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GIS BASED OPTIMAL COLLECTION ROUTING MODEL FOR MUNICIPAL SOLID WASTE: CASE STUDY IN SINGANALLUR, INDIA

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ABSTRACT

In this paper an attempt has been made to develop an appropriate storage and collection plan based on optimal routing model using Geologic Information System in one of the wards of the Singanallur, Coimbatore city, India. The ward map is digitized and geo- referenced. The collection bins are attributed and collection routes of the MSW are optimized for degradable and recyclable wastes separately. The optimized route covered by the collection vehicle during the collection of recyclable wastes is 82.5% lesser than the degradable wastes. This is due to lesser generation of recyclable wastes than the degradable wastes. Also, there is a collection distance saving of 46% and benefit in the vehicle running and maintenance expenditure is 86.7% due to the optimization of collection routes. This study helps the waste management organizers to streamline the collection system in the ward.

INTRODUCTION

The growth in Municipal Solid Waste (MSW) in urban centers has outpaced the population growth in recent years. MSW is produced at alarming rate, particularly due to the rapid growth of urban areas, rural urban migration and the increase in per capita income (Agamuthu and Khan 1997).One of the consequences of the global urbanization is increasing volumes of solid wastes. At present, the annual generation of solid wastes equal to 1.6 billion metric tons approximately (Beede and Bloom 1995). The report of high power committee on urban MSW Management in India stated that there is no system of segregation of organic, inorganic and recyclable wastes at the household levels (Planning commission 1998, Sethuraman 2007). Further, the disposal of the MSW is an unplanned and uncontrolled open dumping at the landfill sites. MSW in cities is collected and transported to designated disposal sites, which are normally located at out-skirts of the city. In most of the areas, the MSW collection is disorganized and less than 25% of the MSW produced is actually collected for disposal and the remaining 75% is allowed to remain, causing health hazards and pollution to the environment

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Go to the previous paragraph. Proper segregation of waste would lead to better options and opportunities for its scientific disposal, otherwise life of existing disposal facilitiesis decreased (Singhal and Pandey 2006). However just collecting the waste from different parts of city does not solve the problem, it requires disposing the waste in environmentally safe and economically sustainable manner. Thus an effective solid waste management system is needed to ensure better human health and safety (Ghose *et al*., 2006). A study conducted in the Istanbul predicted that annual collection expenditure of solid waste can be reduced to 50% when the collection routes are optimized (Kinaci *et al*., 2000). Also by route optimization technique, in Trabzon, there is a reduction of 22% and 20% in collection time and collection distance respectively in the MSW management system (Apaydin *et al*., 2004). Also through optimization process 24.7% in distance and 44.3% in time for collection and hauling is saved and also there is a benefit in the total expenditure of 24.7% for the collection process in Trabzon (Apaydin *et al*., 2007). Hence, it is vital that long-term strategies should be developed for the efficient collection of MSW. In Coimbatore city, India, bins are used for the temporary storage for household wastes. The bins are usually located at the end of each street for the convenience of the citizens. The design of temporary storage includes determination of size and number of bins used in a particular area. The size and number of bins determine the collection frequency. The collection frequency helps to collect the wastes in stipulated time interval. The delay in the transportation of wastes makes the organic material starts to decay and it makes the handling of wastes more difficult and delicate. Among the many available routes for the collection of MSW, the collection vehicle starts moving from bin to bin in an undefined route to collect the wastes. Also the part of the waste is left uncollected in the streets. Many times the collection vehicles are traveling longer distances because the travel route is not identified scientifically. This leads to consumption of more fuel and generates higher pollution. There is also a delay in collection of wastes from all the locations. To reduce fuel cost and emitted pollutants by collection vehicles and to ensure effective MSW collection, the optimized collection routes should be found. Hence, in this paper, a GIS based model is proposed for route optimization of MSW degradable and recyclable wastes collection, separately. This study is carried for the Singanallur, Coimbatore, India.

Study Area

Coimbatore city is located in South India; its latitude and longitude are 11°00´N and 77°00´E respectively while its population of 930,882 spread over an area of 105 km^2. The entire Coimbatore city is divided into four zones viz North, South, East and West. Each zone has 18 wards. Coimbatore Municipal Corporation (CMC) has proposed model wards for implementation of collection strategies of MSW. In this work, Singanallur ward is chosen for the study because this is the proposed model ward to implement the waste management program by the CMC. This ward contains residential areas, business centers, daily vegetable market and small industrial units. The details about the ward such as the population statistics, number of houses, quantity of waste generated etc., are given in Table 1.0.

Table 1.0. Details of Singanallur Ward

1	Ward Number	6
2	Zone	East
3	Population	27,464
4	Quantity of degradable waste generated	13.38 t
	Quantity of recyclable waste generated	0.77 t
5	Number of households	6866
6	Number of shops and establishments	132
7	Number of apartments	7
8	Number of hotels /restaurants	37
9	Number of shopping complexes	-
10	Number of educational institutions	5
11	Number of hospitals/clinics/dispensaries	2
12	Number of cinema theatres	2
13	Number of industries	64
14	Number of railway stations	-
15	Number of vegetable markets	1
16	Number of fruit markets	-
17	Number of flower markets	-
18	Number of meat/fish/chicken stalls	26
19	Number of slums in the ward	3
20	Number of roads	5
21	Number of streets	32
22	Number of lanes	66

There is no proper methodology for collection of segregated wastes from the ward. Also all the wastes are not collected from the entire area of the ward to the treatment yards. This is due to lack of administrative and infrastructure facilities. In order to have proper collection methodology, analysis of the present waste collection system decides the adequate size and the number of bins required to collect the wastes. The CMC has proposed the number and size of the bins based on the population density and per capita waste generation. The location of the bin depends on the availability of space in the street as well as the approachability of collection vehicles to the bins. It is proposed by the CMC that the degradable and recyclable wastes are collected separately to the respective treatment yard. The proper awareness on the segregation of wastes for the residents in the ward is also under progress.

MATERIALS AND METHODS

The ward map is digitized, geo-referenced and the collection bins are attributed from the Global Positioning System (GPS) data using GIS. The network module (ESRI1995) of Arc/Info GIS software is used to find the shortest or minimum impedance path through a network. Thus the shortest route for collecting the MSW is determined. In this analysis, the collection frequencies are proposed for the collection of degradable and recyclable wastes based on the size of the bin and the quantity of wastes generated.

Design of temporary storage

The total quantity of wastes generated per day and the total capacity of the bins determine the daily fill rate. The total capacity of the bins should not exceed the total daily quantity of wastes in the ward.

$$TQ_d = (F_d) \times \left[\sum_{i=1}^{n} C_{di} \right] \quad (1)$$

$$TQ_r = (F_{re}) \times \left[\sum_{i=1}^{n} C_{ri} \right] \quad (2)$$

where

TQ_d = Total quantity of biodegradable wastes generated by ward (t/d)
F_d = Average filling rate of bins for biodegradable waste (%)
C_{di} = Capacity of bin for biodegradable waste (t)
n = Number of bins
TQ_r = Total quantity of recyclable wastes generated by ward (t/d)
F_{re} = Average filling rate of bins for recyclable waste (%)
C_{ri} = Capacity of bin for recyclable waste (t)

Collection routes of MSW

The distance covered during the collection of MSW is analyzed for following three different cases in the ward.

Case I Present system of collection of MSW.

Case II Optimal waste collection vehicle route for biodegradable waste.

Case III Optimal waste collection vehicle route for recyclable waste.

The collection vehicles used in the ward are 3 t diesel lorries. The total distance traveled by these collection vehicle in the above three cases is analyzed as follows. The total distance traveled by the collection vehicle in the present system of collection of MSW is calculated based on the fuel consumption of the vehicle and is given in the equation (3)

$$D_p = (FU) \times (M_c) \quad (3)$$

D_p = Total distance covered by the MSW collection vehicle (km/y)
FU = Fuel consumption of vehicle (L diesel/y)
M_c = Distance covered (km/ L diesel)

The total travel distance of the optimal route for the MSW collection vehicle is based on the number of collection trips:

$$D_f = n_c \times d_c \quad (4)$$

D_f = Annual distance covered during optimal biodegradable/recyclable waste collection vehicle route (km).
n_c = Annual number of trips for biodegradable/recyclable waste collection.
d_c= Round trip haul distance covered by the vehicle during biodegradable/recyclable waste collection (km/y).

RESULTS AND DISCUSSION

The study analyzed the existing number and location of bins in the ward. The proposed number of bins for the separate collection of biodegradable and recyclable waste is calculated for the proposed ward. Furthermore, three different MSW collection cases are discussed in the following sections.

Size and number of bins

The CMC has recommended two different bin sizes based on the population density in the ward. 32 bins were proposed to be located in streets of the ward, 21 bins with capacity 1100 L each and 11 bins with capacity 2500 L each, separately for biodegradable waste and 32 bins correspondingly for recyclable waste. Thus 64 bins are required for the collection of the 2 types of waste. The location and the size of the bins are decided by the population density in the ~~case~~ study area. The current situation is that the produced biodegradable waste is collected by vehicles from 19 bins of 1100 L and 10 bins of 2500 L whilst the produced recyclable waste is collected from 2 bins of 1100 L and 1 bin of 2500 L which are located in the ward. The collection of source separated wastes in the source from households is planned; it will take place in two separate bins for each household. The biodegradable and recyclable waste bins are proposed to be located together, so as residents to be encouraged to separate and dispose their waste to the corresponding bins.

Digitization and Geo-referencing of the ward map

The ward map is digitized, geo-referenced and the collection bins are attributed from the GPS data using the GIS 9.0.The generated map gives efficient information such as collection point locations, MSW transport means and their routes.

Case I - Present system of collection of MSW

Presently the mixed wastes are collected through an undefined route and part of the waste is left uncollected. From the total waste generated from the ward and with capacity of the vehicle, the total distance covered by the vehicle in the ward for the collection of MSW is found as 18,000 km per year. This is based on the fuel consumption of collection vehicle and is found using the Equation (3).

Optimization of MSW collection routes using Network Analyst

Collection routes of MSW are optimized using Network Analyst - a module of GIS Arc view 9.0. The number of bins covered to collect the wastes is based on the capacity of the vehicle and the average rate of filling of bins. In this analysis, it is assumed that all the bins are filled at equal levels during the collection period. The waste collection frequency is determined by the uploading rate of filled bin gets filled and by the capacity of the collection vehicles.

Case II - Collection of degradable wastes through optimized route

The daily biodegradable bin fill rate was calculated to be 62 % (Equation 1). Thus the maximum of five trips is considered for collection of degradable wastes, when the collection frequency is once in a day. The collection configuration of the vehicle such as number of trips, number of bins covered in each trip, quantity of waste collected etc., are shown in the Table 2.0. The total distance traveled by the collection vehicle during the collection of MSW covering all the bins is 11.3 km. So the total round trip haul distances by the vehicle during collection of degradable wastes for collection frequency once in a day are 22.6 km. Thus the total optimized distance covered by collection vehicle for biodegradable wastes is calculated using the Equation (4).

Case III Collection of recyclable wastes through optimized route

The daily recyclable bin fill rate was calculated to be 3.6 % (Equation 2). Thus the average filling rate of the bin for the collection frequency once in four days is 18% only. Therefore only one trip is proposed to collect the recyclable wastes covering all the bins. This is based on the capacity of the collection vehicle. Figure 1.0 shows the optimized collection routes of MSW covering all the bins. The total distance traveled by the collection vehicle in the optimized route covering all the bins is 7.6 km. So the total round trip haul distance by the vehicle during collection of recyclable wastes for collection frequency once in four day is 15.2 km. The optimized total distances covered by the vehicle for the collection of recyclable wastes were calculated by Equation (4).The Figure 2.0 compares distance traveled by the collection vehicle between present MSW collection system and optimized routes of different collection strategies of biodegradable and recyclable waste. It is also known from the above figure that the distance traveled by the collection vehicle at present system is higher than the proposed collection strategies in the optimized route. The optimized distance covered by the collection vehicle for both the wastes

Table 2.0. Collection Configuration of the Vehicle

Trips	Capacity (t)	Bins number covered in a trip	Estimated waste collected in a bin (t)
	3 t	1	0.30
1st trip		2	0.60
(Vehicle No 1)		3	0.30
		4	0.60
		5	0.30
		6	0.30
		7	0.60
2nd trip	3 t	8	0.30
(Vehicle No 1)		9	0.30
		10	0.30
		11	0.30
		12	0.30
		13	0.30
		14	0.30
3rd trip	3 t	15	0.30
(Vehicle No 2)		16	0.30
		17	0.30
		18	0.30
		19	0.30
		20	0.30
		21	0.30
		22	0.30
4th trip	3 t	23	0.30
(Vehicle No 2)		24	0.30
		25	0.60
		26	0.60
		27	0.60
		28	0.60
5th trip	3 t	29	0.30
(Vehicle No 1)		30	0.30
		31	0.60
		32	0.60

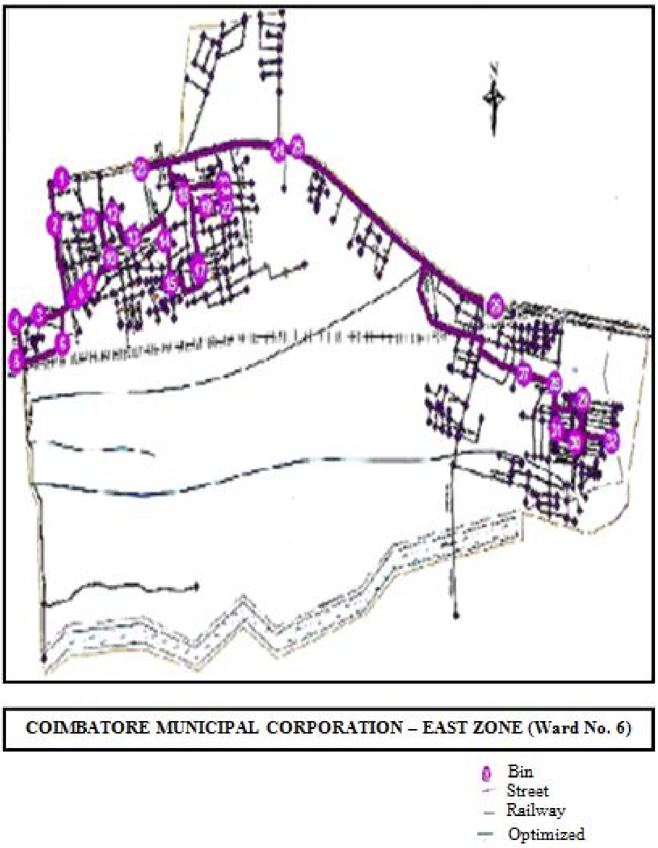

Figure 8.3. Optimized Bin Route for Collection of Wastes in Singanallur Ward

is 46%lesser than the distance covered by the vehicle during the present system of collection of MSW. The optimized distance covered by the collection vehicle during the collection of recyclable wastes are 82.5% less than the degradable wastes. This is due to lesser generation of recyclable wastes than the degradable wastes. Thus the total collection distance of 46 % is saved due to the optimization of collection route. Table 3.0 briefs the total running and maintenance cost of the vehicle for the present system of collection of MSW and optimized route for the collection of both the wastes. From the above table, it is known that benefit in the running and maintenance expenditure for the vehicle is 86.7% due to the optimization of collection routes.

Table 3.0. Estimated Annual Operating Vehicle Cost for Proposed Solid Waste Management Plan of Singanallur Ward

S.No	Cases	Vehicle Running cost including Maintenance in Rs /km	Total cost (Vehicle Running and Maintenance) in Rs
1	Present System of Collection of MSW	20	3,60,000
2	Collection of Degradable Wastes through Optimized Route	20	1,64,980
3	Collection of Recyclable Wastes through Optimized Route	20	27,660

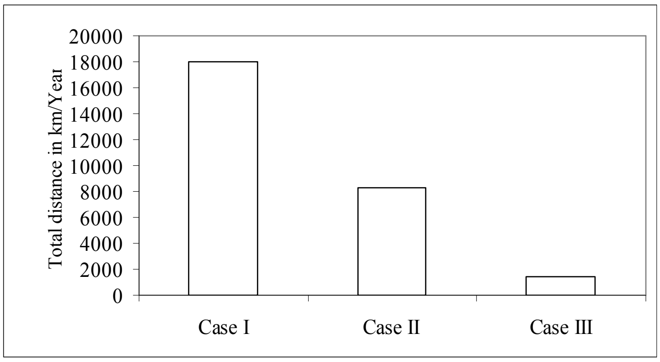

Figure 2.0. Total Distance Traveled by the Vehicle for Collection of MSW in Singanallur Ward for Various Cases

Conclusion

In this work, GIS based optimal routing model is developed for Singanallur ward for collection of MSW. The ward map is digitized, geo-referenced and the bins are attributed in the map. The collection routes of MSW are optimized for the degradable and recyclable wastes. Thus, there is a collection distance saving of 46 % due to the optimization of collection route for the wastes. Besides, the benefit in the total vehicle running and maintenance expenditure in the optimized route is 86.7%. Moreover, optimization of collection route reduces the exhaust emissions due to the vehicle and also the traffic volume on the road. The degradable and recyclable wastes are recommended to collect using separate vehicle to the composting and recycling yard respectively. This study helps decision makers to streamline the collection system which in turn helps to collect the entire quantity of wastes to the disposal yard. Proper awareness about the segregation of wastes among the people ensures the complete successfulness of the collection system. This proposed model is proposed as the decision support tool by the municipalities for the efficient management of MSW.

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