Optimization of waste collection and transportation

7.1 Introduction

For an environmental friendly and cost effective solid waste management system, the optimization of collection and transportation of the waste is a crucial factor. As it is spatial in nature it becomes a complex task. The use of GIS is most suited for such a task. Out of the total amount of money spent for the collection, transportation, and disposal of solid waste, approximately 60-80% is spent on the collection phase (Karadimas et al., 2007). Therefore improvement in the collection operations can result to a significant saving in the overall cost. Saving of cost and time are the main concern in this phase of SWM planning, some of the other points to be taken into consideration are contamination of the environment and hygiene of workers handling the waste.

7.2 The existing system of waste collection and transport

The waste collected from the generation sources and its transfer to secondary waste storage bins, was discussed in chapter 4. The present chapter deals with the collection of waste from these secondary waste storage structures and its transport to the waste dumpsite on the outskirt of the city.

At the start of the present study a survey of the collection and transportation system in place was done to know the existing scenario.

Waste Collection Vehicles

The waste in secondary storage bins and open dumps is collected and transported to the city dump site by a fleet of waste collection vehicles.

The details regarding the type of waste collection vehicles and their number was obtained from the MCR. More details of the vehicles such as number of trips made by each type of vehicle, fuel consumption of the vehicles was collected from multiple visits to the dumpsite and interacting with the supervisor of the dumpsite and drivers of the vehicles.
The municipal corporation has three types of vehicles for the collection and transportation of the waste. A description of the different types of waste collection vehicles is presented in the ensuing text.

Tractor trolley – These are tractors towing dumper trolleys, the tractor are of various makes and horse power ranging from 24hp to 35hp. The waste from the waste bins and the open dumps is manually loaded into the trolleys as seen in Fig. 7.1. At the dump site the waste is off loaded from the trolleys by hydraulic mechanism. The empty tractor trolley then goes back to collect waste from another site. The waste carrying capacity of one tractor trolley is one community waste bin of 1000kg type. This mechanism is time consuming and is highly unhygienic for the workers as the waste has to be manually handled.

![Fig. 7.1 Loading of tractor trolley with waste at a waste bin site.](image)

Dumper placer – Basically these are medium sized truck chassis with a specialized hydraulic system for lifting and loading the waste bin on to the truck. The waste bins itself is loaded and transported directly to the dump site. At the dumpsite the waste bin is emptied by a hydraulic mechanism. After emptying the waste bins are transported back to the site from where they were picked up. Two types of dumper placers are in use, single bin and double bin dumper placer Fig. 7.2. These dumper placers have been designed to carry 1000kg capacity waste bins. These are not designed to handle the 500kg capacity waste bins.
Self loading truck- These are basically dumper trucks with a hydraulic mechanism to lift the waste bins and empty them into the dumper. At the dumpsite the waste in the trolley is off loaded by hydraulic mechanism. These trucks are designed to handle 500 Kg type of the waste bins only. The truck has a capacity to load eight 500kg waste bins at one time.

At the time of the survey, the waste collection fleet consisted of, 24 tractor trolleys (Some additional tractors, as per need are pressed into service by the contractors from time to time.), 4 dumper placer among these, one is a single bin holder and tree are double bin holders. There is 1 self loading truck. The details regarding the numbers of vehicles and their waste handling capacity is presented in table7.1.

Table 7.1. Details of waste collection vehicle.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Number</th>
<th>Collection Cycle</th>
<th>Total waste collected per day</th>
<th>Percentage of waste collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor trolley</td>
<td>24</td>
<td>3</td>
<td>71.2 MT</td>
<td>55.3 %</td>
</tr>
<tr>
<td>Dumper placer</td>
<td>4</td>
<td>7 to 8</td>
<td>49.50 MT</td>
<td>38.4 %</td>
</tr>
<tr>
<td>Self Loading truck</td>
<td>1</td>
<td>3</td>
<td>8.06 MT</td>
<td>6.3 %</td>
</tr>
</tbody>
</table>

Collection efficiency of existing system of waste collection and transportation.

Total waste collected by ULB and authorized service providers versus the total waste generated within the ULB excluding recycling or processing at the generation point. Collection efficiency = [(b/a) x100], a) Total waste that is generated and which needs to be collected b) Total quantum of waste that is collected by the ULB or authorized service providers.
CHAPTER 7

The benchmark value for this indicator is 100%, the total waste generated in the city and the individual waste management zones.

The uncollected waste tends to gradually find its way into recycling, or is strewn along the roads, clogs the drains or in case of bio-degradable waste, it putrefies and degrades. Therefore, collection efficiency is a key performance indicator.

The amount of waste collected daily can be calculated from the load carrying capacity of individual vehicles and the number of rounds they make to the dumpsite. The daily waste collection by the fleet of vehicles is presented in section 7.3.

7.3 Calculation of hauling capacity of the waste collection vehicles.

- Tractor trolley (TT) waste carrying capacity = 1000 Kg/Trip
  Loading capacity of 24 TT - 24 x 1000 = 24000 Kg/Trip
  Number of Trips made by each TT per day = 3
  Total hauling capacity of 72 TT - 24000kg x 3 = **72000 Kg/ Day**

- Dumper placer (DP) waste carrying capacity of two 1000 Kg type bin – 1000Kg x 2 = 2000 Kg/ Trip
  Loading capacity of three DP- 2000kg x 3 = 6000kg/Trip
  Number of trips made by each DP per day= 7
  Total MSW hauling capacity of three DP – 7x 6000kg = **42000 Kg/Day**
  Dumper placer (DP) waste carrying capacity of one 1000 Kg type bin – 1000 Kg/ Trip
  Number of trips made by dumper per day – 8
  8x 1000 Kg = **8000Kg/ Day**

- Self loading truck (SLT)
  Loading capacity of one truck is eight 500 Kg type bins – 8 x 500kg = 4000 Kg/Trip
  Number of trips made by self loading truck – 3
  Total hauling capacity of SLT- 3x 4000kg = **12000 Kg/ Day**
  Total by all types of vehicles= **134 tons/day**
The total waste generation of Rohtak city was estimated in chapter 5 and is approximately 226 MT/Day. Through the fleet of waste collection vehicles 134 MT of waste per day is collected. The daily waste collected is 59.3 % of total waste generated per day. There is a gap of 92 MT/day between the waste generation and waste collection.

The waste collection efficiency is 59.3 %. The waste which remains uncollected is either recycled or reused by the citizen itself, or collected from waste bins by scavengers. This waste will not be a part of the waste collected. Another part of the waste which remains uncollected is the waste that is neither part of waste bins or open dumpsites. This is the waste found dumped into vacant plots of colonies, at various sites in the villages and open space on side of roads.

From the survey and analysis of information gathered, the existing fleet of waste collection and transportation vehicles, it was observed that the technology of waste collection vehicles was obsolete with respect to the available waste collection and transportation technologies.

The carrying capacity of individual vehicles was low, and each vehicle loaded with a small amount of waste has to makes many trips to the waste dump site, thus wasting fuel and time. This increases the cost of per unit of waste collected and transported.

The waste collection efficiency 59.3%, which is low. As per survey conducted by Federation of Indian Chamber of Commerce and Industry (FICCI) for waste collection efficiency reveals Kozhikode (Kerala) has 16% and in greater Mumbai it is 100% whereas, in Delhi and Surat (Gujarat) it is 90%. Except these, rest of other town and cities have collection efficiency less than 90% (Joshi and Ahmed, 2016; Syamala et al., 2016; Nema, A.K., 2004).

Hence, even though the MCR has a large fleet of waste collection vehicles the waste hauling capacity of the vehicles fleet is low and due to which the process of collection and transport of the waste is a lengthy process starting from 7am in morning and extending up to 7 pm in the evening.
7.4 Proposed management model for waste collection and transport.

On the basis of the shortcomings observed in the existing management system, a management plan has been proposed to make, the process more efficient and cost effective.

The proposed management model is designed to achieve the following objectives-
1. Minimize the number of vehicles,
2. Decrease the total distance traveled by the fleet of vehicles,
3. Decrease the time taken to collect and transport the waste to dump site,
4. Increased hygiene (Waste will be isolated from environment due to it being enclosed in a container, leachates from the waste will be contained, more frequency of waste lifting gives less time for the built up of pathogens and their spread through wind and insects. Higher collection frequency also allows less time for waste to decay and cause odour).

Minimization of vehicles- For any material to be transported the two important characteristics to be considered are the weight and the volume of the material. One of these two parameters will limit the loading capacity of the vehicle. Either the weight carrying capacity or the volume of the vehicle’s container will be exceeded. In case of material where the bulk density is low it is usually the volume capacity of the vehicle’s container which is exceeded. For such materials the volume can be reduced by compression of the material. The bulk density of the municipal solid waste of the study area is low i.e. 0.32 Kg/cm³ (Chapter 4, Table.4.6). On an average the municipal solid waste can be compressed to one fourth of its volume or the compression ratio of municipal solid waste is 1:3. Hence, compaction of the waste in the waste compartment of the vehicle can decrease the volume of the waste resulting in increase in the waste carrying capacity of the vehicle. Greater waste carrying capacity of each vehicle will result in requirement of lesser number of vehicles. Municipal waste compactors trucks are available in various sizes. Cost of compactor truck ranges between INR 8-15 lac depending on technical specifications such as, size of waste compression unit and the type of truck chassis.
The use of waste compactor trucks will result in the replacement of the existing large fleet of waste collection vehicles with a limited number of waste compactor trucks. This will be possible due to the much larger waste carrying capacity of each compactor truck. Limited number of compactor trucks will result in lesser travel distance and saving of time.

In the proposed management model compactor of 14 m$^3$ capacities is taken into consideration. The number of bins a 14 m$^3$ capacity compactor truck can service in one trip is shown in section 7.4.1.

Fig.7.3 Waste compactor trucks

In the previous chapter No.6, the community bins were allocated to each zone commensurate with its waste quantity generation. The bins were placed at location adhering to certain rules which ensured the optimum spatial placement of the waste bins. The number of bins and their placement has been utilized in the present objective.

The conceptual flow of the methodology adopted for the collection of bins or wastes from bins and its transportation to dumpsite is shown in Fig.7.4. From the calculations made (Section 7.4.1) each compacter of 12m$^3$ can service a maximum of 15 community bins of 1000 Kg. From the number of community waste bins placed in each zone, the number of compacters for each zone was determined. In the next step each dumper in the zone is given a route for the collection of a number of community waste bins. In the next step using the network analysis tool of GIS the shorted route for the collection of waste from the community bin was determined.
In each route it was ensured that the collection of waste was initiated from the farthest bin within that route. This ensures fuel saving as the vehicles during their travel to the initial bin is empty. And travel unloaded in the farthest bin. In this way the optimum route for each compactor is determined the network analysis tool of GIS.

It was also ensured that route should not be fragmented or overlapping. Collection and transportation time of each route should preferably be constant so as to equalize the workload. It is further suggested that the collection start at 7AM in the morning.

The number of bins and the number of compactor trucks required in each zone is shown in table 7.2.

![Fig. 7.4 Conceptual flow of work](image.png)
Table 7.2 Comparison between Tractor trolley and Compactor.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Number of bins</th>
<th>Number Tractor trolleys required</th>
<th>Need of number of Compactor (12 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>35</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>53</td>
<td>53</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

*Benefits Reason for use of compactor in new model*- Minimize number of vehicles by using compactor.

- Minimize travel time by shifting odd bins to main road or to a road already containing a bin.
- Balance the work load among the vehicles- Bins to different vehicles have been allotted on the bases of distance to be travel to from dump to zone and distance of bins from each other

*Merits of compactor*

- Time saving.
- Less travel distance
- Lesser fuel consumption.
- More hygienic during collection, transportation and off loading of waste.
- Human contact of waste is less.

**7.4.1 Waste carrying capacity of compactor truck**

It is assumed that the waste bins are of 1000kg capacity

Volume of compactor waste container = 14 m³

Volume of 1000 Kg waste (Calculated from bulk density of the waste) = 3.12 m³

Volume of the waste after compaction (1:3)
3.12/4 = 1.04 m³

Number of bins a 14m³ can service in one trip =
Volume of compactor waste container/Volume of waste after compaction.
14/1.04 = 13.5 bins or approx. 14 bins of 1000kg capacity.

Hence each 14m³ compactor truck can load waste from 15 bins of 1000kg capacity in one trip.

This specific has been taken into consideration as per recommendation given in “Specification of solid waste management equipments and machinery” document by Punjab Municipal Infrastructure Development Company (PMIDC), under “Swach Bharat mission”.

7.5 Result and discussion

From the maps from Fig. 7.5 to Fig. 7.18 of the waste collection routes of each zone the distance traveled by each vehicles was calculated. On the basis of total distance traveled by the proposed vehicle fleet and the existing fleet a fuel cost analysis was done based on the distance traveled. A time comparison analysis of the two waste collection fleets has also been presented.

In zone 1 three routes were generated among which Routes 1 of compacters 1 carries 12 bins with distance covered 29510.1 meters. Route 2 and route 3 of compacter 2 and 3 carries 12 and 11 bins with distance 16823.9 meters and 24664.8 meters. Represented in Fig. 7.5 to Fig. 7.7.
Fig. 7.5 Waste collection route of compactor 1 of Zone 1.

Fig. 7.6 Waste collection route of compactor 2 of Zone 1.
Fig. 7.7 Waste collection route of compactor 3 of Zone 1.

In zone 2 two routes were selected to collect the whole waste. Route 1 covers 13 (Fig. 7.8) and Route 2 covers 12 bins (Fig. 7.9) with distance of 1961.1 meters and 13237.5 meters.

Fig. 7.8 Waste collection route of compactor 1 of Zone 2.
In zone 3 three routes generated to carry whole waste. Route R1, R2 and R3 carries 13, 11, and 11 bins. Route R1, R2 and R3 covers 13061.2 meters, 14275.1 meters and 12982.3 meters from first site of collection bin to dumpsite. Spatial maps presented in Fig. 7.10, Fig. 7.11 and 7.12.
In zone 4 four routes were generated among which 13 bins on each route of R1, R2 and R3 covered whereas, on R4 14 bins were covered. The distance up to dumpsite covered by compacter 1, 2, 3 and 4 are 19023.6 meters, 16907.5 meters, 15681.9 meters and 15163.9 meters. Maps given in Fig.7.13, Fig. 7.14, Fig. 7.15 and Fig. 7.16.
Fig. 7.13 Waste collection route of compactor 1 of Zone 4.

Fig. 7.14 Waste collection route of compactor 2 of Zone 4.
Fig. 7.15 Waste collection route of compactor 3 of Zone 4.

Fig. 7.16 Waste collection route of compactor 4 of Zone 4.
In zone 5 and zone 6, one route for each was sufficient to carry whole waste. In zone 5, six bins on routes collected by compacter, which covers 30902 meters (Fig. 7.17). In zone 6, eleven bins were covered by single route compacter, which covers 16578.2 meters (Fig. 7.18).

Fig. 7.17 Waste collection route of compactor 1 of Zone 5.

Fig. 7.18 Waste collection route of compactor 1 of Zone 6.
Fuel cost analysis comparison- Due to the variety of waste collection vehicles, variety of makes variety of models, variety horse power and age of the vehicles and also as the technical data of the vehicles was not available. Apart from the preceding problems the fuel consumption would also differ due to loaded vehicle and empty vehicles. Thus calculation of the fuel consumptions of the fleet of waste collection vehicles is a very complex task. In the present study the distance traveled by the fleet of vehicles to collect all the community waste bins from all the zones has been used to indirectly access the fuel consumption of the vehicle of waste collection fleet at present in use and those proposed in the management model. A comparison has been made between a fleet of tractor trolleys and waste compactors. The distance covered by the tractor fleet and the proposed fleet of compactor trucks is show in Table 7.3 respectively. The distance traveled by the tractor fleet to collect waste from all the zones is 3970986.6 meters or 3970 km (even then only 57% only collected) whereas the distance traveled by the fleet of compactors to collect 100% of the city waste from all the zones is 258953.3 meters or 258 km. The distance traveled by the tractor fleet is at least ten folds the distance traveled by the compactor fleet. This is a drastic difference between the two collection fleets. Tractor trolley fleet is highly inefficient in terms of distance traveled which would translate into much higher fuel consumption also as compared to the dumper fleet. This difference is due to the low carrying capacity of the tractor trolley. Each tractor trolley can carry waste from only one waste bin. Most of the distance covered by the tractor trolley is outside the zones that are to cover the distance to and from the zone. As per “Vehicle Technology Market Report, 2015” a compactor truck on average gives 1.5 -2.5 km per liter of diesel when fully loaded and approx. 3 km/l when empty (Stacy et al., 2015). Whereas, the most efficient tractor gives 10-12 km/l or 2l of diesel/hour.
Table 7.3 Distance covered by compactor for bin collection.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Routes for compactor</th>
<th>Distance up to bypass (Meter)</th>
<th>Number of bins serviced</th>
<th>Total distance from zone to dumpsite (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R1</td>
<td>13744.1</td>
<td>12</td>
<td>29510.1</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>1057.9</td>
<td>12</td>
<td>16823.9</td>
</tr>
<tr>
<td></td>
<td>R3</td>
<td>8898.8</td>
<td>11</td>
<td>24664.8</td>
</tr>
<tr>
<td>2</td>
<td>R1</td>
<td>12883.5</td>
<td>13</td>
<td>19691.1</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>6429.9</td>
<td>12</td>
<td>13237.5</td>
</tr>
<tr>
<td>3</td>
<td>R1</td>
<td>7844.8</td>
<td>13</td>
<td>13061.2</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>9058.7</td>
<td>11</td>
<td>14275.1</td>
</tr>
<tr>
<td></td>
<td>R3</td>
<td>7765.9</td>
<td>11</td>
<td>12982.3</td>
</tr>
<tr>
<td>4</td>
<td>R1</td>
<td>10534.1</td>
<td>13</td>
<td>19023.6</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>8418.0</td>
<td>13</td>
<td>16907.5</td>
</tr>
<tr>
<td></td>
<td>R3</td>
<td>7192.5</td>
<td>13</td>
<td>15681.9</td>
</tr>
<tr>
<td></td>
<td>R4</td>
<td>7124.5</td>
<td>14</td>
<td>15613.9</td>
</tr>
<tr>
<td>5</td>
<td>R1</td>
<td>16751.4</td>
<td>6</td>
<td>30902.0</td>
</tr>
<tr>
<td>6</td>
<td>R1</td>
<td>14760.9</td>
<td>11</td>
<td>16578.2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>258953.3</td>
</tr>
</tbody>
</table>

7.5.1 Average distance for tractor trolley for one bin (Meters)

The following equation 1 was used to calculate the average distance covered by the tractor trolley for carrying the waste of one bin from collection point to dumpsite.

\[ AD = DCZ \times 2W \times CBS. \]  \hspace{1cm} (1)

AD = Average distance for tractor trolley for one bin
DCZ = Distance from centroid of zone
2W = Two way
CBS = Number of Community Bins serviced.

Zone wise average distance-
Zone 1- 17764.54 \times 2 \times 35 = 1243517.8 \text{ Meters}
Zone 2- 11550.39 \times 2 \times 25 = 577519.5 \text{ Meters}
Zone 3- 935.15 \times 2 \times 35 = 654615.5 \text{ Meters}
Zone 4- 995.75 \times 2 \times 53 = 1059549.5 \text{ Meters}
Zone 5- 22585.65 \times 2 \times 6 = 271028.04 \text{ Meters}
Zone 6- 7488.92 \times 2 \times 11 = 164756.24 \text{ Meters}
Total for zone 1-6 = 3970986.6 \text{ meters}

7.5.2 Collection time analysis of waste collection vehicles- The collection time analysis of tractor trolley and dumper truck is shown in subsection 7.5.2.1 and subsection 7.5.2.2 respectively. In case of tractor trolley total time taken for the collection a movement of waste of one bin is 150 minutes. The maximum time is taken by the tractor trolley to travel from the bin to the dumpsite and back (90 Minutes). Loading of waste on to tractor trolley takes 40 minutes.

On the other hand in case of compactor it takes only 340 minutes to collect and transfer waste from 14 bins to dumpsite. Loading time of waste bin on to compactor takes 10 minutes. The average time for compactor to move from one bin to the next bin has been taken as 10 minutes. Has the total time taken to collect waste from 14 bins is 270 minutes.

From the time analysis of tractor trolley and compactor it can been seen that where as it takes 150 minutes per bin in case of tractor trolley it takes only 340 minutes for 14 bins in case of compactor truck. So compactor truck gives much better time management than the tractor trolleys. From the comparison of loading capacity, collection time analysis and travelled distance of tractor trolley and compactor truck it can be concluded that collection and transfer of waste using compactor truck is much faster economical and also leads to fuel waste collection vehicles on the road better hygiene as waste is transported in a contained container and as the collection through compactor trucks is much faster. The collection frequency of twice a day for each bin can be easily managed. The benefit of having a collection frequency of twice a day is that the degradation of organic matter and built up of pathogenic organisms is less as the waste
is shifted to dumpsite at a faster frequency this leads to better quality of air in terms of lesser odor nuisance and airborne pathogens.

### 7.5.2.1 Collection time analysis of Tractor Trolley

- Loading time- 40 Minutes
- Dumping time- 10 Minutes
- To and fro from bin to dumpsite- 90 Minutes
- Trip – one trip per bin (1000 Kg)
- Total time taken for one cycle- 150 minutes

### 7.5.2.2 Collection time analysis of Compactor (14 m³ waste holding capacity)

- Loading time- 10 Minutes
- Dumping time- 10 Minutes
- From one depot to other- 10 Minutes
- Time taken to collect 14 bins- 10min x13 +10x14 = 270minutes
- To and fro from bin to dumpsite- 60 Minutes
- Total time take for one cycle- 340 minutes

From the above study the following conclusions can be drawn.

- The fleet of waste collection vehicles is not sufficient.
- The amount of MSW projected for the city by MCR is 226 MT whereas the total hauling capacity of the vehicle fleet is 128.84 MT which leaves a gap of 97.16 MT.
- Waste collection fleet is technologically obsolete consisting mainly of tractor trolleys.
- Multiple handling of waste causing health hazard to workers.
- Tractor trolleys are not covered resulting in spilling of waste along the way.
• Each tractor trolley can carry only one waste bin to the dumpsite resulting in loss of time and fuel as it has to cover the whole distance for every bin.

• In the proposed model compactor collects up to 14 bins before going to dumpsite. Resulting in time saving and fuel saving as the distance travelled is much less.

• Easy and safe handling of waste, less hazard to workers.

• Waste is totally contained in the storage of compactor, hence no spilling.

• Each compactor can work in 2 shifts as the time required to complete 1 route is maximum 5.06 Hrs.

The proposed management system for the waste collection and transport overcomes the shortcomings of the existing system. Its implementation will result in higher waste collection efficiency, better hygiene and shorter collection time.