Journal of Natural Sciences
June 2014, Vol. 2, No. 1, pp. 29-47
ISSN: 2334-2943 (Print) 2334-2951 (Online)

Published by American Research Institute for Policy Development

Optimization of Green Benefits from Recycling in City of Greensboro

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Abstract

The goal of this research was to optimize green benefits from collecting recyclables from 20 recycling drop-off sitesin City of Greensboro, North Carolina, United States. We collected the data of thelocation of drop-off sites and maximum recycle capacity at each site from City of Greensboro to compute the revenue from the recycling. Also we collected the data of the distance, time, and price of diesel between each site from Google to compute the cost to collect recyclables.And then we found the maximum profit through the mathematical model of maximum revenue and minimum costusing linear programming, integer programming and graph theory with time and fuel cost constraints, and weight of recycled.Finally we computedmost green benefits such as saving energy, saving landfill, and converting to amount of oil from the optimized model of maximizing net gain.Moreover, we found the optimizing route to collect recycling commodities at 20 drop-off sites at city of Greensboro after dividing subgroups depends on a truck's capacity constraints and taking time for each route in the subgroups. We used Maple software for this project.

Keywords: Optimization; Green Benefits; Recycling; Linear Programming

1. Introduction

The objective of this research is to find the maximum profit, optimization of green benefits, and optimization of routingfrom 20 recycling drop-off sites (see Figure 1-1) in City of Greensboro, North Carolina (NC), United States [1].

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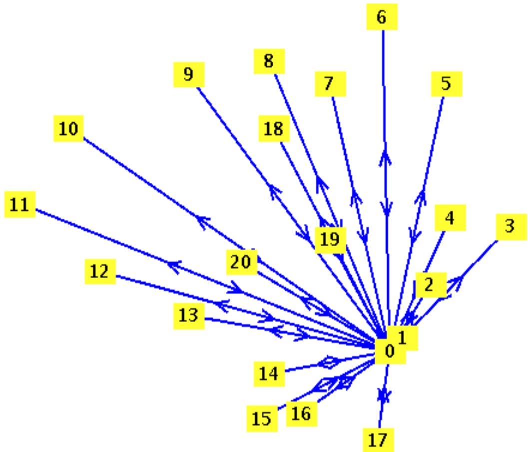
Figure 1-1: Graph of 20 drop-off sites in City of Greensboro



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites
Note that 0 is ReCommunity Center,1 is Gillespie Golf Course,

2is Windsor Community Center, 3is GulfordCouty Cooperative Ext, 4is Fire Station #7, 5is Fire Station #14, 6is FireStation #2, 7is Fire Station #43, 8is Fire Station #41, 9is Fire Station #21, 10is Fire Station #17, 11is Fire Station #20, 12is Fire Station #19, 13is Costco, 14is Smith High School, 15is Hester Park, 16is Fire Station #48, 17is Fire Station #61, 18is Jaycee Park, 19 is Grimsley High School, 20is LindleElementartShool.

There are distances and times between ReCommunity Centerand 20 drop-off sites and number of dumpstersat each site in Appendix, Table 1. It is an open-ended problem in a real life and not enough data, so we set time and cost constraints.First, we optimize the maximum profits each time and fuel cost constraints, only the time constraint and only cost constraint depend on weight recycled. We use linear programming and integer programming, and Maple for this optimization.Finally we find most green benefits such as saving energy, landfill, and oil from the optimized model of maximizing profit. Second, we optimize route to collect recycling commodities at 20 drop-off sites. We divide subgroups with a truck's capacity constraints and compute taking time each sub-route in each subgroup. Thus, we find the minimum of time and cost in each route.

2. Mathematical Modeling

2.1 Optimization profit from 20 recycling drop-off sites in City of Greensboro, NC

City of Greensboro has 20 recycling drop-off sites and a contract with ReCommunity center to process recycling [3]. There are total 36 dumpsters, single stream, at 20 recycling drop-off sites and a dumpster has capacity eight cubic yards (2800 pounds) [1]. They pick up the recyclable commodities once a day on Monday, Tuesday, Thursday, and Friday in a week. One person works a truck for 10 hours a day and drive at most 7 hours for collecting recyclables from drop-off sites. A front loader truck's capacity is 44 cubic yards and the truck drives two miles per gallon using diesel at cost \$3.76/gallon[2]. Thus a truck can drive at most 255 miles a day since speed limit is 35 mph in the city and costs at most \$460/day[3] for fuel. We will assume that a truck will have a round travel between ReCommunity center and each site and spend 10 minutes to load and unload at ReCommunity center and each site [3]. Also we assume that the fixed expenditure of a truck in a day is \$200.00. Under these assumptions, we find the maximum profit from 20 recycling drop-off sites in Greensboro using linear programming and integer programming. Let *R* be total net gain from the drop-off sites. The objective function of *R* and constraints are:

Maximum of

$$R(x_1, x_2, \dots, x_{20}) = \sum_{i=1}^{20} r_i x_i$$

subject to

$$\sum_{i=1}^{20} c_i x_i \leq C \quad \text{and} \sum_{i=1}^{20} t_i x_i \leq T - (1)$$

where the total net gain at site *i* = 1, 2, …,20 is

r = [8, 16, 8, 8, 16, 8, 16, 8, 16, 16, 8, 16, 16, 8, 8, 8, 8, 40, 32, 24],
fuel cost for a round tripbetween ReCommunity center and site *i* is

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[2] Mean value of 31 places of Diesel prices in Greensboro, NC, July 9, 2012
[3]\$1.88 per mile = 0.5 gallon/mile · \$3.79/gallon,
\$460 = \$1.88 per mile · 245 miles

c = [4.14, 8.65, 20.30, 13.91, 25.57, 34.59, 41.36, 41.74, 47.00, 52.64, 49.26, 40.23, 29.33, 24.06, 24.44, 15.42, 10.90, 32.71,

26.32, 20.30], thetotal time for a round tripbetween ReCommunitycenter andsite *i* is

t = [26, 30, 38, 32, 44, 54, 60, 60, 58, 60, 58, 56, 46, 44, 46, 38, 32, 52, 42, 46],

*C*isa fixed fuel cost, *T* is a fixed time, and $x_i \in \{0, 1\}$.Note thatx_i is 1representing as visit at site *i*and 0 representing as not visit site *i*, $i = 1, 2, \ldots, 20$.

2.1.1 Fixed fuel cost *C*is $460 per day

We compute maximum total net gains depend on time in hour, *T* = 6, 7, 8, 9, and 10 hours, using Maple. For example, if *C* = $460 and *T* = 6 hours, then the constraints by equation (1) is:

$$26x_1 + 30x_2 + 38x_3 + 32x_4 + 44x_5 + 54x_6 + 60x_7 + 60x_8 + 58x_9 + 60x_{10} + 58x_{11} + 56x_{12} + 46x_{13} + 44x_{14} + 46x_{15} + 38x_{16} + 32x_{17} + 52x_{18} + 42x_{19} + 46x_{20} \leq 360 - (2),$$

$$4.14x_1 + 8.65x_2 + 20.3x_3 + 13.91x_4 + 25.57x_5 + 34.59x_6 + 41.36x_7 + 41.74x_8 + 47x_9 + 52.64x_{10} + 49.26x_{11} + 40.23x_{12} + 29.33x_{13} + 20.06x_{14} + 24.44x_{15} + 15.42x_{16} + 10.9x_{17} + 32.71x_{18} + 26.32x_{19} + 20.3x_{20} \leq 460 - (3)$$

wherethe coefficients t_i in the equation (2) are time in minutes for round trip between ReCommunity center and each site x_i, and the coefficientc_i in the equation (3) are cost in dollar for round trip between ReCommunity center and each site x_i.

And then maximize the total net gain *R* useMaple. We get the maximum total net is 168 cubic yards recycled at eight drop-off sites$x_1, x_2, x_9, x_{10}, x_{13}, x_{18}, x_{19}, x_{20}$ and its fuel cost is $221.09 for this travel.Thus we have the total cost $421.09 including the fixed cost. Also we find that the maximum total net gain is $7124 using the average price of recycle per pound, $0.12116, see Table 2-1-A[5] and Table 2-1-B. Therefore, the profit is $6703.12.

Table 2-1-A: Percentage of collected recyclables& its Price

	Paper	Plastic	Glass	Metal
Percentage of collected recyclables	29%	12%	5%	9%
Selling price per pound	$0.0242	$0.61	$0.01	$0.45

Table 2-1-B: Price of collected recyclablesin a dumpster

Capacity/ dumpster(lb)	Price of Paper	Price of Plastic	Price of Glass	Price of Metal	Total Price
2800 lb	$19.49	$204.96	$1.4	$113.40	$339.25

Note that the average price of collected recyclables per pound is $0.12116 which is 339.25/2800.

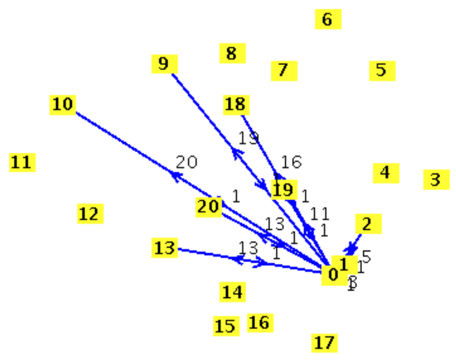
Similarly,we find the maximum total net gain for T =7,8,9,and 10 hours, respectively. See the following table 2-1-C and figure 2-1-D.

Table 2-1-C: Fixed Fuel Cost $460

	6 hr	7 hr	8 hr	9 hr	10 hr
Max. Total Net Gain (yd^3)	168	184	200	216	232
Number of Drop-Off Sites	8	10	11	12	15
Real Fuel Cost ($)	221.09	229.74	282.38	323.74	347.42
Total Revenue	7124.21	7802.70	8481.20	9159.70	9838.19
Total Profit	6703.12	7372.96	7998.82	8635.96	9290.77

Note that hr: hour and fixed cost a truck in a day is $200.00.

Figure 2-1-D: Visiting Drop-Off Sites if Fixed Fuel Cost $460



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites

2.1.2 Fixed Working Time *T* is 10 Hours Per Day

We compute maximum total net gains depend on cost, *C* = 200, 360, 410, 460, 510, and 560 dollar, using Maple. For example, if

T = 10 hours and *C* =$360, then we will optimize the total net gain $R(x_1, x_2, \dots, x_{20}) = \sum_{i=1}^{20} r_i x_i$ with the following constraints by equation (1)is:

$$\sum_{i=1}^{20} c_i x_i \le 360 \quad \text{and} \sum_{i=1}^{20} t_i x_i \le 600$$

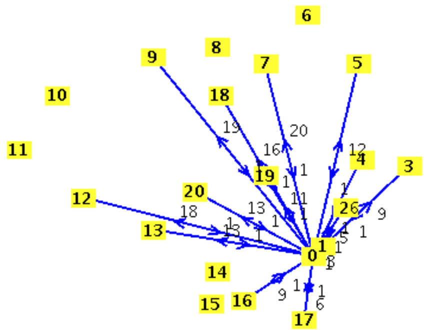
The maximum total net is 232 cubic yards recycled at 14 drop-off sites $x_1, x_2, x_3, x_4, x_5, x_7, x_9, x_{12}, x_{13}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20}$ and its fuel cost is $336.14 for this travel. Also we find that the maximum total net gain is $9838.19 using the average price of recycle per pound, $0.12116, see Table 2-1-A and B. Therefore, the profit is $9302.05. Furthermore, we find the maximum total net gain for *C* = 200, 410, 460, 510, and 560 dollar, respectively. See the following table 2-1-E and figure 2-1-F.

Table 2-1-E: Fixed Time T = 10

	\$200	\$360	\$410	\$460	\$510
Max. Total Net Gain (yd^3)	176	232	232	232	232
Number of Drop-Off Sites	10	14	14	14	14
Real Fuel Cost (\$)	192.13	336.14	347.42	347.42	347.42
Total Revenue(\$)	7463.46	9838.19	9838.19	9159.70	9838.19
Total Profit(\$)	7071.33	9302.05	9290.77	8635.96	9290.77

Note that hr: hour and fixed cost a truck in a day is \$200.00.

Figure 2-1-F: Visiting 14 Drop-Off Sites if Fixed Time T = 10



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites

2.1.3 Only Time Constraints (unlimited cost)

We compute maximum total net gains depend on time, T = 4, 5, 6…16 hours, using Maple. For example, if T = 4, then the constraint is:

$$\sum_{i=1}^{20} t_i x_i \leq 240.$$

The maximum total net is 136 cubic yards recycled at 6 drop-offsites$x_1, x_2, x_5, x_{18}, x_{19}, x_{20}$and its fuel cost is \$117.69 for thistravel. Also we find that the maximum total net gain is \$5767.22 and then the maximum profit is \$5449.53. Furthermore, we find the maximum total net gain and profit for T = 4, 5, 6… 16 hours, respectively. See the following table 2-1-G and figure 2-1-H.

Table 2-1-G: No Cost Constraint

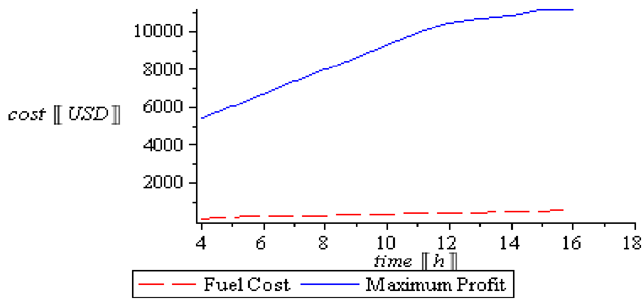
	4hrs	5hrs	6hrs	7hrs
Max. Total Net Gain (yd3)	136	152	168	184
Number of Drop-Off Sites	6	7	8	10
Real Fuel Cost	117.69	170.33	221.09	229.74
Total Revenue	5767.22	6645.71	7124.21	7802.70
Total Profit	5449.53	6075.38	6703.12	7372.96

Time	8hrs	9hrs	10hrs	11hrs
Max. Total Net Gain (yd3)	200	216	232	248
Number of Drop-Off Sites	11	12	14	15
Real Fuel Cost	282.38	323.74	347.42	388.78
Total Revenue	8481.20	9159.70	9838.19	10516.69
Total Profit	7998.82	8635.96	9290.77	9927.91

Time	12hrs	13hrs	14hrs	15hrs	16hrs
Max. Total Net Gain (yd3)	256	264	272	280	288
Number of Drop-Off Sites	16	17	18	19	20
Real Fuel Cost	412.84	437.28	471.87	521.13	562.87
Total Revenue	10855.94	11195.18	11534.43	11873.68	12212.93
Total Profit	10443.10	10657.90	10862.56	11152.55	11450.06

From the Table 2-1-G, we conclude that it takes 16 hours to collect all 288 cubic yards of recyclables (36 dumpsters) at 20 drop-off sites. The actual taking time is 922 minutes. If two drivers work a day, then they can collect all recyclables to maximize total net gain.

Figure 2-1-H: Maximum Total Net Gain and Real Fuel Cost with only Time Constraint



2.1.4 Only Cost Constraints (unlimited time)

We compute maximum total net gains depend on cost, *C* = 100,200, 300… 600, using Maple. For example, if *C* = 200, then the constraints are:

$$\sum_{i=1}^{20} c_i x_i \leq 200$$

The maximum total net is 176 cubic yards recycled at 10 drop-off sites$x_1, x_2, x_3, x_4, x_5, x_{13}, x_{17}, x_{18}, x_{19}, x_{20}$. It takes 888 minutes and its actual fuel cost is $192.13 for this travel. Also we find that the maximum total net gain is $7463.46 and then the maximum profit is $7071.33. Furthermore, we find the maximum total net gain for *C* = 100,200, 300… 600 dollar, respectively. See the following table 2-1-I and figure 2-1-J.

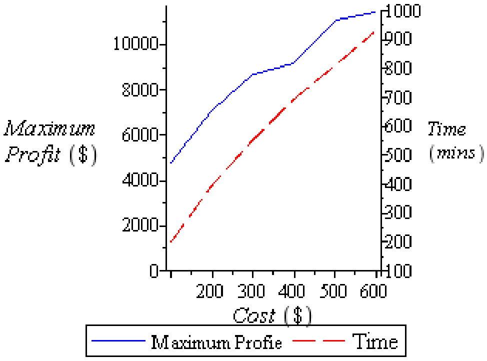
Table 2-1-I: No Time Constraint

Fuel Cost ($)	100	200	300
Max. Total Net Gain (yd3)	120	176	216
Number of Drop-Off Sites	5	10	13
Time (min)	196	388	550
Real Fuel Cost ($)	92.12	192.13	293.28
Total Profit	4796.60	7071.33	8666.42

Fuel Cost ($)	400	500	600
Max. Total Net Gain (yd3)	248	272	288
Number of Drop-Off Sites	16	18	20
Time (min)	690	804	922
Real Fuel Cost ($)	384.64	471.87	562.87
Total Profit	9189.04	10062.56	11450.06

Under unlimited time condition, the actual cost is $562.87 and its taking time is 922 minutes to collect all recyclables, 288 cubic yards, from all 20 drop-off sites. Thus $600.00 is enough money to set up for next the expenditure of fuel to collect recyclables.

Figure 2-1-J: Maximum Profit and Time depends on Time(Only Cost Constraint)



Finally, we can find most green benefits such as saving energy, landfill, and oil when we use recycled one to make a new one. Here is the data of percentage of recycled, saving landfill, energy, and oil to compute the green benefits. See the below Table 2-1-K.

Table 2-1-K: Data of Saving Landfill, Energy, and Oil

	Paper	Plastic	Glass	Metal
Percentage of Recycled	29	12	5	9
Saving Landfill (yd^3/ton)	4.6	30	2	10
Saving Energy[3](%)	45	67	20	95
Oil [4](gallon/ton)	463	685	8	1663

First we convert unit of ton to pound, so we find how much we save landfill, energy, and oil per pound. One pound of oil is 0.778182 gallons and one pound of landfill is 0.0027 cubic yards. Note that 1 lb = 0.000454 tons. We induce the result of most green benefits from maximum profit, Table 2-1-L in section1 and then see derive the green benefits from recycling as in the following Table 2-1-M.

[3] Percentage of energy saving when we use recycled one to make a new one [3]
[4] Gallon of oil saving when we use recycled one to make a new one [3]

Table 2-1-L: Material Estimated Percentage and Selling Price

	Paper	Plastic	Glass	Metal(AL)
[5]Percentage of Recycled (%)	29	12	5	9
[6]Selling Price($)/lb	0.024	0.61	0.01	0.45

Table 2-M: Green Benefits from recycling

Weight of Recycled	Landfill (yd^3)	Saving Energy (%)	Oil (gallon)
2,000	5.4	62	1,556
4,425	11.0	137	3,443
10,000	27	310	7,782
20,000	54	620	15,564
81,200	219.2	2517	63,188

2. 2: Optimization Routing of 20 Recycling Drop-Off Sites in Greensboro

We find minimum time and distance of a route 20 drop-off sites with a capacity constraint of a truck in City of Greensboro. We use graph theory and Maple to find best route. We consider four different routes under capacity constraint since a front loader truck capacity is 44 cubic yards.

Route I: Define 8 area zones in 20 drop-off sites in City of Greensboro (in Figure 1-1) with capacity constraint as:

$$A_1 = \{x_1, x_2, x_3, x_4\}, A_2 = \{x_5, x_6, x_7\}, A_3 = \{x_8, x_{19}\}, A_4 = \{x_{18}\},$$
$$A_5 = \{x_9, x_{10}, x_{11}\}, A_6 = \{x_{12}, x_{13}\}, A_7 = \{x_{14}, x_{15}, x_{16}, x_{17}\},$$
$$A_8 = \{x_{20}\}.$$

Each Area zone, there are $\frac{|A_k|!}{2}$ different sub-routes where $|A_k|$ is number of drop-off sites in area zone k. We compute time and distance each sub-routes in all area zones and find the minimum time and distance in Route1. The objective function is:

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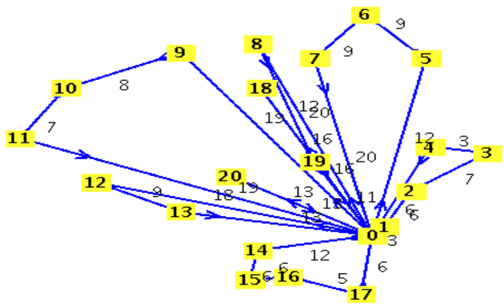
5 Percentage derived from US EPA 2010 total municipal solid waste generation
Data [6].
6 Data from [2]

Minimum of $\sum t_{ij}x_{ij}$wheret_{ij}: taking time from *i* to *j*, x_{ij}: arc from *i* to *j*, $x_{ij} \in A_k$, and$x_{ij} \in \{0, 1\}$.

The sub-routes to optimize the time in Route I are (0,1,2,3,4,0) in A_1, (0,5,6,7,0) in A_2, (0,8,19,0) in A_3, (0,18,0) in A_4, (0,9,10,11,0) in A_5,(0,12,13,0) inA_6, (0,14,15,16,17,0) in A_7, and (0,20,0) in A_8. See the Figure 2-2-A.

Figure 2-2-A: Optimization of Route 1



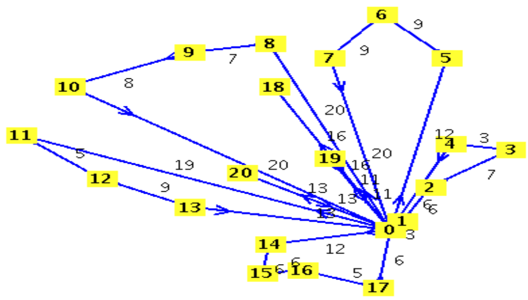
0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites, and number between two sites is travel time The minium total time is 595 minutes, distance is 159.1 miles and its fuel cost is $299.12 in Route I.

Route II: Define 8 area zones with capacity constraint as follow:

$$A_1 = \{x_1, x_2, x_3, x_4\}, A_2 = \{x_5, x_6, x_7\}, A_3 = \{x_8, x_9, x_{10}\},$$
$$A_4 = \{x_{18}\}, A_5 = \{x_9, x_{10}, x_{11}\}, A_6 = \{x_{12}, x_{13}\},$$
$$A_7 = \{x_{14}, x_{15}, x_{16}, x_{17}\}, A_8 = \{x_{20}\}.$$

The sub-routes to optimize the time in Route II are (0,1,2,3,4,0) in A_1, (0,5,6,7,0) in A_2, (0,8,9,10,0) in A_3, (0,18,0) in A_4, (0,11,12,13,0) in A_5, (0,19,0) in A_6, (0,14,15,16,17,0) in A_7, and (0,20,0) in A_8. See the Figure 2-2-B.

Figure 2-2-B: Optimization of Route II



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites, and number between two sites is travel time

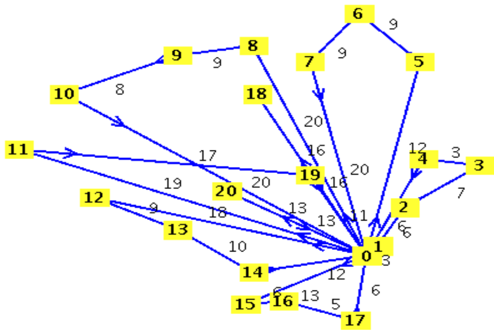
The minium total time is 571 minutes, distance is 154.9 miles and its fuel cost is $291.21 in Route II.

Route III: Define 8 area zones with capacity constraint as follow:

$$A_1 = \{x_1, x_2, x_3, x_4\}, A_2 = \{x_5, x_6, x_7\}, A_3 = \{x_8, x_9, x_{10}\},$$
$$A_4 = \{x_{18}\}, A_5 = \{x_{11}, x_{19}\}, A_6 = \{x_{12}, x_{13}, x_{14}\},$$
$$A_7 = \{x_{15}, x_{16}, x_{17}\}, A_8 = \{x_{20}\}.$$

We find the sub-routes to optimize the time in Route III are (0,1,2,3,4,0) in A_1, (0,5,6,7,0) in A_2, (0,8,9,10,0) in A_3, (0,18,0) in A_4, (0,11,19,0) in A_5, (0,12,13,14,0) in A_6, (0,15,16,17,0) in A_7, and (0,20,0) in A_8. See the Figure 2-2-C.

Figure 2-2-C: Optimization of Route III



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites, and number between two sites is travel time

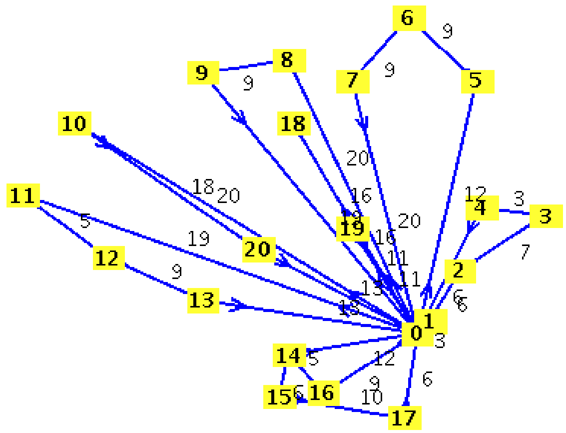
The minium total time is 596 minutes, distance is 169.8 miles and its fuel cost is $319.22 in Route III.

Route IV: Define 8 area zones with capacity constraint as follow:

$A_1 = \{x_1, x_2, x_3, x_4\}$, $A_2 = \{x_5, x_6, x_7\}$, $A_3 = \{x_8, x_9\}$,
$A_4 = \{x_{18}\}$, $A_5 = \{x_{19}\}$, $A_6 = \{x_{10}, x_{20}\}$,
$A_7 = \{x_{11}, x_{12}, x_{13}\}$, $A_8 = \{x_{14}, x_{15}, x_{16}, x_{17}\}$.
We find the sub-route for optimize the time in Route IV:

(0,1,2,3,4,0) in A_1, (0,5,6,7,0) in A_2, (0,8,9,10,0) in A_3, (0,18,0) in A_4, (0,19,0) in A_5,(0,10,20,0) in A_6, (0,11,12,13,0) in A_7, and (0,16,14,15,17,0) in A_8. See the Figure 2-2-D.

Figure 2-2-D: Optimization of Route IV



0: ReCommunity Center, 1, 2, 3, …,20: Drop-off Sites, and number between two sites is travel time

The minium total time is 620 minutes, distance is 170.0 miles and its fuel cost is $319.60 in Route IV.

We conclude that Route II is the best route to have minimum cost and taking minimum time to collect all recyclables all 20 drop-off sites.

3. Results and Discussion

We conclude that the time constraints are more dominant than cost constraints to get maximum total net gain from 2.1.1 to 2.1.4.

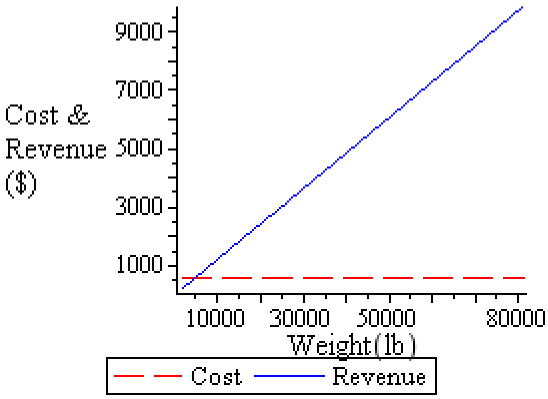
To find the maximum profit, we must consider variety of weights even in the same capacity. We derive a formula that one pound of recycle is equivalent to $0.12116 from the Table 2.1.A.Assume that a truck driver works 10 hours a day with $360.00 for fuel cost in 2.1.2. We know that the maximum total net is 232 cubic yards recycled at 14 drop-off sites.

However, we do not have data of weight in real data. Thus we will consider the weights of recycling commodities are 2000, 4425, 10,000, 20,000, and 81,200 pounds to find its maximum profit, respectively. See the Table 3-1-A and the Figure 3-1-B.

Table 3-1-A: Maximum Profit if T=10 and C=360

Wight of Recycled	Revenue($)/day	Profit($)/day	Profit($)/year
2,000	242.32	−293.82	−61,114.56
4,425	536.14	0	0
10,000	1,211.60	675.46	140,495.68
20,000	2,423.20	1,887.06	392,508.48
81,200	9,838.19	9,302.05	1,934,826.40

Figure 3-1-B: Maximum Revenue and Fixed Cost $536.14 if T=10



We have even when we collect 4,425 pounds this case. Suppose that all 29 dumpsters are full, 232 yd^3, and maximum weight, 81,200 lb. Then the maximum profit is $9,302.05/day and $1,934,826.40/year. Why not recycle!

Also, we conclude that Route II is the best route to have minimum cost and taking minimum time to collect all recyclables all 20 drop-off sites in optimization of routing of 20 Recycling Drop-Off Sites in Greensboro.

4. References

City of Greensboro, North Carolina, Greensboro Goes Green, [Online] Available: http://www.greensboro-nc.gov/index.aspx?page=2781
Fort Gordon Community Credit Union, [Online] Available: http://www.fortgordon.com/recycling_program.php
Mississippi Department of Environmental Quality
[Online]
Available:http://www.deq.state.ms.us/mdeq.nsf/page/Recycling_RecyclingTrivia?OpenDocument
Recommunity Recycling, [Online] Available:http://www.recommunity.com/
A Recycling Revolution, [Online] Available: http://www.recycling-revolution.com/recycling-facts.html
Municipal Solid Waste (MSW) in the United States: Facts and Figures, [Online] Available:http://www.epa.gov/waste/nonhaz/municipal/msw99.htm

Appendix

Table1

Drop-Off Site (x_i)	Time from x_0 to x_i (min)	Distance from x_0 to x_i (miles)	[1]Round trip cost from x_0 to x_i	Number of Dumpsters at site i
x_1	3	1.1	$4.14	1
x_2	5	2.3	$8.65	2
x_3	9	5.4	$20.30	1
x_4	6	3.7	$13.91	1
x_5	12	6.8	$25.57	2
x_6	17	9.2	$34.59	1
x_7	20	11.0	$41.36	2
x_8	20	11.1	$41.74	1
x_9	19	12.5	$47.00	2
x_{10}	20	14.7	$52.64	2
x_{11}	19	13.1	$49.26	1
x_{12}	18	10.7	$40.23	2
x_{13}	13	7.8	$29.33	2
x_{14}	12	6.4	$24.06	1
x_{15}	13	6.5	$24.44	1

Drop-Off Site (x_i)	Time from x_0 to x_i (min)	Distance from x_0 to x_i (miles)	[1] Round trip cost from x_0 to x_i	Number of Dumpsters at site i
x_{16}	**9**	**4.1**	**$15.42**	**1**
x_{17}	**6**	**2.9**	**$10.90**	**1**
x_{18}	**16**	**8.7**	**$32.71**	**5**
x_{19}	**11**	**7.0**	**$26.32**	**4**
x_{20}	**13**	**5.4**	**$20.30**	**3**
Total			$562.87	**36**

Note that * Cost/Mile = gallon/mile × cost/gallon where gallon/mile = 1/(mile/gallon) . In this model, $1.88/Mile = $\frac{1}{2}$ gallon/mile × $3.79/gallon, where $3.79 is the mean value of diesel price in Greensboro, NC, July 9, 2012