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# A Comprehensive Study on Solid Waste Vehicle Routing and Tracking – a Case Study on Kolkata City

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**Abstract**

Kolkata city generates about 3500 Metric Ton (MT) of solid waste per day. Waste collected at storage vats/containers is transported to disposal ground at Dhapa by Kolkata Municipal Corporation (KMC) departmental vehicles and hired vehicles. Collection, segregation and transportation of municipal solid waste in KMC area is unplanned and chaotic; there is no uniformity in the size of containers/open vats and the size and haulage capacity of transport vehicles. The operational efficiency of KMC transport system is about 50%, with a fleet composed of 30-35% old vehicles. KMC spends 70-75% of its budget on collection of solid wastes, 20-25% on transportation and less than 5% on disposal. KMC allocates different types of collection vehicles to different types of containers/open vats depending on waste generation at a location and compatibility of the vehicles with the storage receptacles. It was, thus, a challenge to present an acceptable, realistic solution optimising the waste vehicle routes, thus cutting down on the transportation costs and increasing overall efficiency. ArcGIS Desktop has been used to determine least cost paths for collection and transportation of wastes; while low-cost tracking methods has been attempted using ArcGIS and Garmin 72H GPS set.

Keywords: *Municipal Solid Waste (MSW), vehicle routing and tracking, Geographic Information System (GIS), Kolkata Municipal Corporation (KMC), Global Positioning System (GPS)*

## 1. Introduction

Kolkata is one of the four major metro cities in India and the capital of West Bengal state. The city has an area of about 187.33 sqkm and a population of about 10 million (including floating population of about 6 million). KMC comprises of 15 boroughs and 141 electoral wards; each borough consisting of a cluster of wards. KMC area currently generates a total of about 3500 MT of solid waste per day. Source segregation is absent and house-to-house collection is limited to 65% only. Conservancy staff collects waste from households and streets and dumps them at skips/MS containers (55%) or at open vats (45%). Collected waste is transported directly to disposal ground at Dhapa by KMC departmental vehicles and KMC-hired vehicles. The collected waste has high biodegradable fraction (50.56% by wet weight), high inert content (29.6% by wet weight), high moisture content (46% by dry weight) and a low calorific value of 1201 kcal/kg.

In Kolkata, the major disposal ground is Dhapa (21.47 ha) located in the eastern side of the city. It receives about 3000-3200 MT of solid waste per day. Another site at Garden Reach (3.52 ha) receives only about 100-150 MT of solid waste per day. Waste is simply spread at the landfilling sites by the dozers without any treatment and/or compaction. KMC spends 70 to 75% of its total budgetary allocation on collection of solid waste, 25 to 30% on transportation, thus leaving a meager 5% for final disposal (Chattopadhyay *et al.*, 2009). The researchers had taken three contiguous KMC wards – 65, 66, 67 as their study area. It has been assumed in this paper that collection vehicles at these three wards are dispatched from KMC Transport Depot at Behala. Both Transport Depot (Behala) and Dhapa have garage and workshop facilities. Fig. 1 and Fig. 2 show the Kolkata city with Transport Depot (Behala) and Dhapa and the demarcation of KMC wards/boroughs.

Collection, transportation and disposal of MSW in Kolkata encompass an extremely complex set of operations.

- Street sweeping and cleaning: Using a broom, shovel and handcart municipality staffs execute sweeping and cleaning of the streets in the early morning. Inert materials and solid wastes littered by citizens along roadside/low-lying areas are collected into the handcarts and deposited at the nearby vats/container points.
- Residential, slum and commercial complexes: In the early morning hours, conservancy staff arrive at their assigned

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Fig. 1. Google Map of Kolkata City Showing Transport Depot Near Taratola, Behala (balloon mark) and Dhapa (balloon mark)

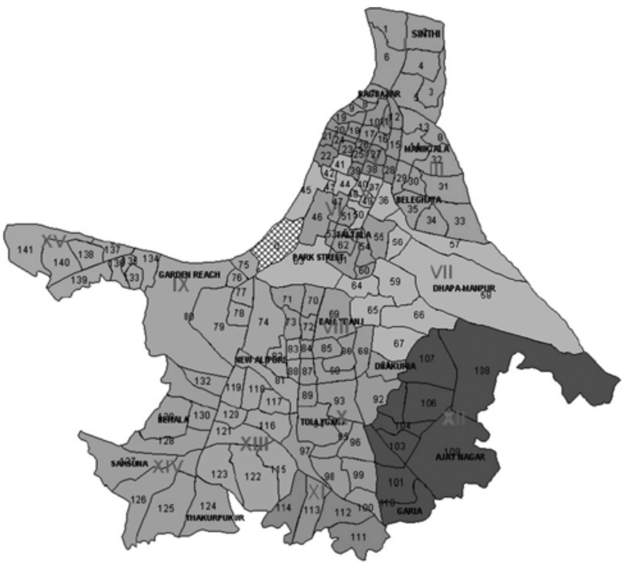



Fig. 2. Map Showing Demarcation of Wards and Boroughs in KMC Area (Source: CGWB literature)

areas with handcarts and blow their whistles requesting residents to deposit wastes in their handcarts. The handcarts are then taken to the nearby vat/container locations and MSW transferred to the vats/container locations. This door-to-door collection has been successfully implemented in about 65% of KMC area and KMC proposes to increase the percentage in coming years.

- Large hotels/restaurants have their own storage containers and waste is collected by KMC on payment basis. Small enterprises, however disposes their wastes to nearby KMC vats. KMC collects wastes from vats/containers located in markets regularly and much of such wastes are putrescible.

Total collection points in the city is around 650 with 365 mild-steel MS skips/containers, 20 direct loading, and 265 open vat points (Chattopadhyay *et al.*, 2009). KMC proposes to convert open vats to closed container systems. Skips/Containers are of two sizes – Normal (4.5 $m^3$) and Big (7 $m^3$). Fig. 3a on the left shows a container (big) and Fig. 3b on the right shows an open vat.

The present transport system utilizes private-owned lorries to transport 60% of the daily generated garbage and most of the silt/rubbish. Haulage capacity of these vehicles is around 4 MT for manually loaded and 7 MT for payloader loaded. Each lorry visits open vat location(s) and after their haulage capacity is exceeded, the vehicles proceed to the dumping ground at Dhapa. The collection and transport mechanism may be compared with Stationary Container System (SCS).

The remaining 40% of MSW is transported by three categories of KMC-owned vehicles:

Container (skip) carrying vehicles (Dumper-Placers): They


Fig. 3. (a) Figure Showing a Container (big), (b) Figure Showing One Particular Type of Open Vat

have a haulage capacity of 2.0 MT. One DP can hoist and transport only one big container at a time to the disposal ground. The collection and transport method may be compared with Hauled Container System (HCS).

Manually loaded Trucks: They haul around 3 MT of MSW to the Dhapa landfill site from various open vats/open dumping areas in one trip. Their collection and transportation mechanism can be compared to SCS. KMC is in favour of discouraging multiple manual handling of waste.

Payloader loaded Tipper Trucks: They haul around 7.0 MT of MSW in one single trip to Dhapa. These vehicles collect MSW from various open vats and after collecting around 7 MT of wastes, it proceeds to Dhapa. Their collection and transportation mechanism can be compared to SCS.

On an average, 305 vehicles collect and transport waste to disposal ground daily, out of which 105 are KMC-owned and 200 are private hired vehicles. There are six main vehicle garages and four subsidiary garages from where KMC vehicles operate daily to transport wastes from vat/container locations to the disposal ground. 30-35% of KMC vehicles are more than 7 years old while 80% of the hired vehicles are more than 20 years old. Operational efficiency of KMC vehicles is around 50% (Chattopadhyay *et al.*, 2009).

Under such circumstances, the researchers focused on increasing the operational efficiency of the existing vehicle fleet (both KMC-owned as well as privately-owned) by using Network Analyst extension of ArcGIS Desktop as a decision support tool for efficient management of solid waste vehicles, route optimisation, managing fuel consumption (thus minimising associated pollution) and generating work schedule for vehicles and workers. Monitoring of the daily operations has been proposed by integrating Tracking Analyst extension of ArcGIS with Garmin 72H handheld GPS sets. Analogous studies reported by several researchers (Ghose *et al.*, 2006; Karadimas *et al.*, 2007; Vijay *et al.*, 2008; Apaydin *et al.*, 2004; Chalkias *et al.*, 2009; Kanchanabhan *et al.*, 2011; Jovičić *et al*., 2011; Islam *et al.*, 2012) had shown promising results for route optimisation of solid waste vehicles using ArcGIS Desktop; however their work did not take into account the various parameters affecting vehicle routing as has been taken into consideration in this present work. Interestingly, Jovičić *et al.* had proposed integration of GIS and GPS technology for optimisation of waste vehicle routes in the city of Kragujevac, Serbia.

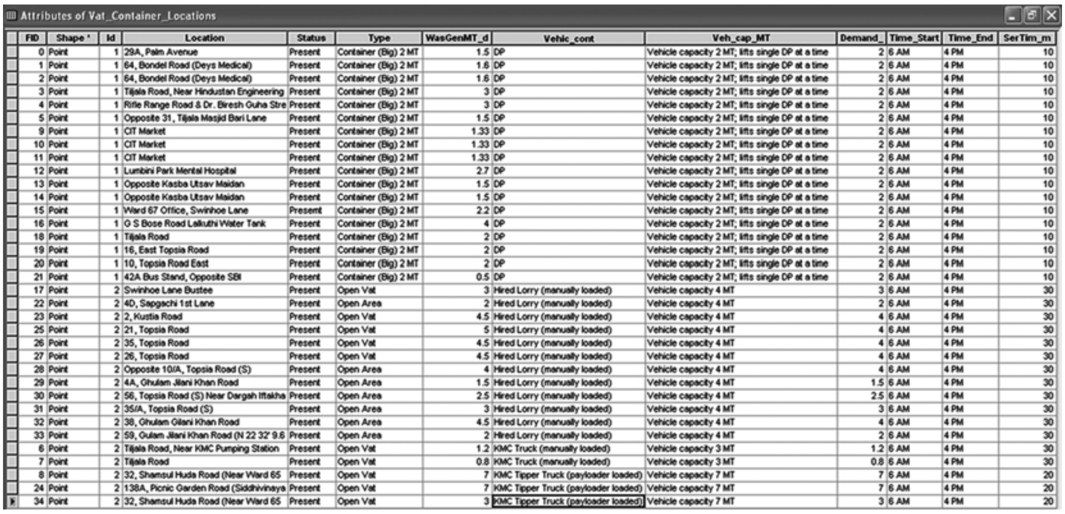
Literature review shows the popularity of GIS for the route optimisation studies. GIS is suitable tool for these kinds of study as it is capable to store, retrieve, analyse and display a large amount of spatial data, under a complicated georelational scheme (Chang *et al.*, 1997). GIS provides network-based spatial analysis and application of ArcGIS Network Analyst make the user able to dynamically model realistic road-network conditions. The authors thus propose an economically and environmentally sustainable GIS-based solid waste transportation model, through which the existing resources are properly utilised by providing the shortest routes, hence minimising overall Municipal Solid Waste Management (SWM) costs. The proposed interactive design procedure using GIS allows a decision maker to analyse many waste collection alternatives before selecting a final operational scenario.

## 2. Materials and Methods

### 2.1 Route Optimisation

Paper maps were scanned, georeferenced and digitised in ArcGIS environment using WGS 1984 UTM Zone 45 N projected coordinate system. Shapefiles for road network (Roads.shp), important landmarks, railway-lines, ward boundaries were extracted for our study area. Update of road networks was done directly in Google Earth and then added it to ArcMap. The Roads.shp was checked for topology errors after incorporating it into a Routes.mdb personal geodatabase and 'Roads' feature dataset. Thus, overlap and gap errors were eliminated using topology rules; the corrected line geodatabase feature class was named 'Streets_Corr' and stored within the 'Roads' feature dataset. The researchers personally visited all the traffic signal locations with handheld Garmin 72H GPS set and recorded the lat/long coordinates of the traffic signals. A point shapefile depicting locations of traffic signals was subsequently incorporated in ArcMap. The visit to the traffic signals also gave an idea about the signal cycles at each of these locations.

In 2005, under Asian Development Bank (ADB) financially assisted Kolkata Environmental Improvement Plan, a master-plan on MSW management was drawn up to ameliorate



Attributes of Vat_Container_Locations

| FID | Shape * | Id | Location | Status | Type | WasGenMT_d | Vehic_cont | Veh_cap_MT | Demand_ | Time_Start | Time_End | SerTim_m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Point | 1 | 29A, Palm Avenue | Present | Container (Big) 2 MT | 1.5 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 1 | Point | 1 | 64, Bondel Road (Deys Medical) | Present | Container (Big) 2 MT | 1.6 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 2 | Point | 1 | 64, Bondel Road (Deys Medical) | Present | Container (Big) 2 MT | 1.6 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 3 | Point | 1 | Tiljala Road, Near Hindustan Engineering | Present | Container (Big) 2 MT | 3 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 4 | Point | 1 | Rifle Range Road & Dr. Biresh Guha Stre | Present | Container (Big) 2 MT | 3 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 5 | Point | 1 | Opposite 31, Tiljala Masjid Bari Lane | Present | Container (Big) 2 MT | 1.5 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 9 | Point | 1 | CIT Market | Present | Container (Big) 2 MT | 1.33 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 10 | Point | 1 | CIT Market | Present | Container (Big) 2 MT | 1.33 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 11 | Point | 1 | CIT Market | Present | Container (Big) 2 MT | 1.33 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 12 | Point | 1 | Lumbini Park Mental Hospital | Present | Container (Big) 2 MT | 2.7 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 13 | Point | 1 | Opposite Kasba Utsav Maidan | Present | Container (Big) 2 MT | 1.5 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 14 | Point | 1 | Opposite Kasba Utsav Maidan | Present | Container (Big) 2 MT | 1.5 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 15 | Point | 1 | Ward 67 Office, Swinhoe Lane | Present | Container (Big) 2 MT | 2.2 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 16 | Point | 1 | G S Bose Road Lalkuthi Water Tank | Present | Container (Big) 2 MT | 4 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 18 | Point | 1 | Tiljala Road | Present | Container (Big) 2 MT | 2 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 19 | Point | 1 | 16, East Topsia Road | Present | Container (Big) 2 MT | 2 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 20 | Point | 1 | 10, Topsia Road East | Present | Container (Big) 2 MT | 2 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 21 | Point | 1 | 42A Bus Stand, Opposite SBI | Present | Container (Big) 2 MT | 0.5 | DP | Vehicle capacity 2 MT; lifts single DP at a time | 2 | 6 AM | 4 PM | 10 |
| 17 | Point | 2 | Swinhoe Lane Bustee | Present | Open Vat | 3 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 3 | 6 AM | 4 PM | 30 |
| 22 | Point | 2 | 4D, Sapgachi 1st Lane | Present | Open Area | 2 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 2 | 6 AM | 4 PM | 30 |
| 23 | Point | 2 | 2, Kustia Road | Present | Open Vat | 4.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 25 | Point | 2 | 21, Topsia Road | Present | Open Vat | 5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 26 | Point | 2 | 35, Topsia Road | Present | Open Vat | 4.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 27 | Point | 2 | 26, Topsia Road | Present | Open Vat | 4.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 28 | Point | 2 | Opposite 10/A, Topsia Road (S) | Present | Open Area | 4 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 29 | Point | 2 | 4A, Ghulam Jilani Khan Road | Present | Open Area | 1.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 1.5 | 6 AM | 4 PM | 30 |
| 30 | Point | 2 | 56, Topsia Road (S) Near Dargah Iftakha | Present | Open Area | 2.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 2.5 | 6 AM | 4 PM | 30 |
| 31 | Point | 2 | 35/A, Topsia Road (S) | Present | Open Area | 3 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 3 | 6 AM | 4 PM | 30 |
| 32 | Point | 2 | 38, Ghulam Gilani Khan Road | Present | Open Area | 4.5 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 4 | 6 AM | 4 PM | 30 |
| 33 | Point | 2 | 59, Gulam Jilani Khan Road (N 22 32' 9.6 | Present | Open Area | 2 | Hired Lorry (manually loaded) | Vehicle capacity 4 MT | 2 | 6 AM | 4 PM | 30 |
| 6 | Point | 2 | Tiljala Road, Near KMC Pumping Station | Present | Open Vat | 1.2 | KMC Truck (manually loaded) | Vehicle capacity 3 MT | 1.2 | 6 AM | 4 PM | 30 |
| 7 | Point | 2 | Tiljala Road | Present | Open Vat | 0.8 | KMC Truck (manually loaded) | Vehicle capacity 3 MT | 0.8 | 6 AM | 4 PM | 30 |
| 8 | Point | 2 | 32, Shamsul Huda Road (Near Ward 65 | Present | Open Vat | 7 | KMC Tipper Truck (payloader loaded) | Vehicle capacity 7 MT | 7 | 6 AM | 4 PM | 20 |
| 24 | Point | 2 | 138A, Picnic Garden Road (Siddhivinaya | Present | Open Vat | 7 | KMC Tipper Truck (payloader loaded) | Vehicle capacity 7 MT | 7 | 6 AM | 4 PM | 20 |
| 34 | Point | 2 | 32, Shamsul Huda Road (Near Ward 65 | Present | Open Vat | 3 | KMC Tipper Truck (payloader loaded) | Vehicle capacity 7 MT | 3 | 6 AM | 4 PM | 20 |

Fig. 4. Attribute Table Developed for Vat_Container_Locations shapefile

environmental conditions in Kolkata city. Guided by ADB 2005 survey data addresses on location of open vats/containers within the study area, the researchers visited the container/vat locations with GPS set and recorded the lat/long of the vats/containers. A few of the vats/containers were found to be relocated while some were found to be non-existent. It is a matter of concern, that with increase in population in KMC area, residents are exerting pressure on KMC to shift vats/containers from their backyards. KMC allocates a particular vat/container to a particular type of vehicle; big containers are hauled by KMC-owned Dumper-Placers, while open vats/open areas are catered to by privately owned lorries/manually loaded KMC Truck / Payloader loaded Tipper Truck. A shapefile layer, Vat_Container_Locations.shp, showing the location of vats and containers was created with all details fed into the attribute table (Fig. 4).

‘Type’ field shows open vat/container type present at the specified location; ‘WasGenMT_d’ depicts the waste generated per day at the location; ‘Vehic_cont’ field elaborates on the type of vehicle KMC dispatches at the location; ‘Veh_cap_MT’ is the field for the capacity of the vehicle visiting the storage location(s); ‘Demand_MT’ field depicts the tonnage of load the vehicle will have to pick at the storage location – in case of DP it is always 2 MT since it will have to hoist the skip/container as a whole. ‘Time_Start’ and ‘Time_End’ is the time window within which the vehicle must visit the vats/containers. ‘SerTim_m’ is the time taken by the vehicles to load the MSW at a storage location.

Similarly, the ‘Streets_Corr’ layer was integrated with a set of attribute data so that Network Analyst extension of ArcGIS is later able to simulate the real-life situation accurately. Planarize Lines command was used to break the lines at each street line

Table 1. Table Showing Different Fields Created in Streets_Corr Layer

| Name of field | Source & Purpose |
|---|---|
| OBJECTID | ArcGIS automatically assigns a particular ID to each street polyline during digitization. This OBJECTID is required during development of turntable layer ‘select_turns’. |
| Road_Name | Name of the roads are assigned in this field. |
| Shape_Length | This field updates automatically during digitization of streets polylines. It stores the length of each road segment in meters. |
| FENAME | Same as Road_Name. This field is used during building the Network dataset. |
| FETYPE | Whether the street segment is Avenue/Road/Highway/Flyover/Lane. |
| NA_HIERARCHY | Roads were classified into Primary, Secondary and Local Road depending on their width and speed of vehicles. |
| ROAD_CLASS | Primary roads are assigned 1, Secondary roads 2 and Local roads 3 |
| HIERARCHY | Same as ROAD_CLASS. |
| SPEED_KMPH | Speeds of vehicles in each road segment are fed in this field. |
| FROM_NODE<br>TO_NODE | These two fields store the from- and to-nodes for each road segment. This was generated automatically using ArcHydro. These two fields were used in generating turntables. |
| ONEWAY | Some of the road segments/lanes are restricted as oneway. |
| METERS | Same values as in Shape_Length field in meters. |
| MINUTES | Time of travel on each road segment was calculated using METERS and SPEED_KMPH fields. |
| TF_MINUTES<br>FT_MINUTES | In case of mutilane roads, where traffic flow is restricted along each lane, TF_MINUTES may not equal FT_MINUTES. In other cases, MINUTES = TF_MINUTES = FT_MINUTES. |
| F_ELEV<br>F_ELEV | These fields simulate the non-planar, non-intersection of two intersecting roads, in case of a bridge/flyover/underpass/over-pass. |

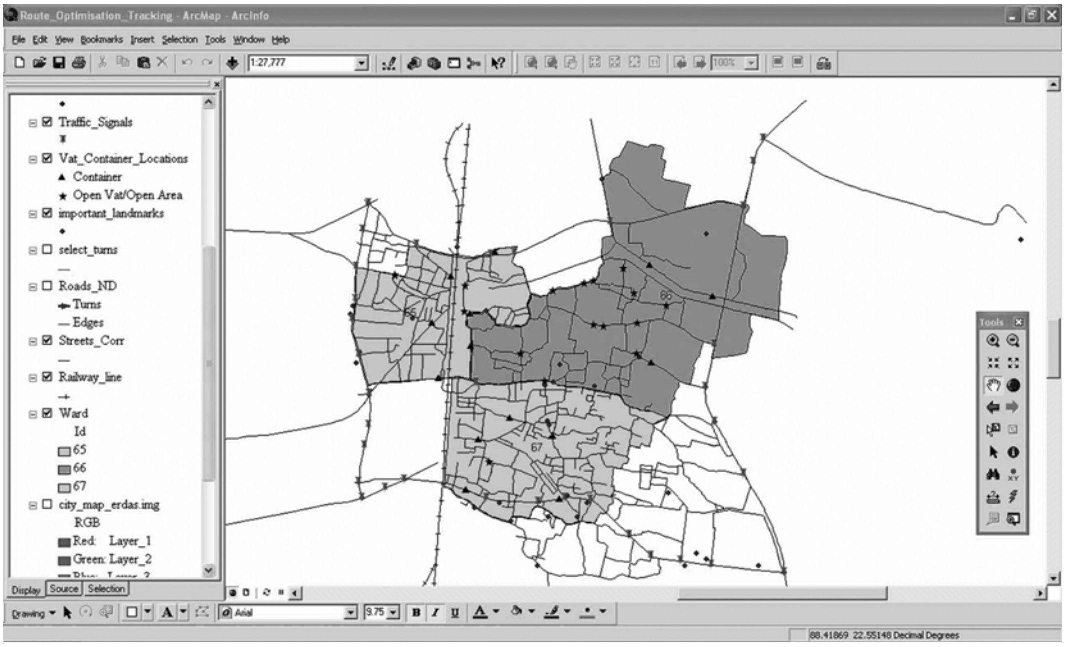



Fig. 5. ArcMap File (Route_Optimisation.mxd) Showing Different Layers and the Study Area

intersection vertex and then attribute fields of 'Streets_Corr' layer were developed (Table 1).

A turntable 'select_turns' layer was developed for street intersections where traffic signals are present. Suitable impedance_time against turns were fed into the attribute table taking into consideration the fact, that no vehicle may encounter full-time red/green signals at every intersection.

A Roads_ND Network Dataset was created under 'Roads' feature dataset in ArcCatalogue using Hierarchy, Meters, Minutes (cost attribute), Oneway, Roadclass attributes - Hierarchy, Oneway, Minutes were kept as default. Hierarchy ensured that conservancy vehicles prefer to use primary and secondary roads for ease in maneuverability. Turntable 'select_turns' and Global Turn Delays (applicable for road junctions where traffic signals are absent) were linked to the Minutes attribute. Fig. 5 shows the different layers in the ArcMap file.

All these shapefiles, geodatabase files, .mxd file and the Network Dataset were placed in Route Optimisation folder. Five copies of the folder viz. Route Optimisation_DP, Route Optimisation_HiredLorry, Route Optimisation_KMCTruck_manuallyloaded, Route Optimisation_KMCTipperTruck_payloaderloaded, Route Optimisation_Tracking were made and the data sources of the different layers in the .mxd file present in each of these folders was set right.

### 2.1.1 Route Optimisation for Dumper-Placers Servicing Containers

The .mxd file (rechristened Route_Optimisation_DP.mxd) in Route Optimisation_DP folder was opened. In the Vat_Container _Locations attribute table, all data pertaining to open vats/open areas were deleted so that only container (big) data remains. In Network Analyst extension, New Vehicle Routing Problem was adopted. In the Vehicle Routing Problem Properties, it was ensured that the network solution is based on time-attribute and U-turns were allowed everywhere. Although maneuvering U-turns is difficult in Local Streets, yet in real life conservancy vehicles take U-turns taking the help of nearby street intersections. Orders( ) layer in Network Analyst window was loaded with all the 18 locations of the skips/containers present in the study area. The following attribute data were simultaneously loaded from the Vat_Container_Locations layer:

Service Time: SerTim_m field i.e. 10 (minutes) implying that it takes 10 mins to hoist the skips/containers in the Dumper-Placers.

Time Window: Time_Start and Time_End fields i.e. 6 AM to 4 PM implying that the vehicle must service the solid waste location within the specified period.

Pickup Quantity: Demand_MT field (2 MT always for DP)

Next, the two depots - Transport Depot, Behala (where the vehicle starts) and the Dhapa site (where the journey ends) were added under Depots( ). The time-window for Dhapa depot was kept at 6 AM to 4 PM. It is assumed that these vehicles (Dumper-Placers) start from Transport Depot, pick-up waste at a location, unload at Dhapa, rush back at the same location to place the empty container and proceed to the next location. The route optimisation has been executed for the journey starting from Transport Depot, Behala to the last trip to Dhapa. At the end of the day, the vehicle may/may not be subjected to cleaning/ servicing at Dhapa depot and later return to Transport Depot.

Three truck routes (Truck_1, Truck_2, Truck_3) were added with the following attribute values:

Start Depot Name: Transport Depot
End Depot Name: Dhapa
Earliest Start Time: 6 AM
Latest Start Time: 6 AM

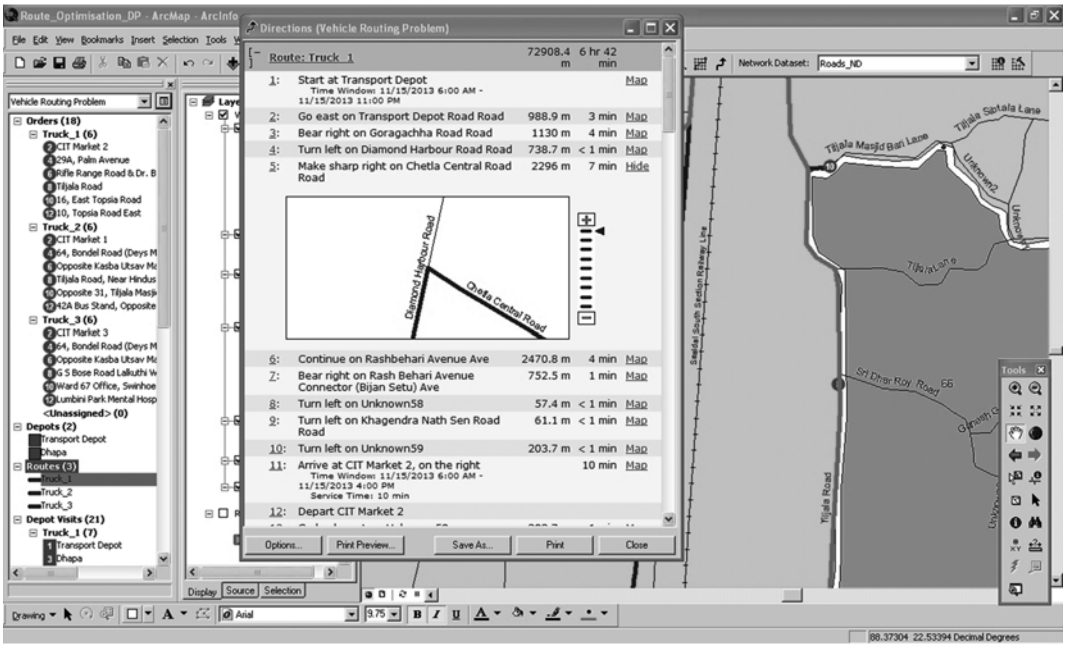



Fig. 6. Route optimisation for Dumper-Placers hauling containers/skips

Max Total Time: 600 minutes. i.e. the working hours of these vehicles including lunch break.

Capacities: 2 MT

Provision for a 60 mins break for these three vehicles was kept. The break must commence between 11 AM to 12-30 PM.

Route Renewal depot for each of the three truck routes Truck_1, Truck_2 and Truck_3 was kept as Dhapa with a service time of 20 mins. - implying that it will take 20 mins for the dumper-placers to empty their skip at Dhapa.

The network was solved and step-by-step journey chart for each truck along the shortest route was obtained from the Directions Window (Fig. 6). A close examination of the Directions Window for Truck_1, Truck_2 and Truck_3 revealed that their entire day is almost covered; otherwise we may need to increase/ decease the number of truck or we may have to feed overtime data in Routes( ).

### 2.1.2 Route Optimisation for Hired Lorries Servicing Open Vats/Open Areas

Within the study area, all the hired lorries were found to be

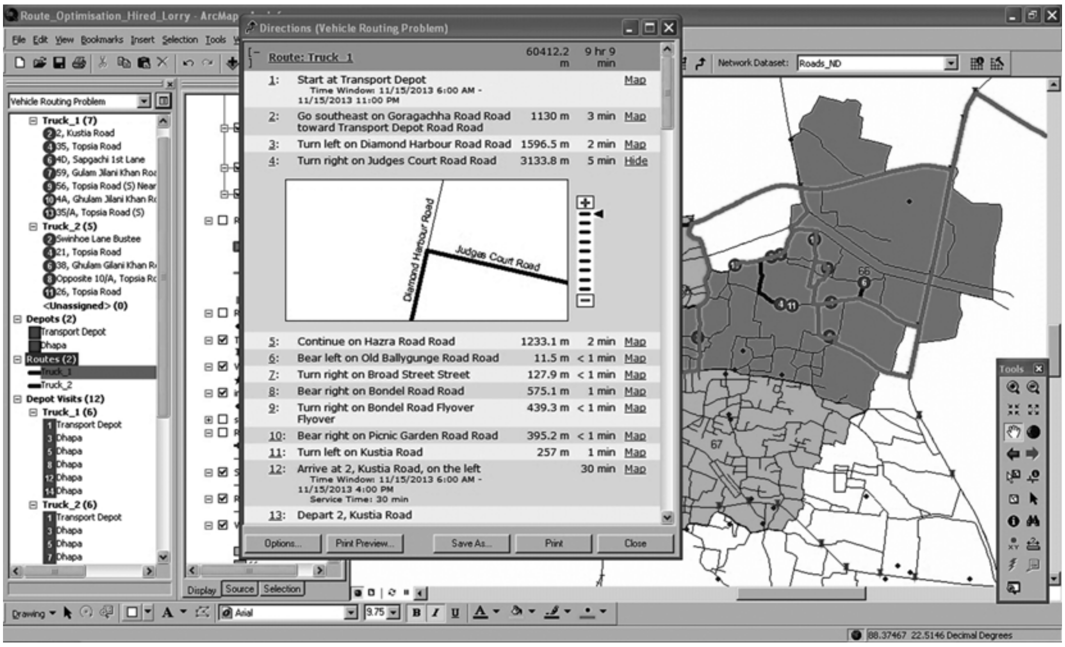



Fig. 7. Route Optimisation for Hired Lorries Servicing Open Vats/open Areas

manually loaded.

The .mxd file (renamed Route_Optimisation_Hired_Lorry.mxd) in Route Optimisation_HiredLorry folder was opened. In the Vat_Container_Locations attribute table, only the data pertaining to the open vats/open areas catered to by the privately-owned hired lorries were kept. Orders( ) layer in Network Analyst window was loaded with all the 12 locations of the vats/open areas present in the study area. The following attribute data were simultaneously fed from the Vat_Container_Locations layer:

Service Time: SerTim_m (assumed 30 mins to load the waste into hired lorries)

Time Window: Time_Start and Time_End fields

Pickup Quantity: Demand_MT field

Two depots, Transport Depot, Behala (where the vehicle start) and the Dhapa site (where the journey ends) were added under Depots( ). The time-window for Dhapa depot was kept at 6 AM to 4 PM.

Two truck routes (Truck_1, Truck_2) were added with the following attribute values:

Start Depot Name: Transport Depot

End Depot Name: Dhapa

Earliest Start Time: 6 AM

Latest Start Time: 6 AM

Max Total Time: 600 minutes. i.e. the working hours of these vehicles including lunch break.

Capacities: 4 MT, since these lorries can load and haul a maximum capacity of 4 MT of MSW at a time.

Provision for a 60 mins break for these three vehicles was kept; the break is to commence between 11 AM to 12-30 PM.

Route Renewal depot for each of the two truck routes Truck_1 and Truck_2 was kept as Dhapa with a service time of 30 mins.

The network was solved and stepwise route chart for each truck along the shortest path was generated (Fig. 7). A printout of Direction Windows may be taken and handed over to the vehicle drivers so as to enable them follow the optimal route.

An approach similar to that used in the case of hired lorries was used for optimising the routes for KMC Tipper Trucks (payloader loaded) and KMC Trucks (manually loaded).

### 2.2 Vehicle Tracking

Recording Method of the Garmin 72H GPS was set to record at a time interval of 30 seconds. The GPS, costing around Rs. 11,000 (1 $ = Rs. 62 approx) was fitted to a private car and proceeded from a container location (Fig. 8) towards Dhapa landfill site. DNR Garmin software was used to download the track from Garmin 72H, saved as a point shapefile and later opened in Route_Optimisation_Tracking.mxd. The spatio-temporal data was then played in ArcGIS Tracking Analyst Playback Manager and the progress of the vehicle monitored both in Playback Manager as well as in the attribute table of the tracking.shp shapefile (Fig. 8 and Video 1). It is suggested that the solid waste vehicles be similarly fitted with GPS so that their movement can be tracked/monitored. This will curtail non-productive activities of the vehicles, cut down fuel costs, increase operational efficiency and eliminate deviation of the solid waste vehicles from the planned optimised route.

Real-time tracking using live temporal data stream from a GPS device can be achieved using an ArcIMS Tracking Server; however, it requires purchase of a server account from ESRI. There are some firms/companies in the market which provide real-time tracking solutions – the authors have, however, confined themselves to a simple cost-effective tracking solution which

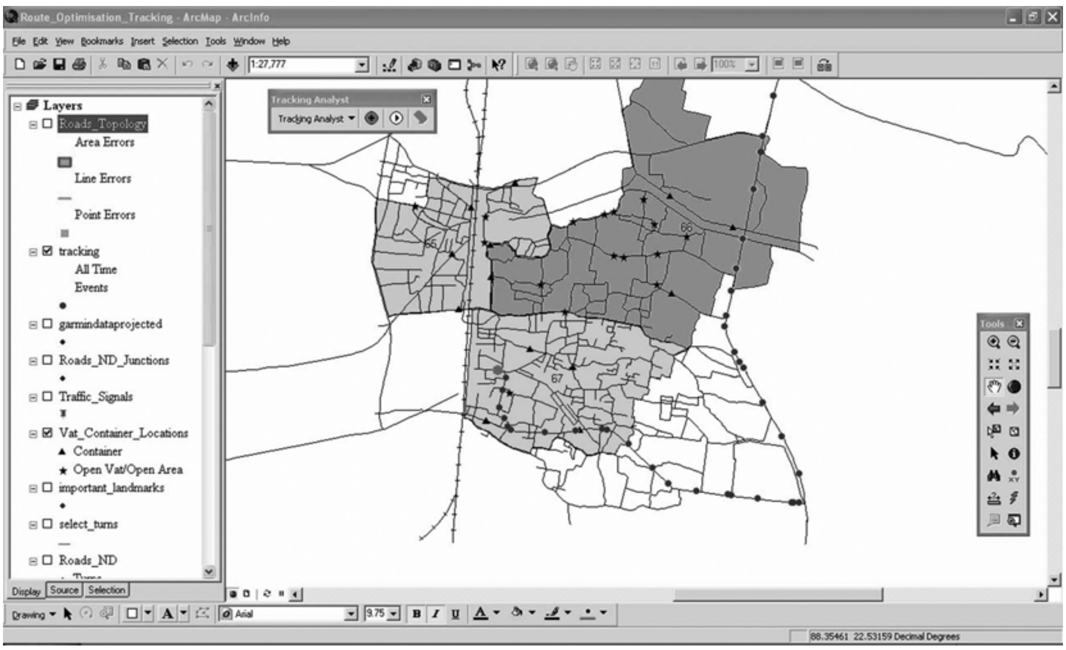



Fig. 8. Vehicle Tracking from Container Opposite Ward no. 67 Office to Dhapa

may suffice KMC's needs at the present moment.

## 3. Conclusions

Being a public utility and an essential service, investment in solid waste management does not warrant a justification in terms of "positive return on investment". Such an investment, however, needs to be justified on the basis of being "the least cost technologically feasible option" for achieving the required degree of efficiency (Ghose *et al.*, 2006).

A GIS optimum routing model taking into account myriad parameters like waste generation capacity, road hierarchy, turn delays, vehicle speed, traffic restrictions, location of traffic signals and signal cycles, size of bins, types of collection vehicles dispatched at each location, haulage capacity of collection vehicles, time window for collection of waste, etc. is developed and used to calculate the time-impedance based shortest route. The user will also be able to define or modify dynamic factors (like a temporary road-block) in a street and easily incorporate the same in the solution. The authors in this paper have proposed use of the complex, yet, powerful Vehicle Routing Problem VRP solver present in Network Analyst extension, since the VRP solver simulates the solid waste collection and transportation process more accurately and convincingly. The proposed technique, if followed, will definitely lead to better fleet utilisation, improve workforce management and increase the operational efficiency of KMC.

Similarly, vehicle tracking is expected to decrease idle labour and increase fuel efficiency by enabling the KMC to monitor and analyse the entire collection and transportation process. The proposed SWM model incorporating GIS/GPS can thus be an effective decision support tool for MSW transport, work distribution for conservancy staff and vehicles and managing fuel consumption.

The present work may be extended to the introduction of separate waste collection for different waste streams e.g., recyclables, biodegradables, etc. One shortcoming of the GIS approach is the inherent assumption that waste generation in the vats/containers remains constant with time. However, waste generation rates are susceptible to vary over a time-span; future work may be carried out to integrate the variable waste generation rates into the analysis. A similar GIS-based work to reallocate vat/container points depending on their waste generation quantity may be taken up in future, so as to minimise the route length to disposal ground, taking into account the existing CPHEEO regulations regarding the maximum distance between two vat points.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Video 1. Tracking Animation, available at http://www.koushikjournals.in/