1. **Introduction and Background**

This technical memorandum (TM) provides information on the analysis of the level of truck traffic associated with the processing and delivery of commercial solid waste in New York City (NYC). It assesses the benefits or impacts of alternative commercial solid waste collection processes, and identifies potential improvements in system efficiency based on standard performance measures used in assessing vehicular traffic activity in a large geographic area. The primary focus of this effort involved truck traffic associated with the elements of recyclables and putrescible waste management processes, including the removal of waste from individual generators, the delivery of waste to transfer stations or recycling facilities, and (to the extent possible) the final movement of waste materials to their points of reuse or disposal. This task complements other tasks in the study involving waste generation modeling and waste classification data collection, recommendations for...
strengthening the ties between generator-based data resources currently used by the Department of Sanitation of New York (DSNY), and on-street truck activity associated with the collection and processing of putrescible commercial waste.

2. Results

There are 233 carting companies of various sizes listed in the NYC Business Integrity Commission (BIC) database, ranging in size from small single-truck businesses to dominant companies in the industry with large truck fleets. The large companies obviously dominate some market segments, but even as the industry has undergone some consolidation over the years, there are still many carters with sizeable market share in New York City. The following statistical information on the carting firms was reported in the BIC database:

- The 10 largest carters (ranked by the number of their customers) serve almost 48 percent of the customers.
- The 20 largest carters serve almost 67 percent of the customers.
- The 50 largest carters serve more than 90 percent of the customers.
- The 100 largest carters serve more than 99 percent of the customers.

These data indicate that 133 of the carting firms listed in the BIC database are minor participants in the industry, combining to serve less than 1 percent of the customer base.

2.1 Scenario 1 – Baseline Condition

The Baseline Condition scenario modelled the approximately 138,000 commercial customers listed in the BIC database and the carters that serve them. The purpose of this scenario was to establish a baseline condition that can serve as the basis for comparison to other potential scenarios with different waste streams, constrained or refined carter-generator relationships based on geographic limitations, and other considerations. In Scenario 1, the total number of customers exceeds the actual number in the BIC database because a single customer may be assigned a separate transfer station for each waste stream, so that a customer that had both putrescible waste and recyclable pickups would be counted twice.

The figures presented in this section are not intended to be a precise estimate of vehicle miles travelled (VMT) and vehicle hours travelled (VHT) figures for NYC commercial solid waste collection process, but are reasonable estimates based on the parameters and broad assumptions discussed within this document. In particular, the conversion of monthly waste tonnages to daily tonnages, and the application of the route optimization tool to a scenario where all customers are served daily results in an analysis that is extremely hypothetical on a route-by-route basis, but lends itself well to reasonable VMT and VHT estimates for the city overall. The proportionate changes in VMT and VHT figures from the Baseline Condition to other scenarios, which will be analyzed in this effort, are likely to be more meaningful than the actual VMT and VHT figures, and will serve as an effective way to measure the benefits and impacts of these scenarios in comparison to the baseline scenario.
A graphical summary of the commercial putrescible waste and recyclable tonnage produced by borough and processed through transfer stations by borough is shown on Figures 1 and 2, respectively (no material was sent to transfer stations in Manhattan).

**Figure 1**

*Destination of Commercial Waste by Borough*
2.2 Scenario 2 – Combined Stream

The Combined Stream scenario consolidates the recyclables (clear bag or separated) and the putrescible waste stream (black bag) into a single unit, where possible, so they can be picked up and transported in the same collection trucks. In Scenario 2, if a customer has daily pickups of both putrescible waste and recyclables assigned to it, they have been assigned and sent to the putrescible waste transfer station only. In addition, a customer with only recyclable waste will go to the recyclable transfer station listed in the database.

A summary of the Baseline Condition (Scenario 1) and Combined Stream (Scenario 2), using average daily data, is shown in Table 1.
### Table 1

**Summary of Scenarios 1 and 2**

<table>
<thead>
<tr>
<th>Category</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Customers</td>
<td>152,740</td>
<td>107,994</td>
<td>-29.3</td>
</tr>
<tr>
<td>Total Tonnage (Putrescible + Recyclable)</td>
<td>8,385</td>
<td>8,385</td>
<td>N/A</td>
</tr>
<tr>
<td>Vehicle-Miles Traveled (VMT)</td>
<td>99,798</td>
<td>65,558</td>
<td>-34.3</td>
</tr>
<tr>
<td>Vehicle-Hours Traveled - Total (VHTT)</td>
<td>6,388</td>
<td>4,946</td>
<td>-22.6</td>
</tr>
<tr>
<td>Vehicle-Hours Traveled - Running (VHTR)</td>
<td>2,467</td>
<td>1,783</td>
<td>-27.7</td>
</tr>
<tr>
<td>Average Operating Speed</td>
<td>15.6 mph</td>
<td>13.3 mph</td>
<td>-15.2</td>
</tr>
<tr>
<td>Average Running Speed</td>
<td>40.5 mph</td>
<td>36.8 mph</td>
<td>-9.1</td>
</tr>
<tr>
<td>VMT per Ton</td>
<td>11.90</td>
<td>7.82</td>
<td>-34.3</td>
</tr>
<tr>
<td>VHT (total) per Ton</td>
<td>0.76</td>
<td>0.59</td>
<td>-22.6</td>
</tr>
</tbody>
</table>

**NOTES:**

a This figure is different from the 138,000 customers described earlier in this section because some customers are modeled separately for the two different waste streams, using the same carter.

b This figure differs from the 152,740 customers in Scenario 1 because any business establishments listed as two separate “customers” in Scenario 1 now have these streams combined into a single carter in Scenario 2. For both scenarios, customers were eliminated if they were located outside the five boroughs, had a daily putrescible or recycling code that was null, did not have a proper transfer station assigned, or were not properly geocoded to the street level.

c Includes time when trucks are moving plus total customer service time.

d Includes only time when trucks are moving between customers and to/from route end points.

#### 2.3 Scenario 1 - Baseline Condition Highlights

The following highlights are based on the analytical results and other research and observations performed during the course of this project:

- Commercial waste haulers observed during the course of this project operate very efficient routes, serving customers in a manner that minimizes travel time and truck miles travelled, while maximizing their resources (labor, truck operating time, etc.).

- Some of these waste haulers also engage in practices that enable them to cover their routes more efficiently than the geographic information system (GIS) based route optimization process used in this study allows. As described in Item 6 of Section 3.2, Analytical Process, reverse moves, illegal right turns on red, and even the blatant disregard of one-way street restrictions (in some cases) were used.

- One of the most substantial impacts of commercial waste collection, from an environmental standpoint, (idling engines) is observed in the time it takes to serve individual customers, not the time it takes for a garbage truck to travel from one location to another. This is reflected in the marked difference between the Average Operating Speed and the Average Running Speed shown on Table 1.
• For carting firms that operate efficient routes and assign trucks based on customers located in close proximity to each other, a substantial portion of the vehicle miles travelled for any given route involves the movement of a truck from the carter's terminal location to the first customer on the route, and the movement of that truck from the last customer on the route to the transfer station. The actual distance travelled between customers on the route is often very short, especially if they are located close together and scheduled for pick-ups in a rational order.

• The three most important factors in the efficiency of a carter's operations, as measured by VMT, are (not ranked):

The location of the carter's terminal relative to its customer base.

The location of the customers relative to the transfer station(s) used to process their waste.

The “density” of the customers in terms of how close they are to each other. Substantial VMT are expended by carters to serve outlying customers located in the outer boroughs that have few other customers around them.

• Businesses that use containers and compactors for their waste disposal typically involve more VHT for their pick-ups, because there are no opportunities for the carter to develop efficient routes based on customer clusters and optimized routing between customers. The process of picking up a container/compactor is performed for a single customer at a time and involves an inherent 50 percent loss of efficiency because the return trip from the transfer station to the customer location is made with an empty container. These containers are used to transport large quantities of waste, however, and may be more efficient when measured on a VMT per ton basis. The movement of a container to and from a customer's location is also a single stop that does not require the extensive lost that is caused by multiple stops and starts along a route for a standard garbage truck.

2.4 Scenario 2 - Combined Stream Highlights

The following Scenario 2 highlights are in comparison to the results from Scenario 1:

• The Combined Stream scenario achieved greater overall efficiency in total VHT (travel time and service time) and running VHT (trucks operating in motion) with a decrease of 22.6 and 27.7 percent, respectively. This efficiency was likely the result of a single carter's ability to service one customer while picking up both sources of waste, and the reduction in the stops made by the carter before going to a transfer station. In this regard, the time of travel for the Combined Stream scenario is made up more of trips to and from a transfer station than trip time between customers.

• The VMT as well as the VMT per ton was reduced from Scenario 1 by 34.3 percent, since the total system wide waste tonnage in the two scenarios was identical.

• Despite improvements in the time that it takes to pick up the same tonnage of putrescible or recyclable waste, and the distance that it requires the trucks to deliver that waste to transfer stations, the average truck travel speed decreases from Scenario 1 to Scenario 2. In this type of
analysis, this decline in speed is likely attributable to the changing characteristics of truck activity with the combination of waste streams for customers using containers instead of bags or dumpsters. A customer with two containers in Scenario 1 only needs a single container in Scenario 2, so a second truck trip to a transfer station for the second container is not required. As a result, the system wide travel speeds in Scenario 2 are more heavily weighted toward trucks making multiple stops to service multiple customers, and less heavily weighted toward trucks picking up containers and then travelling at higher speeds to and from a transfer station. Under this arrangement, average truck speeds may actually decline even as the efficiency of the system improves. A hypothetical scenario where every customer in the city uses containers instead of dumpsters and bags would be less efficient by all relevant measures (higher total and per-ton VMT and VHT figures), but would likely have a higher average speed because these trucks would be spending more time travelling at highway speeds to and from the transfer stations.

- Ultimately, the ability to reduce the time and distance that carters have to operate on NYC streets could have a positive effect on congestion and air quality for the city, and improve operational efficiencies for carters.

2.5 Case Study of Three Sample Carters

A detailed examination of three sample carting firms illustrates some of the complexities of the commercial solid waste collection process in New York City. These three carters are located in a similar area east of Manhattan and serve customer bases that are somewhat similar. The terminal locations for these carting firms, the primary transfer stations they use to serve their customers, and the customer locations are shown in the accompanying figures.

2.5.1 Carter No. 1

Carter No. 1 serves customers that are heavily concentrated in Queens, but also have customers scattered throughout the other boroughs (Figure 3). The company's primary transfer station is in the Bronx, which is a relatively short distance from most of their customers. Nearly all of their customers (99.3 percent) are served using standard rear-load or front-load garbage trucks.

2.5.2 Carter No. 2

Carter No. 2 has a facility in Queens and serves customers scattered over a large area, but has a concentration of large customers in Midtown Manhattan that are handled using container/compactor trucks (Figure 4). More than 90 percent of Carter No. 2's customers are served using standard rear-load or front-load garbage trucks.

2.5.3 Carter No. 3

Carter No. 3 has the tightest concentrations of customers in two distinct clusters in Queens. Of the three carters examined in this case study, Carter No. 3 has the heaviest use of container/compactor trucks (more than 21 percent) (Figure 5). The company's main transfer station is in Queens, which is some distance from one customer cluster but not far away from the other cluster. Carter No. 3 serves very few customers outside of Queens.
Figure 3
Carter No. 1
Figure 4
Carter No. 2

Legend
- Carter
- Transfer Station
- Customers
The VMT and VHT summaries for these three companies are shown in Table 2. Based on the customer and transfer station locations, and the types of trucks used to serve their customers, the information in the table indicates that the use of container and compactor trucks is a major factor in VMT and VHT measurements for carters serving customers. Carter No. 3 has the most heavily concentrated groups of customers and also processes their waste through transfer stations located close to them; however, is the least efficient of the three carriers when measured on a VMT/ton and VHT/ton basis. This is because there is a substantial use of travel time and mileage when processing loads with a container/compactor truck, since there is an empty return trip from the transfer station to the customer for every trip made to pick up a customer’s waste. There is also an inherent inefficiency in VMT/ton and VHT/ton for these trucks in trips where a customer’s container is transported without regard to whether it has reached its maximum load (i.e., a truck hauling a container that is 100 percent full by weight will expend fewer VMT and VHT per ton than a truck making the same trip with a container that is 75 percent filled).
Carter No. 1, which is the most efficient of the three carters on a VMT/ton and VHT/ton basis, has a combination of three factors that all tend to support efficiency:

- Customers concentrated in close proximity to each other.
- Transfer stations located in close proximity to their heaviest concentration of customers.
- Very few customers who use containers and compactors for their waste disposal.

<table>
<thead>
<tr>
<th>Carter Name</th>
<th>Combined Tonnage</th>
<th>Number of Customers</th>
<th>Total Mileage</th>
<th>Total Travel Time (in Hours)</th>
<th>VMT per Ton</th>
<th>VHT per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carter No. 1</td>
<td>101</td>
<td>1,853</td>
<td>1,162</td>
<td>54</td>
<td>11.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Carter No. 2</td>
<td>65</td>
<td>1,850</td>
<td>1,102</td>
<td>80</td>
<td>17.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Carter No. 3</td>
<td>34</td>
<td>1,283</td>
<td>652</td>
<td>102</td>
<td>19.0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

2.6 System Redundancy

This analytical process can be used to develop some measures of system redundancy under the current commercial waste process. One measure would involve a link-by-link examination of street segments to identify locations where multiple carting firms traverse the segment during a route. A weakness of this method of measuring redundancy using this “traversal” calculation in ArcGIS is that it does not readily discern between a truck travelling down a specific street to serve customers and one that uses the same street to travel through the neighborhood between customers or to get to a transfer station. Trucks from multiple carting firms using the same street segment in the first case represent a potential inefficiency due to redundant truck activity, while in the second case the trucks may be using that street segment regardless of whether or not there were multiple carters involved.

An illustration of how multiple carting firms serving customers in an area that requires overlapping use of the street network can be seen when customers are mapped in areas at a sub-borough level and the number of different carters serving those customers. Figure 6 shows New York City’s 59 community districts, along with 13 additional areas designated as “green” or “grey” areas that have public recreational or institutional uses, but have commercial waste customers listed in the BIC database. The table included with Figure 6 lists a random sample of Community Districts from the five boroughs, along with the total customer count and the number of carters serving these customers. The number of carting firms serving customers in a single district can be used to estimate overlapping services and potential inefficiencies in the commercial waste system in New York City.
Segmentation of the commercial solid waste market by geographic areas at the sub-borough level can be examined in Phase 2 of this study.

**Figure 6**

New York City’s Community Districts

<table>
<thead>
<tr>
<th>District</th>
<th>Customers</th>
<th>Carters</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA-1</td>
<td>2787</td>
<td>68</td>
</tr>
<tr>
<td>MA-5</td>
<td>13931</td>
<td>79</td>
</tr>
<tr>
<td>MA-11</td>
<td>1534</td>
<td>55</td>
</tr>
<tr>
<td>GREEN</td>
<td>29</td>
<td>10</td>
</tr>
<tr>
<td>BX2</td>
<td>1432</td>
<td>39</td>
</tr>
<tr>
<td>BX4</td>
<td>1487</td>
<td>38</td>
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<tr>
<td>BX8</td>
<td>930</td>
<td>30</td>
</tr>
<tr>
<td>BX-12</td>
<td>1691</td>
<td>43</td>
</tr>
<tr>
<td>GREEN</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>BK-4</td>
<td>1363</td>
<td>49</td>
</tr>
<tr>
<td>BK-9</td>
<td>792</td>
<td>43</td>
</tr>
<tr>
<td>BK-14</td>
<td>1442</td>
<td>59</td>
</tr>
<tr>
<td>GREEN</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>QN-1</td>
<td>4771</td>
<td>69</td>
</tr>
<tr>
<td>QN-6</td>
<td>1806</td>
<td>48</td>
</tr>
<tr>
<td>QN-10</td>
<td>1471</td>
<td>44</td>
</tr>
<tr>
<td>QN-14</td>
<td>812</td>
<td>26</td>
</tr>
<tr>
<td>GREEN</td>
<td>83</td>
<td>9</td>
</tr>
<tr>
<td>SI-2</td>
<td>1772</td>
<td>31</td>
</tr>
<tr>
<td>SI-3</td>
<td>1474</td>
<td>25</td>
</tr>
</tbody>
</table>

3. **Methodology**

During this effort, several potential measures were identified that would help refine the truck/traffic analysis and improve on the accuracy of the calculated measures documented here. These data sources were never intended for this type of analysis, yet served as very useful resources in doing a network-based analysis of truck operations for commercial waste processing. The methodology used with these data yields reasonable estimates of system-wide performance measures of truck activity (VMT and VHT), and can be applied to similar analyses under different scenarios as documented in this study.

On a “microscopic” level involving individual roadways and facilities, traffic operations are typically measured in terms of congestion, levels of service, delays, and other metrics that relate to the operation of specific elements of a transportation system. For a “macroscopic” analysis at the large
regional scale of this study, parameters for measuring traffic activity include aggregate measures for the roadway system as a whole. Truck activity associated with commercial waste collection and disposal is measured using standard regional measures of vehicular traffic: VMT and VHT.

VMT is a representative aggregate measure for truck volumes and distance travelled. VHT is typically used in conjunction with VMT to document levels of congestion, but for this study, congestion impacts are minimal since most commercial waste collection in NYC occurs at night when overall traffic activity is low. Specialized collections and containerized waste are picked up during daytime more frequently than curb side set-outs, but the amount of truck trips associated with these is necessarily much less for most of the city. VHT is a useful measure, however, for this particular effort because it can be used to assess the impact of stopped time (for making waste pick-ups, assuming a standard or observed time for the average curb side retrieval of waste) on the commercial waste collection process. VHT will increase or decrease not only with the length of routes, but with the number of individual stops they include.

3.1 Data Resources

The following three primary data sources were used in this task:

- The customer and carter registry (CR) maintained by BIC was used to identify the locations of commercial waste generators in the city, the relationship between customers and their respective carters, and monthly waste amounts reported by individual customers. There are approximately 138,000 customers in the database used for the Task 3 effort, which range in size from a small retail store in one of the outer boroughs to a large skyscraper in Manhattan with many separate tenants, but listed as a single customer in the BIC database because all commercial waste is handled for the building through the building management itself.

- The DSNY maintains a Private Operators Database System (PODS) that includes information on private carters, transfer stations, and the quantities of waste transported. The PODS data were used in Task 3 to identify the locations of carting companies documented in the BIC database and of transfer stations used by those carting companies, and to establish a link between customers (from BIC) and transfer stations (from PODS) for truck routing purposes.

- The NYC Department of City Planning maintains a LION file that has linear data for roadways and other features, such as shorelines and rail lines. This data resource was used for mapping locations of carters and customers, and to serve as the base street network for the truck routing processes that were the basis for the truck activity measurements documented in Task 3. These data were supplemented by the data layers for the 2007 NYC Truck Route Map, published and maintained by the NYC Department of Transportation (NYCDOT).

Additional resources, such as InfoUSA and GoogleMaps, were used to fill gaps in data where exact street addresses for customers were not listed or when a carter was listed by a corporate address rather than a yard or operating facility location. The BIC customer list was refined extensively for this task to eliminate redundant business records, where necessary (customers listed separately for different types of waste, for example), so the customer count for Task 3 may not be identical to the customer count for other tasks in this study that relied on the same BIC database for other analyses. The BIC and PODS databases also have a similar data field for waste quantity, but because the data
for these respective sources are reported differently (BIC reported by carters for customers, PODS reported by transfer stations), there was no attempt to balance waste between customers and transfer stations to address discrepancies between the two sources. The waste quantities used in this task were based on the data reported on a customer-by-customer basis in the BIC database.

### 3.2 Analytical Process

The analytical process for this effort was based on the general underlying principles of an optimized truck route network commonly used in the freight industry for making deliveries to multiple locations from a single terminal. A shipper who makes deliveries to a series of retail stores from a warehouse, for example, will use some method to optimize the delivery process based on a set of parameters related to the cost of operating each truck, the time it takes to travel between stops, the time spent at each location making the actual delivery, customer preferences or other limitations on delivery times (e.g., off-peak deliveries required, overnight deliveries prohibited, etc.), and any number of other parameters. The process involved in picking up and hauling commercial waste is similar to this type of delivery, but instead of dropping off shipments at customer locations the trucks are picking up waste. The truck capacity as it gets filled up during the pick-up process is also a limiting factor that is the converse of a delivery process. Whereas a truck making deliveries is loaded at the point of origin and makes multiple stops until all of the loads are delivered, a truck picking up waste is empty at the point of origin and makes multiple stops until it is either filled to capacity or reaches a pre-determined point in the route where it is convenient to empty its load at a nearby transfer station.

The analyses involved a complex application of this basic route optimization process, modified as needed to fit this particular task. It is a very complex process because of the different variables involved, the number of different carting companies in the industry in NYC (233), the number of customers involved (138,000), the difficulty in understanding the exact operating characteristics of each carter, and the complexities of the contractual relationships between carters and customers and the specific requirements of individual customers. To develop reasonable estimates of daily VMT and VHT for commercial waste collection, several assumptions were used to simplify the process, develop system-wide and industry-wide estimates in lieu of actual values that could vary widely from one carter (or one carter/customer pair) to another, and overcome limitations on the capacity of the computing process involved in routing options that get exponentially more complex with such a large numbers of carters and customers. Key estimates and assumptions used in this analysis are as follow:

1. Waste amounts in the BIC database are organized into two basic waste streams: putrescible and recyclable waste. For the Baseline Condition (Scenario 1), it was assumed that these two waste streams would be handled as two completely separate routing processes for estimating truck VMT and VHT. That is, separate trucks would always be used to pick up putrescible and recyclable waste from a single customer. For the Combined Stream (Scenario 2), a single truck could pick up both streams together in a single stop.

2. Two basic waste collection processes were used in this analysis. Many customers that generate large quantities of waste and have regularly scheduled pick-ups have a roll-off container or compactor identified in the BIC database as the method of storage/removal, while other waste is typically picked up as bags or in dumpsters. The pick-up process for a container or compactor
involves an empty truck chassis travelling from a carter to the customer, loading the full container onto the chassis, travelling to the appropriate transfer station, and then returning to the customer’s location with the empty container. The pick-up process for all other types of waste involves a single truck travelling along a defined route to collect waste at multiple stops, with interruptions in the route as needed to empty the truck at the appropriate transfer station once the truck is filled to capacity. Some customers listed in the BIC database use different waste collection processes and garbage trucks for their waste streams. For example, a customer may use a container or compactor for their recyclable waste and loose bags or a dumpster for putrescible waste. For Scenario 2, in which the two waste streams are combined into a single waste stream for collection purposes, it was assumed that the process used by that customer for putrescible waste disposal and removal would be used for the combined stream.

3. This analysis was based on a routing algorithm in which a truck making pick-ups of “loose” or “bag” waste would continue to serve customers along its optimized route (as defined in the next section) until it reached a point where the added waste volume for the next customer on the route would exceed the capacity of the truck. For this analysis, it was assumed that all garbage trucks have a load weight capacity of 13.5 tons.

4. For customers that have their waste collected in a roll-off container or compactor, the weight capacity of the container was not considered and it was assumed that a single truck trip would be made for each container pick-up regardless of the actual weight (i.e., it was assumed that any customer with a daily tonnage more than 13.5 tons would need a container).

5. Customer service time was estimated at 15 minutes for a roll-off container and 5 minutes per ton for all other commercial waste. This estimate was based on field observations conducted during the study.

6. The integrity of the NYC LION roadway network was maintained at all times in the routing process, even though field observations indicated that many carriers employ operating measures that can offer meaningful improvements in operating efficiency. These measures include reverse moves on streets to minimize circuitous routes, illegal right turns on red, and travelling the wrong way along a short block on a one-way street.

7. The routing algorithm was based on daily pick-ups for all customers in New York City, regardless of what the actual garbage pick-up schedule is for any given customer. This base assumption was necessary because one of the limitations of this analytical process was that all routing analyses must be done using a uniform standard of measurement (daily VMT, weekly VMT, etc.). Basing this analytical process on optimized routing is too complex to make adjustments to VMT and VHT on a route-by-route basis using standard post-process adjustments; there is not enough information in these data sources to incorporate customers with weekly pick-up trips into routes with customers served daily without making gross assumptions about exactly which day of the week each such customer is served. The data sources used in this effort contained minimal information about pick-up intervals. Some customers have this information listed in the BIC database in a “Comments” field, but there is no uniformity for this information and no practical way to verify it independently. The Halcrow
Team developed adjusted monthly waste tonnages for customers in the BIC database. These adjusted monthly tonnages were used to compute daily estimates based on 30 days per month.

8. Information obtained during the consultant team’s research on this project indicated that some unknown portion of the carting firms listed in the BIC database actually subcontract many of their customer pick-ups to other carters. No consideration for this type of arrangement was included in this analysis, since the BIC database is the only data source that links customers to carters and there is no practical method to estimate, document, and verify any subcontracting arrangements.

9. Time-of-day and day-of-week information listed in the BIC database was not used in this analysis. This information was typically listed in the “Comments” field and was not filled in consistently for all carters and customers. With the analytical process used to calculate estimated VMT and VHT figures on a system-wide basis, the impacts of these restrictions on the overall operating characteristics across the entire system is negligible.

The analysis of system-wide truck traffic activity associated with commercial waste collection and delivery to transfer stations was performed using ESRI ArcGIS 10.0 and the Network Analyst Extension, with applicable source data from the BIC and PODS databases and the NYC LIION file used as the routable roadway network. Within the Network Analyst Extension the Vehicle Routing Problem (VRP) tool was used, which is a process that will provide the best route for a fleet of vehicles to serve customers at multiple stops along a route. The algorithm in a VRP assigns a fleet of vehicles to a subset of locations to minimize the overall transportation costs.

For the analysis, the fleet assignment process for the VRP was done outside the analytical tool and based on designations of separate “trucks” for each route regardless of how many trucks were actually available in an individual carting company’s fleet. For example, if a garbage truck left a yard and was able to pick up loads from 35 different customers in 2 hours before it reached its 13.5-ton load capacity and emptying its contents at the appropriate transfer station, it was counted as a separate “truck” in the VRP process even if it was then assigned to serve another group of customers after emptying its load. The truck fleet sizes have no bearing on the analytical process for computing VMT and VHT on a city-wide basis because the aggregate VMT and VHT figures are calculated in this process regardless of how many separate trucks are used to serve the customer base for each carter. In other words, there is not a substantial difference in VMT and VHT figures for a carter if it serves 100 customers in one night using a single truck in four 2-hour shifts or if it serves 25 customers each that night using four different trucks that each operate for 2 hours. There will be some variations between these two hypothetical scenarios based on the “first-leg” trip(s) from the carter’s facility to the first customer and the “last-leg” trips(s) from the final drop-off at the transfer station to the carter’s facility, but the combined service time, travel time between customers, and other measures related to the direct waste collection process will not vary significantly.

This hypothetical approach to analyzing truck activity on a system-wide basis was necessary because of the complexity of the NYC commercial waste collection system and the large size of the customer base. The combination of 138,000 customers, two waste streams (putrescible and recyclable), and two garbage truck types (standard and roll-off) yields 544,000 potential combinations for each carter-customer relationship, and the optimization process for each route involves many different possible combinations and street/highway segments to obtain the most optimal pick-up route.
The inputs shown on Table 3 are used to optimize each individual route (defined as a carter serving its customers using a specific type of truck for a specific waste stream handled through the particular container, bag or receptacle type) through the VRP.

### Table 3
**VRP Inputs and Data Sources**

<table>
<thead>
<tr>
<th>VRP Inputs</th>
<th>Description</th>
<th>Sources Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orders</td>
<td>Customer locations where waste is picked up</td>
<td>BIC_201006_v5a</td>
</tr>
<tr>
<td>Depots</td>
<td>The carter’s garage address and the transfer station address</td>
<td>BIC_201006_v5a &amp; DSNYCSW_Locations_v3</td>
</tr>
<tr>
<td>Routes</td>
<td>The number of trucks in a carter’s fleet that will service its customers</td>
<td>Divided total tonnage by 13.5 tons per truck to estimate fleet size (Fleet_Size table)</td>
</tr>
<tr>
<td>Renewals</td>
<td>Allows a truck to unload and then serve more customers</td>
<td>Same as Fleet_Size table</td>
</tr>
<tr>
<td>Network Dataset</td>
<td>A routable street network, including hierarchy and one-way street designations</td>
<td>NYC Department of City Planning’s LION file</td>
</tr>
</tbody>
</table>

To accomplish this task, several data sources were used to compile the necessary inputs. The BIC database version 5a (BIC_201006_v5a.mdb) provided the list of geo-coded customers, carters, and linked the customers to a particular carter and transfer station. The DSNYCSW Locations database version 3 (DSNYCSW_Locations_v3.mdb) provided the geo-coded carter and transfer stations, with a link to the BIC database.

The NYC Department of City Planning’s LION file was used as a base model for the network dataset. This network dataset is the basis for all travel distance, travel time, and routable decision points (turns), hierarchy of roadways, and one-way restrictions. The combined Local and Through Truck Routes from the NYCDOT truck network were used to enhance the base LION street segments and provide a hierarchy for trucks to ensure that they use the designated truck network to the extent possible when not travelling between customers (i.e., at the start and end of each route when travelling to/from the carter’s facility or a transfer station). Parkways and other street segments where trucks are restricted were deleted from the network except in rare cases involving restricted streets where commercial customers were located.

For this analysis, several fields were added to the BIC_Customer table to assist in the process of routing customers, which are included in Table 4.
Table 4  
Fields added to the BIC Database

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good_Customer</td>
<td>Borocode&lt;&gt;0 (Within the 5 boroughs), Putr_daily or Recy_Daily not null, and customer/carter/transfer station were all geo-coded to the street level.</td>
</tr>
<tr>
<td>PickupQuantities</td>
<td>Numerical calculation from Monthly tonnage divided by 30 to represent daily tons</td>
</tr>
<tr>
<td>TruckType</td>
<td>if PickupQuantities &lt; 13.5 tons, truck type 1, else if PickupQuantities &gt;= 13.5 tons, truck type 2, else if the words 'Compactor' in service_type field qualifies for truck type 2</td>
</tr>
<tr>
<td>Service_Time</td>
<td>If TruckType = 1, PickupQuantities * 5, calculating 5 minutes per ton If TruckType = 2, 15 minutes for pickup</td>
</tr>
<tr>
<td>TransferFac</td>
<td>References either Putr_Destination or Recy_Destination fields for a match in the DSNYCSW_Locations_v3.mdb file.</td>
</tr>
<tr>
<td>CurbApproach</td>
<td>Controls whether a truck can make a U-turn once it picks up the waste. Value of 3 corresponds to No-U-turns</td>
</tr>
</tbody>
</table>

Additional details for the analytical process are as follows:

- All necessary tables were stored in a geo-database file (Routes.gdb) for easy referencing within the ArcMap document.

- A BIC_Analysis.mdb was created to assist in the creation of the necessary tables. Tables needed for analysis include:
  - BIC_Customers
  - Transfer_Station
  - Fleet_Size
  - Loop_Table

- The BIC_Analysis.mdb has a form named “NYC Waste Form”. This form facilitates the creation of the tables named Fleet_Size and Loop_Table. The Loop_Table allows the Network Analyst program to extract the criteria for each layer (i.e. Carter, Transfer Facility, and Customers).
To streamline the creation of the VRP layers, an ArcGIS Add-in was created. This add-in does the following steps:

1. Loops through each record in the Loop_Table to get the criteria needed to query the BIC_Customers and Transfer_Stations tables.

- Creates a VRP Layer
- Attempts to solve the VRP Layer
- Upon successful completion of solving it exports the Routes, Orders and Edges files for analysis. These resulting layers provide total miles travelled, hours travelled, and tonnage.

This process is shown schematically in Figures 7, 8, 9, and 10.
**Figure 7**

**Access Database Flow**

**First Steps**
- Import geo-coded BIC_Customers from BIC database
- Import geo-coded Carters from BIC database
- Import geo-coded Transfer Stations from PODS database
- Establish link between Transfer Station in BIC_Customers and PODS database

**Form Inputs**
- Customer per truck — this is the value used to assign the maximum number of customers to a compactor truck before needing to be renewed
- Truck Weight Limit — this is the value used to assign the maximum tonnage in the container before needing to be renewed
- Renewal Service Time — the time in minutes that a truck was at a transfer station
- Truck Service Window — the maximum time in minutes that a truck may be on the road servicing customers

**Establish Grouping for Scenario**
- Currently grouping is based on Carters and where the carter brings the waste, Transfer Station
- Other fields can be used however to calculate other groupings
- When calculating other groupings, i.e. Distincting pick-ups by neighborhoods, Carters and Transfer Stations will have to be created in ArcMap and brought into the corresponding tables, Carter or Transfer Station, with the correct field names

**Establish Truck Types**
- Determined by Manually looking through data
- Currently two truck types — Compactors and Containers
- Compactors have a service time based on total tonnages picked up — Field measured at 5 minutes per ton.
- Containers have a service time based on total time spent — Field measured at 15 minutes.
- Each Compactor truck has a limit of 13.5 tons, so one customer cannot exceed this limit. If a customer does it will not pick-up the waste.

**Step A — Good Customers**
- Geo-Coded to a Street Level
- Boro — Within 5 boroughs only
- Adjusted Monthly Tonnage > 0
- Valid Carter (Geo-Coded to Street Level)
- Valid Transfer Station (Geo-Coded to Street Level and matched to PODS database)

**Step B — Finalize for GIS Results**
- Copies data from the current scenario fields into the final fields for export to the Routes.gdb database

**Legend**
- Manual Edits to Database
- Form Input or Button
Figure 8
Tables contained in Routes.gdb

Tables/Shapefiles Contained in Routes.gdb (Geodatabase)

- Loop_Table
- Transfer_ Stations (From PODS database)
- Carter (from BIC database)
- BIC_Customers
- Fleet_Size

**ID**
- ID
- Carter
- PODS_Code
- TruckType
- Transfer_Text
- MXG_Group
- FinishedDaily_Capacity
- Customer_Count
- UnAssignedCustomers
- AssignedCustomers
- LocatedCustomers

**OBJECTID**
- OBJECTID
- Shape
- PODS_ID
- BIC_ID
- Boro
- CARTER
- Good_Customer
- Scenario_Group
- TransferFac
- MND_Group
- ServiceTime
- PickupQuantities

**FID**
- FID
- ObjectID
- Truck_Name
- Description
- StartDepotName
- EndDepotName
- MaxOrderCount
- Capacities
- MaxTotalTime
- Renewal
- Boro
- MND_Group
- ServiceTime

Network Analyst has a limitation of 1000 customers per layer. In order to manage the analysis, this table was created to group customers by Carter/Transfer Station and split the customers into even groups.

Carter is extracted from the BIC database and linked to the BIC_Customer table through the Carter field. This field describes which carter picked up the waste from that particular customer.

Transfer_ Stations is derived from the PODS database and is linked to BIC_Customers through the use of the From_Destination or To_Destination fields. These fields describe where the particular waste stream will be delivered.

BIC_Customers is extracted from the BIC database. Relevant fields include MND_Group, ServiceTime, PickupQuantities, TransferFac, Good Customer.

Required input for Network Analyst to optimize routes by the number of trucks in the fleet. Fleet Size is calculated based on the number of customers being served by each Carter/Transfer Station pair.

Renewals allow trucks to pickup waste till it reaches a known capacity, then go to a specified Transfer Station to dump waste and then resume pick-ups.
Figure 9

Network Analyst

This process is looped for all rows in the case table.
Figure 10
Obtaining Results

- Export Loop/Table to loop.shp from ArcCatalog
  Then import the table into the Output Results.mdb database (dbf_Type N)

Loop/Table

Tables, Forms and Queries Contained in Output Results.mdb (Access Database)

Import Results (Form)

- Open Import Results
  - Step 1: Select Outputs folder for a particular scenario
  - Step 2: Import Results from the Output folder

Importing of Results will take some time to run. This process imports all dbf files from the Edges, Order, and Route Folders that were created during the solving process.

Import Results

- Result Queries 1, 1a, 2 and 3
  - Results-1
    - Sums the Renewals, Order Count, Total Time, Total Travel Time, and Total Distance from the Route/Layers table.
    - Results-1a
      - Sums the Total Pickup Quantities from the Order/Layers
    - Results-2
      - Sums Total Minutes and Total Miles by borough from the Edges_Layers and JustNYC tables
    - Results-3
      - Sums the Daily Capacities and Customer Count from the Loop/Table by the Finished column. Finished is whether or not the layer successfully solved.

These 4 Queries are then transferred to the Scenario Results excel file.
The Result Data tab is where these 4 Queries are copied to.
Tables 1-3 are then updated with the final results.

Consists of all NYC roadways and the particular borough that is associated with it. This is used to group mileage and travel time results by borough.

Order/Layers

Route/Layers

JustNYC

Results Queries 1, 1a, 2 and 3
4. Additional Considerations

The BIC database is limited in its applicability for the detailed analyses in this task for several reasons. Because it relies entirely on reporting from carters about their individual customers, any analysis performed with BIC data is using information that is “one step removed” from the NYC agency that maintains the database. The BIC information would be more accurate and more appropriate for this type of analysis if reporting were done directly by customers instead of through the carters in the registry. The BIC database also serves primarily as a regulatory resource and is not ideally structured to provide detailed transportation analyses.

One of the original expectations on this project was that the consultant team would have access to on-board global positioning system (GPS) data and/or customer route sheets provided by carting companies. Early efforts to obtain this type of information seemed promising, but even the most cooperative carters were averse to sharing this detailed operations data with a public agency because of concerns about the data sensitivity, competitive aspects of their operations, and their lack of control over who would have access to their proprietary records. As a result, the analysis was heavily influenced by data collected in other tasks by other team members, and field observations in which a sample set of individual trucks were followed for extensive segments of their routes to develop estimates of vehicle speeds, customer service time for different waste pick-up arrangements for customers (dumpsters, bags, roll-off containers, compactors, etc.), time spent at transfer stations, and other parameters.

Despite these limitations, the structure and contents of the BIC database were extremely useful in conducting the routing analyses in Task 3. With some refinement, and new data fields added for this effort, the BIC database was structured to serve as the basis for a robust truck routing model based on standard industry parameters for optimized routing of delivery vehicles, with system-wide performance measures computed as part of the model output. Some recommendations for improving the accuracy of the analytical process by improving the quality and types of data used to support the process are as follow:

- The BIC database currently has fields for “putrescible” and “recyclable” waste. Identifying waste types by industry classification, as done in the development of the waste generation model in this study, would help establish relationships between industry types and waste generation. This would help enhance the value of this network-based analytical process for different future land use scenarios. This should include identification of all transfer stations involved in the process, if they vary from one waste type to another.

- The BIC database includes a field for carters to identify the days of the week when customers are actually served, but this is an open-ended text field that does not lend well to consistency from one carter to another. For example, some carters might enter “daily” in this field without specifying whether this relates to a full 7-day week or five business days. Others may describe multiple days in this field or use abbreviations such as “MWF” to identify Monday, Wednesday, and Friday pick-up dates. A better method for organizing the database would include seven fields representing the seven days of the week, with an “X” used to denote which days the customer is served, or the number of visits per day. This would help refine the estimated daily routing process used in this study by allowing for such scenarios as: (a) a separate analysis to be
done for each day of the week; (b) a single analysis to be done for a typical weekday; or (c) estimates of peak daily activity rather than a broad assumption of uniform daily volumes across an entire week.

- The current process for populating and maintaining the BIC database is based on the contractual relationships between customers and carting firms. In cases where a carter subcontracted its services for some of its customers to other carters, the BIC database should reflect the carter that is actually making the waste pick-ups, not the carter who is initially engaged by the customer. When this information exists, it is not recorded in a consistent and clear way.

- The routing process used in this study was based on some basic assumptions about different truck types used to serve customers. Two truck types were used in this analysis: a typical rear-loading garbage truck and a truck that carries roll-off containers or compactors. These truck types were assigned to customers based on the descriptions contained in the “Set-Out Type” field in the BIC database, with containers or compactors identified as such and standard garbage trucks assigned for all other types (bags, loose, dumpsters, etc.). A more accurate estimate of routing parameters and VMT/VHT estimates could be done if truck types were specifically indicated for each customer or route. Ideally this would be done through a separate field in the BIC database, but this may be impractical because decisions related to truck types may be based on availability of equipment, staffing needs or other factors. Without a mechanism for directly linking truck types and customers, it would be helpful if carters could provide some information periodically about the makeup of their truck fleets. This would at least allow for some additional validation of the network routing process used in this study. Load limits by truck type would also be very helpful to refine truck capacity beyond the general 13.5-ton limit used in this effort.

- Related to the previous recommendation, it would be helpful if carters could report aggregate totals of VMT and VHT for the trucks they use in commercial waste collection in New York City. These are not likely to be very accurate measures (especially for VHT), since these carting firms do not necessarily use dedicated fleets for NYC customers and would not always be able to document their NYC operations separately. However, this information would be useful for establishing some general order-of-magnitude estimates of VMT and VHT figures on a truck-by-truck basis to help calibrate the system-wide VMT and VHT estimates calculated in this process.

- One of the difficulties in this process involved the uncertainty about street addresses for carting firms as reported in the data sources used in this task. In some cases carting firms reported their own addresses as an office location and not a yard or terminal facility where their trucks are stored. This works well from a regulatory standpoint for the BIC reporting, but a substantial research effort was required to determine where trucks are stored so that optimized route scenarios could be developed for the carting firms and their customers. It would be helpful if carters reported exact street addresses for their yard/terminal locations in addition to their business address. This is particularly important if a carter in NYC uses some trucks from a yard outside the city to serve NYC customers.

- The BIC and PODS databases have a lot of information about transfer stations in New York City, but are sometimes less accurate about the exact locations of out-of-state transfer facilities.
The routing process for this task incorporated out-of-state transfer stations at a high level by estimating locations in cases where a generic description such as “New Jersey” was used, but the VMT and VHT estimates developed in this process would be more accurate if better descriptive information (at least a municipality, if not a specific street address) about these transfer stations was available.
\server\name

PSCRIPT Page Separator
Attached is a Notice of Lien (dated 1-24-14) against N.J.D which was sent to the Engineering Bureau.

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