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Minimizing cost for Municipal residential solid waste collection in City of Newark using Goal Programming & GIS tools.

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Case Study
by
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ABSTRACT

The following case studies were developed as research projects of the ORES801 course entitled "Optimization: Models and Methods" taught by Dr. Kent Messer at the University of Delaware in the Fall of 2010.

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1. Introduction

In today's competitive world, industries have to effectively utilize their resources to maximize their returns. One such industry is the solid waste management industry. Every municipality that is responsible for the solid waste management with in its community faces a major challenge of utilizing its resources optimally. These municipalities are constrained with the availability of resources such as – budget for waste management, number of trucks, number of man-hours etc. Many municipalities are opting Operations Research techniques for solid waste management to reduce cost and optimize the routes which was earlier planned by trial and error on maps and judgment of authorities. Trial and error methods are usually time consuming and human error is unavoidable.

Many real time applications of using optimization techniques in such industry to save cost and time can be found in research. For example, municipality of Florida added 13,000 residents to existing 65,000 residents. They also wanted to add recycling collection services. With such major changes and little time to react, they used route optimization techniques to improve their collection efficiency. Similarly, city of Baltimore, Maryland adopted optimization techniques to see a cost savings of $6 million. Municipality of San Francisco in California and City of San Antonio in Texas are a few of the many public sectors that used route optimization to improve their efficiency and services.

Optimization of solid waste management systems using operational research methodologies has not yet been applied to any of the Delaware counties. Over last few years local authorities have been concerned about cost optimization as the city revenues were adversely affected by the economic recession and temperate weather. Government revenue were depressed by lower real estate transfer tax and state funding (Annual Financial Report, City of Newark, 2009). City of Newark Public work department operations includes residential trash collection, yard waste collection, recycling, street and vehicle maintenance. This paper deals with City of Newark residential trash collection. Public works expense was about 4.6 million in 2010, 8% more than 2009(Annual Financial Report, City of Newark, 2010). Therefore, effective municipal solid waste collection is essential due to limited available budget.

Under such circumstances, the productivity of collection and transfer operation of solid waste is significant concern to city administrators. One concern is how to effectively distribute collection vehicle in the city. Several authors have developed various optimization models to minimize operating costs by proper scheduling of trucks. Lia and others (2008) used operations research methodology for allocating trucks to existing collection routes and balancing trip assignment to recycling facilities in Porto Alegre, Brazil. They modeled it as a minimum-cost network flow problem of assigning vehicles to a set of predetermined trips with fixed starting and ending times. The heuristic based solution which dynamically adds penalties to a recycling facility if it's given capacity limit is reached, shows significant savings in cost. In another case study at municipality of Santiago, Arribas and others (2010) used integer programming to determine fleet size which minimizes total number of vehicles given fixed travel time and clusters derived using heuristic approach to yield a 50% cost savings. On the other hand, Kulcar (1996) developed a mixed model to minimize transportation cost by studying different means of transportation (road, train, canal) rather than previous studies on trucks only and deciding on optimal locations for transfer station.

Angelelli and Speranza (2002) presented a model for estimating the operational costs of waste collection strictly related to distance travelled to collect the waste not considering time required to deliver it to the disposal plants. The model can be applied to different collections systems like traditional, side-loaders, side loader with demountable body to perform cost-benefit comparison among the systems. Two case studies are also provided on estimation of operating cost for different system which is critical decision for solid waste collection.

Operations research methodologies for solid waste optimization to answer key questions like number and capacity of collection station (common place to throw waste) to minimize the total system cost was applied by Badran and Haggar (2005). Ruiz and others (2004) applied mathematical model in context of dispatching feed compounds to clients using LINGO tool and further enhanced it by developing real time decision support system. Most of the model above does not provide the flexibility and responsiveness needed in real time logistic problem and are difficult to apply in practice. Most of them also don't account for heterogeneous vehicle fleets or maximum loading capacity of trucks.

Many case studies have been conducted using ArcGIS[1] for route optimization. Tavares and others (2009) solve for minimizing fuel consumption by considering road inclination and vehicle weight. A case study at Athens, Greece by Chalkias and Lasarid used GIS for replacement of the large number of small bins with a smaller number of large bins and their reallocation. This followed finding optimal routes, using proposed bins as stops, utilizing ArcGIS Network Analyst. Frequently, during collection the capacity is reached before visiting all bins assigned to collection routes due to poor design which results into additional trips to serve unserved bins. This problem is addressed by Arribas and others (2010) who performed optimal clustering of bins using Capacity Clustering Problem (CCP) taking into account the capacity of truck, traffic conditions and total travel distance. Many authors investigated route optimization using other commercially available software's. For example, Apaydin and Gonullu (2007) used RouteViewPro to achieve a significant reduction in distance and total time for a case study in Trabzon, Turkey. Similarly, another case study by Filipiak and others (2009) implemented Chinese Postman Algorithm to propose optimal routes for Township of Millburn, N.J. utilizing graph magic. Ogwueleka (2009) adopted for more difficult approach of developing a heuristic based model in Visual basics to implement CCP Algorithm to solve for optimized routes. It resulted in reduced fleet size and total distance travelled by trucks for Onitsha (Nigeria). GIS have also been used to deal with other issues related to solid waste collection. For example, Karadimas and Kolakathi(2007) proposed GIS routes optimization for large items (fallen trees, accidents) that couldn't be collected by standard waste collection trucks, due to size. Fan and others (2010) utilized GIS tools with objective to see mileage improvement with better energy utilization.

Other studies associating both mathematical model and GIS have also been found in literature. Arribas & others (2009) uses regret functions and local search algorithms to cluster bins in collection zones restricted by vehicle capacity and solves the vehicle routing problem using GIS. Total travel time and sequence of visits in each cluster are determined from ArcGIS Network Analyst. A linear integer programming model is then used to design a solid waste collection fleet.

[1] ArcGIS is a suite consisting of a group of geographic information system(GIS) software products produced by Esri

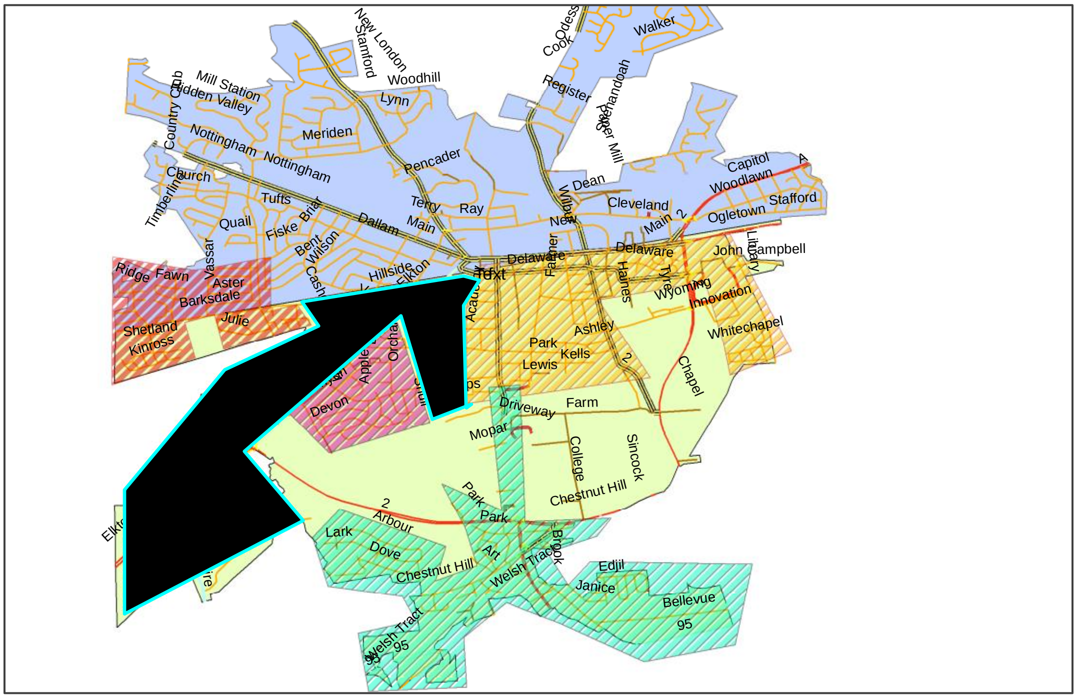
Their design minimizes the number of vehicles while verifying the total travel time doesn't exceed the work shifts. The sequence of these phases is executed iteratively for different numbers of clusters, in order to obtain an efficient solution. The heuristic based approach for clustering is difficult to implement. Hamouz (2008) design minimizes costs while suggesting collection frequencies and schedules, bin re-allocation, and vehicle route minimization. However, the author does not provide explicit details of mathematical tools employed in solving these problems, which makes a practical implementation of this methodology difficult.

Currently in City of Newark, the routes are fixed and they have been used for many years by drivers and it is one of the reasons why managers are reluctant to follow new routes. Present study incorporates this type of constraint and finds a method to optimize the existing routes with minimum changes. The other issues faced by City of Newark solid waste collection are overtime of labors, underutilization of trucks and multiple trips to routes. All these issues are addressed in this paper. Also, more flexible scenarios are explored using GIS tools.

The main objective of this work is to develop a model for solving the real time residential solid waste collection problem using mathematical tools and GIS to develop feasible routes, adequate number of trips, and sensitivity on waste generated and comparative cost study. The paper has been implemented in two phases. In the first phase a goal programming model is proposed to determine the truck type (depending upon the capacity) for each route and number of total trips taking into account the average historical garbage collected on each route. Based on this model it is possible to find the required trips if average waste amount changes (as result of holidays, season etc). In the second phase, ArcGIS extension Network Analyst is used to find the optimal routes. To find the appropriate solver, two scenarios were implemented. In first, the optimal route is found for the existing route. In the second, the reallocation of bins is done to different routes to find the optimal routes for each truck. ArcGIS solver considers the constraints of capacity of the truck, time window of operation, breaks for drivers. Also, both the scenarios takes into account the speed, turn restrictions, traffic, average service time per bin. All the data required to implement the model was taken from municipality of Newark for past one year.

2. Solid Waste Collection-City of Newark

Figure 1-Map of Newark and Collection zones



Municipal solid waste collection in Newark is divided into two zones. Fig. 1 presents the collection zones on a map of Newark. A solid waste collection in the upper half of the city is carried out on Mondays and lower half on Tuesdays. Each of these collection zones are further divided into five sub-sectors. Solid Waste and Recycling is collected in each sub-sector. The city collects waste from curbsides of single family and two-family units. Currently, up to five trucks are used per day to collect the solid waste. Mondays and Tuesdays are for solid waste collection and Thursdays and Fridays are for recycling collection. When there is a holiday during the week, Wednesdays are also reserved for solid waste collections. If there is a holiday on Monday, Monday's solid waste collection is covered on Tuesday and Tuesday's solid waste collection is rescheduled for Wednesday. Similarly, if a holiday falls on Friday, Friday's recycling collection is rescheduled for Thursday and Thursday’s recycling collection is re-scheduled for Wednesday.

The City of Newark owns and uses five side loaders trucks for solid waste collection that needs only one person (driver) for the operations. The side loader trucks are of two different capacities

- two of 33 cubic yards and three of 25 cubic yards. In addition to this, there are some rear loader trucks available as a backup and they require two people for operation. All the trucks start from the depot, which is located at 406 Phillips Avenue and unload the waste at a transfer station located at 400 South Chapel Street and make another trip if necessary and return back to depot in the end. At the transfer station, the waste is transferred to larger trucks which are then transported to incinerator. The operating time for the drivers is from 7:00 am to 3:00 pm.

Although the collection is effective, the trips are unbalanced with some drivers doing overtime while others may be idle. Second challenge is the optimal utilization of heterogeneous fleet available. Other concern among the city officials is related to safety of residents when such big trucks make 3 point turns and U-turns. The next section discusses about the methodology used to solve some of the above challenges.

3. Methodology

The main objective of this study is to enhance the waste collection practice in the city of Newark in terms of minimizing fleet size, total transportation and operational cost, avoiding time imbalance in between different routes. To balance the routes, we must balance the time. Since the time depends upon various factors like drivers efficiency, number of bins/stops drivers makes, traffic conditions in the neighborhood, number of trips made. Driver's efficiency and traffic conditions have limited opportunity to control or improve. Number of stops is proportional to the average waste generated and area travelled. More waste collected means more dense or large area. Number of trips depends upon the capacity of trucks or the type of the truck. If trucks are of smaller capacity and more dense area is allotted, it may have to make more trips.

The first phase of this study uses goal programming (GP) approach to determine truck type on each route and number of trips which depends upon the average amount of solid waste collected in that route. The maximum capacity of truck is determined by taking the maximum load in each truck type in past one year which is less than the actual capacity. The GP model minimizes the deviation, which is over and under loading of the trucks resulting in reduced number of trips ensuring that the total waste is picked up. Additionally, each route should be served by a single truck. Since the solid waste generation can directly affect the number of trucks and trips, so a sensitivity analysis is carried out to determine the change in number of trips and operational cost with change in solid waste generation.

The data related to number of waste bins, types and positions of waste bins, time schedule for the collection process, current routing system for the collection trucks, their capacities, unit fuel and maintenance costs were provided by city of Newark for 2009.

Since the number of trips can vary depending upon the waste generation, the pickup routes will also change and to consider re-designing an optimal route with minimum changes from the one currently used, a second phase is implemented. The second phase involves 2 scenarios to determine the efficiency of route optimization. First solves existing routes for shortest distance using Dijkstra Algorithm and second solves the vehicle routing problem using a topological road network in a GIS environment. Total travel time and sequence of visits in each cluster are determined according to the Travelling Salesman Person Algorithm. Costs associated with transport, restrictions like U-turn, one-way and traffic congestion are employed during solid waste collection. The waste collection optimization routes were developed using ArcGIS 10 Network Analyst software. Network Analyst is based on the distribution network design, which minimizes costs, time and distance while fulfilling the solid waste collection service in terms of capacity.

In order to implement the ArcGIS solver, detailed spatial information is required. This information is related to the geographical background of the area under investigation as well as to other data related to traffic, one-way streets etc. Road networks, streets and its attributes related to restriction and turns which is provided by ESRI ARCGIS Map data 10 and the related annual traffic data for city of Newark is taken from the web (KMZ format) where traffic is measured as number of cars per day on major roads of the city.

4. Phase I: Reduce Trips for existing routes

Goal programming model is as follows:

i. Objective

$$\text{Min} \sum_{j=1}^{N} d_j^+ + d_j^-$$

ii. Goal

$$\left(\sum_{i=1}^{2} C_i X_{ij}\right) + d_j^+ - d_j^- = C_j$$

j = 1, 2, 3…….N

iii. Constraint

a) $$\sum_{i=1}^{2} X_{ij} = 1$$

b) $$\left(\sum_{j=1}^{N} d_j^+\right) - tC_2 \le \sum_{j=1}^{N} d_j^-$$

c) $$\sum_{j=1}^{N} X_{ij} = T_i$$

i=1, 2

where

i :Truck Type(1= Truck Type 1, 2=Truck Type 2)

j : Route number

N: Total Routes

t: Additional trip required

T_i : Number of available vehicle of Type i

C_i : Capacity of each type of Truck i

C_j : Average garbage capacity for each route j

d_j+: Deviation allowed for route j, Overloading

d_j-: Deviation allowed for route j, Underloading

Binary Variables:

X_{ij} = 1 if truck type i goes to route j

0 otherwise

The objective function is the minimization of the overall deviation of garbage during collection. First term in the objective function is positive deviation which is over utilization of truck and second term is under utilization of the truck, both of these should be avoided. However, over utilization must be given more penalties. The goal is to pick the average amount of waste from each route using either of the truck (Type 1 or 2) for all routes and the goal equation (ii) ensures that the capacity of each truck type is greater than the average amount of waste collected in that route with minimum allowable deviations. Constraint (a) ensures that at most one truck goes to each route. Constraint (b) is to check that the capacity of all garbage collected is not more than the capacity of trucks considering all the trucks and additional trips. Constraint (c) in the above formulation restricts the assignment of each type of truck depending upon the availability. This model is solved for both Mondays and Tuesday routes but the results are presented for only Monday routes.

Cost Calculation

Total costs given the number of trucks used X_v, depreciation cost for each vehicle VC, labor cost LC, and total transportation cost TTC.

$$TC = X_v(VC + LC) + TTC$$

The TTC is the sum of the costs associated with trips from the transfer station to the depot for each visit to a cluster and the transport costs related with the solid waste collection at each route

$$TTC = j \cdot TC_{CD} + (TC_{Dj} + TC_{jC} + TC_j)$$

Where TC_{CD} is transport cost from transfer station C to depot D (US$),

j is number of routes,

TC_{Dj} is transport cost from depot D to cluster j (US$),

TC_{jC} is transport cost from cluster j to transfer station C (US$), and

TC_j is transport cost within cluster j (US$).

LC includes the labor cost per year per truck. The overtime cost is included in the cost calculation. The transport cost within each route is calculated using unit fuel cost per vehicle per trip (US$ /trip), and unit maintenance cost per vehicle per trip (US$ /trip). If a trip is reduced it would affect the total transportation cost, and the labor overtime cost. Based on the data available for total fuel cost, maintenance cost and labor cost for 2009, a total cost is calculated. Depreciation cost is not considered for comparison.

5. Results and Discussions

Goal programming model output in Table 1 shows a decrease in the total number of trips from 8 to 5, as a result of the change in assignment of truck types to various routes. This results in a cost saving of $18,000 with overtime reduction in 40%. The assignment has changed depending upon the average amount of waste to be picked from existing routes, vehicle availability and capacity of the vehicle. For example, for route 1 – in the current collection scenario, two trips are made by a lower capacity truck (type 1) where as in the optimized scenario a bigger capacity truck (type 2) is able to pick up the same amount of waste in a single trip. Similar improvement is observed for route 2. Route 3 and 5 operate with larger trucks in the current collection routes but in the optimized scenario smaller trucks on both the routes will be able to pick up the same amount of waste. However, with this optimization output we have some waste left over to be picked up from route 4 as shown in table 1. This small amount of waste is considered as a deviation of the model.

Table 1-Comparsion of current collection and optimized collection

Routes	**Current Collection**		**Optimized Collection**		
	Truck Type	Trips	Truck Type	Trips	Waste Left over(lb)
Route 1	1	2	2	1	0
Route 2	1	2	2	1	0
Route 3	2	1	1	1	0
Route 4	1	2	1	1	1168
Route 5	2	1	1	1	0
Total Trips	-	8	-	5	1168

To overcome this scenario of left over waste, there is a second scenario which is a more conservative, where the average amount of waste plus one standard deviation is considered as the total amount of waste on each route. The same goal programming model is run and the results are as shown in table 2.

Table 2-Comparsion of current collection and conservative-optimized collection

Routes	Current Collection		Optimized Collection		
	Truck Type	Trips	Truck Type	Trips	Waste Left over
Route 1	1	2	2	1	0
Route 2	1	2	2	1	0
Route 3	2	1	1	1	1888
Route 4	1	2	1	1	3168
Route 5	2	1	1	1	925
Total Trips	-	8	-	5	5981

Table 2 shows that there is some amount of waste left on each route. In order to collect the left over waste on each route we will have to make one more trip with a smaller size truck. The problem is that each route will have several pockets of areas or bins which would be having left over waste and these areas can be very distant from each other. The distantly located bins can cause a decrease in the efficiency of the collection time as the truck would now cover more distance to pick up the waste. Although the total number of trips will still be 6 (5 regular trips + 1 extra trip) but it can cause an increase in the overtime costs. In order to overcome this issue, re-designing of the routes is essential which is discussed in the 2nd phase of this study.

Sensitivity Analysis: Waste generated

This section presents a sensitivity analysis on solid waste generation. Number of trips and amount of solid waste generated are important variables that directly affect the cost. Therefore, sensitivity analysis on amount of waste generated is necessary to accommodate changes in scheduling the truck as a result of the national holidays, festive seasons and school sessions.

Table3 –Sensitivity analysis of change in amount of waste generated and operational cost

	Solid Waste Generation				
	50%	80%	100%	120%	150%
Number of Trips	3	4	5	6	7
Number of Trucks	3	4	5	5	5
Numberof Drivers	3	4	5	5	5
Fuel cost	$6,114	$6,862	$7,350	$8,099	$9,059
Labor cost	$29,128	$38,838	$48,547	$48,547	$48,547
Overtime cost			$6,017	$8,111	$8,602
Maintenance cost	$14,033	$15,507	$16,628	$18,102	$20,848
Total Cost	$49,275	$61,208	$78,543	$82,859	$87,057

Table 3 shows the sensitivity analysis results for variations of ± 20% and ± 50% with respect to the original solid waste generation. If solid waste generation is decreased by 50%, total solid waste collection costs calculated from above equations were reduced by 36% compared to the original situation. It can also be noted that transportation costs increase proportionately with the number of trips.

Initially, when the waste decreases, the saving is due to the decrease in the number of trips (from 5 to 3) and the total number of workers (from 5 to 3) reducing the overall maintenance, labor and fuel cost. However, when solid waste generation is increased by 20%, the total solid waste collection costs increases by 11.5%. In this case, the fleet and labor sizes remain constant, given that the vehicle shifts had sufficient available time to collect solid waste in the five clusters even after increasing the number of trips.

6. Phase II: Vehicle routing using GIS tools

As discussed in the last section redesigning of route is needed to minimize the time required to make the extra trip by the truck. As we see in figure 2, route 1 has portion A which is left, route 2 has portion B left and route 3 has part C which is uncovered and these are scattered all over the area. It is therefore required to implement a route optimization such that the uncovered parts which are left because of capacity constraint should be nearby each other as shown in figure 3, such that time to pick up the waste can be minimized.

Figure 2- Routes with scattered uncovered portion

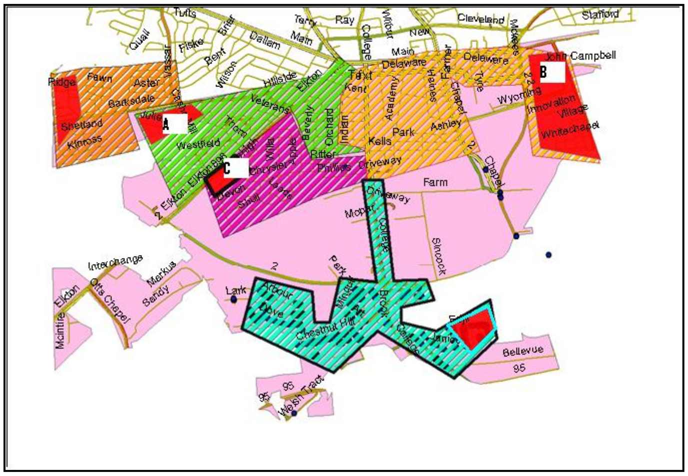
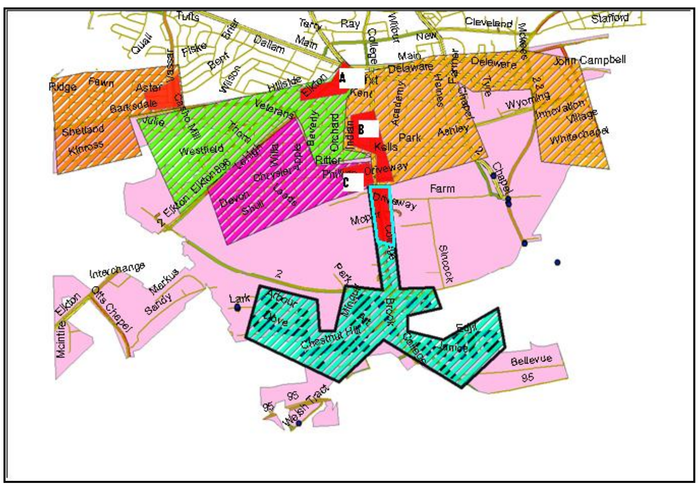


Figure 3- Uncovered part closer to each other



Another reason to do route optimization is that if there is a decrease in the waste because of the decrease in demand, then the same truck can cover more houses to pick up the same amount of waste and would result in reduced number of trips. We thus need to change the number of routes as shown in sensitivity analysis in Table 2.

To implement the route optimization, ArcGIS extension Network Analyst is used in this phase. It is used to find the appropriate route depending upon the average waste to be collected. It has inbuilt solvers like shortest route, closest facility, location-allocation, vehicle routing problem. In order to find the appropriate solver to be applied for our problem, two scenarios are implemented. In scenario 1, section I(Monday collection area) of the city has been solved using shortest route algorithm on existing route. In scenario two, section II (Tuesday collection area) is solved using standard Vehicle Routing Problem considering the truck capacities, average amount of waste to be picked from each bin, drivers breaks, time window for collection, overtime cost. VRP solves for the shortest distance visiting sequence for each cluster for section II with constraints of capacity, available time, maximum bins to be picked.

For both scenarios, travel times through the road network were computed using traffic directions and turn restrictions of the topological network for city of Newark. Average speeds for different road typologies, highways and main roads present an average value of 50 miles/h and 25 miles /h, respectively, while local roads have an average speed of 15 miles/h. Average times for serving each bin, turning at right junctions, turning at left junctions and U-turns were assumed to equal 18 s, 10 s, 20s and 50 s, respectively (calculated by field experiment)

Additionally, an average solid waste drop-off time at the transfer station was used for each truck according to average values measured during the 2009 period. Each vehicle worked 1 shift per day of approximately 8 hour each (between 7am and 3pm including 1-hour break in between). The maximum number of bins for each route is assumed to be 800 to make it a non-binding constraint which is according to data is average 500.

In the first scenario, a shape file is created for the houses to be serviced for each route and shortest path algorithm is run with a constraint that the truck must approach the curb from right side. Routes optimized by using the ArcGIS were compared with present routes. The comparison results are presented in Table 4. According to Table 4, if the optimized routes are used in solid waste collection system, distance will be decreased by 4-15% on each route with average 9% improvement in mileage. The improvement in mileage decrease the fuel cost by $1,500 and $7,000 in maintenance cost per year. This analysis is done only for Mondays collection and if we include other sections, we can a further decrease in fuel cost. This may also decrease the overtime since the new routes are shorter in distance and would require less time.

Table 4- Scenario1 (Monday Collection)-Route optimization of existing route

Section I	Distance(miles)		%change
	Current	Optimized	
Route 1(411)	25	22.8	9%
Route 2(454)	22	19.9	10%
Route 3(410)	16.8	14.3	15%
Route 4(409)	17	14.8	13%
Route 5(453)	27	26	4%
Total	122.7	97.8	9%

In the second scenario, a Vehicle Routing Problem is solved with about 3,200 homes in Tuesday collection to be serviced by 5 trucks. Two types of truck with capacity of 25,000 lb and 19,600 lb were used which is the maximum that each type of truck has loaded itself in past. Depending upon the historical data, it is found that each home has an average of 35 lb garbage generated. The trucks start from the depot at 7:00 am and maximum available service time is 8 hours for each truck including 1 hour break and then go to the transfer station to unload the waste. The average time in transfer station is different for each truck which is calculated from the historical data. The start location and transfer station, end location needs to be addressed. Another constraint of truck to approach the curb always from the right side has been added. The model is solved to minimize distance and time with all constraints. The results indicate a 16% improvement in total miles from 157 to 131 miles. The mileage improvement is similar to the shortest path approach used in scenario I. It depends upon management which way to go as shortest path won't require to change the current routes which drivers are accustomed to whereas scenario II results are with new routes.

7. Conclusions

This case study presents a two-phase methodology for improving the solid waste collection in City of Newark. These are (i) Assigning optimal capacity truck to various routes (ii) ArcGIS based route optimization for solid waste collection routes. The paper uses goal mathematical programming tools with GIS tools to estimate the total trip, total distance and visiting sequence of bins through a topological road network. The vehicle fleet phase and required trip were addressed by solving a goal programming model utilizing Risk Platform Solver. In the second phase, two scenarios are presented to solve for optimal route to be traversed by each truck – (i) Travelling Salesman Person Problem was employed using GIS tools to solve the vehicle routing problem (ii) Dijsktras algorithm to solve shortest path problem. Both approaches need to be implemented in real time to compare the simulation result with the actual result which is in progress currently.

Goal programming model resulted in 19% reduction in yearly transportation cost with respect to the current situation, mainly due to the decrease in the number of trips by change in truck assignment. The total transportation cost includes the fuel cost, maintenance cost, labor cost. A sensitivity analysis result on solid waste generation indicates that the methodology can successfully accommodate higher solid waste generation rates without significantly affecting costs.

Additionally, this study shows that route optimization decreases the total miles ranging from 4-15%. Vehicle routing problem reallocates the bins to different routes, which in turn shows a decrease of approximately 16% in terms of miles taking into account the real world constraints like turn restrictions, main road traffic, and one-way street. It also incorporates the operational constraints like vehicle capacity, time windows and local constraints like maximum number of vehicles, routes, lunch breaks and working schedule of employees, route zones etc.

Further research is needed to incorporate more detailed traffic data that has not been considered in this study. Traffic data depending upon the different times of the day needs to purchased from external source. Additionally, since the density of customers along streets is sufficiently high to consider the associated arc the key network element to be served with similar operational constraints as used before, Chinese Postman Algorithm would be more suitable in this case. The use of Chinese Postman Routing algorithm to minimize distance would result in optimal solution. Currently it is required to run the pilot run to see the actual results and compare it with the simulation results. Also, add recycling into the analysis as many people are using recycling bins.

References

Angelelli and MG Speranza (2002). The application of a vehicle routing model to a waste-collection problem: two case studies. Journal of the Operational Research Society (2002) 53, 944–952

Apaydin, O. & Gonullu, M. (2006). Route Optimization for solid waste collection: Trabzon (Turkey) case study. Global NEST Journal, Vol 9, No 1, 6-11.

Arribas, C., Blazquez, C., & Lamas, A. (2010). Urban solid waste collection system using mathematical modeling and tools of geographic information systems. European Journal of Operations Research, 28, 355-363.

Badran, M. & Haggar S. (2006). Optimization of municipal solid waste management in Port Said – Egypt. Waste Management 26, 534–545.

Baptista, S., Oliveira, R. & Zuquete, E. (2002). A period vehicle routing case study. European Journal of Operational Research 139, 220–229

Bhat, V. (1996). A Model for the optimal allocation of trucks for solid waste management. Waste Management & Research 14, 87–96.

Christos Chalkias, Katia Lasarid. A GIS based model for the optimisation of municipal solid waste collection: the case study of Nikea, Athens, Greece. WSEAS Transactions on Environment and Development.

Detofeno, T. & Steiner, M. (2010). Optimizing routes for the collection of urban solid waste: a case study for the city of Joinville, state of Santa Catarina, Iberoamerican. Journal of Industrial Engineering, vol. 2, n 1, 124-136.

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. Numerische Mathematik, 1, 269-271.

Filipiak, K., Malek, L., Hsieh, H. & Meegoda, J. (2009). Optimization of municipal solid waste collection system: Case Study. Practice Periodical of Hazardous, Toxic, and Radioactive waste management, Vol.13, No. 3.

Hamouz, Amer M. El (2008), Logistical management and private sector involvement in reducing the cost of municipal solid waste collection service in the Tubas are of the West Bank Waste Management, Volume 28, Issue 2, 2008, Pages 260-271

Karadimas, N., Kolokathi, M., Defteraiou G. & Loumos, V.(2007). Municipal waste collection of large items optimized with ArcGIS Network analyst. Proceedings 21st, European Conference on Modelling and Simulation.

Kulcar, Thierry. (1996). Optimizing solid *waste* collection in Brussels European Journal of Operational Research. Vol. 90, Iss. 1, Pg 71.

Lia, J., Borensteinb D. & Mirchandania, P.(2008). Truck scheduling for solid waste collection in the City of PortoAlegre, Brazil. Omega 36, 1133 – 1149.

Ogwueleka, T.C.(2009) Route optimization for solid waste collection: Onitsha (Nigeria) case study. J. Appl. Sci. Environ. Manage. June, 2009, Vol. 13(2) 37 – 40

Rubén Ruiz, Concepción Maroto, Javier Alcaraz. (2004). A decision support system for a real vehicle routing problem. European Journal of Operational Research, Volume 153, Issue 3, 16 March 2004, Pages 593-606.

Shieh, H. & May, M. (2010). Solving the capacitated clustering problem with Genetic Algorithms. Journal of the Chinese Institute of Industrial Engineers, 18:3, 1-12.

Tavares, G., Zsigraiora, Z., Semiao, V. & Carvalho, M.(2008). A case study of fuel savings through optimisation of MSW transportation routes. Management of Environmental Quality, 19. 4