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Sustainable Waste Management Model

Rishabh Jain, Shreya Garg, Tarushi Agrawal, Saurabh Gangal, Indu Chawla, Shikha Jain

Department of Computer Science and Information Technology

Jaypee Institute of Information Technology

Noida, India

rishijain1998@gmail.com, shreyagarg011@gmail.com, tarushi.agrawal17@gmail.com, saurabhg1000@gmail.com, indu.chawla@jiit.ac.in, shikha.jain@jiit.ac.in

***Abstract*—The problems concerning waste management in the world are rapidly increasing day by day. Improper planning of waste management and lack of technical support are the main reasons of these problems. This greatly affects the health conditions of the citizens. Consequently, it is vital to propose a feasible solution for this problem. This paper represents a sustainable waste management system which can be adopted by any city. It can be served as a guiding tool to the municipal corporation. The system ensures a sequential execution of the procedures following collection, disposal, transportation and processing of waste. The idea is to divide the management system into four modules - division of the city into zones to reduce the problem size, assignment of scrape yards to each zone, optimization of waste collection route and setting an efficient budget for investing in waste processing machines, thereby designing an overall waste management model. This management model helps both ways, environmentally and economically. The proposed model gives precise results for the dataset.**

Keywords—Waste Management; Clustering; Scrape Yard; Vehicle Routing; Budget Handling.

I. INTRODUCTION

Today, the world is facing various problems related to disposal of waste and its management. Every day wastes of all kind are improperly disposed and rarely managed favorably, starting from household waste materials to waste generated by factories. It has become a problem which is certainly difficult to control if not supervised systematically. In India, it's becoming difficult to handle large volume of waste generated by rising population, which directly affects the environment and public health [1].

Basically, waste management in India refers to collecting waste material from residential and industrial areas and dumping it at disposal sites. Taking into account various environmental concerns we should unload the waste in a structured way or reuse the waste in a productive manner. The need of hour is to develop efficient managerial techniques digitally [2][18] and attain better results.

This paper presents a model to enhance the overall waste management system which provides better outcomes environmentally and economically. The system is divided into four modules. Each module is planned so as to generate finer output accordingly.

The initial approach is to divide the city into several zones using clustering algorithm [3]. The results obtained from the initial step are utilized in further modules. The next part involves the detection of location of dump yard in each zone and determining its maximum capacity. Now after obtaining the suitable dump yard site for each zone, it is desired to build the most optimal route for the waste disposal garbage trucks, thereby gaining economic benefits. This is achieved by modifying the vehicle routing problem [4] [17]. The final module proceed towards effectively reducing the budget required for major financial investments including purchasing appropriate number of waste processing machines required for a particular zone. It aims to reduce the service cost to a significant amount. The system also keeps track of the maximum capacity of dump yard so as to ensure elimination of its over-filling. The objective is to propose a prototype model that can be used in any city for optimal waste management.

II. RELATED WORK

As a matter of the fact there exist different perceptions among people. Large number of researchers has devoted tremendous time and effort to solve the problem of waste management in India. Various methods and management techniques are proposed to design the most optimal way for managing waste in our country. These solutions were widely adopted by various municipal corporations in several places and are renowned for bringing about appreciable results.

For instance, a decision support system was submitted by Costi et al. [2], which is designed to help authorities of a municipality in the development of incineration, disposal, and treatment of waste. According to Yeomans et al. [5], many uncertain factors exist in the planning for Municipal Solid Waste (MSW) management. They suggested an evolutionary algorithm combined with simulation to determine solutions for the MSW management problem. It is observed that the approach provided many practical planning and implementation benefits for problems operating under uncertain conditions.

Waste collection management largely depends on the route optimization problem that involves a large outlay in transportation costs, labor, fuel cost and other operational costs. Thus, it is crucial to optimize the route that the waste collection trucks must take in order to minimize the above mentioned expenses. The authors [6] introduced the capacitated vehicle routing problem for solid waste collection to find the most optimal route on the basis of waste collected and distance travelled.

As per the research conducted in ref [7], it is difficult to collect garbage from the city without divided it into several zones based on a particular parameter. Thus, a pre processing clustering algorithm is used to gain more appreciable results. The author [8] studied the aspects of solid waste management and a mechanism to locate the appropriate site for landfill or dump yard for dumping the waste collected using the genetic algorithms. A similar approach to the solid waste management is prensented by Otoo et al. [9]. They proposed the use of heuristics algorithms to generate a feasible solution for the routing problem as well as for the waste collection schedule.

Moreover, Karadimas et al. [10] suggested improvement in the solid waste collection and transportation problem by identifying collection routes through ant colony system algorithm. An intelligent garbage management system in real time based on decision algorithms [11] is the practically applied automated system towards smart solid waste management. The real time monitoring system is based on decision algorithms for detecting solid waste data through a wireless network.

A number of surveys have been conducted on the waste management problem in India. Chavan and Pattanshetti [12] conducted a survey on municipal waste collection management in a smart city. The survey highlights the use of Internet of Things (IOT) to acquire efficient waste collection routes and reduce transportation costs.

This paper focuses on the waste management from the prospective of developing country like India. The proposed model takes care of complete waste management process while considering environmental and economical need.

III. METHODOLOGY

Considering the need of the waste management in India, we propose a framework of the waste management model (shown in figure 1). For technical execution, the data set contains a graphical representation of the city wherein each node represents a waste generating point such as houses, industries or commercial building. Each node in the graph contains attributes including the identification number of point and the zone to which the point belongs, its location, amount of waste collected by each point, number of people residing in the building. Each zone is a collection of waste generating points. The system is divided into four modules (shown in fig 1). Each module is explained below:

A. *Division of city into zones*

Figure 2 illustrates the city map for a sample dataset consisting of 11 garbage collection points. The points on the x-axis and y-axis define x and y coordinates of the building respectively. Each edge connecting two points depicts the path from one point to the other. Algorithm 1 describes the procedure for dividing the houses into separate zones.

Algorithm 1:

total_waste : Total waste generated by all houses

capacity: Average capacity of scrape yard

Step 1: Calculate the value of K using eq 1, where K represents the total number of zones in which the city is divided, as per the following method.

$$K = \text{ceil}\,(total\_waste / capacity) \qquad (1)$$

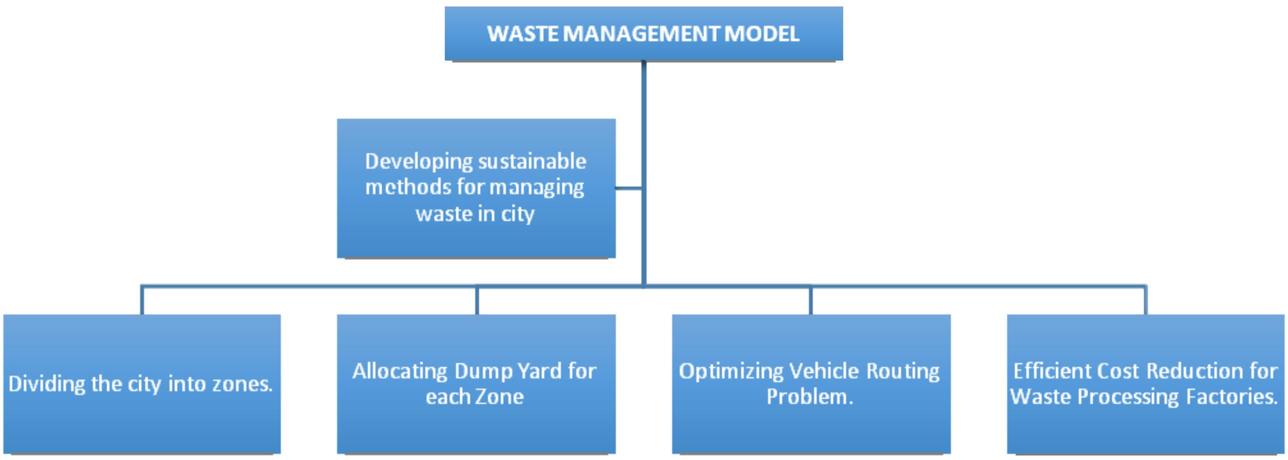

Fig. 1. Proposed model of waste management

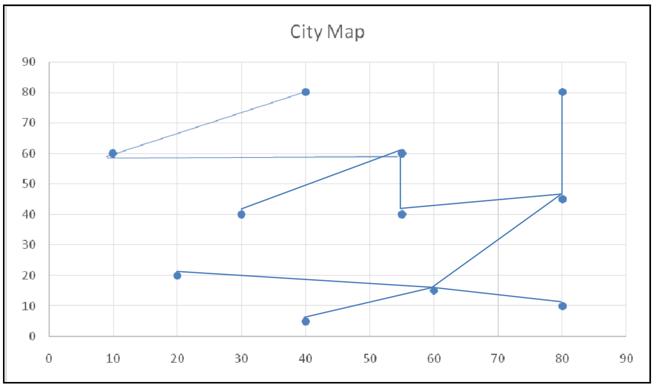

Fig. 2. City map for a sample dataset

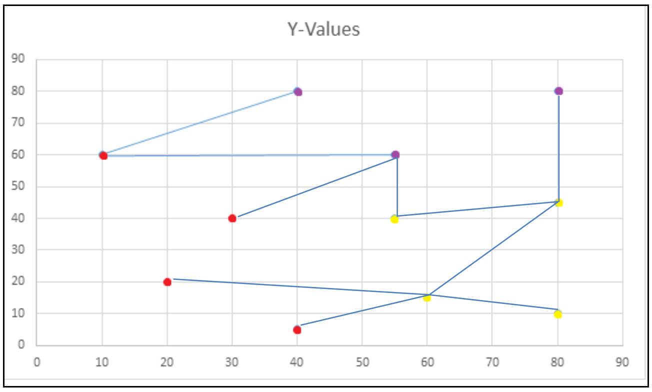

Fig. 3. City map after zone division

Step 2: Choose K number of points randomly from the dataset. Each point represents one zone.

Step 3: Use Euclidean Distance (eq 2) to find the distance between each data point and the zone. Pick the nearest data point.

$$\text{ED= square root } ((x_2\text{-}x_1)^2 + (y_2\text{-}y_1)^2) \qquad (2)$$

Step 4: Repeats steps 2 and 3 till the convergence.

Figure 3 shows the results after applying the algorithm with K =3. The points in the same color belong to the same zone.

B. Allocation of suitable dump yard site

After cities are divided into zones, every waste collection point belongs to a unique zone. The task ahead is to assign a dump yard to each zone at the most appropriate location. As per the guidelines of MSW and the research conducted on the landfill site suitability assessment [13], at least 150m is the authorized distance of dumping site from residential and commercial areas specified by the government. Algorithm 2 describes the method for searching suitable site for dump yard.

Algorithm 2:

x_i : x coordinate of i^{th} house of zone Z

y_i : y coordinate of i^{th} house of zone Z

n: Total number of houses in a zone Z.

Step 1: Repeat the steps 2-6 for each zone.

Step 2: Locate the centroid of the zone (C_z) using eq. 3.

$$(x_{cz}, y_{cz}) = ((\sum x_i /n) , (\sum y_i /n)) \qquad (3)$$

Step 3: Calculate the distances between of all houses (or points) in the zone and the centroid of the zone (C_z) using eq 2.

Step 4: Choose the house (or point) H_z which is the farthest from the centroid. Let the distance between (C_z) and H_z is D_z.

Step 5: To follow MSW guidelines,

$$D_z = D_z + 150 \qquad (4)$$

Step 6: Construct a circle, with center as C_z and radius as D_z. All points on the circumference of the circle are the possible locations for the scrape yard. Figure 4 shows all possible locations of dump yard lying on the boundary of three zones.

Step 7: Find the intersection points of every two circles [14].

Step 8: To obtain the suitable location for the dump yard site, a line segment is drawn through the intersection points of two zones as shown in figure 5. If the resultant location lies within the overlapping region of two zones, then this location is avoided and the steps are repeated until a non-overlapping zone is found. Then this location is declared as the suitable location for the dump yard site.

C. Optimizing garbage collection route

Next, an optimal route needs to be determined in order to reduce operational and transportation costs. Optimizing the garbage collection route problem resembles the famous travelling salesman problem (TSP) [15] under a given set of constraints. Now, the next step involves the idea behind backtracking algorithms, that is, explore all the possible paths in each zone and find the best possible route that can be adopted by the garbage collection trucks.

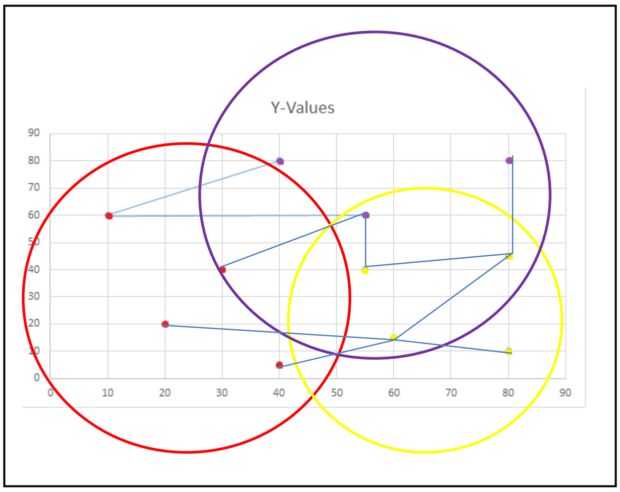

Fig. 4. Possible dump yard site

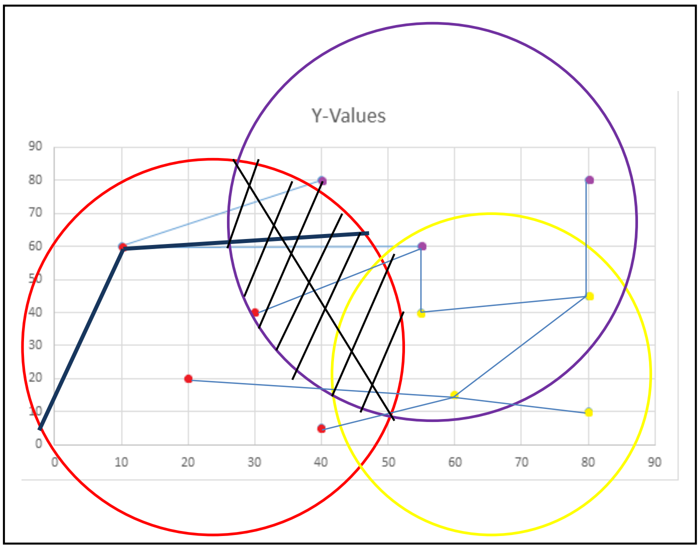

Fig. 5. To find suitable dump yard site

As the exact locations of the dumpsite are known, the waste collection trucks depart from a single depot at the beginning and return to the same depot at the end. All trucks are assumed to have the same loading capacity. It is assumed that:

1) Each house is visited exactly once (by a single waste collection vehicle).

2) The total garbage load on any garbage collection truck associated with a given route is in accordance with the maximum capacity of dump site.

Using this way we minimize the total travelling distance for all waste collection vehicles to gain economic benefits.

D. *Efficient cost reduction for waste processing factories*

Next important step is to process the garbage dumped in an environment friendly manner as well as with better economic means. The final step put forward a cost reduction method in such a way that an efficient budget can be set up for the waste processing factories. We need to maximize the number of machines required for processing waste disposed in minimum expenditure possible. According to data collected by World Bank about waste generation [16], in South Asia, approximately 70 million tons of waste is generated per year, with per capita values ranging from 0.12 to 5.1 kg per person per day and an average of 0.45 kg/capita/day. The total waste accumulated by all the waste collection points in every zone is randomly generated. This is formulated by setting a lower and upper limit for each waste collection point as per the data collected by [16]. The data obtained from the above calculations is further utilized to calculate the total amount of garbage collected from each residential area, depending upon the family size. To minimize the expenses, we consider the following parameters: amount of waste collected from each zone (w), total working hours of the labor (h), cost of each waste processing machine (c) and rate at which waste processed by each machine per hour (r). Consequently, the variable parameter turns out to be the total expenditure which needs to be decreased using eq 5.

$$\text{Expenditure} = \sum_{\text{for each zone}}(\text{ceil}\ ((w / r * h) * c)) \qquad (5)$$

On solving these we get the desired output. This model efficiently helps in cost cutting in the major investments done in waste processing factories. Furthermore assisting the government in gaining better profit financially as compared to other trends.

IV. RESULTS AND DISCUSSION

For simulation purpose, a dataset of 30 houses is collected from a city of India. The data points of 11 houses the plotted in the figures 2-5 to keep it more understandable. The implementation is done using C++ platform. The simulation results of each of the module are described below:

A. *Division of city into zones*

After applying algorithm 1, the houses are clustered into 4 zones based on their waste generation amount and the proximity of one house from the other. The output achieved for the dataset is shown in Fig. 6 (a) - (d) with coordinates of each house zone-wise. For instance the house with id ‘10’ belongs to zone no. ‘1’ with location specified by coordinates (141 units, 212 units). Also, for each zone, its centroid value is computed which denotes the central value of the zone formed.

B. *Allocation of suitable dump yard site*

Now the data obtained above is further added to use for the dump site allocation using the method illustrated in Fig. 5 and algorithm 2. The output attained in this case is the exact location of the dump yard for each zone specified by its coordinates. As shown in Fig. 7, say for zone no. ‘0’ the dump yard should be ideally located at (265 units, 399 units) from the central location of the cluster keeping in mind the environmental and health issue associated with landfill site allocation.

```
Zone 0
House No. 23: (300, 122)
House No. 19: (250, 161)
House No. 21: (289, 43)
House No. 25: (326, 218)
House No. 26: (372, 75)
House No. 28: (388, 234)
House No. 29: (391, 175)
House No. 20: (236, 85)
Centroid of Zone (319, 139.125)
```

Fig. 6 (a). Division of city: Zone

```
Zone 1
House No. 4: (70, 335)
House No. 0: (26, 295)
House No. 1: (22, 209)
House No. 5: (86, 280)
House No. 6: (73, 214)
House No. 9: (143, 313)
House No. 10: (141, 212)
Centroid of Zone (80.1429, 265.429)
```

Fig. 6(b). Division of city: Zone 1

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Zone 2
House No. 14: (168, 96)
House No. 2: (10, 150)
House No. 3: (20, 80)
House No. 7: (64, 136)
House No. 8: (65, 30)
House No. 11: (133, 136)
House No. 12: (97, 64)
House No. 13: (190, 145)
House No. 15: (125, 15)
House No. 16: (190, 29)
Centroid of Zone (106.2, 88.1)
```

Fig. 6(c). Division of city: Zone 2

```
Zone 3
House No. 17: (223, 332)
House No. 18: (218, 236)
House No. 22: (262, 264)
House No. 24: (328, 314)
House No. 27: (374, 283)
Centroid of Zone (281, 285.8)
```

Fig. 6(d). Division of city: Zone 3

```
ASSIGNING SCRAPE YARDS TO EACH ZONE

For Zone 0  (265, 399)

For Zone 1  (72, 34)

For Zone 2  (152, 346)

For Zone 3  (522, 310)
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Fig. 7. Result of Algorithm 2

C. *Optimizing garbage collection route*

Next, once the management system is aware of the location of the dump yard site and the location of each house, then the waste collection is optimized by using the idea of backtracking algorithm. As demonstrated in Fig. 8 (a), for zone no. '0' the total distance to be travelled by the garbage collection truck is 623 units. Assuming that truck begins journey from scrape yard itself it shows the houses covered in the path along with their ids and the amount of waste collected from each house and proceeds towards the scrape yard again carrying the total waste collected. The outputs obtained for zone no. '1', zone no. '2' and zone no. '3' are demonstrated in Fig. 8 (b) - (d) respectively.

D. *Efficient cost reduction for waste processing factories*

The proposed model extends the idea towards decreasing the expenses made by waste processing factories and thereby offering an optimized budget to be made by the government to plan the waste management schemes accordingly. As illustrated in Fig. 9 the amount of waste collected for the day from each zone is presented along with the number of waste processing machines required for each zone. The cost price of each machine and number of machines required for each zone define the minimum budget needed for each zone to efficiently sort out the waste materials. Assuming that the machine labour works for 10 hours a day, the amount of waste processed by machine per hour is 50 kg and the cost of each machine is 5 lacs, we get the overall expenditure to be made by the city on waste processing machine as shown in Fig. 9.

```
For zone 0

Distance to be travelled in most Optimised path is: 623 metres


Houses in path :

Scrapeyard->
( hid: 23 waste: 29.16 ) ->
( hid: 19 waste: 10.54 ) ->
( hid: 20 waste: 32.08 ) ->
( hid: 21 waste: 7.08 ) ->
( hid: 26 waste: 20.16 ) ->
( hid: 29 waste: 4.08 ) ->
( hid: 28 waste: 42.16 ) ->
( hid: 25 waste: 25.08 ) ->
Back to Scrapeyard with waste 170.34 kg

Distances Travelled Along the Most Optimised Path: ( 25 m ) -->
( 63 m ) -->
( 77 m ) -->
( 67 m ) -->
( 88 m ) -->
( 101 m ) -->
( 59 m ) -->
( 64 m ) -->
( 79 m )
```

Fig. 8(a). Garbage collection route optimisation, Zone 0

```
For zone 1

Distance to be travelled in most Optimised path is: 501 metres


Houses in path :

Scrapeyard->
( hid: 5 waste: 5.54 ) ->
( hid: 9 waste: 5.16 ) ->
( hid: 4 waste: 16.54 ) ->
( hid: 0 waste: 49.16 ) ->
( hid: 1 waste: 1.54 ) ->
( hid: 6 waste: 10.08 ) ->
( hid: 10 waste: 31.16 ) ->
Back to Scrapeyard with waste 119.18 kg

Distances Travelled Along the Most Optimised Path: ( 16 m ) -->
( 65 m ) -->
( 76 m ) -->
( 59 m ) -->
( 86 m ) -->
( 51 m ) -->
( 68 m ) -->
( 80 m )
```

Fig. 8(b). Garbage collection route optimisation, Zone 1

```
For zone 2

Distance to be travelled in most Optimised path is: 653 metres


Houses in path :

Scrapeyard->
( hid: 12 waste: 3.08 ) ->
( hid: 8 waste: 8.16 ) ->
( hid: 3 waste: 0.54 ) ->
( hid: 2 waste: 24.62 ) ->
( hid: 7 waste: 8.54 ) ->
( hid: 11 waste: 1.54 ) ->
( hid: 13 waste: 20.62 ) ->
( hid: 14 waste: 2.54 ) ->
( hid: 16 waste: 14.54 ) ->
( hid: 15 waste: 34.16 ) ->
Back to Scrapeyard with waste 118.34 kg

Distances Travelled Along the Most Optimised Path: ( 25 m ) -->
( 46 m ) -->
( 67 m ) -->
( 70 m ) -->
( 55 m ) -->
( 69 m ) -->
( 57 m ) -->
( 53 m ) -->
( 70 m ) -->
( 66 m ) -->
( 75 m )
```

Fig. 8 (c). Garbage Collection Route optimisation, Zone 2

```
For zone 3

Distance to be travelled in most Optimised path is: 430 metres


Houses in path :

Scrapeyard->
( hid: 22 waste: 0.54 ) ->
( hid: 18 waste: 24.08 ) ->
( hid: 17 waste: 3.54 ) ->
( hid: 24 waste: 2.54 ) ->
( hid: 27 waste: 49.16 ) ->
Back to Scrapeyard with waste 79.86 kg

Distances Travelled Along the Most Optimised Path: ( 28 m ) -->
( 52 m ) -->
( 96 m ) -->
( 106 m ) -->
( 55 m ) -->
( 93 m )
```

Fig. 8(d). Garbage Collection Route Optmisation, Zone 3

```
EFFICIENT COST REDUCTION FOR WASTE PROCESSING FACTORIES

Waste Collected for the day :
Zone0 : 170.34 kg
Zone1 : 119.18 kg
Zone2 : 118.34 kg
Zone3 : 79.86 kg

Number of machines needed by each Zone :
Zone0 : 1 machines
Zone1 : 1 machines
Zone2 : 1 machines
Zone3 : 1 machines

Overall machines needed are:- 4

Budget needed for each zone :

Zone0 : 5Lakhs
Zone1 : 5Lakhs
Zone2 : 5Lakhs
Zone3 : 5Lakhs


Overall budget needed for machines is 20Lakhs
```

Fig. 9. Expenditure Calculation

V. CONCLUSION

This paper presents a complete solution for Waste Management. First, we obtain the zonal division of garbage collections point precisely. Further, the location of the dump yard is searched in a suitable manner with output tested for small data points. Moreover, the waste collection route is searched among all possible paths available in minimum amount of time by modifying vehicle routing problem. At the final stage, we are trying to reduce the operational costs and financial investments spent by government on waste processing machines, thereby reducing the expenditure.

The implementation of the proposed model takes into account all possible economic costs and major environment concerns; and the constraints arise from technical and environmental issues. The system is designed with an objective of developing the most efficient ways for the management of waste materials. As of now, we obtained precise results for a dataset of 30 houses which can further be extended safely for large dataset as well. This method can be successfully implemented to cities with small population. It can be served as a guiding tool to the municipal corporation.

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