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SOLID WASTE COLLECTION ROUTING OPTIMIZATION: THE CITY OF VIRGINIA BEACH STORY

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ABSTRACT

The City of Virginia Beach is the largest city in Virginia, with a population of nearly 450,000. The City encompasses approximately 307 square miles, of which 248 square miles is land area and the rest water or wetlands. The City self- performs residential solid waste collection for approximately 122,000 customers. The northern sector of the City is devoted to more urban uses, while the southern area generally remains rural. Solid waste services include weekly automated residential household pickup, weekly manual yard waste collection, and scheduled bulky waste pickup. The City contracts with a private company to collect and process single stream recyclables on an every other week basis.

In 2011-2012, the City contracted with SCS Engineers and C2Logix to conduct a study to evaluate optimizing its residential solid waste collection system. The project optimized the use of the City's existing and projected future collection vehicles (size and type) and personnel resources, taking into account the unique geographic characteristics of the resort/beach community. At the time, the City's current routes consisted of 153 total residential weekly trash routes, using a combination of 19 single and 20 tandem axle automated trucks. Over the years, the City developed its own collection routes, including equipment and personnel allocations. The equipment and personnel allocations were not always based on optimizing resources, but more on an equitable distribution of the single axle and tandem axle equipment inside the route coordinator boundaries. The route coordinator boundaries were geographic segmentations of the City assigned to route supervisors to manage collection operations for all City services in their respective areas: waste, yard, and bulky.

The primary impetus for the routing study was to increase efficiency while incorporating the newly purchased tandem axle waste collection trucks that had a higher capacity than the single axle trucks that were being decommissioned. The purchase of these new trucks was being conducted over a 3-year period. The routing study and its implementation followed the truck delivery schedule over a three phase implementation. Another objective of the routing study was to not only increase efficiency, but to also evaluate increasing the safety of collection in the streets that had maneuverability issues. Virginia Beach encompasses varied collection geographies, including dense urban, suburban and rural collection areas, further complicated by numerous back down, alleys, and other travel restricted service streets. The backdown streets and alleys are largely in beach areas that have significant population densities during the summer months, which increase safety issues.

The first phase of the study was completed and identified significant modifications to optimize the City's routing system, while improving safety. Although the number of daily routes was reduced from 38-39 to 35 per day, there was actually an increase of three routes during the week in certain areas to use a spotter to improve safety when the truck required backing down the congested dead end streets in the beach neighborhoods. The first phase routing was implemented in the Spring of 2013.

In 2013, the City contracted with SCS Engineers and Route Optimization Consultants LLC for a second phase re-routing to incorporate the purchase of another vive tandem axle automated collection vehicles to replace eight single axle trucks and further increase efficiency. The second phase of routing is utilizing a new route optimization modeling approach that highly integrates the route logistical data gathered after the first phase, in addition to scale weight data and GPS tracking data. Phase III is currently being conducted by SCS Engineers and Route Optimization Consultants LLC.

This paper discusses the technical, personnel, and equipment issues that were considered during the routing study, routing methodology used, lessons learned during the implementation of the re-routing, and the results of the next Phase of the City's re-routing.

MANUAL ROUTING, SOFTWARE OR ROUTE OPTIMIZATION SERVICES

The City had solely used manual methods for developing routes with assistance by their geographic information systems (GIS) services staff within the City. The route coordinator boundaries were mapped, but the individual routes were not defined for the drivers. The City utilizes a “helper” system, wherein every crew inside a route coordinator boundary would help each other until all the stops were serviced within their collective area. From an effectiveness standpoint, this system worked very well, with few stops being missed.

It was expected that route efficiency was not optimized due to the helper system, but without mapped route boundaries, it was difficult to ascertain the route efficiency levels. The manual routing process provided indicators that the routes were not efficient. The routes were manually balanced based on house counts and not travel time. The City’s population density varies significantly from dense urban to extreme rural areas. Without considering travel time in a calculated and accurate manner, manually developing balanced routes would be very difficult. The City also had a mixed fleet of single axle and tandem axle trucks that had capacities of 4 and 11 tons, respectively. Developing routes for such widely varied vehicle loads further exacerbated the need to factor in travel times for dumps, as the single axle trucks could have four dumps a day versus the tandem axle vehicles would typically have two dump trips. Other issues with not having maintained and mapped route boundaries were that operators would take a seemingly long time to learn the routes and collection boundaries sometimes changed between operators without supervisor knowledge. In addition, the extensive time that it would take the City’s Waste Management and GIS staff was one of the major reasons cited for deciding to procure outside assistance.

The City considered buying route optimization software with associated training and implementation services. However, it was observed in the industry that many municipalities had purchased the software, but the adoption and continued usage of the software was not the standard. Although the reasons that the adoption of the software vary, in the City’s case, there was a lack of staff time and lack of having staff with both collections and computer expertise. Further, the City envisioned that using highly experienced consultants could make the implementation, its timeliness, and staff buy-in more likely to succeed. For these reasons, the City decided to procure route optimization services and forego that procurement of routing software.

PHASE I ROUTING STUDY

The Phase I Routing study required conducting route reviews, and analyzing GIS street data, scale weights, route logs; and running the City’s current routes in the FleetRoute software. In addition to developing new optimized routes, the Phase I study addressed the following major questions:

- Are any collection day changes required?
- How much time is saved by running tandem axle trucks versus single axle?
- What areas are better suited to run single axles?
- How many single routes can be combined to create tandem?
- How many trucks is the optimum amount to be running? What if four tandem trucks are acquired next year?

The Phase I study included an initial run of the FleetRoute model on the existing routes to better understand the dynamics of the model in the context of the City’s road network and geographic constraints. The understanding was that calibration and manual adjustments would ultimately be needed. A primary purpose of running the current routes was to compare the model with the actual times in order to modify the parameters and assumptions to be closer in-line with the current route times. Although the actual path currently taken by the drivers was not known, the routes were run with an optimized path, with the expected result being route times less than the current actual route times. The assumption was that if the times from the model are higher, this indicates that parameters may need adjustment or that there are inaccuracies with the street or customer data and their associated services requirements (e.g., backdown streets, miscoded travel directions).

Data Setup

The City provided route performance and GIS data, which was supplemented by field observations of selected routes. The City-provided data included database of residential customers, census of cards and handicap list, GIS shapefiles for streets, route boundaries and land parcels, scale ticket data, route logs, and summary of 2011 weights. As seen in Exhibit 1, the current routes consist of 153 total residential trash routes for the week. Of these residential trash collection routes, the current routes were modeled using 20 tandem axle automated trucks per day with the remainder of trucks being single axle automated trucks.

Exhibit 2 shows the current collection day boundaries. It is acknowledged that the assessment of the usage of tandem versus single axle trucks in the City was likely not completely accurate because the City routinely assigns "helper" trucks at the end of the day to routes that are especially heavy and that would not otherwise be completed during normal work hours. These helper trucks are assigned after they have already completed their assigned routes.

Data Issues

When setting up data for the purpose of modeling routes, especially on complex collection systems such as the City's, data issues typically are encountered. A number of issues were discovered and reasonable efforts were made to resolve the issues. The major issues that were encountered are discussed below:

- The street centerline data, which was provided for routing purposes, was found to contain some connectivity issues and miscoded fields. For example, some streets were miscoded as one way streets. The issues that were encountered with the street data have been corrected. It is possible, if not likely, that some miscoded streets or other street data inaccuracies still exist.

- The provided street centerline data did not contain streets outside of the City's municipal boundary to visit the dump facility locations. These streets were added and connected to the street network.

- Because of the fact that drivers often share work, based on the "helper system", it was not possible to calculate an average tons per route and an average service time per route. An average tons per household was used (38.92 pounds/week), which is based on tonnage collected not in the peak season in 2011 (see Seasonal Variances below for more information).

It should be noted that the route optimization software utilized in Phase I, FleetRoute, required complete and highly accurate street and customer data, as each individual customer required a unique stop time and weight and each individual street segment required an accurate travel time. In Phase II, the assessments of times and weights was not required to be provided at the individual customer and street level in using the WMDesign software, which made the data set-up process significantly easier.

Seasonal Variances

The City oceanfront includes vacation areas which are heavily occupied in the peak season from June through August. These oceanfront vacation areas are referred to as the North End (Atlantic Ave. and Oceanfront Ave. areas), South End (Pacific Ave. area), and Sandbridge (Sandpiper Rd, Sandfiddler Rd, etc.). During the peak season, a significant increase occurs in the number of container set-outs and the total amount of trash collected. Other constraints during the peak season, such as heavy traffic, tourist parking, narrow streets, and collection time windows also can significantly increase collection times and restrictions on certain routes. The specific increases in weights in North End, South End, and Sandbridge could not be accurately assessed, due to the use of helper trucks and the routes for these areas also including inland areas. Sandbridge also had an additional weekly day of collection by a private hauler during the peak season. However, the total city-wide tons per week collected increased by 9.3% from 2,418 to 2,642 tons during June-August.

Due to the fact that the peak season only accounts for 1/4 of the year and mostly effects select oceanfront vacation areas, the model was set up to be based on the non-peak season. During the peak season, the assumption was made that additional trucks would potentially be needed in the oceanfront vacation areas and this reallocation would be manually coordinated by the route managers.

Route Performance Parameters

The route performance parameters provide the fundamental constraints to the routing model, including assumed workdays, working hours, service times, set-out weights, vehicle capacities, etc. The parameter values were provided by the City, assessed from scale data, derived from field work, or based on benchmarks from previous waste collection routing experience. Exhibit 3 shows values for some of the key parameters for trash collection.

Breakdown time was assessed as 18.9 minutes per route per day, which is based on an annual average of eight breakdowns per day (for tandem trucks) or 21% of trucks; it takes an average of 1.5 hours to fix or replace a truck in the field.

Field Time Study

Field studies were conducted over two days, during which trucks were followed and timed to gauge an assessment of an average stop time. During these field studies, a variety of different collection circumstances were presented, including tandem-axle trucks, single-axle trucks, high density areas, narrow streets, heavy parking, alleys, and back-down streets. Based on the times collected from the study, it was deemed that an average stop time of 11.7 seconds be applied to the routing model.

Special Service Issues

The following special service items were identified:

1) Back-down streets
   a) Back-down streets are narrow, dead-end streets in which it is necessary to perform the following sequence:
      i) Drive in and service the right side
      ii) Backdown the street
      iii) Turn around
      iv) Back down the street again and service the left side
   b) Because of the multiple maneuvers required to service these streets an additional time factor was applied to these streets of 2.5 times the normal driving time or 250%.

2) Same-side collection

3) Alley collection

4) Pup truck collection

5) Streets with service time constraints

Current Trash Collection Routes and Collection Day Balance

The results of running the route optimization model estimated that the current Trash Collection routes were slightly unbalanced between collection days, based on the variance in calculated hours per day (See Exhibit 4). The longest trash collection day of 356.1 total hours (or 9.1 hours per route), Tuesday, is 12.2% higher than the lowest day, Thursday, with 317.5 hours (8.4 hours per route). However, the stop and container counts were relatively close within a range of 1,340 and 841, respectively. This demonstrates how the manual routing maintained the aggregate collection day to be balanced, but without factoring in the travel time, the collection days were slightly off-balance by a range of 11% in hours. Given the complexity of changing collection days and the relative current balance between the days, Phase I was decided to not include a collection day change. Although the collection days were balanced, the individual routes had a wide variance in total time between 7.5 hours and 11.3 hours.

Phase I Conclusions and Recommendations

The routing model showed that there was a substantial savings that could be realized by moving to all tandem axle automated trucks. Furthermore, balancing all of the routes to have an even workload would facilitate the reduction in the total number of routes. To obtain the most even workload per day and achieve the lowest amount of trucks run per day (30 trucks), a minor collection day change was recommended in Phase III. However, once the route boundaries are refined/optimized, the day change may not be required.

The Phase One implementation realizes a reduction in routes, time, dump trips and mileage from the previous routing system. In Phase One, automated curbside trash collection routes are estimated to result in a reduction of 11% in labor hours, a 12% reduction in mileage, and a 17% reduction in dump trips. The number of automated trucks deployed daily is reduced by three trucks. The current routes being optimized by the routing software and does not reflect actual statistics of the original route performance. For Phase I, no collection days were changed.

A significant change from the previous, original operations was having routes dedicated to the vehicle type (tandem or single axle) and having adequate spare vehicles close to the industry best practice of a 20% spare factor. These operational adjustments partially alleviated the need to have vehicles help on other routes (when they were completed early). An objective of the development of the new routes was to make the routes more even on time to also help alleviate the need for helper trucks. Breakdowns are expected to also have less of a negative impact on route completion times, as a spare vehicle of the same type would be available and the route will be able to be completed with the planned number of dump trips. A significant safety improvement was removing automated trucks from servicing the backdown streets by now having these streets serviced by rear loaders. Customers on backdown streets account for 1,214 stops on Tuesday, 339 customers on Wednesday, and 319 on Thursday. There will be an additional two routes on Tuesday and two partial/half day routes on Wednesday and Thursday. For comparison purposes, including the three additional rear loader routes brings the count of routes per week at 143 versus the original 153 routes.

Phase I attempted to utilize the paths generated by the FleetRoute software, which had to be significantly modified by the consultants. The paths were too difficult to communicate to operators effectively using paper maps and travel direction reports from the FleetRoute software. Utilizing the defined paths also became ineffective when deviations were needed in the routes. The City's experienced operators are able to quickly establish efficient travel paths and are very good at making adjustments as needed. It was decided in Phase II to save time and costs by foregoing the development of travel paths for the drivers and solely provide route boundaries. Another issue with the Phase I implementation was that the route boundary maps generated by the software lacked detail. In the rural areas, the street names were too small. In the urban areas, the names of small streets were not displayed on the maps. The only way to achieve the required map detail would be to create custom route maps. Given that the City crews had been using the fire maps developed by the City's Center for Geospatial Informaton Services, it was decided for Phase II to not use the route optimization software's built in map-making functionality, but to use the City's fire map template directly developing maps in ESRI's ArcGIS.

Three Phase Implementation Plan

A three phase program was developed to be implemented between 2013 and 2015. The assumption was that the actual number of vehicles utilized in each phase would be modified after route performance data were made available following the first phase of implementation.

- Phase I – 2013
  - 22 tandem trucks and 12-13 single axle trucks = 34-35 routes per day
  - 27 total tandem trucks in fleet
- Phase II – 2014
  - 27 tandem trucks and 4-6 single axle trucks = 31-33 routes
  - 32 total tandem trucks in fleet
  - One truck less than the target fleet size with spares of 33 tandems
- Phase III – 2015
  - 30-32 tandem routes per day
  - 36-38 total tandem trucks in fleet

Upcoming issues that would need to be addressed in the subsequent Phase II and Phase III studies were identified:

- A spare factor for trucks is targeted at 20%. This assumption was found to significantly too low after the new emissions trucks were put into operation in 2013.

- Five tandem trucks will be purchased annually, which may be inadequate for a reasonable spare factor.

- Targeted fleet size will be determined during the development of routes for Phases II and III.

- Population will increase during the implementation timeline, which will increase the workload accordingly.

- Backdown streets that are clustered will be serviced by a rear loader to improve safety. This assumption could not be implemented. Instead a spotter system was used for backing down with an assistant guiding the driver of the single axle automated truck.

- No day changes will be implemented in Phase I. Once the backdown streets are removed, Tuesday will go from the heaviest to being lighter, which helps correct the day workload imbalances.

- Routes will be developed to be only dedicated to the type of truck, i.e., tandem routes will only be serviced by tandem trucks.

- Older tandem trucks will surpass their useful life during the implementation, which can be used as spares.

- There is a concern about the final number of routes not being divisible by the eight coordinators, resulting in each coordinator not having the same equipment resources. 32 final routes per day would give each coordinator four routes per day.

- Peak season weights will be used and a lower capacity of 11 tons for the tandems, which may limit the reduction in trucks beyond what is provided below in Phases (as this was based on off-peak weights).

PHASE II ROUTING STUDY

SCS Engineers and Route Optimization Consultants LLC prepared the routing analyses for Phase II and subsequently for Phase III. Phase I, with 140 individual routes, was implemented in March of 2013 resulting in 35 trucks being routed daily with 22 trucks being tandem axle. Phase II coincided with the delivery of five more tandem trucks delivered by the end of 2013. The purpose of the Phase II routing was to optimize routes without changing any collection days, which would be considered as a part of the Phase III routing. Phase II had 27 tandem truck routes and five single axle routes per day for a total of 32 daily routes and 128 total routes. However, Tuesday had 26 tandems and six single axle trucks, including two backdown routes using single axle trucks. Wednesday and Thursday each had one backdown truck running a half day route.

In order to review the model used to develop the Phase I routes, a quantitative and qualitative analysis was conducted by interviewing Route Coordinators and summarizing the scale ticket data to compare the "planned" route statistics versus the "actual" route statistics. In addition, a new model was developed for use in the Phase II route modifications to more closely model the actual route statistics by using the weight a productivity statistics from the Phase I implementation. The WMDesign software was used, which provided a means for basing the route times on the actual travel times, instead of the more time consuming approach in FleetRoute using unique variables at the customer and street segment level.

Comparison of Phase I Planned Versus Actual

Scale ticket data was summarized to assess the accuracy of the route optimization model used to develop the Phase I routes and to create a new model utilizing the actual parameters from running the Phase I routes. Because the Phase I routes were implemented in March of 2013 and drivers were not comfortable and proficient with the routes until June, scale ticket data from June and October was utilized for the analysis. Further June through August were peak months, which follows the objective of the routing project to create optimized routes for peak months.

For each route, the "actual" average hours, tons collected, and dump trips were compared to the "planned" route parameters. Recording of the actual mileage on the routes was not available for comparison.

Exhibit 5 summarizes the data by collection day and by vehicle type. It demonstrates that the Phase I model estimates overstated the actual route times. For the tandem routes, the average route time from the model was 0.825 hours longer than the actual time to complete the route. Given that the workday was for 10 hours, the Phase I routes continued to leave a significant amount of time available for the crews. Regardless, the Phase I routes still resulted in a reduction in 13 routes per week.

PHASE II ROUTES

The Phase II routes were designed using the WMDesign route optimization software. The routes were designed to minimize changes to the Phase I routes, while accommodating five new tandem routes. Eight singles axle routes were converted into five tandem routes. In some cases, other adjacent tandem routes had to increase their size to allow for the five new tandem routes to have the vehicle capacity while maintaining two dumps per day. All of the Phase I Tuesday routes were modified to accommodate the increase in backdown customers that were added after Phase I routes were designed. The average route time is 7.9 hours, but this value is skewed as it includes the partial days for the pup truck and backdown routes.

Exhibit 6 displays the summary statistics by day, route and truck type. Including the backdown routes, there are six single axles on Tuesday, Wednesday and Thursday and five on Friday. However, on Wednesday and Thursday, the backdown routes are half day routes.

As shown in Exhibit 7, the aggregate hours for each day range from 250 on Wednesday to 269 on Tuesday. The range of 19 hours provides a difference of more than two routes being required for Tuesday. Although in Phase II, the 32 trucks per day could absorb the extra work on Tuesday, as the number of daily routes is further reduced in Phase III, Tuesday will not be able to accommodate the larger workload. The higher number of customers serviced by single axle trucks on Tuesday (5,002 versus 4,101, 3,841 and 3,637 on Wednesday, Thursday and Friday, respectively), also contributes to the imbalance on Tuesday being longer than all the other days. Further, Tuesday has the lower portion of the City that includes the driving times to service the rural areas. It is anticipated that the vast majority of the customers on single axle routes on Wednesday through Friday will be successfully converted to be serviced by tandem trucks. However, Tuesday has a concentration of streets that are difficult to maneuver with significant on-street parking in the North End beach areas that require extra safety precautions.

Phase II Conclusions and Recommendations

The limiting factor in maximizing productivity is not the available time in the day, but the capacity of the vehicles, the availability of spare trucks, and the concentration of Tuesday customers that are being serviced by single axle trucks. In order to maximize the productivity of the tandem routes, there will be a need to have routes make three dump trips in a day. This will not create routes exceeding the workday, but these three dump routes will likely be longer than their counterpart two dump single axle routes. Without adequate spare trucks, as the tandem routes become larger in Phase III (and Phase II), using single axle trucks to complete a tandem route may result in overtime.

Given that the route days will become further imbalanced in Phase III with Tuesday being significantly longer as it accommodates less tandem trucks than the other days, there may be a need to make moderate collection day changes in Phase III to keep an equal number of trucks being dispatched each day. The collection day changes will allow for a more even workload between the collection days. Any changes to collection days should account for future growth while attempting to minimize the current number of trucks to be utilized. The recommended target would be to make collection day changes that will account for the next five years of growth. Changes to collection days will impact all of the routes, requiring a complete re-route.

Phase I used the FleetRoute software and Phase II used the WMDesign software. Both applications had their strengths and weaknesses. FleetRoute and WMDesign allowed for unique modeling of the routes at a granular level. FleetRoute allowed for estimating travel and route times by setting parameters, such as stop time and travel speed. WMDesign additionally allowed for setting productivity rates that were based on the Phase I times. This was a more simplified and more accurate way to set up the route model. However, when route time data was not available or the vehicle type was changing, WMDesign's simplified method of data set-up was not as accurate. The route areas from Phase I that were serviced by single axle trucks were being converted to be serviced by tandem trucks. Thus, those areas did not have historical route time data when using a tandem truck. In such cases, parameters from nearby and comparable single axle routes were used. FleetRoute more accurately handled the mixed density areas with rural and suburban neighborhoods being intermixed in a new route that was being created. WMDesign processed significantly faster, which may the development of route scenarios more expedient. Both applications did not create highly usable travel paths, which is a commonly known shortcoming of all high density residential route optimization software applications.

Final Implementation Phase III

The final implementation of the transition to tandem axle trucks is limited by the two primary and intertwined constraints of waste collection: time and vehicle capacity. Although the tandem trucks have nearly three times the capacity for each load at 12 tons versus the single axle trucks at 4 tons per load, the tandem trucks approach a time constraint when exceeding two dumps per route. Exhibit 8 displays the current implementation of 22 tandem axle routes and 13 single axle routes, excluding the backdown and pup truck routes. The current routes average 8.1 hours per route. The longest day is Tuesday with 288 hours, which is understated when the two backdown street routes are added. In the final phase where only tandems are utilized in all service streets that are safely serviced by the larger trucks, the average route time becomes 8.8 hours per route. Although from a time constraint, the reduction to 30 trucks per day is feasible, the vehicle capacity provides another ceiling to be factored into the feasibility of 30 trucks per day.

Issue – Aggregate Vehicle Capacity

The final phase of utilizing all tandem trucks and maximizing the labor hours of the workday is only feasible with a number of the tandem routes having three dump trips. Even if all 30 tandem trucks maximized their capacity for each of their two dumps, there would be a total capacity of 660 tons. However, the tonnage generated daily is already at 637-673 tons per day (in June and July, 2013). Adding a third partial load to those routes that are adjacent to the disposal facilities will add the needed capacity to maximize efficiency in Phase III, while not exceeding the ten hour workday. Given that some of the long distance Tuesday routes in the Southern areas are less than 15 tons per day, the number of three dump routes will need to be higher or collection day modifications will be required to create balanced workdays.

Issue – Route Completion Time Imbalance

The single axle routes were planned for Phase I to be those closest to the disposal facilities. These single axle routes will be converted to tandems in Phase II and Phase III. However, after the implementation of Phase I, the City increased the extent of the single axle truck utilization to encompass a majority of the downtown beach areas.

The current routes were designed to favor utilization of single axle trucks close to the disposal facilities, which is partially evident on each of the collection days. The design of the current routes placed a higher importance on balancing the route completion times. By placing less concern on route time balance and more concern on efficiency, the final phase of the implementation will have the least total hours to complete the routes, but with sacrificing the evenness on completion times.

Imbalanced route completion times may be compensated by alternating crews between having a "long" route on one day and a "normal" route the next day. Even a "long" route cannot be designed to be exactly 10 hours and must not exceed 9.5 hours, due to the inconsistency of waste collection set-out weight, set-out rates, road and traffic conditions. The total workday is even more adversely affected by breakdowns, which prior to the first phase of implementation averaged 19 minutes per route per day.

Issue – Spare Vehicle Availability

Another factor impacting the duration of the workday is the availability of spare vehicles, which the City of Virginia Beach is especially vulnerable. Prior to Phase II, the City had 27 tandem trucks and runs 22 daily for a spare factor of 23%. With the next five tandem vehicles being purchased and a forecasted number of routes to be 32 routes with 26 tandem and 6 single axle routes daily, the tandem spare factor will also be 23%. With a 7-8 year replacement cycle and prior to the new emissions equipment that causes more repair downtime, a 20-25% spare factor would be adequate. However, the City does not currently have the spare tandem vehicles available to consistently substitute its downed tandem trucks with spare tandem trucks. With inadequate spare vehicles, the single axle trucks must be utilized on the tandem routes. This significantly increases the time to complete the route, because the single axle trucks have a maximum capacity of 4 tons versus 12 tons for the tandem trucks. With the average tons on a tandem route being 20.45 tons (or more as three dump per day routes are implemented), a single axle truck may require five or more dumps to complete a route without exceeding the legal weight limit or getting assistance from other crews. With each dump trip taking an average 37 minutes (for the current tandem routes), three additional dump trips increases the route by 1.85 hours.

Reportedly, anomalies on an individual route are compensated by other crews assisting the route affected by breakdowns, reduced staff availability, extreme conditions, or using a single axle on a tandem route. Although this "helper" method currently works, it is less efficient to have multiple vehicles driving out of their route area to assist on another route. It is the objective of efficient waste collection routing to have adequate spare vehicles for that driver affected by a breakdown to complete their route without assistance while still not requiring overtime. The system currently has adequate excess collection capacity for the "helper" approach with an average of 8 hours per day. As the average day approaches 9 hours with a larger number of tandem trucks being utilized and limited spare tandem trucks, there will be more tandem routes being run with single axle spare trucks and less time available for the crews to help the beleaguered route. Overtime will likely be required, especially if the average route time (without anomalies or breakdowns) is in the 9.5-10 hour range. Even with a 9 hour day tandem route, a single axle spare truck can be expected to take an estimated 11 hours to complete the same route (including breaks, pre-trip, and post-trip).

Issue – Collection Day Balance

As more tandem trucks are utilized the total hours for that day are reduced, mainly by the time eliminated for the additional dumps when using single axle trucks and the reduction in non-service times (breaks, pre-trip and post-trip). As Tuesday has considerably more travel time than the other days, the margin in total time increases between the days. With the range of total hours per day in the final implementation of 30 trucks being from Tuesday with 270 hours and Wednesday with 255 hours (Exhibit 18), there will be a need to balance the collection days by making changes to customers' days of collection. Collection day changes will balance the workday, maximize efficiency and maintain an equal number of routes per day.

Significant changes are not required the collection days to have an impact. At 40.3 pounds per household, moving only 1,000 customers, shifts 20 tons. Although there may not be a need to drastically change the collection days, there is a "ripple effect" to any changes given that the system currently utilizes a mixed fleet of tandem and single axle trucks with varying productivity levels and the need to maximize the productivity of all routes for the final phase. As tandem trucks are increased to three dump trips per day on some routes, the impact to the time margins between days will be further increased. During the implementation of the next increase of five tandem vehicles to the fleet, any day changes done at this phase may need to be revisited and expanded for the final phase of implementation.

PHASE III ROUTING

At the writing of this paper, the Phase III routing has just been initiated. Phase III will also coincide with the delivery of five more tandem trucks. To maximize efficiency, single axle trucks will only be utilized where the streets have significantly limited maneuverability and safety issues, such as "backdown" streets. The number of routes in this last phase of route updates to implement the tandem fleet is forecasted to not exceed 30 routes per day. Actual field data from the Phase II routes' travel times and scale data will be utilized to further refine the accuracy and precision of the routing model.

The objectives for the Phase III work are as follows:

- Conduct a quantitative and qualitative review of the Phase Two routes implementation by analyzing scale tickets, GPS track logs and interviewing OWNER managers and crews.

- Develop a route model that is based on Phase Two and desired modifications for Phase Three for collection attributes (e.g., backdowns), set-out weights and productivity rates.

- Modify and balance collection days that maximize productivity, but also account for growth.
- Develop new routes and route coordinator boundaries.
- Update implementation plan for Phase Three.

The Phase III routing should be completed in the fall of 2014, with implementation scheduled for the first quarter of 2015.

**Exhibit 1. Collection Current Trash Routes
Daily Truck Utilization**

Day	Single Axle	Tandem Axle	Total
Tuesday	19	20	39
Wednesday	18	20	38
Thursday	18	20	38
Friday	18	20	38
Total	**73**	**80**	**153**

Exhibit 2. Map of Current Trash Collection Days

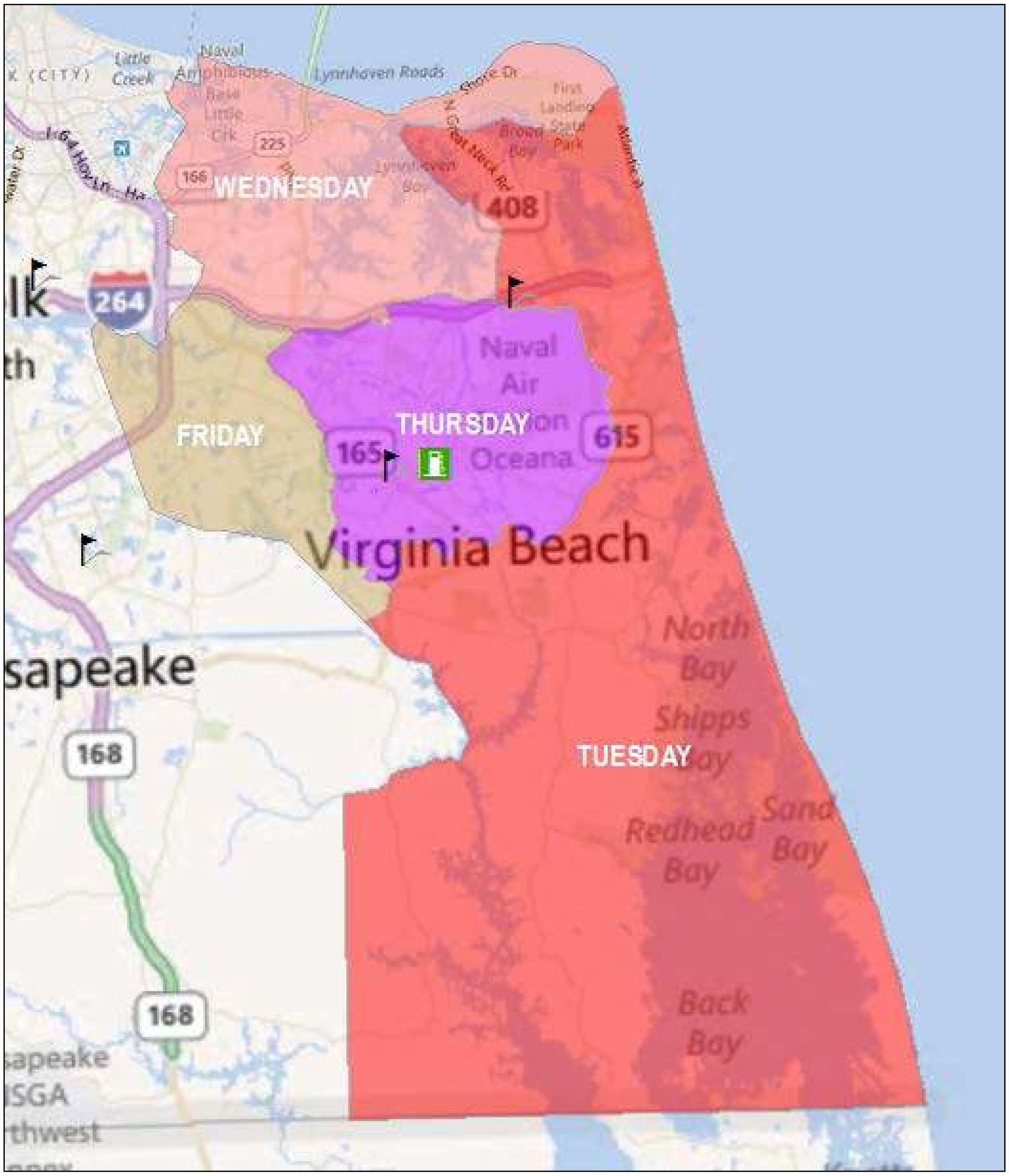

Exhibit 3. Key Routing Parameters

Parameter	Trash Collection
Total Number of Stops	124,071
Total Number of Containers	139,803
Stop Time Per Collection	11.7 seconds
Average Weight Per Household	38.92 pounds
Maximum Quantity Per Vehicle	Tandem Axle: 12 tons Single Axle: 4 tons
Maximum Allowed Workday	10 hours
Collection Days Per Week	4 days
Daily Break Time	30 minutes
Pre/Post Trip Time	15/15 minutes
Dump Time	20 minutes
Average Daily Breakdown Time	18.9 minutes
Additional time added to each dead-end street	26 seconds
Additional time added to “backdown” streets	Regular Street driving time, multiplied by 2.5
Additional non-service time	11.1 minutes

Exhibit 4. Modeled Trash Collection Routes Statistics Before Re-routing

Day	Time (hrs)	Stops	Containers	Mileage	Total Tons	Dump Trips	Number of Trucks	Average Time per Route (hrs)
Tuesday	356.1	30,185	35,530	2,461	587	116	39	9.1
Wednesday	344.5	31,048	34,794	2,266	604	114	38	9.1
Thursday	317.5	31,313	34,689	1,259	609	115	38	8.4
Friday	337.2	31,525	34,790	1,925	613	115	38	8.9
Total	1,355.2	124,071	139,803	7,911	2,414	460	153	35.4
Average	338.8	31,018	34,951	1,978	604	115	38	8.9
Range	38.6	1,340	841	1,202	26	2	1	0.8

* Excludes customers on pup-truck streets serviced by rear loaders.

Exhibit 5. Summary of Route Performance by Day for Phase I Planned Versus Actual

Day	Vehicle Type	Hours Planned	Hours Actual +Break	Hours Margin	Hours Actual +Break Total	Tons Planned	Tons Actual	Tons Margin	Tons Actual Total	Dumps Planned	Dumps Actual
Tue	Single	8.7	8.1	0.6	105.3	15.1	15.7	-0.6	204.3	4.0	3.7
Wed	Single	8.9	7.9	1.1	102.1	15.5	15.4	0.1	199.9	4.0	3.6
Thu	Single	7.7	8.2	-0.5	106.3	14.3	14.9	-0.6	193.9	4.0	3.7
Fri	Single	8.1	8.3	-0.2	107.6	15.3	15.4	-0.1	199.7	4.0	3.6
Tue	Tandem	8.9	8.3	0.6	182.5	19.1	19.7	-0.6	432.6	2.0	2.1
Wed	Tandem	8.9	7.8	1.1	171.8	20.5	20.0	0.5	441.0	2.0	2.1
Thu	Tandem	8.5	8.0	0.5	176.8	21.5	20.6	0.9	454.1	2.0	2.2
Fri	Tandem	9.0	7.9	1.1	174.8	21.4	21.5	-0.1	473.0	2.0	2.2

Exhibit 6. Phase II Route Statistics Summarized by Day and Type

Day	Route Type	Number of Routes	Route	Time (hrs)	Stops	Weight (tons)	Weight Per Stop (lbs.)	Miles
Tuesday	Single		Min	7.7	656	12.7	38.0	52.5
	Single		Max	8.7	1,097	21.2	39.5	81.3
	Single		Average	8.3	796	15.3	38.6	67.7
	Single	4	Total	41.4	3,981	76.7	192.8	338.4
	Tandem		Min	7.5	678	14.1	38.0	27.6
	Tandem		Max	9.6	1,190	23.1	43.8	136.4
	Tandem		Average	8.4	1,012	20.7	41.0	61.2
	Tandem	26	Total	209.7	25,302	517.7	1026.0	1529.3
	Backdown	2	Average	8.2	511			
	Pup	1	Average	2.0	30			
	Single/Tandem/Backdown		Min	7.5	477	12.7	38.0	27.6
	Single/Tandem/Backdown		Max	9.6	1,190	23.1	63.0	136.4
	Single/Tandem/Backdown		Average	8.4	947	19.5	41.8	63.4
	Single/Tandem/Backdown	32	Total	267.4	30,304	594.4	1218.8	1867.7
Wednesday	Single		Min	7.5	647	14.2	41.9	54.5
	Single		Max	9.1	746	16.4	44.0	88.9
	Single		Average	8.4	715	15.5	43.3	69.8
	Single	5	Total	42.2	3,576	77.3	216.4	349.2
	Tandem		Min	7.3	801	15.6	38.0	31.7
	Tandem		Max	9.2	1,123	23.1	44.0	72.8
	Tandem		Average	8.1	1,013	20.2	39.8	51.8
	Tandem	27	Total	202.9	25,337	503.8	996.0	1293.8
	Backdown	1	Average	5.3	525			
	Single/Tandem		Min	7.3	647	14.2	38.0	31.7
	Single/Tandem		Max	9.2	1,123	23.1	44.0	88.9
	Single/Tandem		Average	8.1	954	19.3	40.6	55.2

	Single/Tandem	32	Total	245.1	28,913	581.2	1212.4	1643.0
Thursday	Single		Min	6.1	634	13.0	35.2	19.1
	Single		Max	7.7	739	15.8	48.3	55.1
	Single		Average	6.6	704	14.6	41.7	33.3
	Single	5	Total	32.9	3,518	73.0	208.4	166.6
	Tandem		Min	7.2	928	15.3	31.4	19.9
	Tandem		Max	8.5	1,126	22.4	45.3	46.3
	Tandem		Average	7.9	1,019	20.2	39.7	30.7
	Tandem	27	Total	212.8	27,510	546.6	1073.2	829.1
	Backdown	1	Average	4.1	323			
	Pup	1	Average	2.2	12			
	Single/Tandem		Min	6.1	634	13.0	31.4	19.1
	Single/Tandem		Max	8.5	1,126	22.4	48.3	55.1
	Single/Tandem		Average	7.7	970	19.4	40.0	31.1
	Single/Tandem	32	Total	245.7	31,028	619.6	1281.5	995.7

Exhibit 6. Phase II Route Statistics Summarized by Day and Type

Day	Route Type	Number of Routes	Route	Time (hrs)	Stops	Weight (tons)	Weight Per Stop (lbs.)	Miles
Friday	Single		Min	7.1	702	14.9	41.5	42.0
	Single		Max	7.9	755	16.1	44.0	61.8
	Single		Average	7.5	727	15.7	43.1	49.0
	Single	5	Total	37.3	3,637	78.3	215.3	244.9
	Tandem		Min	7.7	950	18.1	38.0	28.7
	Tandem		Max	8.5	1,112	22.7	44.0	60.8
	Tandem		Average	8.1	1,032	20.8	40.2	42.3
	Tandem	27	Total	219.9	27,871	560.5	1085.9	1141.5
	Pup	1	Average	1.6	5			
	Single/Tandem		Min	7.1	702	14.9	38.0	28.7
	Single/Tandem		Max	8.5	1,112	22.7	44.0	61.8
	Single/Tandem		Average	8.0	985	20.0	40.7	43.3
	Single/Tandem	32	Total	257.2	31,508	638.8	1301.2	1386.3
	Single		Min	7.1	702	14.9	41.5	42.0

Exhibit 7. Statistics for Phase I Routes (actual) Versus Phase II Routes (planned)

Day	Phase I Total Hours	Phase II Total Hours	Phase 1 Stops	Phase II Stops	Phase I Routes	Phase II Routes	Phase I Average Route Hours	Phase II Average Route Hours
Tuesday	288	259	28,971	29,794	35	32	8.2	8.1
Wednesday	274	250	30,709	29,438	35	32	7.8	7.8
Thursday	283	250	30,994	31,351	35	32	8.1	7.8
Friday	282	257	31,525	31,508	35	32	8.1	8.0
Total	1,127	1,017	122,199	122,091	140	128	32.2	32.2
Average	282	254	30,550	30,523	35	32	8.1	7.9
Range	14	10	2,554	2,070	0	0	0.4	0.3

Exhibit 8. Current Versus Estimated Final Phase Truck Utilization

Day	*Current*							*Final Phase - All Tandem**					
	Trucks	**Actual Hours +Break Total**	**Hours Per Route**	**Total Dumps**	**Total Stops***	**Total Carts**	**Total Tons**	**Tandems**	**Total Estimated Hours**	**Hours Per Route**	**Stops Per Route**	**Carts Per Route**	**Tons Per Route**
Tue	35	288	8.2	95	28,971	34,168	637	30	270	9.0	966	1139	21.2
Wed	35	274	7.8	94	30,709	34,419	641	30	255	8.5	1024	1147	21.4
Thu	35	283	8.1	96	30,994	34,348	648	30	265	8.8	1033	1145	21.6
Fri	35	282	8.1	95	31,525	34,790	673	30	264	8.8	1051	1160	22.4

*There will be a yet to be determined number of customers on backdown and other streets with maneuvering issues that cannot be serviced via a tandem truck.