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Development of Vehicle Routing model in urban Solid Waste Management system under periodic variation: A case study

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Abstract: Collection cost of municipal solid waste constitutes the maximum portion in fund allocated for waste management. It can be minimized by taking the proper strategic decisions regarding the vehicle routing of collection vehicles. In this study, collection routes have been identified for 15 wards of Bilaspur city, India. A daily variation in waste generation from different sources has been considered. Constraints on a number of vehicles, routes and vehicle capacity were considered for the routing of vehicles. The Clark and Wright algorithm has been applied to find the optimal route of the vehicle. The network analyst tool set available in ArcGIS was used to find the optimized route for solid waste collection considering all the required parameters. The study also demonstrates the significant cost and carbon reductions that can be obtained due to the proper routing of the vehicle.

Keywords: GIS, Clark and Wright logistics, Solid waste, vehicle routing, vehicle types.

1. INTRODUCTION

Municipal solid waste (MSW) also termed as 'garbage' or 'trash' is an inevitable by-product of human activity. It is generated by many sources (household, hospitals, shops, hotels, etc.) and are of mainly two types organic (food, fruit, plant leafs, etc.) and inorganic (paper, plastic, glass, dust, etc.) (Minoglou & Komilis, 2013; Hazra & Goel, 2009). The number of sources of MSW are increasing due to rise in urbanization, and is leading to the production of a huge quantities of solid wastes which in turn has a high negative impact on collection cost and environment (Rathore & Sarmah, 2019).

Municipal solid waste (MSW) transportation consists of multidisciplinary activities which include forecasting, generation, storage and collection, transportation, treatment, and waste disposal. Of all these activities, transportation alone account for 50–70 % of the total cost of the system (Rada et al., 2013; Tavares et al., 2009). This collection cost is increasing due to population growth, the increment in MSW generation rate, unavailability of lands nearby for landfills, and high collection time.

The time needed for dumping the collected waste depends upon three factors: (i) the number of collection points (waste bins and open dumping) in between sources (hospital, garden, commercial, market and residential) and landfills; (ii) the idling time of vehicle at each collection points; and (iii) routing of vehicle during collection (Hemmelmayer et al., 2014).

Vehicle routing is the most influential factor and mostly depends on the location of collection points and vehicle capacity. It also affects the collection cost and carbon emission. Nguyen et al. (2010), estimated the fuel consumption of a vehicle during the curbside collection of waste and found that more than 60% of the total fuel is consumed during transportation of MSW. This consumption of fuel results in fuel cost and carbon emission.

The consumption of fuel by a vehicle depends on distance traveled and the amount of load it carrying (Tavares et al., 2009). Thus, improper vehicle routing and a large amount of MSW can result in high collection cost and carbon emission on local authorities and environment. Such situations are common in developing countries, for instance, India, where municipal authorities are unable to implement a proper methodology for management of MSW. At present, India generates around 133,760 metric tons MSW per day (MTPD) but due to inefficient collection system only 91,152 MTPD gets collected and remaining waste goes to low-lying urban areas. It is estimated that 50% of the population will live in urban cities by 2050 and this increase in urbanization and change in lifestyle will lead to increase in the volume of waste generated every year at the rate of 5%. It is estimated that urban India will generate solid waste 276342 MTPD by 2021, 450132 MTPD by 2031 and 1195000 MTPD by 2050 (Planning commission, 2014; CPHEEO, 2016).

The novelty of this study lies in two parts. First, grouping of wards (clusters) to collect the MSW generated in each group of wards. Second, consideration of variation in waste generation periodically along with vehicle routing. This study, will help municipal official in decision making of vehicle routing and ward cluster for waste collection. It encourage other researchers to work on this problem. The work present here proposes the best fit solution for the transportation of MSW for the domain defined. In this study, a cost-minimization model has been formulated on the basis of cost-saving matrix.

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2. RELATED WORKS

In this section we have presented some works related to proposed study. Akhtar et al., (2017) presents a modified Backtracking Search Algorithm (BSA) in capacitated vehicle routing problem (CVRP) models with the smart bin concept to find the best optimized waste collection route solutions. The objective function minimizes the sum of the waste collection route distances. Huang and Lin (2015) proposes a bi-level optimization formulation to model the split delivery VRP with multiple trips to determine the minimum-distance route. Malakahmad et al., (2014) proposed solid waste collection routes optimization using Geographical Information System (GIS). Five routes were selected in different area of Ipoh city for pilot study and the present routes were optimized to reduce the length of the routes and consequently the time taken to complete the collection. Results indicate up to 22% length minimization in the routes. The collection duration was also reduced from 6934s to 4602 s. Bhurjee and Panda, (2012) presented the efficient solution for interval optimization problem which discussed about the interval valued function and propertied thereof. Nguyen, and Wilson, (2010) proposed a fuel consumption multi-criteria facility allocation model for MSWM facilities of Central Macedonia region in North Greece. In their concerned objectives they tried to minimize the cost of fuel consumption while collecting the municipal solid waste (MSW) with different methodology of dynamic routes for the vehicle in a particular interval. Kim et al., (2006) address a real life waste collection vehicle routing problem with time windows (VRPTW) with consideration of multiple disposal trips and drivers' lunch breaks.

In most of the research till now, only the cost analysis has been mentioned, although papers have been published with uncertain and probabilistic approach of the generation of MSW in the concerned areas, but the same cannot be rooted down for all cities as there are sudden and abrupt changes within the periodic interval too. Here, the work on Indian context fulfils the periodic variability of waste generation within the wards of the city which needs to be taken into account while routing the vehicle for dumping of the MSW generated. Centre of collection points have been calculated by considering the distance between all waste bins within one ward as negligible, because the highest distance between two bins comes out to be of few meters. The overall central points for the wards have been proposed which adds up new dimension to the problem. The above mentioned methods solve the problem of sub routing of vehicles within the wards at each dustbin. The proposed model helps in decision making for multiple trips of the vehicles under the corporation or to hire new vehicles for proposed clusters. The defined approach can be extended to the multiple large number of wards and can provide the result with minimum error. All these factors have been considered in this study which were absent in the earlier work and thereby contributed to the existing literature.

3. PROBLEM DESCRIPTION

In this section, we describe the problem of transportation of the collected waste, faced by authorities in a waste collection system along with the different scenario of the problem. Vehicle routing for the collection of waste is a very important decision because it minimizes the collection cost, traffic congestion and improves the collection efficiency of MSW Management system (Khan and Samadder, 2014). It is divided into two parts; first, determination of a number of clusters formed by the method and second, a collection of MSW generated within the clusters at a periodic interval and finding the optimal route of vehicles for dumping the same. First, we determine the number of clusters so that, we able to utilize all vehicles available with the BMC for transporting of MSW. Proper utilization of collection vehicles improves the collection efficiency and minimizes the cost and emission. The objective of the model is to determine the optimal route for the vehicles, collecting all the waste generated at the site with minimum cost.

3.1 Development of Model

A mathematical model is developed considering the Indian city scenario where big vehicles carrying MSW cannot enter due to space constraints. The notations used in the model are presented in Table 1and it is followed by the assumptions considered in the development of the model.

Table 1. Notations used in the model.

Notations	Definition
n	Number of collection points.
i	Collection points.
j	Collection points. ($i \neq j$)
D	Depot from where vehicle start.
$d(i, j)$	Distance between collection points i and j.
$s(i, j)$	"Savings" resulting from combining points i and j in a single tour.

Assumptions:

(i) There is no constraint on the particular route to be followed.

(ii) There is no cap on budget allotted for dumping all the waste collected from wards. Bifurcation: Plot of local maxima of x with damping a decreasing (Fig. 1).

3.1.1 Cost Saving Matrix

Depot and demand points were considered. Initially, the solution to the VRP consists of using all the collection points separately and having one vehicle to each point. The total tour length of this solution is.

$$2\sum_{i=1}^{n} d(D,i) \quad (1)$$

If we use a single vehicle to serve two points, say i and j, on a single trip, the total distance *traveled* is reduced by the amount.

$$s(i,j) = 2d(D,i) + 2d(D,j) - [d(D,i) + d(i,j) + d(D,j)]$$

$$= d(D,i) + d(D,j) - d(i,j) \quad (2)$$

The quantity $s(i,j)$ is known as the "savings" resulting from combining point i and j into a single tour. The larger $s(i,j)$ *is, the more desirable it becomes to combine i and j in a single tour.*

The algorithm for solving the model can be described as follows*:*

Step 1- Calculate the savings $s(i, j) = d(D, i) + d(D, j) - d(i, j)$ for every pair (i, j) of demand points.

Step 2- Rank the savings $s(i, j)$ and list them in descending order of magnitude. This creates the "savings list." Process the savings list beginning with the topmost entry in the list (the largest $s(i, j)$).

Step 3- For the savings $s(i, j)$ under consideration, include the link (i, j) in a route only if:

a. Neither *i* nor *j* has already been assigned to a route. If assigned than a new route is initiated including both *i* and *j*.
b. Exactly one of the two points (*i* or *j*) has already been included in an existing route and that point is not interior to that route (a point is interior to a route if it is not adjacent to the depot *D* in the order of traversal of points), in which case the link (i, j) is added to that same route.
c. Both *i* and *j* have already been included in two different existing routes and neither point is interior to its route, in which case the two routes are merged.

Step 4- If the savings list $s(i, j)$ has not been exhausted, return to *Step 3*, processing the next entry in the list; otherwise, stop: the solution to the VRP consists of the routes created during *Step 3*.

3.2 Finding the centre points

Step1- Identification of the coordinates of sources within the site:
The coordinates of sources have been identified. Since the number of residential sources is very large in comparison to other sources, a *centre* of the residential source (RS) is needed to find. Determination of *centre* of residential source depends upon the population density across the site. It is like determining the *centre* of mass of a body.
For the given collection points in the city, the problem arises of how to route the vehicle through the collection point location, such that all the generated waste can be collected. In this section, procedure has been described for the identification of *centre* point of each ward.

Step 2- Identification of centre of source:
There are different types of sources of MSW generation within a site. Therefore, a centre is identified by considering all the sources in such a fashion that centre location is more close to the source which generates the most and far from the source which generates less comparatively. The formula for the calculation of centre is:-

$$\text{Latitude} = \frac{\text{Sum of MSW generated from sources} \times \text{latitude of source}}{\text{Sum of MSW generated from source}} \quad (3)$$

$$\text{Longitude} = \frac{\text{Sum of MSW generated from sources} \times \text{longitude of source}}{\text{Sum of MSW generated from source}} \quad (4)$$

4. RESULTS AND DISCUSSION

To illustrate and validate the proposed models and methods, it was applied in the city of Bilaspur, India. Bilaspur (Latitudes $21^0.37"$ to N$23^0.07"$ Longitudes $81^0.12"$ to $83^0.40"$ E) is one of the districts of the state Chhattisgarh, India, with a total population of 3,55,745 residing in 55 wards. The study area consists of 15 wards (Fig. 1) with about 16,314 households and an average of 4.7 persons per household. The rate of per capita generation of waste in Bilaspur varies from 300gm to 400gm per day. Presently, Bilaspur Municipal Corporation (BMC) is the sole authority responsible for the collection and disposal of wastes every week and due to lack of proper transportation of waste in the city, 60% of the generated wastes lie in the open areas which are unhygienic and hazardous to environment and health. The data has been collected exhaustively by the Bilaspur Municipal Corporation and gave us the maximum probable limits for each waste generating point in different wards of the city.

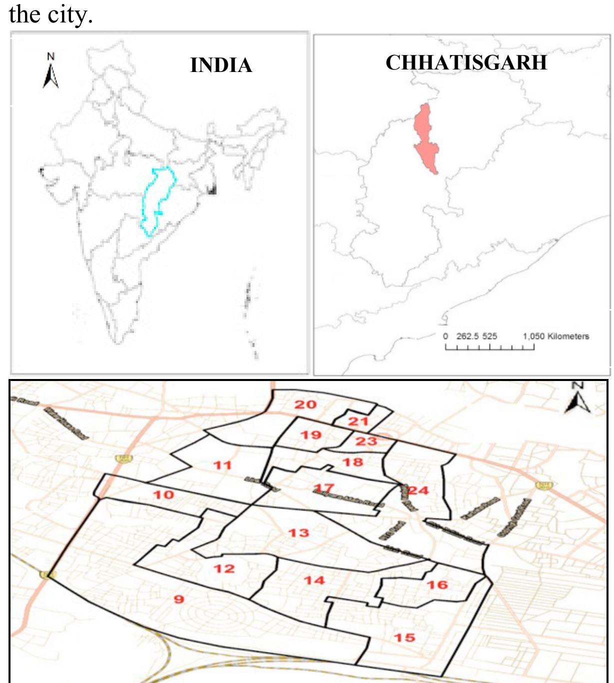

Fig 1. The study area.

The sources in all 15 wards are shown in Fig. 2 and the data of daily MSW generation is presented in Table 2. The distance between the centres of wards has been measured to form the cost-saving matrix (Table 3).

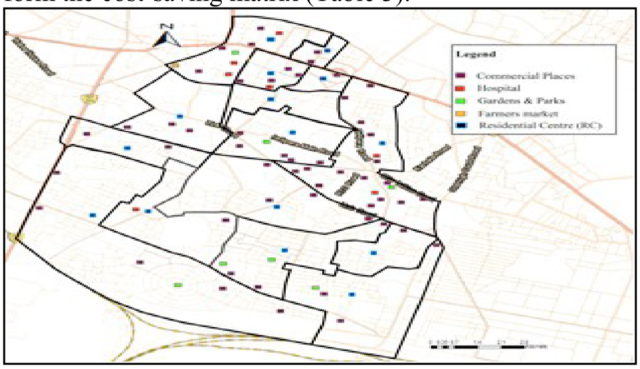

Fig. 2. Sources in all 15 wards

Table 2. Daily MSW generation in wards.

Ward No.	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
20	1154.4	1154.4	1158.5	1154.4	1154.4	1293.4415	1291.2915
21	670.86	670.86	670.86	670.86	670.86	753.695	752.095
19	604.41	604.41	604.41	604.41	604.41	664.851	664.851
23	710.05	710.05	710.05	710.05	710.05	814.54	814.54
18	1170.964	1170.964	1170.964	1170.964	1170.964	1341.725	1341.725
17	1291.646	1291.646	1291.646	1291.646	1291.646	1483.3825	1483.3825
11	1285.512	1285.512	1285.512	1285.512	1285.512	1455.845	1448.04
10	1445.01	1445.01	1445.01	1445.01	1445.01	1595.847	1595.847
13	1893.345	1893.345	1893.345	1893.345	1893.345	2082.30975	2082.30975
24	1651.026	1638.246	1647.826	1647.826	1647.826	1813.559	1807.959
14	2355.435	2355.435	2355.435	2355.435	2355.435	2590.396	2590.396
12	2460.73	2460.73	2460.73	2460.73	2460.73	2708.411	2708.411
16	914.08	914.08	914.08	914.08	914.08	1006.26	1006.26
9	2014.8	2014.8	2014.8	2014.8	2014.8	2216.87	2216.87
15	1897.58	1897.58	1897.58	1897.58	1897.58	2088.438	2088.438

Table 3. Distance between all the centres of wards and Clark and respective cost saving matrix

	ward 20	ward 21	ward 19	ward 23	ward 18	ward 17	ward 11	ward 10	ward 13	ward 24	ward 14	ward 12	ward 16	ward 9	ward 15
ward 20	0	0.429	0.451	0.528	0.53	0.887	0.917	1.363	1.641	1.252	2.095	1.894	2.178	2.037	2.585
ward 21	23.253	0	0.239	0.22	0.606	0.847	1.142	1.585	1.569	0.976	2.018	2.005	1.998	2.2	2.436
ward 19	23.403	23.849	0	0.096	0.383	0.608	0.944	1.378	1.337	0.813	1.788	1.77	1.794	1.972	2.224
ward 23	23.361	23.903	24.199	0	0.383	0.648	1	1.457	1.324	0.769	1.8	1.827	1.778	2.037	2.215
ward 18	23.431	23.589	23.984	24.019	0	0.354	0.565	0.994	1.11	0.859	1.557	1.413	1.667	1.599	2.059
ward 17	23.428	23.348	24.113	24.108	24.474	0	0.619	0.938	0.755	0.634	1.21	1.189	1.316	1.42	1.704
ward 11	23.108	23.117	23.487	23.466	23.973	24.273	0	0.449	1.07	1.253	1.467	1.013	1.747	1.123	2.05
ward 10	22.902	22.914	23.293	23.706	23.784	24.194	24.393	0	1.077	1.533	1.363	0.673	1.757	0.703	1.969
ward 13	23.398	23.704	24.108	24.156	24.442	25.151	24.546	24.779	0	0.856	0.454	0.829	0.686	1.134	0.985
ward 24	23.406	23.916	24.251	24.33	24.312	24.891	23.982	23.942	25.393	0	1.223	1.598	1.058	1.88	1.514
ward 14	23.379	23.69	24.092	24.115	24.43	25.131	24.584	24.928	26.611	25.461	0	0.884	0.523	1.17	0.616
ward 12	23.043	23.166	23.573	23.551	24.037	24.615	24.501	25.081	25.699	24.549	26.079	0	1.38	0.306	1.458
ward 16	22.759	23.861	24.237	24.288	24.471	25.176	24.455	24.685	26.53	25.777	27.128	25.734	0	1.677	0.459
ward 9	22.841	22.912	23.312	23.282	23.792	24.325	24.332	24.992	25.335	24.208	25.734	26.061	25.378	0	1.721
ward 15	21.376	23.815	24.199	24.243	24.471	25.18	24.544	24.865	26.623	25.713	27.427	26.048	27.735	25.726	0

Wright's algorithm were applied to get the clusters of wards on the basis of cost-saving matrix and vehicle capacity. Total 5 clusters of wards were formed during weekdays and 6 clusters were formed during weekends. Weekends having more clusters due to more generation of MSW comparatively.

The cluster 3 of weekdays has been presented in Fig. 3 with vehicle routing. Cluster 3 is considered for a presentation from all other clusters because it contains all type of sources and other parameters. Similarly, cluster 5 has been considered for weekends and presented in Fig. 4.

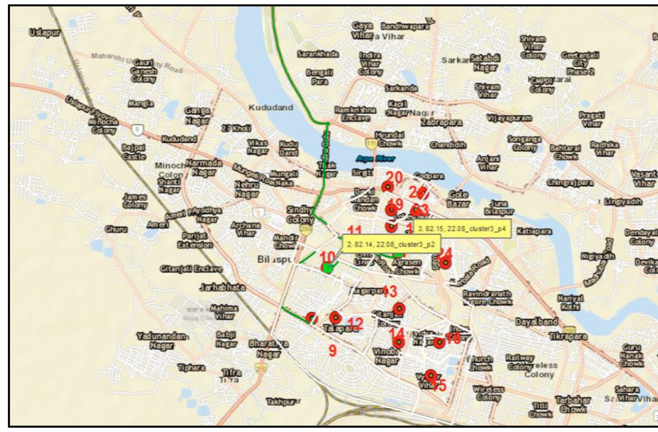

Fig. 3 Transportation route for the vehicle for 3rd cluster

Fig. 4 Route of the vehicle carrying MSW for 5th cluster during weekend.

5. CONCLUSION

The economic viability of any municipal solid waste (MSW) management system is an essential concern for the municipalities. To model an economically feasible MSW management system, mathematical models are to be developed by taking account of various constraints concerned with the problem. Further uncertain parameters (e.g. waste generation rate, fixed cost and the variable cost of the vehicle used, transportation cost and the revenues) make these models more complicated. This complication should not be compromised for real outcomes. In many instances, the uncertainty present in the MSW needs to be modelled under a situation of data scarcity for generating the probable outcomes of the data involved under study. Collection of MSW from each of the collection points require a lot of time and is not the feasible option for the larger vehicle to ply within the subareas of each of the wards involved in the city, due to the space constraints. To address this limitation, this paper has presented the central geographical location for each of the wards, which gives the modelled location for each of the wards. The developed model finds the central point for each of the wards based on geographical location and the amount of waste generated at sub-points within wards. Further, routes of the vehicles have been identified for the determined clusters of wards.

Clark and Wright algorithm has been used to determine the clusters and vehicle routing is done using Network analyst tool of ArcGIS 10. The algorithm yields 5 cluster points during weekdays and 6 cluster points during weekends.

The methodology present in this study will be helpful for BMC and researchers to tackle the problem of vehicle routing on daily basis. However, the presents study takes considered some assumptions which can be taken as future work.

The proposed model is highly flexible and robust as it can be used for different scenarios extended to the maximum number of wards with minimum error as compared to other methods. It is applicable to special events like festivals when the generation of waste is very high compared to normal scenarios, the only thing to do is increase the frequency of vehicle for the locations to meet the demand of all the wards or hire the required number of vehicles.

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