematical models.

7.0 Conclusion

There are more nonlinear relationship among the variables, which are encompassed with the activities of solid waste collection, transportation and disposal. This study emphasized that application of Network analysis which is based on Dijkstra's Algorithms and Transportation Problem method which are more suitable to cope with such non-linear optimization problem on deciding on the most efficient routing for solid waste collection and transport in the Matale MC Area.

The collection process has been improved through the application of Network Analysis and Transportation Problem Model, which minimizes the total distance travelled by the collection vehicles and improves the assignment of required solid waste quantity to IRR centres. This proposed mechanism of using mathematical models for planning solid waste collection and transport activities, in this case study will save up to Rs.2065.50 per day.

8.0 References

1. Business plan for Resource recovery in Matale city project 2011 – 2015. *SEVANATHA Urban Resource Center*

2. Donati,A.V., Montemanni, R. Casagrande, N., Rizzoli, A.E. and Gambardella, L.M (2003)Time-dependent Vehicle Routing Problem with a Multi Ant Colony System.*Technical Report* TR-17-03, IDSIA, Galleria 2, Manno, Switzerland

3. Ghiani,G.,Guerriero,F.ImprotaG.andMusmannod, R (2005), Waste collection in Southern Italy: solution of a real-life arc routing problem.*Intl. Trans. in Op. Res.* 12, 135-144

4. Hsieh, H.N. and Ho, K.H.(1993) Optimization of solid waste disposal system by linear programming technique.*Journal Resource. Management Technology*, Vol. 21, no. 4, 194-201

5. Katkar.A.A.(2012) Improvement of solid waste collection by using optimization technique.*Zenith international journal of multidisciplinary research* vol.2 issue 4

6. Klundert, A. and Anschutz, J. (1999) Integrated Sustainable Waste Management: the selection of appropriate technologies and the design of sustainable systems is not only a technical issue. Paper presented at the conference on CEDARE/IETC Inter-Regional Workshop on Technologies for Sustainable Waste Management, Alexandria, Egypt. 13-15 July.

7. Koo,H.J., Shin, H.S. and Yoo, H.C(1991) Multi objective siting planning for a regional hazardous waste treatment center.*Waste Management Res*., Vol. 9, 205-218.

8. Korner, I., Stegmann, R., Vishvanatha, C., Norbu, T., Gadia, R., Cossu, R., Awang, M., Abdul Aziz, A., Hassan, M.N., Chong, T.L. and Ming, C.T. (2009) TETRAWAMA - Teaching and Training Modules for Higher Education in the Waste Management Sector. ed. Hamburg University of Technology, Institute of Waste Resource Management, Germany

9. Ludwig, H.F. and Black, R.J. (1968) Report on the solid waste problem, Journal of the Sanitary Engineering Division, American Society of Civil Engineers

10. Lund, J.R. and Tchobanoglous, G.(1994) Linear programming for analysis of material recovery facilities.*J. Environ. Eng.,* ASCE, Vol. 120, No. 5, 1093-1095.

11. Maniezzo,V. (2004) ,Algorithms for large directed CARP instances: urban solid waste collection operational support.*Technical Report UBLCS*-2004-16.

12. Sahoo,S.,S. Kim and B.I. Kim, (2005) Routing Optimization for Waste Management .Interfaces Journal (SCIE), Informs (OR/MS), 35(1), 24-36.

13. Schübeler, P.(1996) Conceptual Framework for Municipal Solid Waste Management in Low-Income Countries.*UNDP/UNCHS (Habitat)/ World Bank/SDC Collaborative Programme*.

14. Tchobanoglous G, Hilary Theisen, Samuel A. Vigil (1993) Integrated Solid waste Management - Engineering Principles and Management Issues, *McGraw Hill International Edition*.
15. Technical Guidelines on Solid Waste Management in Sri Lanka. Available from: URL: http://www.cea.lk/pdf/Solod%20Waste%20Management%20Guidlines.pdf

16. Shaida, M.N. (2011) Integrated solid waste management plan for Herat City, Afghanistan, *School of Environment, Resource and Development, Thailand*

Evolution of Female Costume in Sinhala Tradition

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Abstract

According to the Oxford English dictionary the meaning of costume denotes 'the distinctive style of coiffure, jewellery, and apparel of a period, country, class or a group'. Costumes are considered as things that are laid on the human body for beauty, aesthetics and function. Body shape or figure is believed to be the cumulative result of a woman's skeletal structure and distribution of muscle on the body. The female figure in many cultures has been worshipped as the symbol of fertility and prosperity. The female form is considered as more attractive than its male counterpart. In general female figures are narrower at the waist than at the bust and hip area, and accentuated with long hair that falls along the back.

This study intends to identify deeper meanings in costumes that were practiced in local traditions, by mapping out the visible connections between costumes/dress and the social, material, and philosophical aspects of female dress. The research problem is the examination of the principles that have evolved in the history of Sinhalese female costume. In the world of costume design today, it is important to always look back to tradition, for creative inspiration in design. This has been the main objective of the research paper. A wide range of costumes, from the royalty to the commoners can be identified in the Sinhalese culture. This wide range of costumes has evolved to make the female figure a focal point for design and creativity. The traditions of costumes have been subjected to external changes from outside influences. The concepts behind dress design that have evolved from local traditions need to be brought in to focus. For instance, the ancient temple paintings of Sri Lanka depict the life style of a bygone era and in these paintings we come across stories illustrated with people at different events in their various costume and ornament. As such, it is possible to derive the social significance, philosophy of life, customs and beliefs, and design aesthetics of the era from these paintings. Much of the information has been collected by visiting ancient temples in Kandyan region and Southern coastal areas. Line drawings were then prepared from the scanned photographs. The dresses of the royals, variations of the costumes of the commoner, Kandyan villagers costume, costume according to Robert Knox, the occupations related to costumes, costumes of the dancers, costume and its western and Indian influences are some of the sections that will be discussed in this study.

Key words - female, costume, tradition, Sri Lanka, design, evolution

Evidence from Literary and Epigraphic Sources

Direct and indirect literary sources include the chronicles (Mahavamsa & Chulavamsa) and the written dissertations, books and silpa texts. The Mahavamsa, (Geiger W, 1953) the ancient chronicle of the Sinhalese (5th century A.D) and the Chulavamsa (Geiger W, 1953) give some idea of the dress and ornaments worn by the Sinhalese in ancient and medieval times. The Mahavamsa states that the Yakkhini woman Kuveni was first seen by the Aryan prince Vijaya from Bengal, seated under a tree spinning cotton. This event is believed to have taken