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IoT based Smart Garbage Management –Optimal Route Search

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Abstract - One of the main objectives of smart cities is keeping the environment clean and neat. In garbage management system, there are multiple dustbins located throughout the city, these dustbins are provided with low cost embedded device which helps in tracking the level of the garbage bins. When it reaches threshold a message is sent via GSM to the concerned person to clean it as soon as possible. Garbage Collection System uses algorithms such as Nearest Neighbor, Genetic algorithm, Sweep algorithm ,Ant colony and many more that provide better scheduling and shortest route generation for Garbage Collection Truck used in Garbage collection system. This paper provides a comparative analysis on different algorithms used for Garbage collection System such as Nearest Neighbour, Sweep algorithm and TSP Solver.

Key Words: **Garbage Management System, Nearest Neighbor, Optimal Route, Sweep algorithm, TSP Solver**

1. INTRODUCTION

Due to rapid population growth, disorganization of city governments, a lack of public awareness and limited funding for programs, garbage management is becoming a global problem. Due to the lack of care and attention by the authorities the garbage bins are mostly seem to be overflowing. It can be reduced by using smart garbage management system. Our present Prime Minister of India, Sri Narendra Modiji has introduced the concept of implementing 100 smart cities in India. "Swachh Bharat Abhiyan" was initiated to ensure a clean environment. Communication over the internet has grown from user - user interaction to device –device interactions these days.

IoT can be used to provide a platform for smart garbage management. Some of the commonly used methods are implemented using sensors and microcontrollers. The details of each bin are monitored by the authority with the help of GUI. Effective actions will be taken if the corresponding authority is not concerned regarding the cleaning of bins. The implementation of smart garbage management system using sensors, microcontrollers and GSM module assures the cleaning of dustbins soon when the garbage level reaches its maximum. If the dustbin is not cleaned in specific time, then the record is sent to the higher authority who can take appropriate action against the concerned contractor.

This system also helps to monitor the fake reports and hence can reduce the corruption in the overall management system. This reduces the total number of trips of garbage collection vehicle and hence reduces the overall expenditure associated with the garbage collection. It ultimate helps to keep cleanness in the society. Smart collection bin works with the sensors will show us the various levels of garbage in the dustbins and also the weight sensor gets activated to send its output ahead when its threshold level is crossed. If dustbins are not cleaned in time, the details will be forwarded to higher authority.

Garbage Collection Truck (GCT) would be used for the purpose of collecting garbage. These GCTs are scheduled daily according to areas but there is no proper management of truck scheduling, as there is absence of IoT in Garbage Collection System due to which there is wastage of fuel. However, there are situation when Garbage Collection Truck arrives the dustbins are overflowed or not fully filled or empty so if IoT comes in the consideration then there would be proper management in whole system .

In mega city, the garbage collection system is very complex, as there is a large area to cover which consist of lots of dustbin. A dynamic transit consists of large number of garbage from street to depot. The main problem is to generate optimal routes for truck for collecting garbage for each Garbage Collection Truck (GCT), with better utilization of available space of Garbage Collection Truck (GCT) and to decrease the wastage of fuel. This problem is being divided into two sub-solutions,

a) Providing smarter dustbin which consists of number of sensors connected over cloud.
b) Generating optimal path for Garbage Collection Truck.

This paper provides a comparative analysis on different algorithms used for Garbage collection System such as Genetic Algorithm Ant Algorithm, Integrated Nearest Neighbor Algorithm and Genetic Algorithm.

1.1 Smart Dustbin

Every smart bin is equipped with ultrasonic sensors which measure the level of dustbin being filled up. The container is divided into three levels of garbage being collected in it. With its continuous use the levels get filled up gradually with time. Every time the garbage crosses a level the sensors receives the data of the filled level. This data is further send to the garbage analyzer as instant message using GSM module. Every message which is received at the garbage analyzer end is being saved as data which is further used for the process of analysis and predictive modelling. The data received at real time is used by the application interface for better viewing of the filled level. The data received is saved in the database keeping all its attributes intact as time and date. A history of data collected in months is used by the department of data analysis for prediction and report making. The application interface shows the real time level to the garbage analyzer and using that it directs its team of garbage collector to collect the garbage to avoid overflow. This will help the waste management department to optimize the route for the collection of waste every time garbage collector moves around the city for garbage collection. This helps in saving time, resources of the waste department and work is then performed in more efficient manner

The major components of Smart Dustbin are as follows:

- ARM CORTEX M3 LPC 1768
- PIR Sensor
- Load Cell
- GSM Modem
- Ultrasonic Sensor

1.2 Generating Path for Garbage Collection Truck

This is the important aspect, as it will decide what would be overall cost, overall complexity etc. The path would be calculated using the major steps involved are as follows:

- The path is being generated according to the data received from each dustbin and priority to each dustbin is given according to status of dustbin.

- There are many different algorithm used for generating shortest path for GCT such as Nearest Neighbor Algorithm, Genetic algorithm, Ant Colony and many more.

- Shortest path which provide optimal route for GCT and stop the wastage of fuel and other resources. This is some of the features of IoT that makes whole system very reliable and bring automaticity.

Using IoT whole system is centrally managed and monitor, there is no requirement of monitoring particular sensors all sensors are being connected over internet and are being commanded centrally.

2. OPTIMAL PATH ALGORITHMS

2.1 Data Collection

Sanjaynagar ward 19 is located in Jaipur 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. 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.

<u>Sanjaynagar Statistics Ward no. – 19</u>

Area (in sq. km.) – 1.5

Population – 34,865

Allotment of resources for SWM:

Push Carts – 70

Auto Tipper – 6

Solid waste Truck – 1

Solid waste Compactor – 1

2.2 Algorithms & Methods considered

- Nearest Neighbour Method
- Sweep Algorithm
- TSP Solver
- Present Traditional Method

3. METHODOLOGY

The aim of this method is to decide on 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

3.1 Steps

1. Collect data on costs of transportation, time, distance, solid waste volume(calculated by the help of IOT based intelligent dustbin), 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

Finally, on the basis of above steps we try to create distance matrix and cost matrix. The table of distance matrix takes into consideration, the total 19 parts and the distance from 1 path to reach another path.

- The 19 point of garbage collection is divided into (13 points+6 points) for better understanding and convenience.
- The cost matrix table focuses on what would be the total cost that would be incurred if travelled from one path to another using the Garbage Collection Truck (GCT).

	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

Fig1 - Distance 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	61.8	0															
L5	45.8	34.6	61.8	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	48.3	59.3	65.5	0								
L12	29.8	21.5	37.6	37.6	37.6	45.8	48.8	48.3	59.3	65.5	77.6	0							
L13	29.8	21.5	37.6	37.6	37.6	45.8	48.8	48.3	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	15.6	16.6	16.6	0

Fig2 - Cost Matrix

3.2 Calculative analysis of different algorithms

a) 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

b) Sweep Algorithm

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

c) 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.

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

d) Present method (traditional method)

Route: 13-Point Trip

Distance = 171.50units = 4.2875km

Route: 6-Point Trip

Distance= 115.9units = 2.8975km

3.3 Simulation

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 3-Simulation

4. RESULTS

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

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

Fig 4 -Cycle-times and Uncollected Solid waste recorded from simulation of – 6-point route

In the similar way,the comparison would be done on the 13 point route .

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

Fig 5 -Cycle-times and Uncollected Solid waste recorded from simulation of – 13-point route

On the basis of both the comparisons , a complete analysis is carried out to see the best possible paths in the various aspects on the basis of the different factor.

A graph could be plotted to give a better understanding on the comparitive analysis of different algorithms

Cycle Time vs. Days

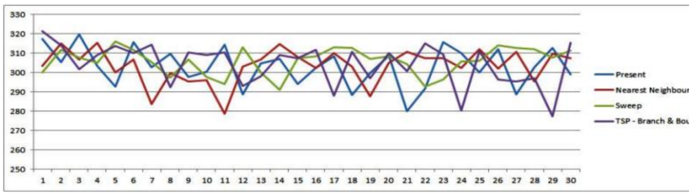

Chart 1-Cycle time vs day for 6 point route

Uncollected Solid waste vs. Days

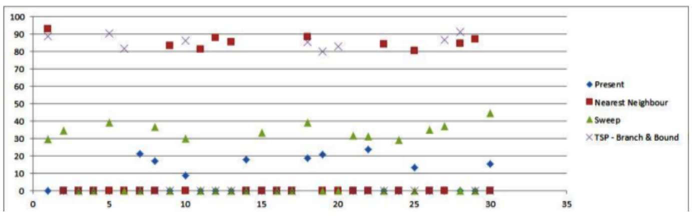

Chart2-Uncollected solid waste vs day for 6 point route

Cycle Time vs. Days

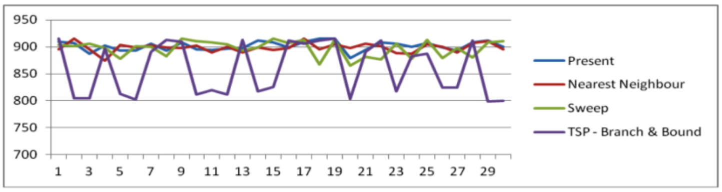

Chart 3 -Cycle time vs day for 13 point route

Uncollected Solid waste vs. Days

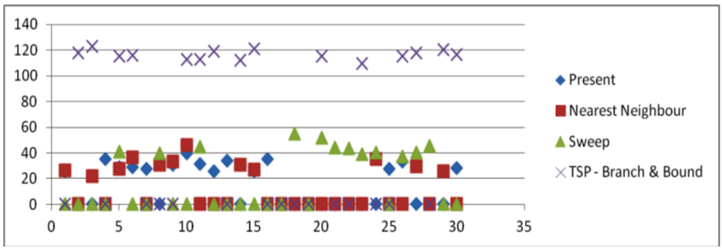

Chart 4- Cycle time vs day for 13 point route

On the basis of graph obtained , we can easily calculate the overall summary of all the four major algorithms used for the route calculations ,which canbe as follows:

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

6 point route calculaton

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

13 point route calculaton

Overall on the basis of above results, it can be concluded that:

4.1 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

4.2 Based on Least Garbage Uncollected

1) 13-point route: **Nearest Neighbour**

DC→2→1→6→3→4→5→7→8→9→10→11→12→13→DC

- 10.25% saving from present route

2) 6-point route: **Present Method**

DC→14→15→16→17→18→19→DC

5. CONCLUSIONS

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.

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 analysis, 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 behavioral, which cannot be standardized 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.

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