February 12, 2015

MEMORANDUM

TO:	Mr. Zaidoun ElQasem – Greater Amman Municipality
CC:	Ms. Swarupa Ganguli – U.S. Environmental Protection Agency
FROM:	Ms. Sandra Mazo-Nix and Ms. Dana Murray – SCS Engineers, consultants for the CCAC/EPA Amman Team
SUBJECT:	Best Management Practices for Optimizing Waste Collection Routes

Introduction

The City of Amman (the City) seeks to improve waste collection coverage and efficiency by optimizing its waste collection routes. In particular, the City would like to explore different strategies for optimizing collection routes. This memorandum provides a summary of the best management practices used to optimize waste collection routes and takes into account the current condition of waste collection in the City.

This memorandum is based on research done on the internet and through interviews with waste collection routing experts. The research showed that currently the best management practices used to optimize waste collection routing are based on strategies developed in the United States Environmental Protection Agency (EPA) in the 1970s and are still used for developing routes by hand and as a basis for computer models. The research showed that there is an abundance of academic literature that deals with optimizing collection routes, but the mathematical models proposed are site-specific and limited to being academic exercises.

Improving the waste collection routes in the City will help reduce labor, operation, and transport costs. In addition, efficient routes will mitigate impacts on public health, safety, and the environment by reducing the need for vehicles on the roads, lessening traffic congestion, increasing public safety, and decreasing atmospheric and noise pollution.

Routing

Definition

A *collection route* is a series of established residential and commercial waste collection points that are regularly visited by a collection vehicle[1]. *Routing* is the process which defines the route that a collection vehicle will follow as it collects residential or commercial solid waste.

Benefits of Optimizing Collection Routes

Optimizing collection routes can lead to a number of economic, environmental, and other benefits:

- *Reduced labor costs*. In most cases, collectors are paid by the hour, including overtime if necessary. The longer the collectors are on the road collecting waste, the greater the labor costs incurred by the city. Efficient routing can help reduce the amount of time collectors need to complete their waste collection responsibilities.
- *Reduced fuel costs.* In most cities, fuel consumption is on the rise because more vehicles and collection loops are needed to pick up increasing quantities of waste; the population is also expanding into peripheral areas. These effects are exacerbated by reliance on inefficient collection routes. Improving collection efficiency by optimizing routes can significantly reduce vehicle fuel consumption.
- *Reduced vehicle maintenance costs.* Waste collection vehicles that are used more efficiently will have fewer maintenance costs.

The investment in resources to optimize the routes can be recouped in a few months, given the considerable potential for cost savings.

In addition to reducing waste collection costs, reduced travel distances from optimized vehicle routes also results in lower vehicle emissions, including less black carbon. Reduced emissions can have considerable environmental and health benefits.

Characteristics of Optimized Collection Routes

Optimized collection routes share common characteristics:[2]

- Maximizing the ratio of time that collection vehicles are actually collecting solid wastes and/or recyclables compared to the time that the collection vehicles are involved in nonproductive activities (e.g., driving from collection point to collection point or idling)
- Minimizing the amount of time required to complete collection tasks
- Maximizing route balancing (i.e., distributing the workload as equally as possible between collection crews)
- Maximizing productive time for the collection crews and the collection vehicles and, at the same time, establishing fair day's work.

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[1] SWANA (Solid Waste Association of North America). *Getting More For Less, Municipal Solid Waste and Recyclables Collection Efficiency Workbook.* SWANA, 1996.
[2] Hickman, H. Jr. *Principles of Integrated Solid Waste Management*. American Academy of Environmental Engineers. 1999.

In most cases, the distance traveled by collection vehicles should be minimized. This is particularly important when independent vehicles that are contracted to collect waste incur costs on a per-vehicle- and per-kilometer-travelled basis. However, minimizing distance is not always possible because, at times, achieving the goals stated above will require longer traveling distances for some waste collection vehicles.

Waste Collection Route Optimization

Optimizing waste collection routes is a complex problem. Planning collection routes typically requires the consideration of many factors, including city layout, traffic conditions, vehicle capacity, drivers' working periods, and multiple depots where routes should start and finish. This section provides information on best practices for optimizing collection routes.

Optimization Process

Optimizing waste collection routes can be achieved through a five-stage process developed by the EPA's Office of Solid Waste Management Program (OSWMP)[3]. The five stages are:

1. *Review existing policies, methodologies, and alternatives, including institutional structure and objectives of the delivery system*. This review involves examining the current system and operational policies and determining whether these policies are being followed.

    - System policies are generally decided by top city management and include policies regarding general organization and level of service. Reviewing system policies should involve an examination of the institutional structure of the public department responsible for the management of waste collection, in terms of the department's capacity as operator, private contracts supervisor, or both.
    - Operational policies include route, labor, and management policies. These policies are generally established at the operating level, for example by the public works department or private contractors. Appendix A presents a list of some of the elements of system and operational policies that should be reviewed.

2. *Macro-route the service area*. Macro routing involves determining the optimum assignment of the daily collection routes to travel to existing or proposed processing and disposal facilities. This can be achieved by:

    - Determining the optimum amount of solid waste that can be processed or disposed of each day at the existing or proposed treatment or disposal facilities
    - Dividing the whole service area into areas that can be serviced by all collection crews on a given day (e.g., by the day of the week)
    - Dividing the total area serviced in a given day into the areas or districts to be serviced by each collection crew and vehicle. District territories can be delimited

[3] U.S. EPA. *A Five Stage Improvement Process for Solid Waste Collection Systems*. Environmental Protection Publication SW-131. Washington, US Government Printing Office. 1975.

by geographical barriers, such as railroad embankments, rivers, and roads with heavy competing traffic.[4]

3. *Perform route balancing and districting*. Route balancing involves assessing the workload, for example in terms of volume of waste collected, for the routes serviced by each collection crew and vehicle, and then redistributing that workload (i.e., by redistricting) as needed to ensure it is approximately equal. Route balancing is an option if a new collection system is being developed, if the present system will be restructured (e.g., when adding a separate collection of recyclables), or if the collection contract is up for re-bid.

   The analyses of crew and vehicle workload that are a part of route balancing and districting can also be useful for:

   - Estimating the number of trucks and workers required to collect waste in a new or revised solid waste system
   - Evaluating crew performances, as a whole or individually
   - Determining a fair day's work or a work standard, which is necessary for task and wage incentive systems
   - Determining the optimum size for new trucks or optimizing the use of existing trucks
   - Developing or evaluating a bid price for a collection contract.

   This third stage, performing route balancing and districting, is explained in more detail in the EPA publication *A Five Stage Improvement Process for Solid Waste Collection Systems*[5]. The publication includes an explanation of the mathematical model used to quantify a day's work for each collection crew and vehicle.

4. *Micro-route the areas to be served by each collection crew and vehicle*. The goal is to determine the path or route each collection vehicle is to follow as it collects waste from individual service points in a specific area. Micro-routing should take into account input and review by experienced collection drivers. Micro-routing is explained in more detail in the section "Micro-routing."

5. *Implement the choices and necessary changes made in the first four steps*.

Micro-routing

Micro-routing is seen as one of the most important aspects of optimizing collecting routes; solid waste departments in many cities focus on this aspect of waste collection because it has significant cost implications. Proper micro-routing can result in considerable cost savings. For this reason, this document will focus on the concept of micro-routing and the diverse approaches to finding optimal or best routes in a pre-determined micro area.

[4] U.S. EPA. *Decision Maker's Guide to Solid Waste Management, Volume II*. EPA 530-R-95-023. 1995.
[5] U.S. EPA. *A Five Stage Improvement Process for Solid Waste Collection Systems*. Environmental Protection Publication SW-131. Washington, US Government Printing Office. 1975.

Objective

The basic objective of micro-routing is to determine an appropriate path and size for each route. The appropriate path and size of a route depends on a wide variety of factors, including geographic features, demographic considerations, vehicle design, point-of-collection features (e.g., curbside, alley, or communal container), set-out requirements, collection frequency, and demographic and institutional considerations. These and other factors are shown in Figure 1.

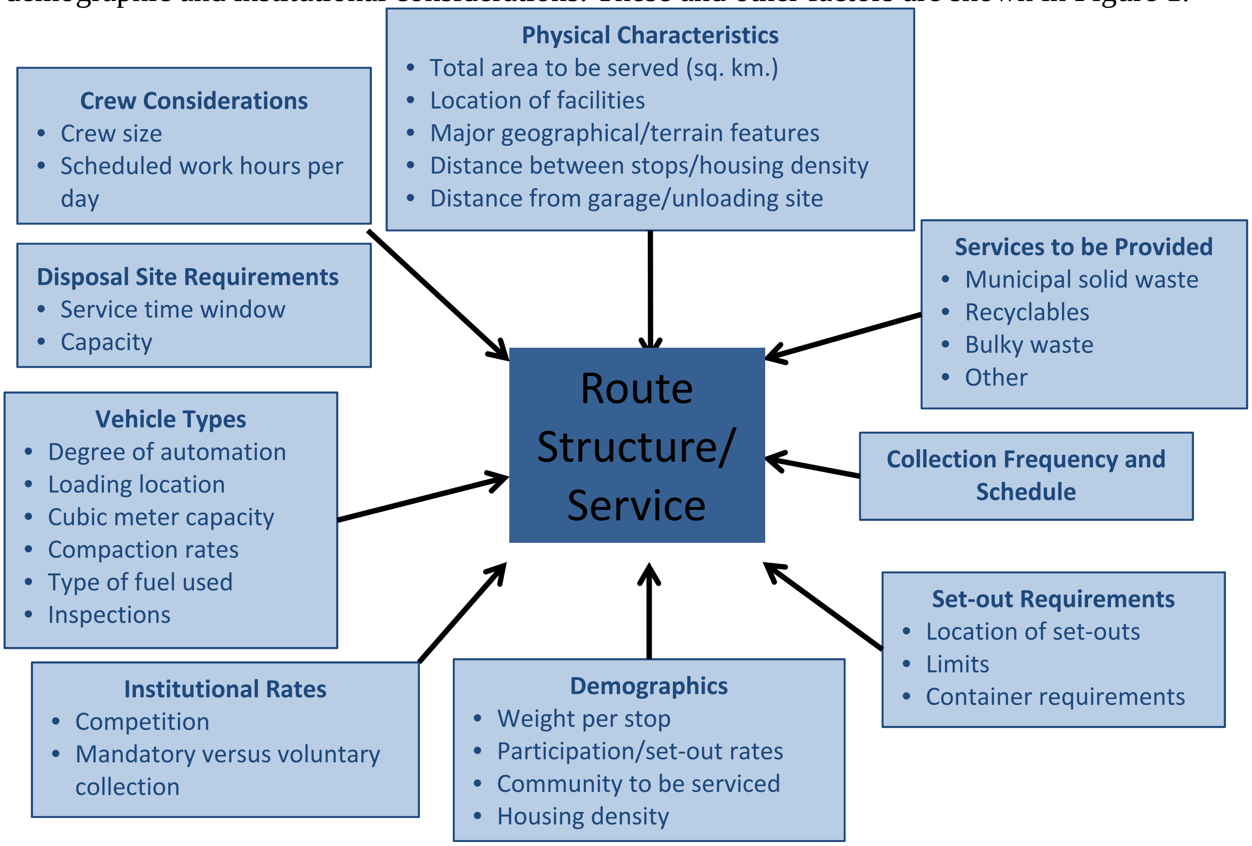

Figure 1. Factors to Determine the Path and Size of Micro-Routes[6]

An important aspect to consider when micro-routing is that routes might need seasonal and yearly adjustments. Seasonal fluctuations in waste generation can be addressed by providing an increased number of routes during the high-generation periods (typically during the spring, summer, and fall seasons) and providing fewer, longer routes during low-generation periods (usually the winter season).

Also, population growth and expansion into peripheral areas can lead to longer collection times on some routes. In such instances, rebalancing can help determine whether it is necessary to create new routes to keep the routes equalized.

Micro-routing Approaches

Micro-routing can be accomplished through computer-based and manual approaches.

[6] U.S. EPA. *Getting More for Less – Improving Collection Efficiency*. EPA 530-R-95-038. 1999.

Regardless of which approach is used, waste collection routes should be planned to abide by the following general safety considerations:

- Avoid zigzagging of collection routes
- Reduce travel during busiest pedestrian activity times of day in specific zones, such as near schools, churches, shopping areas, etc.
- Avoid crossings where there are no traffic lights
- Minimize backing and double siding.

Computer-based Micro-routing

One approach involves using a computer to examine and design routing alternatives and to select the best alternatives based on a heuristic algorithm. Different routing software applications can be used for this purpose. These applications use computerized geographic information of every street address within a service area. A locality's Geographic Information System (GIS) map provides a street map database that can include items such as address ranges per block, paving surfaces, road weight limitations, current traffic flows, turning restrictions, geographical features, and elevations. GIS street maps are used to identify the location of each customer. A disadvantage of using computerized routing systems is that not all localities have GIS maps of their jurisdictions. A list of some available software applications can be found in Appendix B.

The routing software applications can be purchased as stand-alone products, or as part of a package from a consulting firm that may offer additional services.

Manual Micro-routing

A second type of approach deals with micro-routing by using a manual procedure to develop acceptable collection routes without examining many possible alternatives. Although the manual approach is more labor and time intensive, it might be more practical to municipalities in developing countries that cannot afford the cost of obtaining GIS maps, routing software applications, or the services of routing consultants. The manual approach also offers the advantage that municipal personnel can readily understand the basis for routing. After gaining this understanding, personnel ,can implement the route, and make necessary modifications as conditions change either temporarily or permanently. The steps involved in manual routing are described below and are summarized in Table 1.

Table 1. Manual Routing Steps[7]

Step	Description	What You Need to Know
1.	Define collection service areas that are well-balanced. As a starting point, consider total number of customers to be	▸ Number of customers to be served in each region ▸ Number of collections per week ▸ Number of collection days per week ▸ Natural boundaries (e.g., major roadways, topographical features, or railways)

[7] U.S. EPA. *Getting More for Less – Improving Collection Efficiency*. EPA 530-R-95-038. 1999.

	served, multiplied by collections per week, divided by collection days	
2.	Divide the collection service areas into individual truck and crew areas of responsibility	▸ Data on house or customer count, on a block-by-block basis ▸ Vacancy and occupancy data ▸ Number of available collection vehicles ▸ Average set-out rates (and differences by region, if known) ▸ Average weights per set-out (and differences by region, if known) ▸ Time required per stop (including travel time between stops) ▸ Nonproductive time (e.g., to route, disposal/processing locations, vehicle yard) ▸ Maximum number of customers who can reasonably be served by each type of vehicle and crew combination (take into account differences in materials being collected, set-out container types, vehicle capacity, compaction ratios, vehicle age and reliability, and crew size)
3.	Design path routes, using EPA heuristic routing guidelines (see Table 2)	▸ Location of one-way streets and dead-ends ▸ Location of other topographic or traffic-related features that affect heuristic route design
4.	Drive routes to test for practicality	▸ Real-life conditions on the route

Step 1 – Define collection service areas that are well-balanced

The first step in the manual routing approach involves defining collection service areas that are well-balanced. As a starting point, consider total number of customers to be served, multiplied by collections per week, divided by collection days. Defining collection service areas requires having access to demographic and geographic information, in addition to basic waste collection parameters (e.g., collection frequency).

Step 2 – Divide the collection service areas into individual truck and crew areas of responsibility

After the collection service areas have been defined, they can be divided into the areas that will be covered by individual trucks and crews. These areas should be defined in accordance with the various pieces of required information that are identified in Table 1.

Step 3 – Design path routes, using EPA heuristic routing guidelines

As noted in Table 1, manual routing depends on heuristic routing guidelines. Heuristic techniques involve using knowledge, experience, and common sense to develop an acceptable solution to a problem. An acceptable solution is not necessarily an optimum, but is one that is reasonably good and derived within reasonable effort, time, cost, and resource constraints.

The US EPA developed a set of heuristic routing guidelines (see Table 2) to help promote efficient route layout and to minimize the number of left turns, overlaps, and dead space encountered. These guidelines have been accepted for several decades as the foundation of effective and efficiently planned routes. A route manager can apply these guidelines using tracing paper placed over a fairly large-scale block map. The map should include the locations of the collection service garages, waste treatment and/or disposal facilities, one-way streets, dead-end streets, natural barriers, and streets with heavy automobile and pedestrian traffic. The preliminary routes for each of the areas defined in Step 2 should be traced onto the paper according to the guidelines for heuristic routing, identified in Table 2.

Table 2. Guidelines for Heuristic Routing[8]

1.	Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.
2.	Total collection time plus hauling time should be reasonably constant for each route in the service area, ensuring equalized workloads.
3.	The collection route should be started as close to the garage or motor pool as possible, taking into account heavily traveled and one-way streets (see guidelines 4 and 5).
4.	Waste on heavily traveled streets should not be collected during rush hours.
5.	In neighborhoods with too many one-way streets, it is best to work through it through a series of overlapping loops (Figure 2).
6.	Services on dead end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment. To keep left turns to a minimum, collect the dead-end streets when they are to the right of the truck (Figure 3). Depending on the length of the street and turning restrictions, waste on the dead-ends can be collected by either walking down, backing down, or making a U-turn.
7.	When practical, waste on steep hills should be collected from both sides of the street while the collection vehicle is moving downhill. This practices facilities safety, ease, and speed of collection. It also lessens wear on the collection vehicle and conserves fuel and oil.

[8] Shuster, K & Schub, D. *Heuristic Routing for Solid Waste Collection Vehicles*. Environmental Protection Publication SW-113. Washington, U.S. Government Printing Office. 1974.

8.	Higher elevations should be at the start of the route.
9.	For collection from one side of the street at a time, it is generally best to route with many clockwise turns around blocks. This guideline and the following one emphasize the development of a series of clockwise loops to minimize left turns, which generally are more difficult and time-consuming than right turns. Right turns are safer, especially for right-hand-drive collection vehicles.
10.	For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the route before looping clockwise.

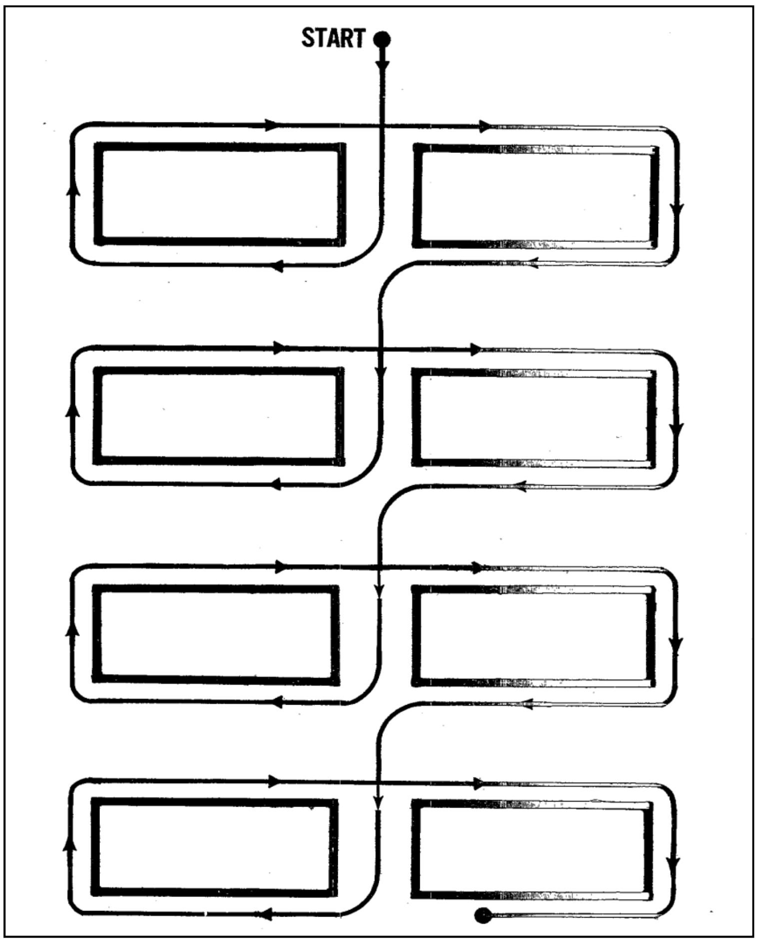

Figure 2. Routing pattern for one-way street with collection on either one side or on both sides; this pattern also works for busy or wide one-way streets using one-side-of-the street collection with looping process.

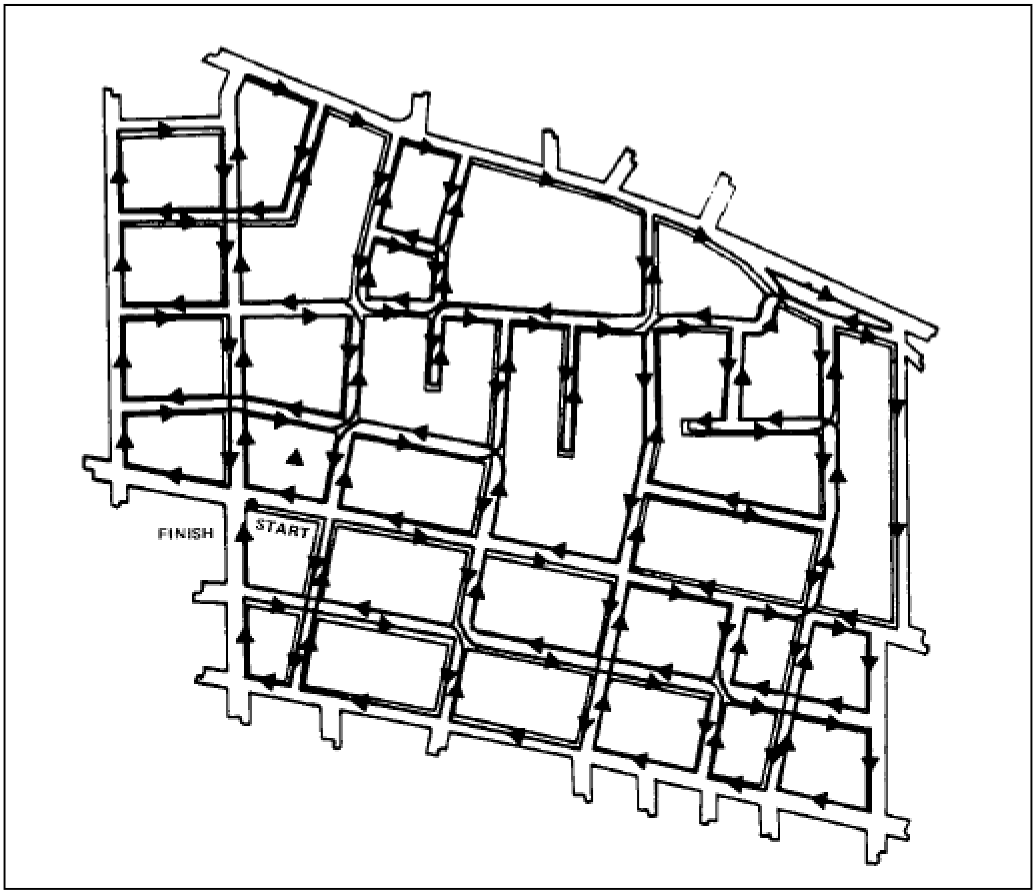

Figure 3. Sample routing pattern for a two-way street with collection on one side or on both sides of the street; this pattern also works for collecting on one side of the street on dead-end streets.

Step 4 - Drive routes to test for practicality

After route managers design a theoretical route path following the heuristic guidelines identified in Table 2, they should balance it and then evaluate the route through "trial and error" under actual field conditions. Balanced routes prepared in the office are given to the drivers of the collecting vehicles to implement them in the field. Based on the driver's field experience, any specific conditions that were not accounted for and each suggested modification to the route should be reported so any necessary changes can be made to the route. All reported new specific conditions should be registered in a database for future reference.

Micro-routing Resources

More information on the procedures to establish micro-routes can be found in the EPA report, *Heuristic Routing for Solid Waste Collection Vehicles*. The report includes information on preparations needed for routing, what data is required for routing, how the routing is done, factors to consider for implementation, a micro-routing example, and various patterning method exercises.

Chapter 4 of H. Lanier Hickman's book, *Integrated Solid Waste Management*, provides a step-by-step process for adding or changing routes by macro- and micro-routing, and determining crew production, the number of trucks, and related costs.

For additional resources concerning waste collection route optimization, please refer to Appendix C.

Assessing the Need to Optimize Waste Collection Routes

Experts recommend asking the following questions to assess whether the current waste collection routes need to be evaluated for optimization:

- Do the crews have assigned route boundaries?
- Was the last re-route less than five years ago?
- Have the crews' maps been updated in the past two years?
- Were the current routes developed based on most of the factors discussed above, including time, distances, weight, and geographical features?
- Has waste generation remained approximately constant since the last update of the waste collection routes?
- Are all of the crews completing their routes as scheduled?
- Does the collection services supervisor know how many stops and containers are included in each individual route?
- Does the collection services supervisor know how long each route should take?

An answer of "no" to any of these questions is a good indication that operations are not efficient and optimizing the waste collection routes could be beneficial.

Other Recommendations

Computer-assisted Routing Implementation

As discussed above, the planning of optimal waste collection routes is a complex enterprise. All the factors that need be considered to create efficient and balanced routes add to the challenging complexity of optimizing routes. Route optimization software applications have been created to take advantage of computers' ability to handle complex problems. These software applications reduce the complexity and assist in developing routes, streamline changes, generate maps, and produce reports. However, to ensure that localities can take advantage of these software applications, the software vendor needs to configure and set up the software application given the requirements of the locality. The vendor also should offer training to the locality personnel to use the software application and to maintain and update the data. This training could be given to the route supervisor or a GIS staffer, but experts recommend training someone with a technical background in waste operations and a familiarity with computers and complex software applications.

Remember that route optimization software applications are not perfect and the routes they generate will depend on the quality of the input information. The benefit of this type of software application is not in developing perfect routes, but in providing the ability to quickly generate many routes with accurate completion times and other parameters. Also, different software applications use different parameters and have varying degrees of complexity. Some waste collection routing applications are more appropriate than others, depending on the type of routing being optimized. Waste collection routing can be done for:

- Residential curbside collection of waste, yard waste, and recyclables
- Residential point-to-point collection for multi-family dwellings
- Commercial curbside collection
- Commercial point-to-point collection
- Industrial point-to-point collection
- Industrial paired collection
- Specialized collection of residential bulky items or construction debris

Multiple applications are needed to route all types of waste collection because available applications cannot handle all types of waste routing effectively[9]. Localities should research the different types of software applications available and obtain the one that would address the more pressing waste collection routing needs of the locality. Another option is to hire a consultant who has experience with the various routing software applications and who can develop and maintain the waste collection routes for the locality. The hired consultant should have expertise with waste collections, data analysis, safety, equipment, and industry practices.

[9] Waste Collection Routing Software. http://routeoptimizationconsultants.com/waste-collection-routing-software/. Accessed December 22, 2014

Glossary

Double-siding	Collecting waste from both sides of the road or street.
Heuristic	Using experience to learn and improve.
Manual routing	Process by which personnel of the waste services department of a localities develops routes for the waste collection using hard copies of maps of the locality and information on the locations of waste generators.
Paired routing	Collecting waste from an established point of collection and pairing the waste with a specific solid waste facility. For example, a container of waste from an industrial facility is picked up by the waste collection vehicle and is taken to a specific solid waste facility because of contract specifications or type of waste.
Point of collection	Location where waste is picked up; residential and commercial solid waste can be collected from several places: the alley, backyard, side of the house, curbside, and drop-off containers.
Point-to-point	Collecting waste from an established point of collection and then collecting waste from another point of collection.
Service area	A geographic region that is provided with solid waste collection services.
Set-outs	Waste or recyclables that have been place aside in a designated location for the waste collection service to collect.
Set-out requirements	Location and schedule of set-outs, together with limits on what waste generators can put out for collection, and container requirements.

Appendix A – Checklist of Policies and Practices

I. System Policies
   A. Organizational Policies
      1. Institutional arrangements
      2. Financing methods
      3. Billing system
      4. Subsidization of particular groups
      5. Legal issues
   B. Level-of-Service Policies
      1. Who receives services
      2. Citizen option versus mandatory services
      3. Point of collection
      4. Frequency of collection
      5. Type of storage devices
      6. Limit on amount of waste or number of containers
      7. Mechanized collection
      8. Specialized collection
         a. Yard waste
         b. Bulk items
         c. Construction and debris
      9. Separate collection of garbage and recyclable materials
      10. Inner-city cleanup programs
      11. Service for elderly and disabled clients

II. Operational Policies
   A. Route Policies
      1. Crew size
      2. Type and size of equipment
      3. Whether drivers collect
      4. Shuttle system
      5. Reservoir system
      6. Whether collection vehicle must be full before going to disposal site
      7. Times and sites for lunch and breaks
      8. Scheduling and overtime allowances
      9. Vehicle routing and districts
      10. Dealing with enclosures and other obstacles
      11. Dealing with excessive haul times
      12. Seasonal variations of routes
   B. Labor Policies
      1. Wage structure
      2. Career ladder, seniority
      3. Training
      4. Safety measures and preventive health care
      5. Insurance and pension plans
      6. Holidays, vacations, sick leave
      7. Absenteeism
      8. Incentive system
   C. Management Policies
      1. Organizational structure
      2. Management information system
      3. Cost-accounting system
      4. Handling requests and complaints
      5. Supervisory communications system
      6. Public relations program

Appendix B – Route Optimization Vendors

Vendor Name	*Website*
My Route Online	http://www.myrouteonline.com
FleetRoute	http://gbbinc.com/products/fleetroute-route-optimization-software-and-services
C2RouteApp Web-based Routing	http://gbbinc.com/products/c2routeapp-web-based-routing
RouteSmart Technologies	http://www.routesmart.com/about-routesmart-routesmart-technologies-route-smart/success-ctr-routing-scheduling-software-solutions/success-ctr-public-works-routing-scheduling-software-solutions
eRouteLogistics	http://www.e-iit.com/WasteHauling.html
Trash Flow	http://trashflow.com/products/routing.php
Fleet Mind	http://www.fleetmind.com/fleet-management-solutions/waste-recycling

Appendix C – Resources for More Information

Title	*Organization*	*Link*
Heuristic Routing for Solid Waste Collection Vehicles (1974)	U.S. EPA	http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=10003IHZ.TXT
Getting More for Less – Improving Collection Efficiency (1999)	U.S. EPA	http://www.epa.gov/osw/nonhaz/municipal/landfill/coll-eff/r99038.pdf
A Five-Stage Improvement Process for Solid Waste Collection Systems (1975)	U.S. EPA	http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100RVVR.TXT
Planning a High-Performance Collection System	University of Wisconsin-Madison and Waste Age	http://infohouse.p2ric.org/ref/08/07951.pdf
Route Management – More than just route optimization	Fleet Mind	http://www.fleetmind.com/pdfs/white-papers/whitepaper-route-management.pdf