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OPTIMIZING ROUTING OF MUNICIPAL SOLID WASTE COLLECTION VEHICLES IN DEIR EL-BALAH – GAZA STRIP

Salah R. Agha
School of Industrial Engineering, Islamic University-Gaza
E-mail address: aghasr@yahoo.com
Tel:+972 8 2067577; fax +972 8 2066477

الملخـص: إن مـن أهـم عناصر إدارة النفايات الصلبة هو الطرق التي تسلكها عربات التجميع، وبالـرغمِ مـن أن تكالـيف عملية التجميع تصل إلى 74% من التكاليف الإجمالية لإدارة النفايات الصلبة، فإن اهتماماً قليلاً قد أعطى لهذه العملية وخاصة في الدول النامية، وتزداد أهمية هذه العملية خاصة في الصيف، فهذا البحث يهدف إلى إيجاد الحل الأمثل للطرق التي يمكن أن تسلكها عربات التجمـيع فـي منطقة دير البلح بقطاع غزة. وذلك باستخدام (Mixed Integer Programming) حيـث يهدف النموذج إلى تقليل المسافة الكلية المقطوعة، وتفيد النتائج أن تطبيق هذا النموذج في مديـنة دير البلح يمكن أن يؤدي إلى تقليل المسافة الكلية بحوالي 23.47% وبهذا يتم توفير حوالي 1140$ شهرياً، و نظراً لأن معظم المجالس المحلية ضعيفة مالياً، فإن التوفير الناتج يعتبر كبيرا و سـبب هـذا التوفـير من الممكن أن يعزى إلى حقيقة أنه في أغلب الدول النامية ليس من الشائع استخدام الأدواتِ العمليةِ لاتخاذ القرارات، ومن هنا يتضح أن تطبيق هذا النموذج في بلديات أُخرى من الممكن أن يوفر الآلاف من الدولارات شهرياً.

ABSTRACT: Solid waste collection routing is one of the main components of solid waste management. Despite the fact that the collection process constitutes 74% of solid waste management cost, it has been given little attention. The collection process becomes more serious especially in the hot and arid seasons in Gaza. This research optimizes the routing system for Deir El-Balah, Gaza Strip, using Mixed Integer-Programming (MIP) model. The model minimizes the total distance traveled by the collection vehicles. Results show that the application of the model improves the collection system by reducing the total distance by 23.47% thus saving around US$1140 per month. Given the fact that most local authorities are financially weak, the resulting savings are so significant. The large savings may be attributed to the fact that in most developing countries, scientific tools of decision making and performance analysis are hardly used. It is recommended that the model be applied and implemented in other municipalities, thus several thousands of dollars can be saved every month.

Keywords: solid waste management, MIP, routing, optimization, Deir El-Balah

Introduction

Deir El-Balah is located in the middle of Gaza Strip and has an area of 7-8 km^2 and a population of 44,000 inhabitants. The average amount of solid waste generation in Deir El-Balah is 41.77 tons per day. Administratively, Deir El-Balah city is divided into 29 areas as shown in Figure (1). Solid waste management in Deir El-Balah area is administered by both the municipality of Deir El-Balah and the Solid Waste Management Council (SWMC). The SWMC is the one responsible for secondary collection which is the focus of this paper.

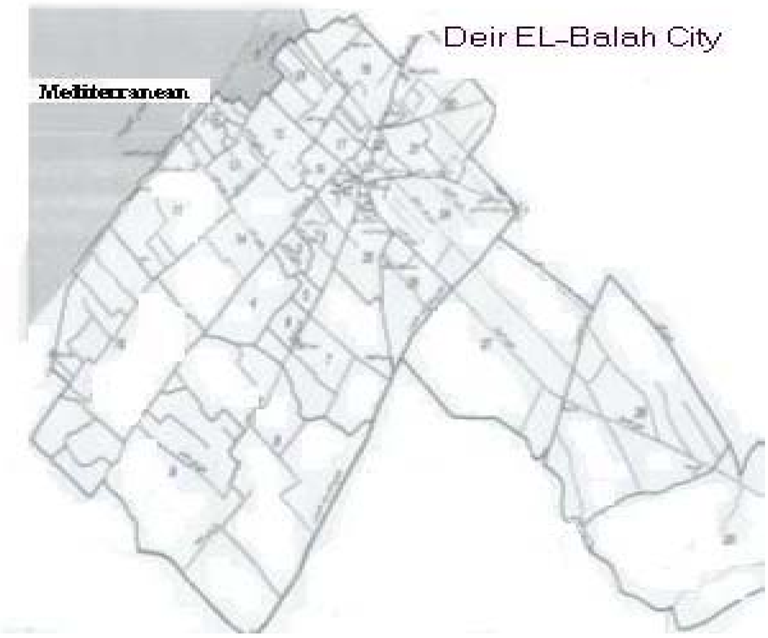

Figure 1 Administrative areas in Deir El-Balah

As it is the case in most developing countries, the existing management system suffers from the lack of a real plan for containers location and vehicle routes since the existing system is largely based on experience. This, along with the quest for offering customer satisfaction at a low cost is forcing the parties in charge to focus on cost reduction. Cost reduction strategies in solid waste routing may include minimizing the number of truck trips to disposal site, or optimizing the collection routing, thus minimizing the traveled distance and traveling time. A third strategy involves maximizing the number of fully loaded trips to the disposal site.

Utilizing the maximum extent of the available equipment is another strategy. This paper focuses on the second strategy which is optimizing the secondary collection routing for solid waste collection vehicles. Kulcar (1996) used operations research and simulation to minimize transportation costs of collecting solid waste in Brussels. Several transportation means were evaluated including vehicles, rail, and canals. Moreover, he evaluated the location of transfer stations. Ghiani et al. (2005) studied waste collection in Southern Italy using arc routing problem. Yurteri and Siber (1985) used a linear programming model to decide the location of transfer stations. Kirca and Ekrip (1988) and Gottinger (1988) proposed a mathematical model to determine the optimal transfer stations in addition to determining the optimal allocation of trucks to disposal sites. Clark and Gillean, (1975) used simulation for solid waste management operations in Cleveland, Ohio. It is clear that most of these studies dealt with finding the optimal or near optimal location of transfer stations. Moreover, all of these studies are performed in developed countries. This study realizes the limitations that transfer stations are not feasible in the area under study due to its small size and high population density in addition to the fact that the disposal site is within the perimeter of the area under study. Therefore, the focus of this study is on routing optimization. No attempt has been made to work on recycling since it is very minimal.

2- Problem Description

Deir El-Balah city has three collection vehicles that work six days a week and perform two trips every day. Each vehicle has a driver and one assistant. Collection vehicles start at 7:00 am and finish at 12:30 pm except on Tuesdays, where the second trip is postponed until the weekly market closes at 5:00 pm. Table (1) shows the available trucks and their capacities. These three available vehicles are stationed at one central garage. The number of containers in Deir El-Balah is around 390. Each container has a volume around 1m^3. The collection process differs from one area to another depending on the frequency at which the containers are picked up during the week (SWMC, 2003). Data needed for the model formulation is shown in Table (2).

Table 1 Available collection vehicles and their capacities [SWMC, 2003]

Capacity (no. of containers)	Volume (m^3)	No. of vehicles	Vehicle type
20	20	2	VOLVO 614
28	28	1	VOLVO 619

Table 2 Input data required for the model

<u>From truck operators</u>
Number of containers at each pick- up point.
Number of collection times at each pick- up point per week (frequency) (in case it is different from the calculated one)
<u>From management</u>
Distances from each point to the other points.
Number of vehicles available and the capacity of each
Number of collection trips per day.

3. Input Data Preparation

3.1 Pick up Frequency Calculation

The frequency of containers pick-up in a certain area is computed using the formula:

$$f = \frac{6S}{350N} \qquad (1)$$

Where,

f : is the collection frequency per week, which is the number of times a container in a given area is picked up per week

S: total solid waste produced in a given area in kilograms, which is the population of the area multiplied by the rate of solid waste generation per person (0.91 kg/ person)

N: is the number of containers in the area.

The multiplication by 6 is to transform the frequency per day to frequency per week. The formula is divided by 350 kg. (Capacity of one container) to transform the amount of solid waste from kilograms to number of containers.

Using the above equation, the frequency of container collection per week was calculated for the twenty nine administrative areas. For example, area 1 that has 11 containers and a population of 1411 would require a collection frequency of twice a week. For the sake of brevity, the rest of the calculation is omitted.

3.2 Clustering

The 390 containers were clustered in such a way that the twenty-nine administrative areas of Deir El-Balah were divided into 58 pick-up points, so one area may contain more than one pick up point. All pick-up points within the same area have the same collection frequency. In other words, the containers, in the same area, belong to one pick-up point. Moreover, traveling from one container to another is easy. Number of containers and collection frequency for each pick up point are shown in the Appendix.

3.3. Demand Balancing and Construction of the Summary Table for the Collection Process

In order to roughly evenly distribute the vehicle loads among the week days, a collection summary table was constructed in accordance with (Tchobanoglous et al., 1993). The collection summary table shows the number of containers for each trip distributed according to frequency, demand and capacity of each trip.

Table 3: Collection Summary Table

Thu		Wed		Tue		Mon		Sun		Sat		no. of containers per week (f)* (n)	No. of containers (n)	No. of points	Frequency (f)
Trip		Trip		Trip		Trip		Trip		Trip					
2	1	2	1	2	1	2	1	2	1	2	1				
	5		5		5		5		5		5	30	5	1	6
	12		12		12		12				12	60	12	2	5
	25		28		25		28		25		28	159	53	7	3
62	6			64	14			62	6	64	14	292	146	20	2
	2	56	12			65	20		14		6	175	175	28	1
62	50	56	57	64	56	65	65	62	50	64	65	716	391		Demand
68	68	68	68	68	68	68	68	68	68	68	68				Capacity

4. Model Assumptions and Formulation

The objective function of the model is to optimize the routing process of solid waste collection by minimizing the total collection distances traveled by vehicles among the pick-up points of containers. The following

paragraphs summarize the assumptions used in formulating the model.
First, on a given day, the first trip starts from the garage and ends at the landfill. While, the second trip starts from the landfill and ends also at the landfill, then it returns empty to the garage. Second, for each trip there is a model which may differ from other models for other trips for other days
Third, routes between the pick-up points, which are so far from each other, are not considered. In other words, the route from one point to another is not considered if there is another point closer to the first point in the same direction. Figure 2 shows that the vehicle may move from pick up point 1 to pick up point 2, from pick- up point 2 to pick-up point 3 or vise versa, but it may not directly move from pick -up point 1 to pick- up point 3 or vise versa.

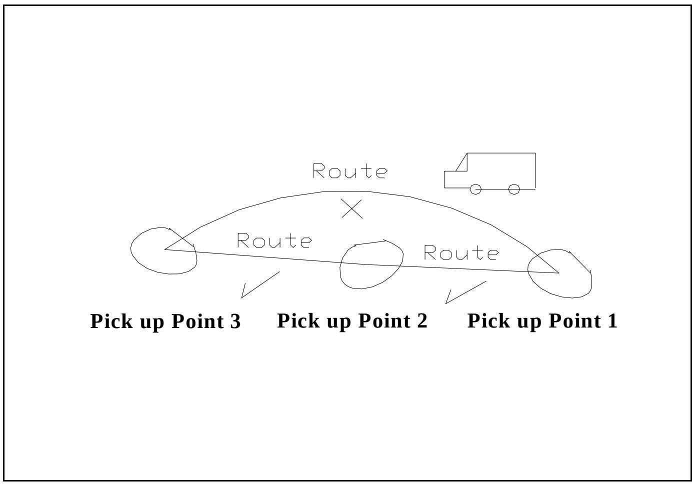

Figure 2: Suggested routes for picking for vehicles movement.

Finally, the distance is measured from one point center to another. Thus the total distance traveled by the vehicle equals to the distance from point to point centers plus the distances among containers within the pick- up point as shown in Fig. 3. Therefore, after solving the model, distances among containers are added to the center -to -center distances.

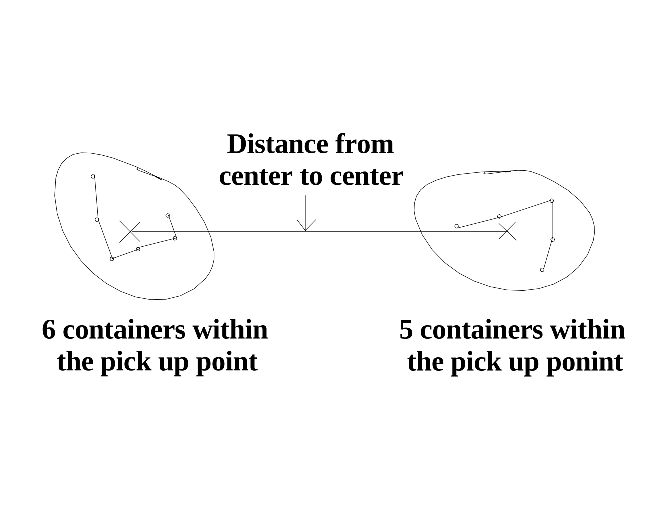

Figure 3: Distances from center -to -center and within the pick-up points.

4.1 Objective Function and Constraints

In this section, the model is expressed in terms of variables and constraints.

$$X_{ijk} = \begin{cases} 1 & \text{if car } k \text{ travels directly from } P_i \text{ to } P_j \\ 0 & \text{otherwise} \end{cases}$$

$$z_{ik} = \begin{cases} 1 & \text{if car } k \text{ picks up container(s) at } P_i \\ 0 & \text{otherwise} \end{cases}$$

y_{ik} = number of containers at point P_i picked by car k

d_{ij} = travel distance from P_i to P_j

f_i = number of containers to be picked up at P_i

c_k = capacity of vehicle k in (tons)

The objective function can be written as follows:

$$\min \sum_{k=1}^{k} \sum_{i=0}^{n} \sum_{j=0}^{n+1} d_{ij} x_{ijk} \qquad (2)$$

Subject to

$$\sum_{i=1}^{n} y_{ik} \le c_k \qquad \text{(k=1, 2,..,k)} \qquad (3)$$

$$\sum_{k=1}^{k} y_{ik} = f_i \qquad \text{(i=1, 2,…,n)} \qquad (4)$$

$$\sum_{i=0}^{n} x_{ilk} = \sum_{j=1}^{n+1} x_{ljk} \qquad \text{(i=1, 2,.., n; k=1, 2,…,k)} \qquad (5)$$

$$\sum_{i=1}^{n} x_{i(n+1)k} = \sum_{j=1}^{n} x_{0jk} = 1 \qquad \text{(k=1,2,…, k)} \qquad (6)$$

$$\sum_{j=1}^{n+1} x_{ijk} \geq z_{ik} \qquad \text{(i=1, 2,.., n; k=1,2, .., k)} \qquad (7)$$

$$y_{ik} \leq f_i z_{ik} \qquad \text{(i=1, 2, n; k=1,2, …, k)} \qquad (8)$$

$$x_{ijk} + x_{jik} \leq 1.......... \qquad \text{(i , j = 1, 2 ,....n; k=1,2,…k)} \qquad (9)$$

$$\sum_{j=1}^{n} x_{jik} \leq 1 \quad , \quad \sum_{j=1}^{n} x_{ijk} \leq 1 \qquad (10)$$

The set of constraints in equation 2 represents the vehicle capacity constraints. While the constraint in equation 3 guarantees that all containers are picked up. Constraints 4 and 5 are for flow continuity. If a vehicle picks up a container at a point, it must visit that point and this is represented by constraints number 6 and 7. Constraint 8 guarantees that a container is picked up by one vehicle. Constraint 9 is added to make sure that a vehicle moves from point i to only one point j and vice versa. To decrease the computational effort, sub-tours were avoided by solving the model first and in the case where a sub-tour occurs, a constraint was added.

5. Application

5.1 First Trip

From Table (3), it can be seen that the highest demand occurs on Monday, so the model was formulated for the first trip on Monday. Table (4) shows the selected pick-up points for the first trip in accordance with the collection summary table. Moreover, the table shows the number of containers and the collection frequencies for each of these pick-up points.

Table 4 Number of containers and frequencies for the selected pick- up points for the first trip

Frequency per week	Number of containers	Pick- up point
3	7	2
1	5	4
1	6	9
1	5	11
1	5	12
6	5	24
5	5	25
3	8	32
3	8	39
3	4	40
5	7	57

5.2 Second Trip

In this section, the model is formulated for the second trip on Monday. In Table (5), pick- up points, for the second trip, are selected according to the collection summary table (3) for each of the selected pick-up points.

Table 5 Number of containers and frequencies for the selected pick- up points for the second trip

Frequency per week	Number of containers	Pick up point
1	13	42
1	5	43
1	3	44
1	3	45
1	5	46
1	8	47
1	4	48
1	4	49
1	6	50
1	5	51
1	5	53
1	4	54

6. Results and Analysis

This section shows the model solution for the vehicles routing. The two trips models are solved by LP-Solve software[1] and their results are illustrated in terms of traveled distances, comparison between traveled distances of the existing and proposed systems of the collection process.

[1] Available at www.geocities.com/lpsolve

Cost savings are calculated for the proposed system of routing process.

Table 6 Results of the first and second trips

	Sequence of pick up points (No. of containers)									
	1	2	3	4	5	6	7	8	9	Total distance (km)
Vehicle 1										
1st trip	G[2]	32 (8)	25 (5)	4 (5)	LF[3]					13.24
2nd trip	LF	43 (5)	42(13)	LF	G					19.01
Vehicle 2										
1st trip	G	2(7)	39(8)	40(4)	LF					15.64
2nd trip	LF	47(8)	46(5)	44(3)	45(3)	LF	G			20.21
Vehicle 3										
1st trip	G	24(5)	57(7)	12(5)	11(5)	9(6)	LF			13.16
2nd trip	LF	48(4)	50(6)	49(4)	51(5)	54(4)	53(5)	LF	G	19.43

Table (6) shows the results of the model for the three vehicles and the trips made by each. The table shows the pick-up points that each vehicle must visit and the sequence at which these pick-up points are visited. For example, it is clear from the table that the first trip of vehicle 1 starts at the Garage then moves to pick-up point (32) where it picks 8 containers. Then, it moves to pick-up point (25) and picks 5 containers. The vehicle then visits pick-up point (4) picking 5 more containers. Now that the vehicle reaches its capacity, it goes to the landfill to unload and start its second trip from there. The total distance of this trip as the table shows is 13.24 km. It is also clear from the table that all the second trips end up at the garage. Figures 4-6 show the containers that are picked up by each of the three vehicles on the two trips they make. Tables (7-9) show a comparison between the existing and proposed routes in terms of loads and distances.

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[2] G.: Garage or Depot

[3] LF.: Landfill

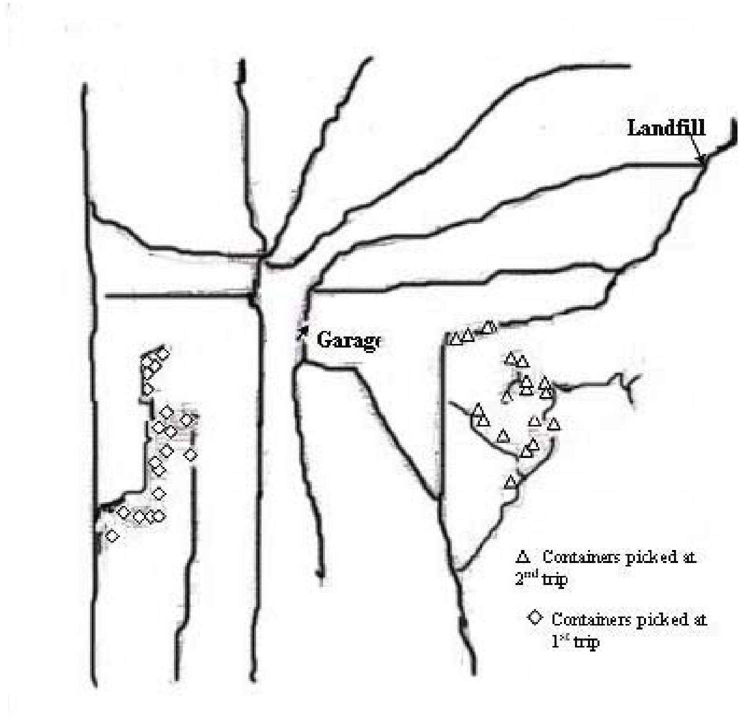

Figure 4 Containers collected by vehicle 1 in 1st and 2nd trips

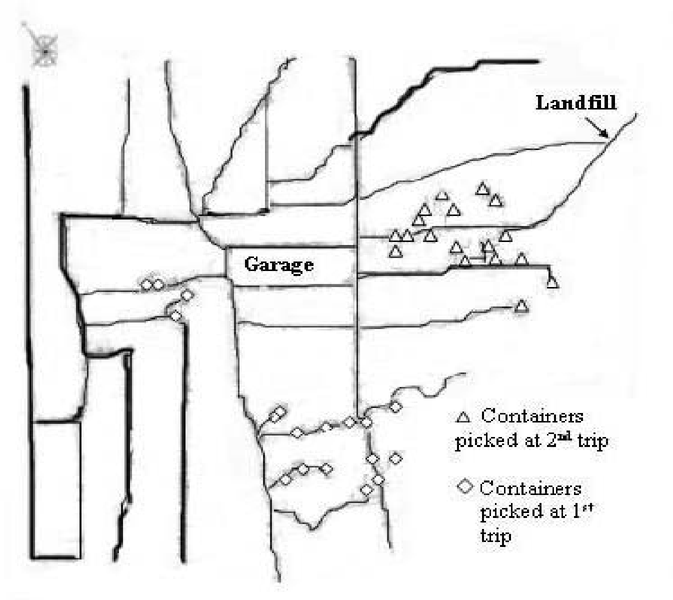

Figure 5 Containers collected by vehicle 2 in 1st and 2nd trips

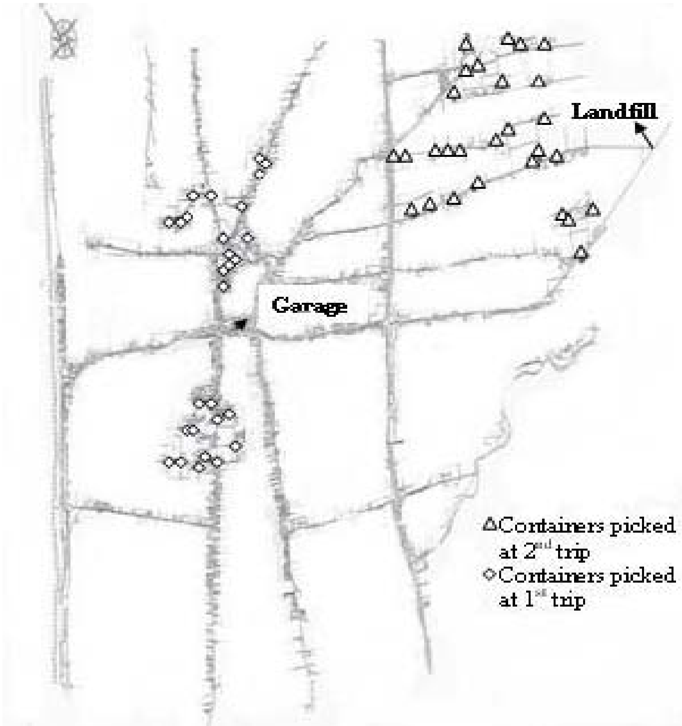

Figure 6 Containers collected by vehicle 3 in 1st and 2nd trips

Table (7) Comparison between existing and proposed systems for the first trip.

Vehicle	Capacity (number of containers)	Total demand (number of containers)		Total distance (km)	
		Existing	Proposed	Existing	Proposed
1	20	18	18	23.5	13.24
2	20	19	19	19	15.65
3	28	28	28	22.5	13.16
Total	68	65	65	65	42.05

Table 8: Comparison between existing and proposed systems for the second trip.

Vehicle	Capacity (number of containers)	Total demand (number of containers)		Total distance (km)	
		Existing	Proposed	Existing	Proposed
1	20	20	18	25	19.02
2	20	19	19	19	20.21
3	28	26	28	22.5	19.43
Total	68	65	65	66.5	58.66

Table 9 Comparison between the total distance of the existing and proposed systems for the two trips:

	Results of model	Existing values
Total distance (km)	100.72	131.5[4]

Assuming that the transportation cost per km is around NIS 7, the savings per day would be around $50. This leads to savings around US $1140 per month.

7. Conclusions

In this project, the collection process has been improved by the application of mixed integer programming model which minimizes the total distance traveled by the collection vehicles and thus reduces the total solid waste management costs. The result of the model is an efficient routing for vehicles; it determines the responsibility of each vehicle. The application of the model improves the collection system. It reduces the total distances by 23.4 % and saves approximately $1140 per month.

Acknowledgement

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[4] This number was directly obtained from the vehicles log book

Appendix

Table A1 Pick- up points, number of containers of each pick up point and collection frequency per week.

Frequency per week	Number of containers	Pick up point	Frequency per week	Number of containers	Pick up point
1	6	30	2	22	1
2	5	31	3	7	2
3	8	32	3	6	3
1	16	33	1	5	4
2	4	34	2	7	5
2	7	35	2	14	6
2	7	36	3	11	7
2	3	37	2	8	8
2	9	38	1	6	9
3	8	39	2	8	10
3	4	40	1	5	11
2	4	41	1	5	12
1	13	42	2	6	13
1	5	43	2	5	14
1	3	44	1	10	15
1	3	45	1	5	16
1	5	46	1	5	17
1	8	47	1	9	18
1	4	48	1	6	19
1	4	49	2	6	20
1	6	50	2	6	21
1	5	51	2	3	22
1	2	52	2	8	23
1	5	53	6	5	24
1	5	54	5	5	25
1	7	55	2	8	26
3	8	56	2	6	27
5	7	57	1	5	28
1	12	58	1	5	29

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