Solid Waste Management In Urban India

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Abstract

The complete process of waste management is a complex one involving multiple systems and sub-systems. This project analyses the process of solid waste management in Ward 19, Sanjaynagar. The problem area which is the focus of this project is the routing of the solid waste collection trucks in ward 19.

Critical Observation: Presently there are no official instructions given to the drivers regarding the route to be followed. The route is decided by the driver and supervisor using their experience.

Hence this project aims at finding the most optimal routes for the trucks using various methods of routing and scheduling in transportation. It also includes the simulation of the process to explain the process better and to compare the various options on the basis of different parameters. The project critically reviews the present practices of collection and disposal of solid waste management which involves the following steps such as: Collection of data relevant to the issue from various sources such as data on available resources to manage solid waste, amount & nature of solid waste, layout/route/timing data. Followed by, preparing and conducting surveys to develop a deeper understanding of the situation. We then proceeded to use the mathematical models for the routes and the simulation model using appropriate Industrial Engineering tools and techniques.The new routes obtained from the route improvement methods achieved a distance savings of 16.30% for the Compactor and 21.29% for the Truck in terms of reduced distance compared to the present route.

However, the simulation of the collection process showed that the route with the least distance is not necessarily the best route, when we take into consideration the amount of solid waste left uncollected at the end of each trip.

Introduction

Solid Waste management is the collection, transport, processing or disposal, managing and monitoring of waste materials. The term usually relates to materials produced by human activity, and the process is generally undertaken to reduce their effect on health, the environment or aesthetics. Solid Waste management is a distinct practice from resource recovery which focuses on delaying the rate of consumption of natural resources.

Due to population growth, industrialization, urbanization and economic growth, a trend of significant increase in Municipal Solid Waste (MSW) generation has been recorded worldwide. MSW generation, in terms of kg/capita/day, has shown a positive correlation with economic development at world scale. Due to rapid industrial growth and migration of people from villages to cities, the urban population is increasing rapidly. Waste generation has been observed to increase annually in proportion to the rise in population and urbanization. The per capita generation of MSW has also increased tremendously with improved life style and social status of the populations in urban centers. As more land is needed for the ultimate disposal of these solid wastes, issues related to disposal have become highly challenging.

Solid Waste Management in India

Generally, in India, MSW is disposed of in low-lying areas without taking proper precautions or operational controls. Therefore, municipal solid waste management (MSWM) is one of the major environmental problems of Indian mega cities. SWM involves activities associated with generation, storage and collection, transfer and transport, treatment and disposal of solid wastes. However, in most Indian cities, the MSWM system comprises only four activities, i.e., waste generation, collection, transportation, and disposal. Poor collection and inadequate transportation causes the accumulation of MSW at every nook and corner.

The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amounts of MSW generated daily in metropolitan cities. Adverse impact on all components of the environment and human health occurs due to unscientific disposal of MSW. The MSW amount is expected to increase significantly in the near future as India strives to attain an industrialized nation status by the year 2020.

Solid Waste Management in Bangalore:

As per the Municipal Solid Waste Management rules of the year 2000 [9], BBMP is responsible for the waste management as per the stipulation.

Bruhat Bangalore Mahanagara Palike is divided into 8 administrative zones, 3 zones in old area (core area) & 5 zones in new area(adjacent 7 CMC's & one TMC).

- About 70% of the MSW (Municipal Solid waste) activity starting from primary collection to disposal has been outsourced & 30% is managed by BBMP.

- There are about 4300 Pourakarmikas (Sweepers) of BBMP & 10000 Pourakarmikas (Sweepers) from contractors who perform Door to Door collection & sweeping activities.

- In some of the area in the new zones the Door to Door collection activity is entrusted to Self Help Groups (SHG's), which are basically below poverty women's groups.

- In some of the residential areas the Residential Welfare Associations (RWA's) are involved in Door to Door collection & decentralization of composting the waste.

Primary Collection (Door to Door collection)

- The primary collection is performed using pushcarts & auto tippers.
- There are around 11000 pushcarts & 650 auto tippers for Door to Door collection of waste.
- Waste is collected in the unsegregated form as segregation is not practiced at source.

Secondary collection and Transportation

- There are about 600 MSW transportation vehicles including Compactors, Tipper Lorries, Dumper placers & Mechanical Sweepers both BBMP and contractors.
- The waste collected from the households is brought to a common point ie., secondary locations from where the waste is shifted to the treatment sites through compactors & tipper lorries.
- There is no segregation at source and secondary storage. Hence, unsegregated waste reaches the processing plants.

Street Sweeping activity

- Street sweeping is performed both manually & mechanically. In areas with high commercial activity sweeping is done at night & in the VIP areas the sweeping is done mechanically. The street sweeping waste is carried along with the primary collection waste to the land fill sites.

Decentralized processing plants

- Some of the areas where RWA's are performing Door to Door collection, the waste is segregated at source & the organic waste is composted in the community in a small scale.
- BBMP has setup a 15-ton capacity decentralized plant to process organic waste as well as recycle the plastic, metal etc

- BBMP has established a decentralized one ton capacity aerobic composting unit at Malleshwaram market (West Zone) using organic waste convertor.

Dry waste collection centers

- Dry waste collection centers have been set up for recycling the dry materials like plastic, paper, glass, metals etc

Processing & Disposal sites

To comply with MSW rules, The BBMP has setup processing & Disposal facilities on PPP model. Following are the processing & disposing facilities.

- The combination of technologies for processing of MSW attempted for sustenance & viability.
- Generally, around 30 to 40 % of inert rejects which includes recyclables are going to the scientific landfill.
- Attempt is being made to utilize all the recyclables.
- Small quantity of Waste Plastic is segregated and used in the construction of pavement roads. 8% of Poly blend is mixed in the asphalt.

Bangalore Statistics:

- **Area**: 800 sq km
- **Population (2008)**: 78 lakhs
- **Households**: 25 lakhs
- **Commercial Properties**: 3.5 lakhs
- **No of Zones**: 8
- **No of Wards**: 198

Bangalore SWM Statistics

- Estimated MSW generation Projection, from all sources for BBMP zones: 3000 tpd
- Per capita waste – 350 grams per day (gmpd) (domestic waste)

- **Contribution to total waste**:
- Households: 54%
- Markets & function halls: 20%
- Commercial establishment & institutions: 17%
- Others: 9%
- Segregation of waste at source: 10%

Composition of Municipal Solid Waste:

Physical composition of MSW (%)

Sl.no.	Vegetable	0.30
1	Paper	0.09
2	Plastic	0.12
3	Cardboard	0.04
4	Textiles	0.04
5	Grass/leaves/wood	0.06
6	Leather	0.00
7	Battery	0.00
8	Electronic item	0.02
9	Metal	0.01
10	Organic	0.23
11	Glass	0.03
12	Debris	0.05
13	Biomedical	0.02
Total		1.00

Table. 1 Physical Composition of Municipal Solid Waste

Wake Up, Clean Up Bangalore

We visited the “Wake up Clean up Bangalore” symposium which was held on Thursday, the 7th of February, at Freedom Park, Bangalore. The day consisted of two main events- “Let’s Talk” and “Solutions Showcase”.

Let’s Talk

This was a discussion between representatives of different corporations working on waste management as a full-time or side business and with an audience consisting of about a hundred people. Each of the representatives first spoke about the work being undertaken by/in their companies in order to reduce waste generation or to recycle the generated waste or both. Then, each of them made a commitment that they would deliver particular results by the 5th of June 2013, which happens to be World Environment Day.

The representative from ITC spoke about their WoW (Wealth Out of Waste) initiative where they encouraged citizens to manage their waste properly by buying source-segregated waste from them. It was claimed that 25% of daily waste is completely recyclable and by making good use of this 25%, we would be saving around Rs. 3.5-4 Crore per annum. Their main recyclable is paper. Around 11.3 mil tons of paper is produced each year but only 3 mil tons make it back. They also recycle laminates like chips bags by processing them to produce hard laminate sheets which have many uses. It was also stated that the main issue with solid waste disposal was the shortage of land.

The representative from Bosch, Adugodi talked about their green campus consisting of 3000 trees all being watered with completely recycled “zero-discharge” water. They also make sure that the excessive food from the canteens goes to charitable organisations like Little Sisters of the Poor, Ahayashrama, etc. Their wet wastes consist of food wastes which get sent to piggeries, garden wastes which go to the Karnataka Compost Yard and canteen water wastes which are used for gardening and toilet-flushing. Their dry waste is recycled to make office stationery, packaging materials, etc.

Their commitment for the 5th of June is to manage dry wastes with the help of the khadigram udyog and their wet wastes with Excel industries, tie up with Saahas for SWM solutions and help in the SWM of two areas in the Adugodi neighborhood apart from their own campus.

The Saahas representative mainly spoke about the kind of work they do, which is managing the Solid Waste Management systems in institutions and work campuses. They've worked in Bangalore for 13 years and work with 24 institutes like IIM-B, Sri Kumarans School, etc.

After this there was a general discussion between the representatives and the general public which comprised of the various issues which deter progress when it comes to establishing proper solid waste management systems in the city. The issues ranged from the lack of stern legislation to the apathy and lack of self-realization in the people who live in the city. Solutions to these issues were quite straightforward, like bringing in strict legislation and fining when it comes to waste management, delineating acceptable behavior and hygiene and coding it, authorizing bodies like the BBMP to take strict action against the offenders, striking an emotional chord with the community, creating a ripple effect by setting a good example, etc.

Solutions Showcase

This, as the name suggests, was a showcase of the different solutions available to tackle waste management issues at different levels. It consisted of stalls put up by different companies showcasing their products and services. There were stalls of the different companies in the SWMRT (Solid Waste Management Round Table) Bangalore. These include Saahas, JGI, Clean Bengaluru, RadioActive, WasteWise Trust, Project Green Diamond, The Green Cow, Green Commandos, FullCircle, Green Technologies and YIMBY. Apart from them, there were corporates like ITC and Brittania. The technology suppliers mainly consisted of those into Composting, like Reap Benefit and Ecoman and those into Recycling, like ITC, Saahas, Tetrapak, ASAE (e-waste recycling), khadigram Udyog, Prithvi Ecosciences, etc.

At the event, we observed the discussions between the different corporate representatives and spoke to different people about our project and the solid waste collection scenario in general. We also collected contact details from different people, groups and companies involved with waste management.

Literatue review

The study of solid waste truck routing by “Savings matrix” approach by Mr.Krittanate Tungjidvittayakul in Mae Fah Luang University, Thailand showcased the use of routing and scheduling in transportation in solid waste management. The aim of the study was to develop efficient solid waste truck routing in Nang lae district, Chiang Rai province by using Bing map analysis. The study showed that costs, distances, and time of the present solid waste truck routing is over much by comparing to heuristic savings matrix approach. The key variables involve number of vehicles, capacity of vehicle, amount of solid waste, the distance between nodes, costs, and time.[2]

The SWIM, Solid Waste Integrated Management Approach by F.S.Wang,RMIT University, Melbourne, Australia describes the use of Deterministic and stochastic simulations for solid waste collection systems . The SWIM model is the first systems model in Australia that deals with integrated waste management systems. The main modelling approach adopted is simulation, which is based on both deterministic and stochastic models for collection systems. These models are described in this paper, after a number of modelling approaches are reviewed. An example of the application of the SWIM model is given, and planned extensions to the SWIM model are briefly outlined.[5]
In his paper on Routing Optimization Algorithms for Urban Solid waste Transportation by N.V.Karadimas of University of Athens, Greece describes the use of Geographic

Information System (GIS) which is increasingly becoming a central element for coordinating, planning and managing transportation systems, and so in collaboration with combinatorial optimization techniques they can be used to improve aspects of transit planning in urban regions. Here, the GIS takes into account all the required parameters for the MSW collection (i.e. positions of waste bins, road network and the related traffic, truck capacities etc) and its desktop users are able to model realistic network conditions and scenarios. Finally, the optimal solution is estimated by each routing optimization algorithm, followed by a comparison between these two algorithmic approaches on the newly designed collection routes.

Problem description

Poor solid waste management causes a variety of problems on a daily basis. It leads to overflow of drains as various plastics clog them leading to death of domestic or stray animals who rummage through the solid waste for food, accumulated solid waste emits foul odour which acts like a breeding ground for mosquitoes and flies which eventually lead to large scale epidemics. The problem becomes more visual with the pile up of waste at various locations and on roads.

The complete process of waste management is a complex one involving multiple systems and sub-systems. This project analyses the process of solid waste management in ward 19, Sanjaynagar. The problem area which is the focus of this project is the routing of the solid waste collection trucks in ward 19.

The following critical observation was made: Presently there are no official instructions given to the drivers regarding the route to be followed. The route is decided by the driver and supervisor using their experience. This leads us to believe that solid waste management may not be done in the most efficient way as they haven't followed a systematic scheme to collect and dispose the solid waste.

Problem investigation

We began the investigative process by, firstly, trying to narrow down exactly what geographic area we were planning to conduct our study in. This involved the magnitude (ward-wise or city-wise), which part of the city to choose, etc. This was an especially important part of the process because we had to choose a location which could represent partly; if not wholly, what an average location would be to study SWM.

Wards in Bangalore

As per the Municipal Solid Waste Management rules 2000 BBMP is responsible for taking the waste management as per the stipulation. For Administrative purpose BBMP is divided into 8 zones, 3 zones in old area (core area) & 5 zones in new area (adjacent 7 CMC's & one TMC).

Ward	Ward No.	Population	Area (sq.km)	Overall Ward Score	Pourakarmika (Nagar Palike)	Pourakarmika (Contract)	Auto Tipper	Push Carts	Compator	Closed Tipper	Tractors
Horamavu	25	40617	17.32	3.76	0	312	33	0	3	5	12
HAL Airport	87	47682	6.8	4.71	0	67	11	0	1	1	3
T.Dasarahalli	15	37565	0.88	5.3	0	36	4	18	0	2	0
Bagalkunte	14	40818	4.43	5	0	36	4	18	0	2	1
Peenya	41	39608	5.59	5.01	0	50	7	0	0	4	2
Hegganahalli	71	44543	1.96	4.48	0	40	3	0	1	0	1
Yeshwantpur	37	51872	0.78	5.85	47	56	7	90	0	4	0
Kengeri	159	35863	4.77	4.95	4	75	8	8	0	3	0
Bommanahalli	175	35051	1.85	4.24	0	45	11	0	0	3	1
HSR Layout	174	35689	6.98	4.24	0	132	18	0	0	7	1
Malleshwaram	45	52376	1.81	6.03	45	48	8	69	0	0	4
Mathikere	36	51743	0.91	5.87	0	85	5	62	0	0	3
Jayanagar	153	51860	2.5	5.73	51	32	6	75	1	3	1
Sanjaynagar	19	34865	1.5	5.8	0	97	5	70	0	3	0
Shivajinagar	92	51538	0.4	4.8	40	0	5	48	2	1	0

Table. 2 Details of wards considered for study

Reasons to choose Sanjaynagar, Ward 19

Sanjaynagar, ward 19 is located in Bangalore North and has proximity to the centre of the city (Majestic) as well as the outskirts. It has a mix of commercial establishments such as shops, markets, theatre, hospitals etc. as well as a number of residential layouts. It is in close proximity to industrial areas, tech parks, agriculture campus, airport etc.

The population of the ward and the area is close to the city average ward. Also the allotment of vehicle and human resource for SWM was closely comparable to the average per ward in the city. Conducting the field work in Sanjaynagar proved to be advantageous in many respects. There is active government interest i.e. BBMP in Solid Waste Management. Hence there was assistance in data collection as well as obtaining permissions for various interactions and data collection. The location was convenient in terms of its accessibility from college when needed.

Sanjaynagar Statistics

Ward no. – 19

Area (in sq. km.) – 1.5

Population – 34,865

Allotment of resources for SWM:

Pourakarmikas – 97

Push Carts – 70

Auto Tipper – 6

Solid waste Truck – 1

Solid waste Compactor – 1

Present System of SWM

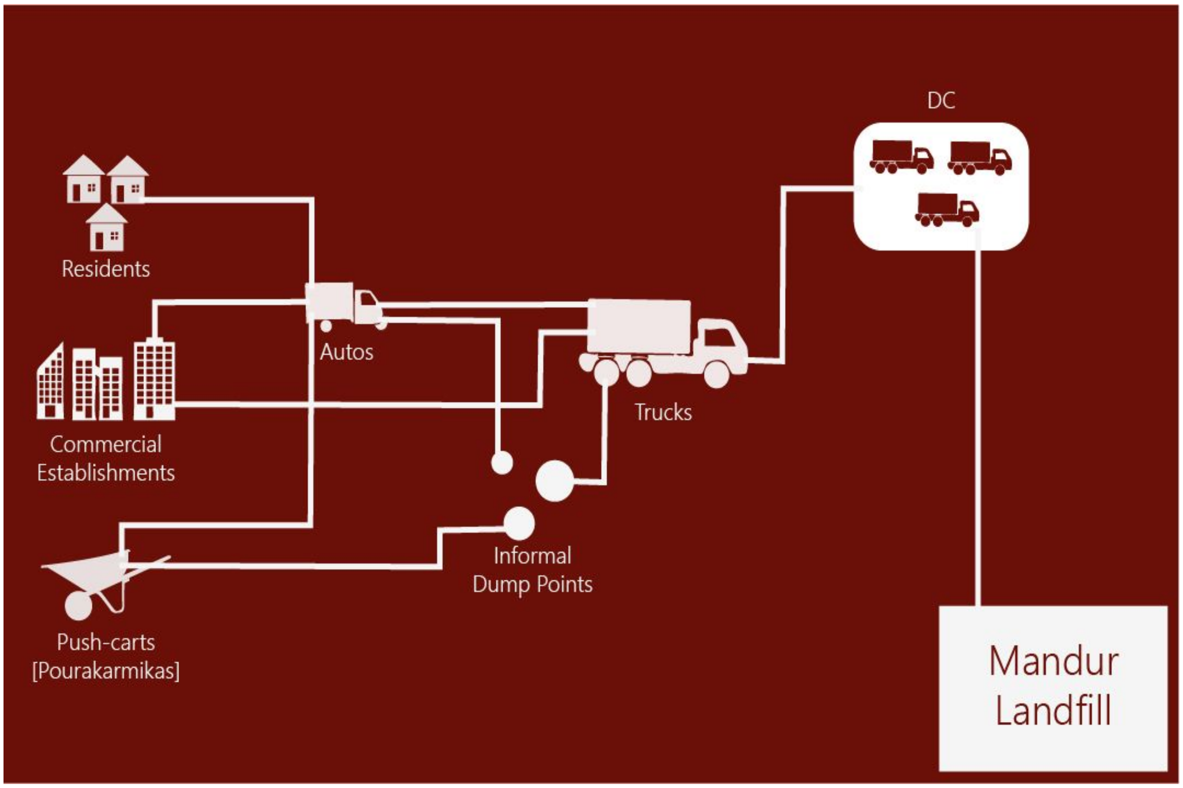


Fig. 2 Current System of Solid Waste collection in Ward 19

Fig. 2 represents the solid waste management process at ward 19. The wastes generated from residential houses are collected by autos and that from the roads are swept and collected in the push carts. The waste from commercial establishments are directly collected by the collection trucks. In the informal dump points the waste is accumulated from commercial establishments, residents who choose to dispose waste at these points and also push carts. These are the points that the solid waste collection trucks collect waste on a daily basis.

After collection from all the informal points, the trucks proceed to the central location where all vehicles for solid waste management are parked. Then it proceeds to the landfill in Mandur in the outskirts of Bangalore for disposal. The prime issue faced in the present system is the pile up of solid waste in the informal points which are mainly on roads causing inconvenience to the citizens.

Data Collection

Research Questions

- What are the policies governing the collection of solid waste presently and in the pipeline?
- What are the available resources present in the solid waste collection system?
- What are the constraints present in the solid waste collection system?
- What is the behavior of the stakeholders involved in solid waste disposal and collection?
- How much solid waste is being collected right now, and using what methods/procedures?

Data Required:

- Is waste being segregated?
- Amount of solid waste generated
  - Types – Wet & Dry
  - Consistency of amount
  - Patterns (seasonal solid waste fluctuations)
- Methods of collection
  - Based on type of building – independent houses, apartments, restaurants, commercial establishments, etc.
  - Direct disposal/use of covers
  - Pick-up points (door-to-door/common bin)
- Frequency of collection
  - Patterns
  - Consistency
- Timing of collection

    - Present
    - Preferable
    - Consistency
- Pick-up points
    - Common mini-dumping sites
    - locations
- Time spent in collecting
    - Daily working hours
    - Travel time
- Number of houses covered
    - Expected and actual targets per day
    - Number of trips
- Nature of location
    - Area
    - Type- Residential/Industrial/Commercial
    - Density
- Available Resources
    - Number of vehicles
    - types of vehicles
    - Capacities of vehicles
- Behavioural data (applicable differently to different stakeholders)
    - Adherence to methods and procedures
    - Convenience
    - Awareness
- Policies governing waste collection
    - Regulations and guidelines
        - Present
        - In the pipeline

- Alternate methods of disposal
    - In case of absence of regular collection
    - Proactive efforts taken

Target Audience

- Residents
- Collectors
    - Door-to-door (Pourakarmikas)
    - Drivers
- Supervisors
- Commercial establishments
- Experts on SWM
- Municipal bodies

We conducted surveys and interviews with the stake-holders mentioned above.

< Details of surveys and interviews>

What we did

We started the data collection process with obtaining a copy of the map of Ward 19 from the BBMP ward office. Then, while observing the solid waste collection process, we collected data on the resources available for the process, in terms of the types and number of vehicles and manpower. We also documented the exact points where solid waste is being piled up and also recorded the average amount of solid waste piled up each day by following the truck and compactor. Lastly, we tabulated the distances of the shortest paths between these pick-up points. We simultaneously worked on the surveys and interviews.

Ward Map

Fig. 3 Map of Ward 19 (Scale- 1:2500)

A map of Ward 19 was obtained from the BBMP Ward Office. It is a 1:2500 scale map which was used to mark the various pick-up points and measure the shortest-distances between the different pick-up points.

Pick-up Points Table

Point	No. of bins		
	Trial 1	Trial 2	Avg. no. of bins
1	112	120	116
2	9	11	10
3	146	160	153
4	8	13	11
5	27	11	19
6	97	54	76
7	153	192	172
8	141	113	127
9	61	36	48
10	107	119	103
11	38	44	41
12	11	8	9
13	33	26	29
14	79	88	84
15	91	125	108
16	40	27	34
17	28	59	43
18	31	23	27
19	10	22	16

Table 3 Number of bins of solid waste piled up at different pick-up points

These are the 19 unofficial points in Ward 19 where solid waste is piled up on a daily basis. At these points, the solid waste is dumped by residents and commercial establishments. The solid waste trucks go through these points every day, collecting the solid waste piled up there and transferring solid waste from filled autos which wait at those points.The numbers of bins at each point were noted by observation for two runs of the truck and compactor on two different days.

Pick up Points Table – Mean No. of Bins

For the 19 pick-up points the table shows the mean number of bins. These mean values are used in the savings matrix model as well as the simulation.

Point	No. of Bins
1	116
2	10
3	153
4	11
5	19
6	76
7	172
8	127
9	45
10	103
11	41
12	9
13	26
14	84
15	108
16	34
17	43
18	27
19	16

Table. 4 Average number of bins of solid waste piled up at different pick-up points

Distances Table

The distances of the shortest paths between every pair of pick-up points have been found out from the ward map provided and tabulated in the table below.

In the table, 1 unit = 25m

	Origin	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19
Origin	0																			
L1	22.9	0																		
L2	17.3	5.6	0																	
L3	31.9	9	14.6	0																
L4	33.8	10.9	16.5	1.9	0															
L5	34.8	11.9	17.5	2.9	1	0														
L6	30.9	8	13.6	9.2	11.1	12.1	0													
L7	29.5	14.4	15.1	18.4	20.3	21.3	9.2	0												
L8	22.8	19	17.9	25.1	27	28	15.9	6.7	0											
L9	32.3	20.1	22.8	21.3	23.2	24.2	12.1	7.7	9.5	0										
L10	35.4	23.2	25.9	24.4	26.3	27.3	15.2	10.8	12.6	3.1	0									
L11	38.8	31.9	34.6	33.1	35	36	23.9	19.5	21.3	11.8	8.7	0								
L12	41	34.1	36.8	35.3	37.2	38.2	26.1	21.7	23.5	14	10.9	2.2	0							
L13	45.1	38.2	40.9	39.4	41.3	42.3	30.2	25.8	27.6	18.1	15	6.3	4.1	0						
L14	44	66.9	61.3	75.9	77.8	78.8	74.9	73.5	66.8	76.3	73.8	77.2	79.4	83.5	0					
L15	43.3	66.2	61.3	75.2	77.1	78.1	74.2	72.8	66.1	75.6	74.7	78.1	80.3	84.4	3.6	0				
L16	37.8	60.7	55.1	69.7	71.6	72.6	68.7	67.3	60.6	70.1	69.2	72.6	74.8	78.9	9.2	5.6	0			
L17	22.4	45.3	39.7	54.3	56.2	57.2	53.3	51.9	45.2	54.7	52.2	55.6	57.8	61.9	21.6	22.5	17	0		
L18	20.4	43.3	37.7	52.3	54.2	55.2	51.3	49.9	43.2	52.7	50.2	53.6	55.8	59.9	23.6	24.5	19	2	0	
L19	8.3	31.2	25.6	40.2	42.1	43.1	39.2	37.8	31.1	40.6	40.8	44	46.2	50.3	35.7	35	29.5	14.1	12.1	0

Table. 5 Distances of shortest paths between pick-up points

Resource Data:

Two Trucks for solid waste collection in ward 19 its characteristics:

Truck

Capacity: 3,800kgs – 316 bins

Compactor

Capacity: 11,000kgs – 916 bins

1 bin = 12 kgs

Total Number of Solid Waste Pick-up Points: 19

Fig. 4 Regular Solid waste Truck

Fig. 5 Solid waste Compactor

Problems encountered in Data Collection:

- Permissions from the Executive Engineer, Hebbal Constituency, BBMP. This was necessary to obtain the ward map from the Assistant Executive Engineer, Sanjaynagar who was reluctant to help until we obtained the permission.
- Delay in meeting the various officials due to their non-availability during working hours. A lot of time was spent waiting in government offices.
- The supervisors in-charge of solid waste collection were apprehensive to a large extent to divulge any sort of information. We found it especially difficult to obtain the weight slips of the solid waste collection Truck and Compactor which were vital to know their respective load capacities. Also, different supervisors provided different versions of the same information.
- The pourakarmikas, auto and truck drivers were hesitant to participate in the surveys and interviews as they were apprehensive about our motives. It took us a few days to befriend the workers and gain their trust
- It was difficult to communicate with the pourakarmikas as a majority spoke did not speak the local language Kannada. They spoke only in Telugu and hence it had to be translated with the help of someone who knew both languages

- Most the pourakarmikas are inebriated during work. This made it challenge during the surveys and interviews.
- Although a majority of the residents were largely co-operative with the resident survey, we had to face a few adverse reactions from some, as we had approached them at the wrong time.
- The entire process of following the collection trucks which took about 6 hours each time was tedious. We also had to put up with the stench of the solid waste throughout the process.

Observations made during Data Collection

- The waste is loaded into the trucks using circular bins or floor mats.
- The pourakarmikas do not use protective gloves, masks or shoes.
- The waste accumulated in informal points are not segregated
- Some part of the waste like milk covers, glass bottles etc are separated and collected by the pourakarmikas and sold unofficially at paper marts.
- In the case of waste not being collected on a particular day, the some residents/ commercial establishments dispose it at the nearest informal dump point.
- Some residents do not oblige to the pleas of the pourakarmikas to segregate waste.
- The pourakarmikas feel empowered in their tasks when a citizen accompanies them during the collection process
- The resources (collection vehicles) allocated to one ward may be diverted to another ward on a particular day when the need arises.
- Once the trucks reach their capacity the remaining points are left uncollected until the next collection drive
- The normal route for collection is discarded when instructed by the Supervisor. The vehicle is diverted to clear the waste accumulated in certain points. This may be due to a resident complaint, arrival of an important personality, official or politician etc

- The trucks once fully loaded proceeds to the landfill in Mandur where the trucks from various areas are lined up. The trucks are allowed to enter the landfill post 10 p.m. Hence the truck loaded with waste is parked in the ward itself. This causes a stench in its vicinity throughout the day.

Methodology

Routing and Scheduling of Trucks Using Savings Matrix Method

The aim of this method is to decide on customers/points to be visited by particular vehicle and sequence in which they will be visited. Its objectives are:

- Minimize total distance travelled by vehicles
- Minimize total travel time of vehicles

Steps:

1. Collect data on costs of transportation, time, distance, solid waste volume, and also vehicle's capacity.

2. Create distance matrix table.

3. Used saving equation to form the savings matrix.

4. Find a lower saving link in the saving matrix until all links are adding in routing –

    a. If a total volume of solid waste in the link is capacity overload, then assort another lower link

    b. If a total volume of solid waste in the link is not overload, then add new another route in a trip.

5. Improve sequence of points within routes

6. Compared actual routing and saving routing to conclusion

Distance Matrix

	Origin	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19
Origin	0																			
L1	22.9	0																		
L2	17.3	5.6	0																	
L3	31.9	9	14.6	0																
L4	33.8	10.9	16.5	1.9	0															
L5	34.8	11.9	17.5	2.9	1	0														
L6	30.9	8	13.6	9.2	11.1	12.1	0													
L7	29.5	14.4	15.1	18.4	20.3	21.3	9.2	0												
L8	22.8	19	17.9	25.1	27	28	15.9	6.7	0											
L9	32.3	20.1	22.8	21.3	23.2	24.2	12.1	7.7	9.5	0										
L10	35.4	23.2	25.9	24.4	26.3	27.3	15.2	10.8	12.6	3.1	0									
L11	38.8	31.9	34.6	33.1	35	36	23.9	19.5	21.3	11.8	8.7	0								
L12	41	34.1	36.8	35.3	37.2	38.2	26.1	21.7	23.5	14	10.9	2.2	0							
L13	45.1	38.2	40.9	39.4	41.3	42.3	30.2	25.8	27.6	18.1	15	6.3	4.1	0						
L14	44	66.9	61.3	75.9	77.8	78.8	74.9	73.5	66.8	76.3	73.8	77.2	79.4	83.5	0					
L15	43.3	66.2	61.3	75.2	77.1	78.1	74.2	72.8	66.1	75.6	74.7	78.1	80.3	84.4	3.6	0				
L16	37.8	60.7	55.1	69.7	71.6	72.6	68.7	67.3	60.6	70.1	69.2	72.6	74.8	78.9	9.2	5.6	0			
L17	22.4	45.3	39.7	54.3	56.2	57.2	53.3	51.9	45.2	54.7	52.2	55.6	57.8	61.9	21.6	22.5	17	0		
L18	20.4	43.3	37.7	52.3	54.2	55.2	51.3	49.9	43.2	52.7	50.2	53.6	55.8	59.9	23.6	24.5	19	2	0	
L19	8.3	31.2	25.6	40.2	42.1	43.1	39.2	37.8	31.1	40.6	40.8	44	46.2	50.3	35.7	35	29.5	14.1	12.1	0

Table 6 Distance Matrix

Savings Matrix

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19
L1	0																		
L2	34.6	0																	
L3	45.8	34.6	0																
L4	45.8	34.6	63.8	0															
L5	45.8	34.6	63.8	67.8	0														
L6	45.8	34.6	53.6	53.6	53.6	0													
L7	38	31.7	43	43	43	51.2	0												
L8	26.7	22.2	29.6	29.6	29.6	37.8	45.6	0											
L9	35.1	26.8	42.9	42.9	42.9	51.1	54.1	45.6	0										
L10	35.1	26.8	42.9	42.9	42.9	51.1	54.1	45.6	64.6	0									
L11	29.8	21.5	37.6	37.6	37.6	45.8	48.8	40.3	59.3	65.5	0								
L12	29.8	21.5	37.6	37.6	37.6	45.8	48.8	40.3	59.3	65.5	77.6	0							
L13	29.8	21.5	37.6	37.6	37.6	45.8	48.8	40.3	59.3	65.5	77.6	82	0						
L14	0	0	0	0	0	0	0	0	0	5.6	5.6	5.6	5.6	0					
L15	0	0	0	0	0	0	0	0	0	4	4	4	4	83.7	0				
L16	0	0	0	5	0	0	0	0	0	4	4	4	4	72.6	75.5	0			
L17	0	0	0	5	0	0	0	0	0	5.6	5.6	5.6	5.5	44.8	43.2	43.2	0		
L18	0	0	0	5	0	0	0	0	0	5.6	5.6	5.6	5.6	40.8	39.2	39.2	40.8	0	
L19	0	0	0	5	0	0	0	0	0	2.9	3.1	3.1	3.1	16.6	16.6	16.6	16.6	16.6	0

Table. 7 Savings Matrix

Assigning customers to routes from Savings Matrix

Compactor:

Capacity: 11000 kgs – 916 bins

Allocation:

Point	No. of bins
1	116
2	10
3	153
4	11
5	19
6	76
7	172
8	127
9	45
10	103
11	41
12	9
13	26

Table. 8 Pick-up point allocation – Solid waste Compactor

Truck:

Capacity: 3800 kgs- 316 bins

Allocation:

Point	No. of bins
14	84
15	108
16	34
17	43
18	27
19	16

Table. 9 Pick-up point allocation – Regular Solid waste Truck

Sequence Customers within routes

Nearest Neighbour

Nearest Neighbour- starting at the DC this procedure adds the closest customer to extend the trip. At each step the trip is built by adding the customer closest to the point last visited by the vehicle until all customers have been visited.

Route: 13-Point

DC → 2 → 1 → 6 → 3 → 4 → 5 → 7 → 8 → 9 → 10 → 11 → 12 → 13 → DC

17.3+5.6+8+9.2+1.8+1+21.3+6.7+9.5+3.1+8.7+2.2+4.1+45.1

= 143.60units = 3.59kms

- Savings in distance travelled: 0.7kms
- 16.3% saving from present route

Route: 6-Point

DC → 19 → 18 → 17 → 16 → 15 → 14 → DC

8.3+12.1+2+17+5.6+3.6+44

= 92.60units = 2.315kms

- Savings in distance travelled: 0.582kms
- 20.2% saving from present route

Sweep

In the Sweep procedure, any point on the grid is selected (generally the DC itself) and the line is swept either clockwise or counter-clockwise from that point. The trip is constructed by sequencing customers in the order they are encountered during the Sweep

Route: 13-Point

DC→5→4→3→2→1→6→7→8→9→10→13→12→11→DC

34.8+1+1.9+14.6+5.6+8+9.2+6.7+9.5+3.1+15+4.1+2.2+38.8

= 154.50units = 3.8625kms

- Savings in distance travelled: 0.42kms
- 10% saving from present route

Route: 6-Point

DC→19→18→17→14→15→16→DC

8.3+12.1+2+21.6+3.6+5.6+37.8

= 91units = 2.275kms

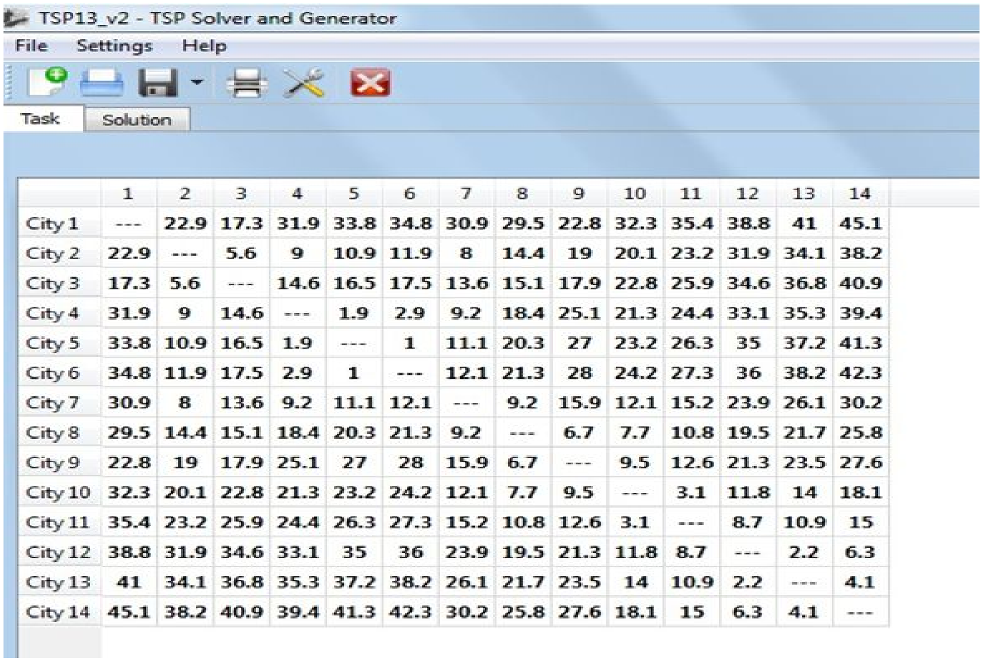
- Savings in distance travelled: 0.62kms
- 21.49% saving from present route

TSP Solver using Branch and Bound Algorithm

Concorde TSP Solver

The Concorde graphical user interface can be used to apply the Concorde TSP Solver to a specified set of cities. The Concorde solver uses the cutting-plane method, iteratively solving linear programming relaxations of the TSP. The interface shows the solver's progress at the end of each major iteration of cutting planes by coloring the edges according to their current LP values. Once the optimal tour is found it is shown by adding red edges to the display. The algorithm used in the TSP solver in this problem is the Branch and Bound Algorithm.

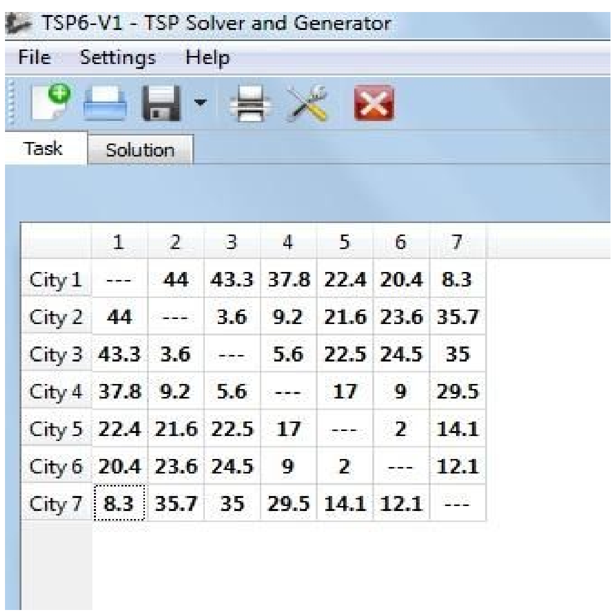
Formulation of table in Solver for 13-Point route



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
City 1	---	22.9	17.3	31.9	33.8	34.8	30.9	29.5	22.8	32.3	35.4	38.8	41	45.1
City 2	22.9	---	5.6	9	10.9	11.9	8	14.4	19	20.1	23.2	31.9	34.1	38.2
City 3	17.3	5.6	---	14.6	16.5	17.5	13.6	15.1	17.9	22.8	25.9	34.6	36.8	40.9
City 4	31.9	9	14.6	---	1.9	2.9	9.2	18.4	25.1	21.3	24.4	33.1	35.3	39.4
City 5	33.8	10.9	16.5	1.9	---	1	11.1	20.3	27	23.2	26.3	35	37.2	41.3
City 6	34.8	11.9	17.5	2.9	1	---	12.1	21.3	28	24.2	27.3	36	38.2	42.3
City 7	30.9	8	13.6	9.2	11.1	12.1	---	9.2	15.9	12.1	15.2	23.9	26.1	30.2
City 8	29.5	14.4	15.1	18.4	20.3	21.3	9.2	---	6.7	7.7	10.8	19.5	21.7	25.8
City 9	22.8	19	17.9	25.1	27	28	15.9	6.7	---	9.5	12.6	21.3	23.5	27.6
City 10	32.3	20.1	22.8	21.3	23.2	24.2	12.1	7.7	9.5	---	3.1	11.8	14	18.1
City 11	35.4	23.2	25.9	24.4	26.3	27.3	15.2	10.8	12.6	3.1	---	8.7	10.9	15
City 12	38.8	31.9	34.6	33.1	35	36	23.9	19.5	21.3	11.8	8.7	---	2.2	6.3
City 13	41	34.1	36.8	35.3	37.2	38.2	26.1	21.7	23.5	14	10.9	2.2	---	4.1
City 14	45.1	38.2	40.9	39.4	41.3	42.3	30.2	25.8	27.6	18.1	15	6.3	4.1	---

Fig. 6 Solver – 13-point Route

Formulation of table in Solver for 6-Point route



	1	2	3	4	5	6	7
City 1	---	44	43.3	37.8	22.4	20.4	8.3
City 2	44	---	3.6	9.2	21.6	23.6	35.7
City 3	43.3	3.6	---	5.6	22.5	24.5	35
City 4	37.8	9.2	5.6	---	17	9	29.5
City 5	22.4	21.6	22.5	17	---	2	14.1
City 6	20.4	23.6	24.5	9	2	---	12.1
City 7	8.3	35.7	35	29.5	14.1	12.1	---

Fig. 7 Solver – 6-point Route

Route: 13-Point

DC→2→7→8→9→10→11→12→13→6→4→5→3→1→DC

17.3+15.1+6.7+9.5+3.1+8.7+2.2+4.1+30.2+11.1+1+2.9+9+22.9

= 143.80units = 3.595km

- Savings in distance travelled: 0.69kms
- 16.16% savings from present route

Route: 6-Point

DC→19→17→18→16→15→14→DC

8.3+14.1+2+19+5.6+3.6+44

= 96.60 units = 2.415km

- Savings in distance travelled: 0.48kms
- 16.7% savings from present route

Present method

Route: 13-Point

Trip Distance = 171.50units = 4.2875km

Route: 6-Point

Trip Distance= 115.9units = 2.8975km

Simulation

NetLogo

NetLogo is a programmable modeling environment for simulating natural and social phenomena. It was authored by Uri Wilensky in 1999 and has been in continuous development ever since at the Centre for Connected Learning and Computer-Based Modeling. NetLogo is particularly well suited for modeling complex systems developing over time. Modelers can give instructions to hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level behaviour of individuals and the macro-level patterns that emerge from their interaction.

Assumptions made for this model

- The truck moves at the same speed throughout the trip and every trip.
- The amount of solid waste generated at each collection point is according to normal distribution.
- Amount of time taken to load 1 bin is constant.
- The amount of solid waste in every bin loaded is constant.
- Waiting time at each point is directly proportional to the solid waste at the point.

If it is seen that the total solid waste generated is greater than the truck's capacity, the truck doesn't collect any solid waste from that point onwards. These amounts are documented under uncollected solid waste

The Simulation Process

To simulate the solid waste collection process in Ward 19, first, a digital representation of the routes followed and the ward itself had to be made. This was done using the GIS (Geographic Information System) data obtained and then by constructing the routes on Quantum GIS Software and exporting them as Shape Files.

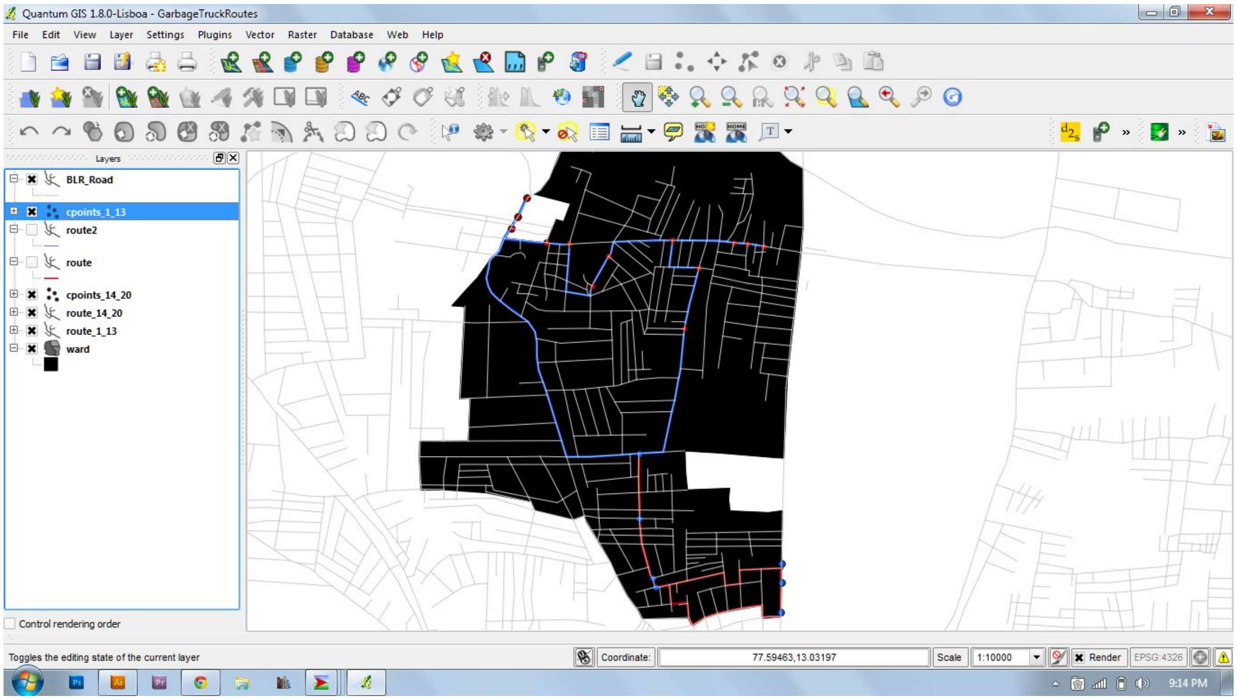


Fig. 8 Map of Ward 19 with routes in Quantum GIS

This was done for all the routes obtained using the different routing methods. These GIS maps and routes were then imported into the NetLogo simulation software to depict the solid waste collection process. In the simulation, the 2 solid waste trucks are allotted to the 2 routes, and their capacities are set in the software in terms of number of bins.

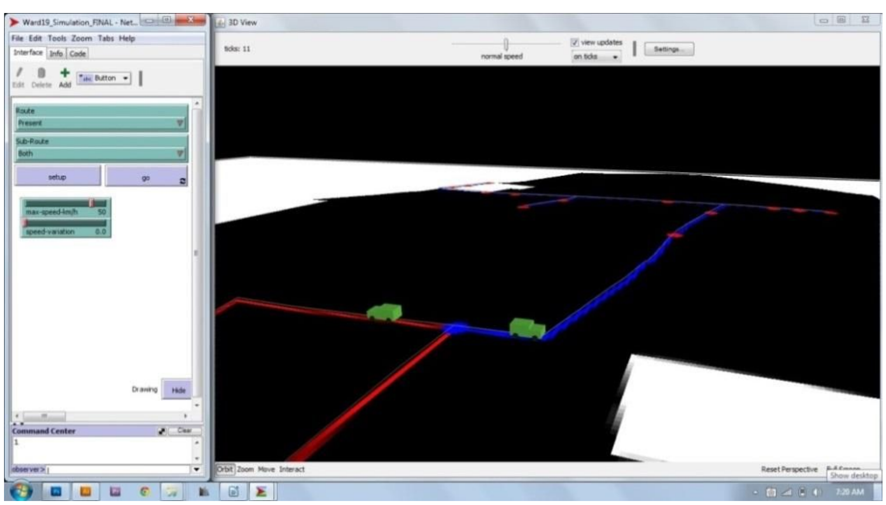


Fig. 9   Simulation of the two trucks in their respective routes

The trucks move along the set paths according to the route they're following, and when they come across the pick-up points in the right sequence, they stop at those points. The amount of time they wait at each point depends on the number of bins of solid waste generated at the respective point. This is obtained by generating random numbers according to normal distribution with the mean number of bins (which has been obtained through data collection) with a standard deviation of 5. Once a point has been crossed, the amount of solid waste at the point will be set to zero.

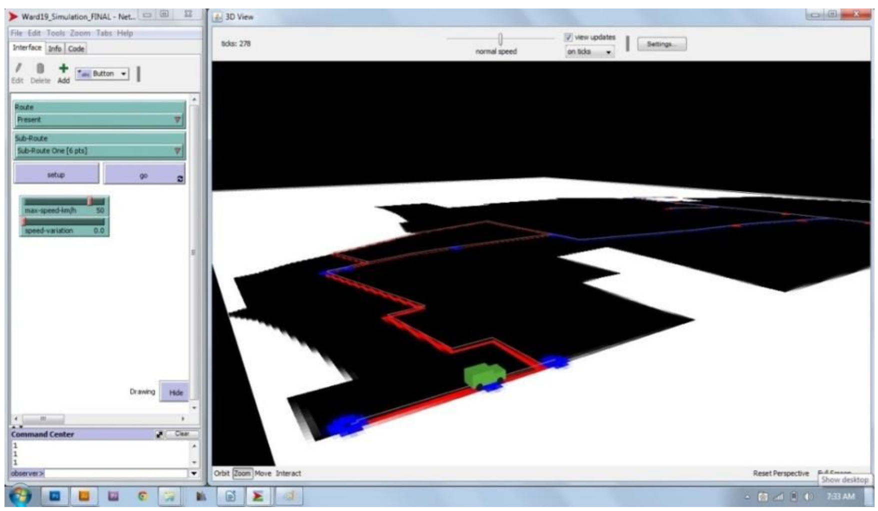


Fig. 10 Simulation of truck stopping at a pick-up point

This happens at every point until it's finished the last point and goes back to the origin. Once it reaches the origin, it resets the pick-up points, that is, it generates new random values for the number of bins at each point. Also, at this point, the cycle-time and amount of uncollected solid waste of the previous trip is calculated and stored in separate excel spreadsheet files.

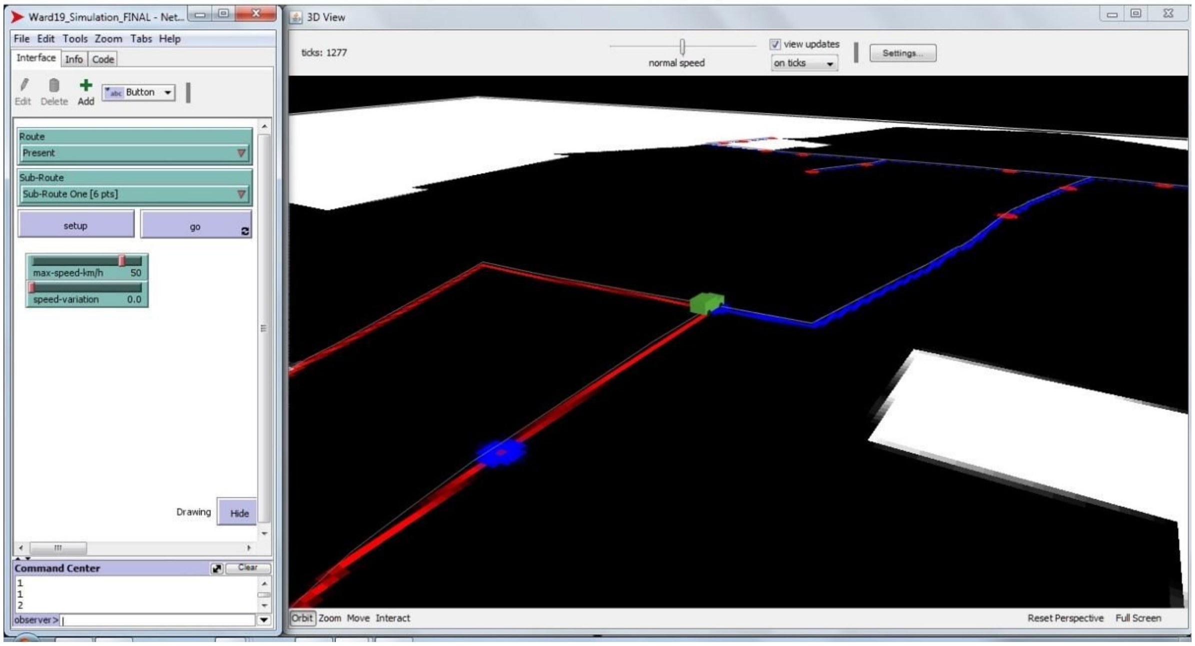


Fig. 11 Simulation of truck passing through origin at end of one cycle

Once the simulation of each route option has been run for 30 cycles (1 month), the results of the simulation were documented in the excel files.

Cycle Time:

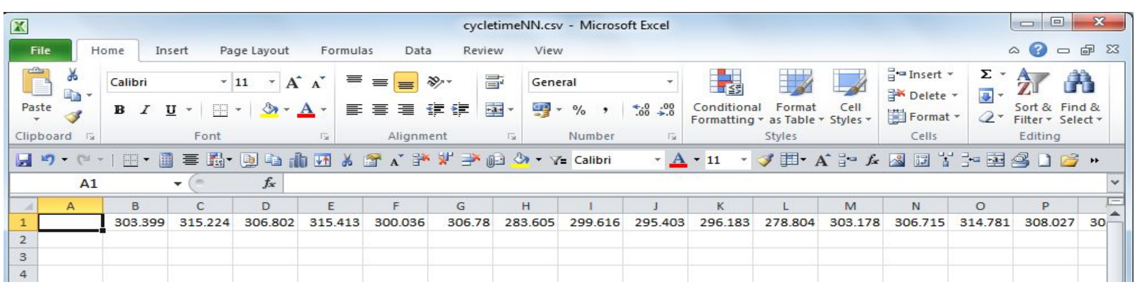
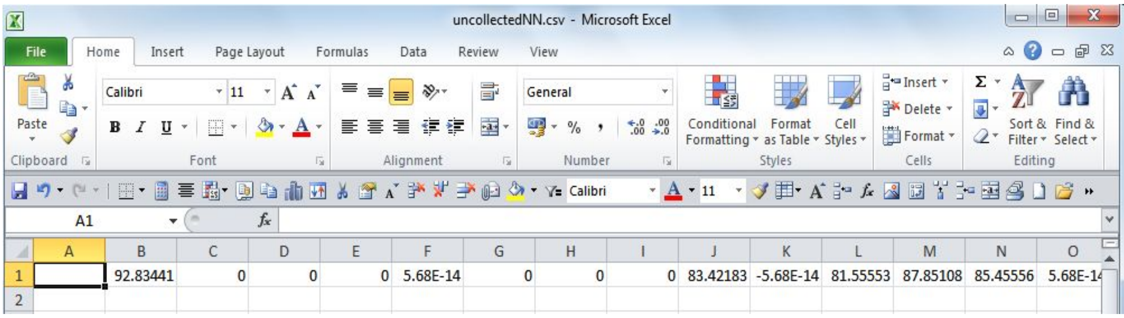


Fig. 12 Cycle times of the simulation recorded in an Excel file

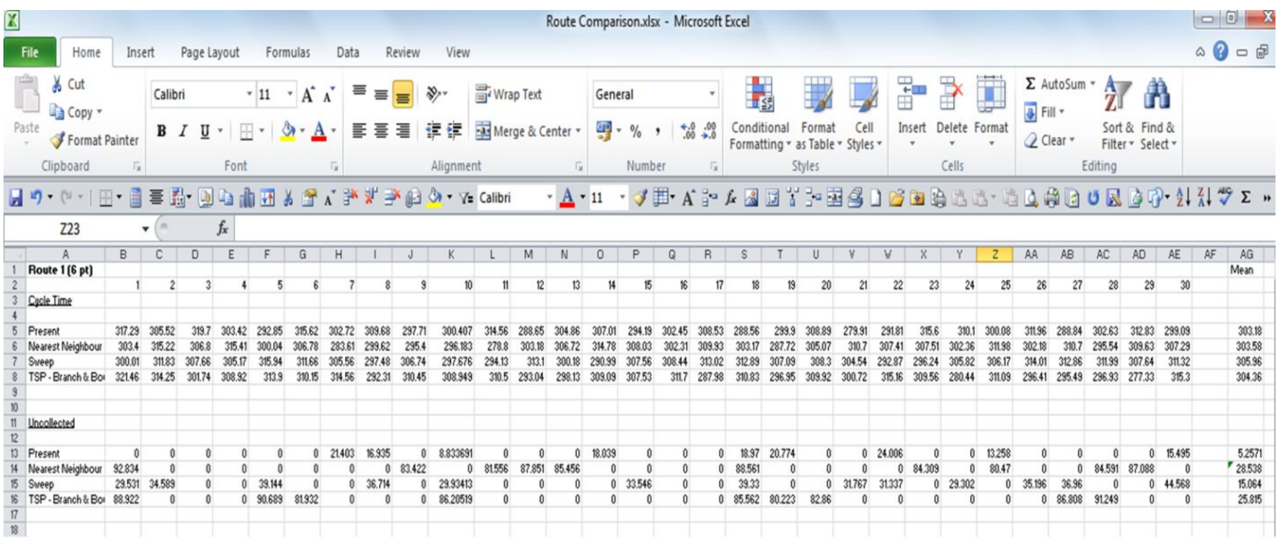
Uncollected Solid waste:



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	92.83441	0	0	0	5.68E-14	0	0	0	83.42183	-5.68E-14	81.55553	87.85108	85.45556	5.68E-14

Fig. 13 Uncollected solid waste of the simulation recorded in an Excel file

Then, a comparison was made between them on the basis of their cycle-times and the uncollected solid waste at the end of each trip.



Route 1 (6 pt)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cycle Time															
Present	317.29	305.52	319.7	303.42	292.85	315.62	302.72	309.68	297.71	300.407	314.56	288.65	304.86	307.01	294.19
Nearest Neighbour	303.4	315.22	306.8	315.41	300.04	306.78	283.61	299.62	295.4	296.183	278.8	303.18	306.72	314.78	308.03
Sweep	300.01	311.83	307.66	305.17	315.94	311.66	305.56	297.48	306.74	297.676	294.13	313.1	300.18	290.99	307.56
TSP - Branch & Bo	321.46	314.25	301.74	308.92	313.9	310.15	314.56	292.31	310.45	308.949	310.5	293.04	298.13	309.09	307.53
Uncollected															
Present	0	0	0	0	0	0	21.403	16.935	0	8.833691	0	0	0	18.039	0
Nearest Neighbour	92.834	0	0	0	0	0	0	0	83.422	0	81.556	87.851	85.456	0	0
Sweep	29.531	34.589	0	0	39.144	0	0	36.714	0	29.93413	0	0	0	0	33.546
TSP - Branch & Bo	88.922	0	0	0	90.689	81.932	0	0	0	86.20519	0	0	0	0	0

Route 1 (6 pt)	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Mean
Cycle Time																
Present	302.45	308.53	288.56	299.9	308.89	279.91	291.81	315.6	310.1	300.08	311.96	288.84	302.63	312.83	299.09	303.18
Nearest Neighbour	302.31	309.93	303.17	287.72	305.07	310.7	307.41	307.51	302.36	311.98	302.18	310.7	295.54	309.63	307.29	303.58
Sweep	308.44	313.02	312.89	307.09	308.3	304.54	292.87	296.24	305.82	306.17	314.01	312.86	311.99	307.64	311.32	305.96
TSP - Branch & Bo	311.7	287.98	310.83	296.95	309.92	300.72	315.16	309.56	280.44	311.09	296.41	295.49	296.93	277.33	315.3	304.36
Uncollected																
Present	0	0	18.97	20.774	0	0	24.006	0	0	13.258	0	0	0	0	15.495	5.2571
Nearest Neighbour	0	0	88.561	0	0	0	0	84.309	0	80.47	0	0	84.591	87.088	0	28.538
Sweep	0	0	39.33	0	0	31.767	31.337	0	29.302	0	35.196	36.96	0	0	44.568	15.064
TSP - Branch & Bo	0	0	85.562	80.223	82.86	0	0	0	0	0	0	86.808	91.249	0	0	25.815

Fig. 14 Comparison between cycle-times and uncollected solid waste recorded for each route

Snapshots of the NetLogo simulation of the different routes

Present Method

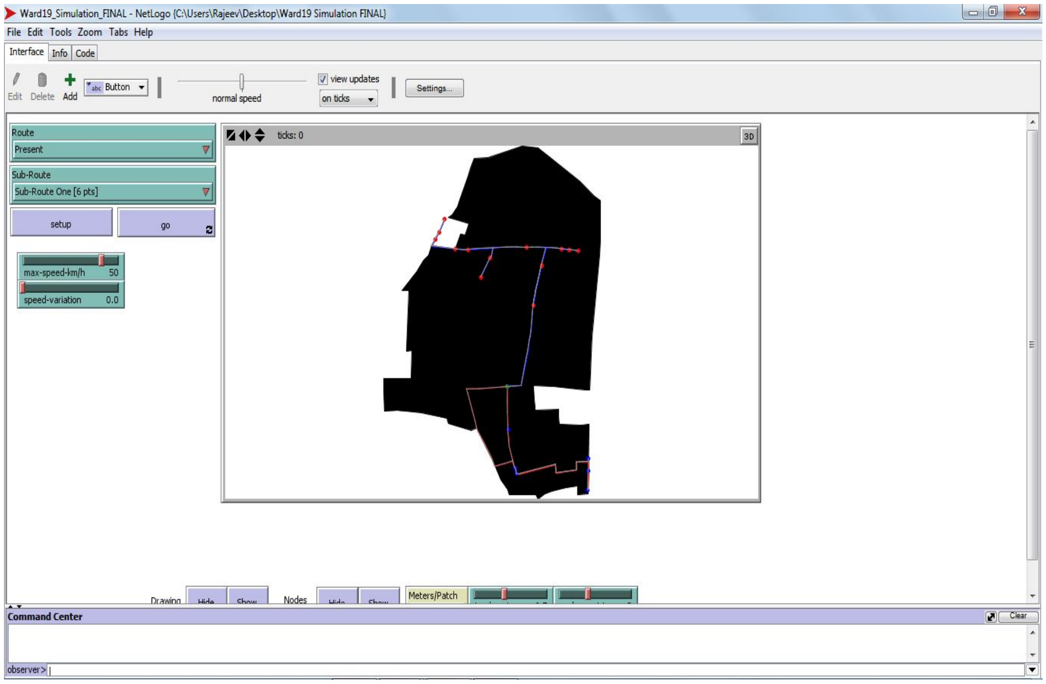


Fig. 15 Present Method Route – NetLogo Simulation

Nearest Neighbour

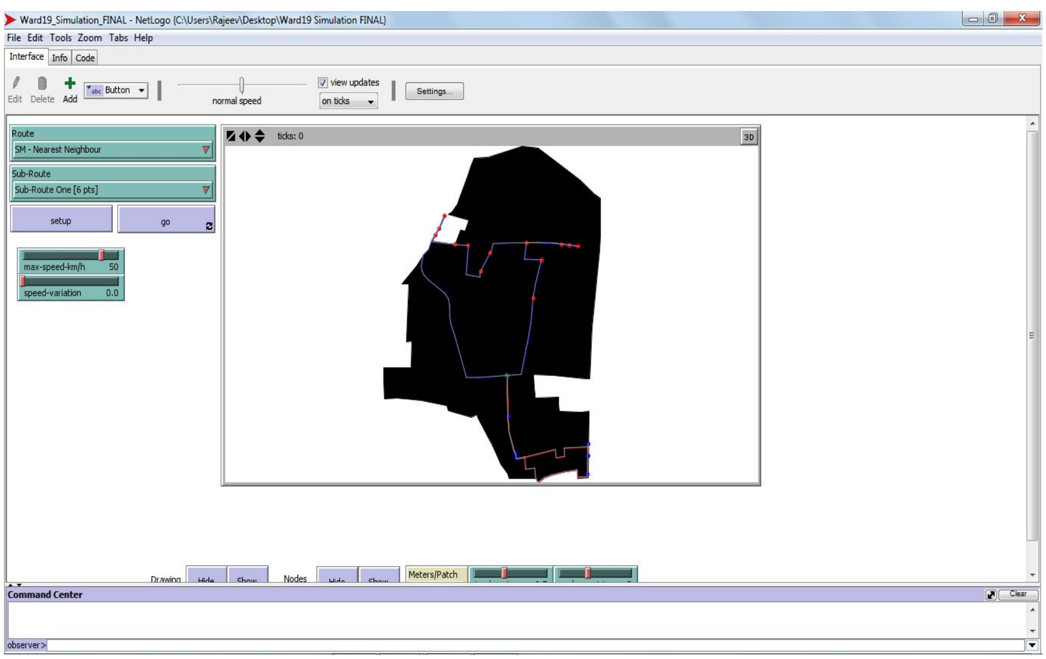


Fig. 16 Nearest Neighbour Route – NetLogo Simulation

Sweep

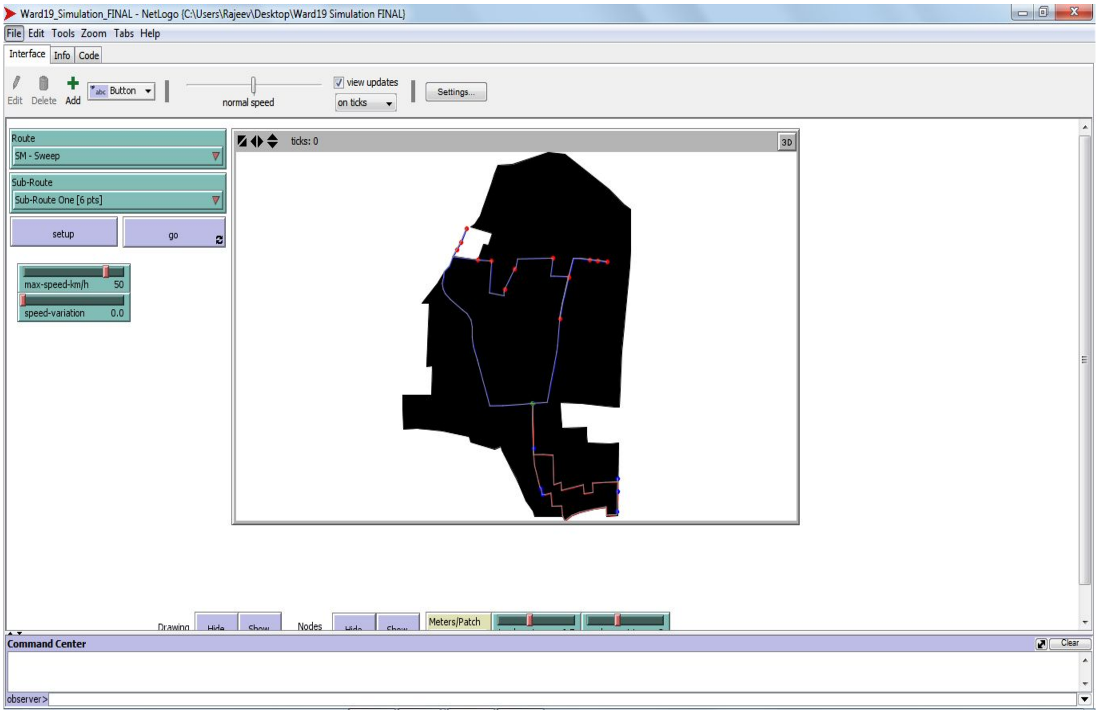


Fig. 17 Present Method Route – NetLogo Simulation

Solver

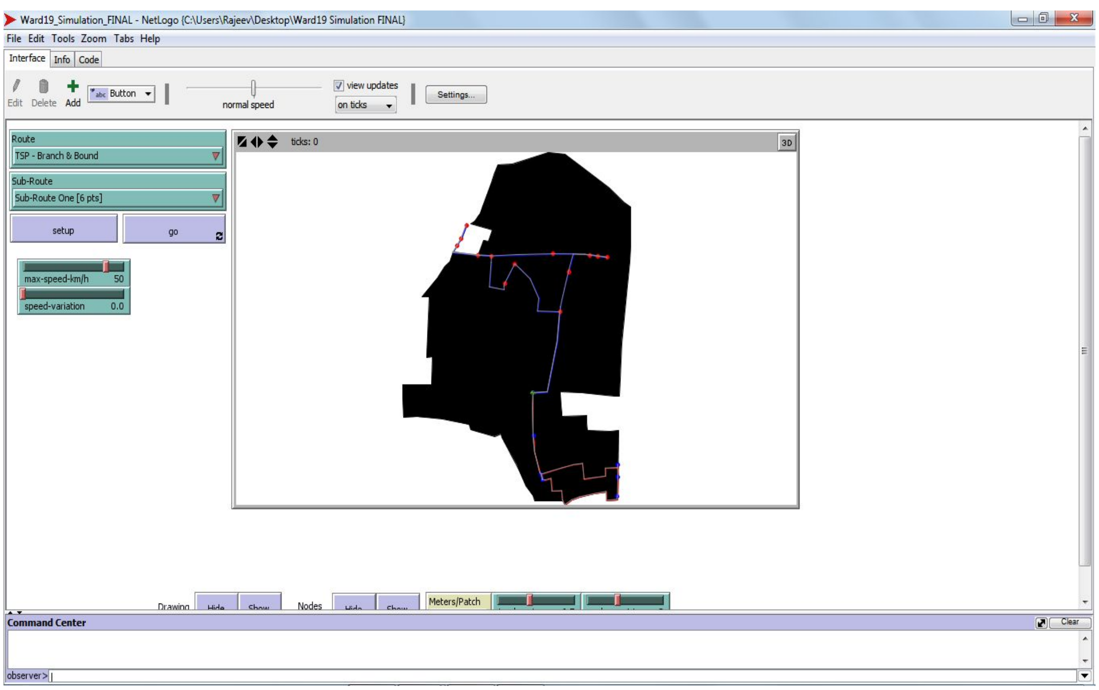


Fig. 18 Solver Route – NetLogo Simulation

Results from the simulation

The two quantitative outputs from the simulation are the cycle-times and amount of uncollected garbage at the end of each run of the simulation. Both of these were exported from NetLogo to separate Excel files. Once the simulation had been run for 30 iterations (days), the outputs for each route were compared using line graphs and scatter diagrams.

9.4.1 6-Point Route

Route 1 (6 pt)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cycle Time															
Present	317.289	305.524	319.701	303.423	292.851	315.615	302.719	309.676	297.707	300.407	314.557	288.653	304.865	307.007	294.192
Nearest Neighbour	303.399	315.224	306.802	315.413	300.036	306.78	283.605	299.616	295.403	296.183	278.804	303.178	306.715	314.781	308.027
Sweep	300.014	311.832	307.656	305.171	315.935	311.664	305.562	297.483	306.736	297.676	294.128	313.095	300.183	290.99	307.564
TSP - Branch & Bound	321.455	314.251	301.742	308.917	313.896	310.149	314.559	292.308	310.447	308.949	310.501	293.039	298.13	309.086	307.525
Uncollected															
Present	0	0	0	0	0	0	21.40312	16.93484	0	8.83369068	0	0	0	18.03852	0
Nearest Neighbour	92.83441	0	0	0	0	0	0	0	83.42183	0	81.55553	87.85108	85.45556	0	0
Sweep	29.53117	34.58905	0	0	39.14411	0	0	36.71432	0	29.9341281	0	0	0	0	33.54624
TSP - Branch & Bound	88.92183	0	0	0	90.68947	81.93233	0	0	0	86.2051902	0	0	0	0	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cycle Time															
Present	302.452	308.531	288.565	299.903	308.895	279.912	291.805	315.602	310.095	300.078	311.957	288.841	302.625	312.827	299.086
Nearest Neighbour	302.313	309.928	303.173	287.716	305.068	310.696	307.406	307.507	302.359	311.979	302.177	310.698	295.536	309.631	307.289
Sweep	308.443	313.022	312.888	307.089	308.297	304.541	292.873	296.242	305.815	306.167	314.01	312.856	311.992	307.636	311.319
TSP - Branch & Bound	311.695	287.984	310.832	296.951	309.922	300.716	315.155	309.559	280.443	311.09	296.406	295.49	296.932	277.325	315.298
Uncollected															
Present	0	0	18.97049	20.77426	0	0	24.00641	0	0	13.25774	0	0	0	0	15.49481
Nearest Neighbour	0	0	88.56084	0	0	0	0	84.30906	0	80.46952	0	0	84.59134	87.0881	0
Sweep	0	0	39.32953	0	0	31.767	31.33711	0	29.30178	0	35.19632	36.95989	0	0	44.56818
TSP - Branch & Bound	0	0	85.56229	80.22277	82.8602	0	0	0	0	0	0	86.80805	91.24861	0	0

Table 10 Cycle-times and Uncollected Solid waste recorded from simulation of – 6-point route

Number of Cycles: 30

Graphs:

Cycle Time vs. Days

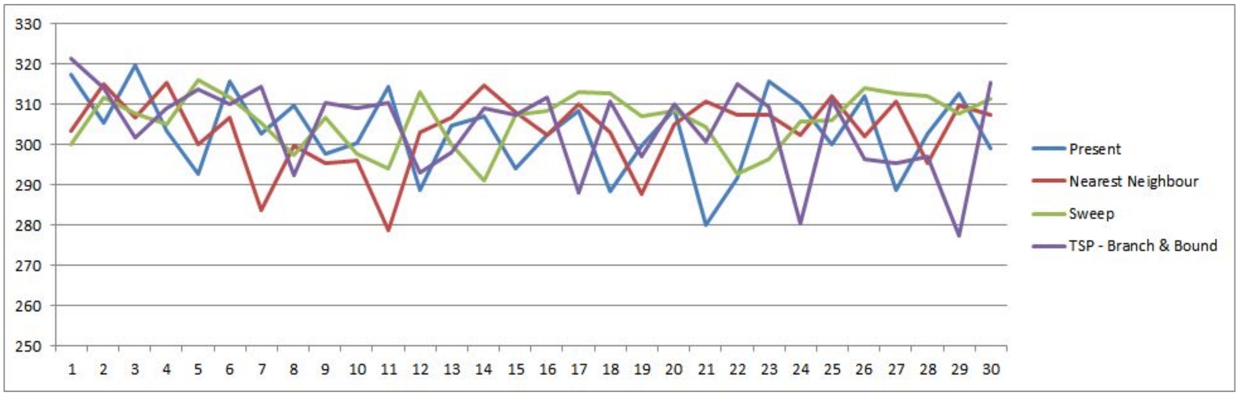


Chart. 1 Cycle-time vs. Days for the 6-point route

Uncollected Solid waste vs. Days

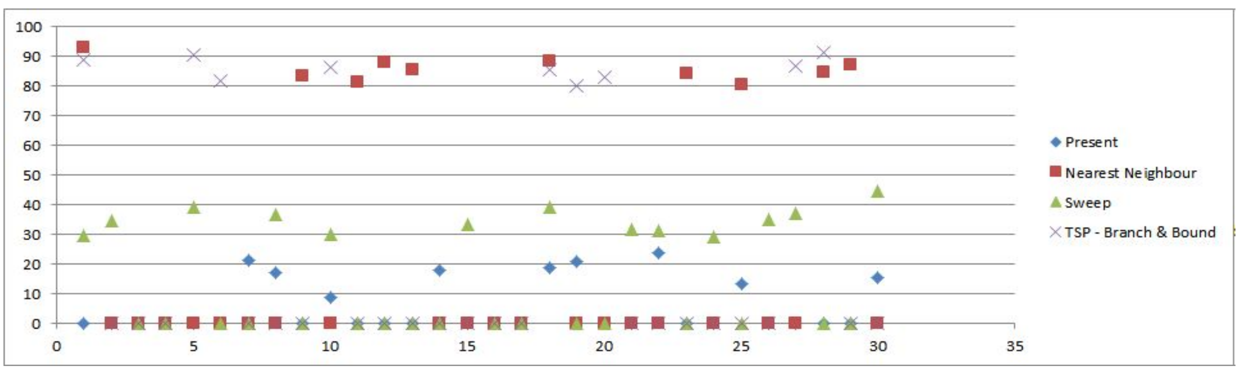


Chart. 2 Uncollected Solid waste vs. Days for the 6-point route

Summary

Cycle Time		Uncollected	
Present	303.1787	Present	5.257129
Nearest Neighbour	303.5814	Nearest Neighbour	28.53791
Sweep	305.9626	Sweep	15.06396
TSP - Branch & Bound	304.3584	TSP - Branch & Bound	25.81503

13-Point Route

Route 2 (13 pt)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cycle Time															
Present	909.526	906.879	886.796	901.857	893.282	893.624	905.409	893.388	908.183	895.657	894.255	896.795	898.194	911.157	907.982
Nearest Neighbour	894.987	915.544	895.57	875.004	903.887	899.042	902.112	898.472	897.214	902.312	889.65	900.487	889.351	898.877	893.855
Sweep	903.834	901.055	906.226	897.673	878.489	901.609	900.153	882.842	914.715	910.291	908.07	904.342	893.462	898.847	915.564
TSP - Branch & Bound	915.634	804.422	804.201	896.982	813.164	802.655	890.838	912.843	909.371	811.43	819.654	811.52	912.46	816.955	825.247
Uncollected															
Present	25.94948	0	0	35.38143	28.89386	29.1268	27.85019	0	30.71614	39.7189617	31.55105	25.98383	34.20949	0	25.59301
Nearest Neighbour	26.34977	0	22.006962	0	27.81711	36.50211	0	30.62084	33.04786	46.3189485	0	0	0	30.87087	26.72711
Sweep	0	0	0	0	41.06755	0	0	39.92925	0	0	44.70825	0	0	0	0
TSP - Branch & Bound	0	117.8882	122.895873	0	115.0257	115.7551	0	0	0	112.982481	112.9588	119.0191	0	111.9931	120.7173

Route 2 (13 pt)	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cycle Time															
	898.473	909.229	914.856	915.459	878.918	894.782	908.716	906.129	899.623	906.658	898.77	892.6	907.775	912.204	900.531
Present	897.458	915.261	895.795	905.214	897.521	906.01	900.799	887.912	887.492	904.974	900.52	889.7	907.463	910.699	895.97
Nearest Neighbour	906.777	913.261	868.019	912.518	864.564	881.829	876.855	905.595	878.163	912.973	879.562	897.881	880.381	907.719	910.842
Sweep	911.406	906.32	911.186	915.428	803.971	890.974	911.323	817.383	882.743	887.741	824.59	824.669	912.117	798.594	799.521
TSP - Branch & Bound															
Uncollected															
Present	35.14298	0	0	0	0	0	0	0	0	27.70841	33.40684	0	0	0	28.36635
Nearest Neighbour	0	0	0	1.14E-13	0	0	0	0	35.51238	0	0	29.81403	0	25.75301	0
Sweep	0	0	55.23732	0	51.68354	43.92338	43.5791	39.21122	40.24825	0	37.39739	40.58056	45.3937	0	0
TSP - Branch & Bound	0	0	0	0	115.5164	0	0	109.855	0	0	115.1174	117.6746	0	120.5086	116.6522

Table. 11 Cycle-times and Uncollected Solid waste recorded from simulation of – 13-point route

Number of Cycles: 30

Graphs

Cycle Time vs. Days

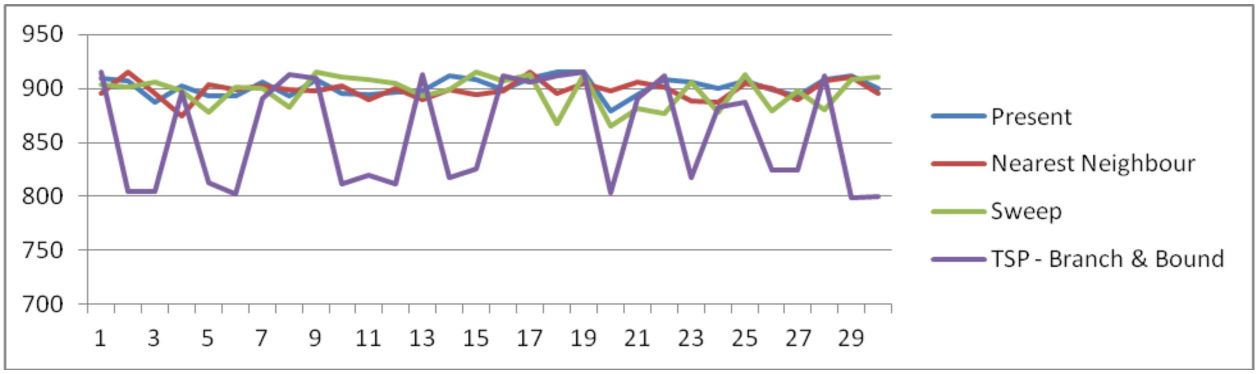


Chart. 3 Cycle-time vs. Days for the 13-point route

Uncollected Solid waste vs. Days

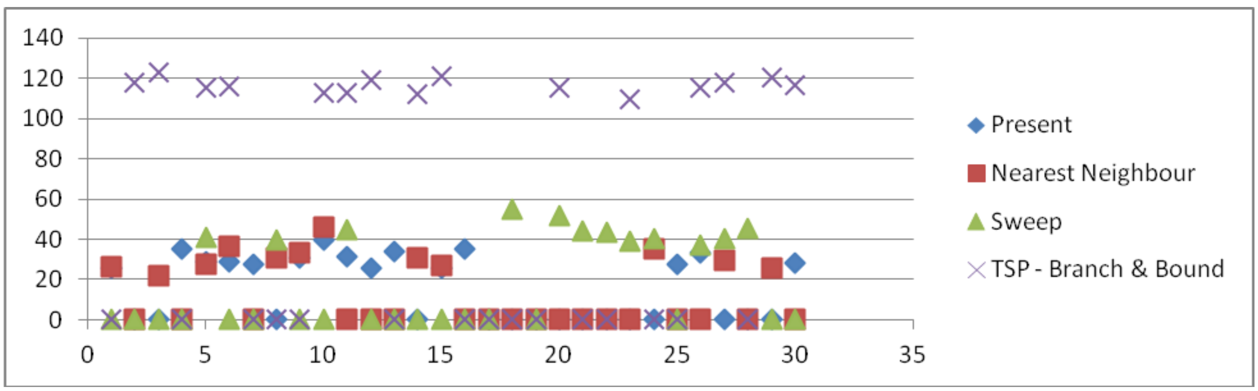


Chart. 4 Uncollected Solid waste vs. Days for the 13-point route

Summary

Cycle Time		Uncollected	
Present	901.59	Present	15.32
Nearest Neighbour	898.64	Nearest Neighbour	12.378
Sweep	897.14	Sweep	17.432
TSP - Branch & Bound	858.18	TSP - Branch & Bound	58.152
Minimum	858.18	Minimum	12.378

Recommendations and conclusion

Basing the recommendation solely on the distances would not necessarily give us the best alternative because the system depends on many more aspects apart from the distance travelled and the fuel expended. This is seen through the observations made in the simulation. It is seen that the shortest route, sometimes, is the one with the most amount of solid waste uncollected at the end of the trip. Also, it is seen that there are two reasons why there could be a decrease in cycle-time. One, because the route followed is shorter. Two, because the last pick-up point is let unattended because of the truck being full, which means that when there is uncollected garbage, the cycle-time is shorter. The former is a positive while the latter isn't.

Hence, the concept of the best route really depends on which perspective is being given priority. Given below are the recommendations based on distance saved and amount of garbage uncollected.

Based on Distance:

1. **13-Point Route**

   Nearest Neighbour

DC → 2 → 1 → 6 → 3 → 4 → 5 → 7 → 8 → 9 → 10 → 11 → 12 → 13 → DC

17.3+5.6+8+9.2+1.8+1+21.3+6.7+9.5+3.1+8.7+2.2+4.1+45.1 = 143.60units = 3.59kms

- Savings in distance travelled: 0.7kms
- 16.3% saving from present route

2. **6-point Route**

Sweep

DC → 19 → 18 → 17 → 14 → 15 → 16 → DC

8.3+12.1+2+21.6+3.6+5.6+37.8 = 91units = 2.275kms

- Savings in distance travelled: 0.62kms
- 21.49% saving from present route

Based on Outcome of Simulation:

Least Garbage Uncollected

13-point route: Nearest Neighbour

DC → 2 → 1 → 6 → 3 → 4 → 5 → 7 → 8 → 9 → 10 → 11 → 12 → 13 → DC

6-point route: Present Method

DC → 14 → 15 → 16 → 17 → 18 → 19 → DC

Conclusion

Using various routing algorithms like nearest neighbour, sweep etc. we have obtained new routes for the solid waste collection compactor and truck in Sanjaynagar, ward 19.

In terms of reduced distance, the following routes are recommended:

- For the 13-point route, the Nearest Neighbour method provided the maximum savings of 16.3% when compared to the present method.
- For the 6-point route the Sweep method provided the maximum savings of 21.49% compared to the present method.

In terms of reduced uncollected solid waste, from the Simulation the following routes are recommended:

- For the 13-point route, the Nearest Neighbour method provided the least uncollected solid waste.
- For the 6-point route, the Present method provided the least uncollected solid waste.

At the end of this project, the main conclusion we arrived at, is that the process of collection and disposal of solid waste is a very complex one, even when we're considering just the transportation part of it. It was interesting to see that even after finding the best route to take in terms of least distance, that wasn't necessarily the best route when compared with the outcome of the simulation study in terms of uncollected solid waste.

We understood that there a multiple perspective we must look from and multiple parameters we must take into consideration when solving such a problem. Many of these parameters are quantitative, but there are many which are qualitative and behavioural, which cannot be standardised for any group of people. Hence, this kind of an issue must look at all the intersecting systems on a holistic fashion in order to solve a problem of such a complex nature and magnitude.

FUTURE WORK

In our future work with the project, we aim to implement the new routes of trucks in ward 19. We would like to look at the scalability of the simulation i.e. modifying it such that that it can be used in other wards and also add more agents involved in the process like autos, push carts etc. in the simulation and study their effects.

We would also like to study in detail some of the other problems thrown to light through the interviews, surveys and field observations importantly the study of the behavioural data of various stake holders in detail and its effects on the system feeding into the simulation.

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