What to do with all this Food? Examining the Emerging Food Waste Hauling Network in Western New York State

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ABSTRACT

Given the recent interest in food waste recycling from a sustainability perspective and the impending New York State (NYS) policy banning the disposal of food waste in landfills, the demand for food waste hauling services will soon increase in NYS. Commercial establishments generating two tons of food waste per week will be subject to these new regulations, but will expect to pay no more than their current disposal costs for food waste collection. However, new services will face more complex decisions than traditional waste hauling due to the variability in food waste generated and material constraints of food waste recycling facilities. This paper considers the shift in transportation practices to meet the complexities of food waste management. Current transportation perspectives exist to help waste hauling companies solve their allocation and routing decision problems, but material blending during network routing is relatively new. A formulation that presents allocation and blending of food waste to different recycling facilities is presented and applied to Western NYS, showing a small transportation cost decrease. As promising as the results from this example are, future work should focus on combining allocation, routing, and blending of food waste to create a complete picture of waste hauling in emerging food waste recycling networks.

Keywords: Logistics, Networks, Trucking, Hauling, Food Waste

1.0 INTRODUCTION AND BACKGROUND

The trucking or hauling of commercial food waste is quickly emerging as a critical issue in the waste hauling industry as commercial organizations and institutions gain interest in moving food waste to recycling facilities to improve public image. Additionally, state policies banning landfill disposal of food waste have created a pressing need to address gaps in food waste hauling services to fulfill regulatory requirements. Massachusetts bans disposing food waste at landfills by any commercial entity that generates more than one ton per week (1). Connecticut enforces a similar disposal ban for generators that produce more than 104 tons per year (2). New York City has their own food waste landfill disposal ban (3), and the rest of NYS is expecting to implement regulations within the coming years that requires large generators of food waste, producing more than two tons per week, to recycle food scraps rather than sending to a landfill (4). Support for these policies comes from research stating that recycling technologies can recover energy embodied within food waste, while reducing environmental impacts of waste management (5). From a trucking perspective, this growth in demand for food waste hauling to landfill alternatives will require the trucking industry to consider new decisions that require optimization over varying time and geographic scales.

Diverting food waste from landfills to recycling facilities adds a new, complex layer to waste hauling. Conventional municipal solid waste collection considers geographic scope, waste type, vehicle type, and disposal facilities (6). In the context of new recycling technologies, supply and demand contracts, network configurations, and sourcing of organic material (7) will further complicate hauling services. Insight into these new problems may benefit from perspectives in freight delivery, supply chain logistics and reverse distribution with open-loop recycling system (8). However, variability in recycling technology feedstock requirements, food waste composition, and generation rates presents additional challenges to practitioners not currently addressed in literature.

1.1 Study Objectives

This paper motivates and frames the range of decisions food waste hauling companies must consider, focusing on decisions of food waste allocation to recycling technologies, routing of collection locations, and blending of food waste to meet the requirements of recycling technologies. The United States Environmental Protection Agency has developed a Food Recovery Hierarchy (9) to guide the diversion of food from landfills based on potential energy recovery and second use. This paper only considers the hauling of non-edible food waste originally designated for landfill disposal, but still containing potential for recycling technologies and composting. This paper will outline current issues implementing food waste truck hauling and the current situation of food waste management NYS (excluding the five boroughs of NYC) using publicly available data sources.

2.0 BACKGROUND: FOOD WASTE HAULING AND TRUCKING

2.1 Current Food Waste Management and Trucking Practice

In NYS, commercial municipal solid waste (MSW) management considers both food and non-hazardous wastes. MSW is routinely collected every week from commercial generators and hauled to a landfill or a waste-to-energy (WTE) facility for disposal. While commercial composting can also process food wastes, fewer compost facilities are permitted to accept food waste. For example, in Monroe County only 1 of 18 composting facilities accept food waste. Characteristics of food waste have no bearing on landfill or WTE disposal, allowing for disposal at those facilities without further constraint. From the trucking perspective, necessary decisions include delivering waste to transfer stations and/or landfills depends on environmental factors and other logistic objectives, typically minimizing transportation operation costs (personal communication with Nicole Fornof). If food waste is collected separately, an allocation service contract typically exists between generator and disposal facilities dictating the food waste origin-destination flows. However, a contract for food waste between generator facilities and hauling companies provides decision flexibility for hauling companies moving waste. This same flexibility may be critical for making network decisions when the food waste diversion network expands.

In NYS, only 27 landfills, 10 WTE facilities, and 44 composting facilities exist that service an estimated 17,000 large commercial food waste generators. Although decisions are currently limited for conventional waste disposal due to the relatively small number of disposal locations, the decisions for waste haulers will grow as recycling facilities are constructed to manage the estimated 8,000 tons of food waste generated per week (10).

2.2 Food Waste Diversion and Sustainability

In states with food waste disposal bans, policy requires nearly every large food waste generator to divert food waste from landfills to recycling facilities if facilities exist within a minimum distance, typically between 20 miles to 100 miles. The distance requirement presents a capacity issue with current recycling facilities with fixed capacity. Unlike landfills, which usually accept thousands of tons of MSW per week, existing recycling facilities in New York State accept considerably less material: approximately hundreds of tons per week.

Current research and analysis supports infrastructure investments that will lower waste management system costs by separating food waste and creating valuable products through recycling (11). As this food waste recycling network evolves, waste haulers are at the center of trucking decisions that satisfy both collection and delivery for clients.

Regardless of how food waste recycling networks will evolve, trucking companies that anticipate hauling waste must consider the following:

- Characteristics of food waste generated are variable and certain types of food waste might be undesirable or incompatible with specific recycling technologies, influencing allocation of food wastes from generators to recycling facilities (12),
- Coordination between different trucking companies and recycling facilities based on the food waste characteristics may emerge,
- Scheduling of collection and delivery may need to coincide with both generators and recycling facilities to maintain consistent supply, and
- Co-collection of food waste and additional organic wastes may be necessary because recycling technologies require more than food waste alone (11).

How the food waste recycling network evolves depends on the interactions between stakeholders: generators, recycling facilities, and haulers.

3.0 ACTORS IN THE FOOD WASTE DIVERSION NETWORK

Figure 1 presents an overview of the actors in the food waste management system, including their interrelationships.

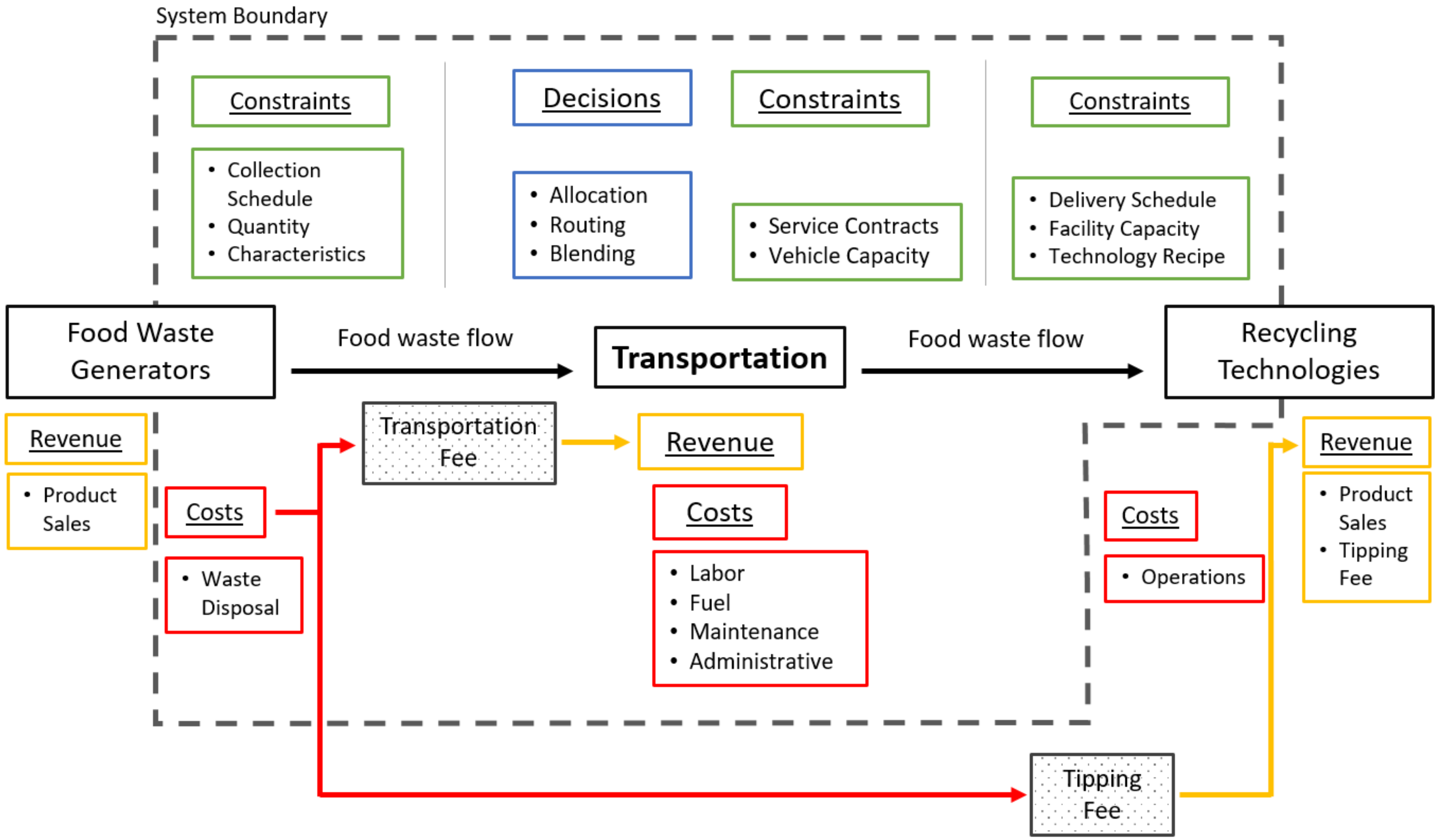

FIGURE 1 Concept Diagram of Waste Hauling Company Decisions and Considerations

Figure 1 depicts the factors that waste hauling companies will have to consider when making food waste service decisions. Constraints on decisions comes from all three actors within the network and waste hauling companies must consider these while balancing their own costs.

3.1 Waste Hauling Companies Trucking Food Waste

A waste hauling company's main function is to provide timely collection of unwanted material for clients and transport them to appropriate disposal or recycling facilities, typically for a fee. Food waste comprises an estimated 15% (13) of MSW, constituting a non-trivial amount of the waste stream that could result in lost revenue for hauling companies that do not offer food waste management services. The promotion of sustainability through separation, collection, and recycling of the food fraction of MSW will complicate material flows, interactions, and decision making from the hauling company to its clients on either end of the waste management network.

Hauler considerations are similar to conventional MSW hauling; however, differences specific to food waste alter solutions to transportation optimization decisions. Introduction of variability in food waste characteristics from generators in conjunction with recipes and delivery schedules for recycling technologies create more constraints compared to the traditional allocation. Routing decisions of food waste introduce additional blending decisions to satisfying recipe constraints for recycling facilities. Many existing freight and trucking concepts can help inform research and decision making in emerging food waste recycling networks; however, the origins and destinations of these new networks need to be characterized.

3.2 Origins: Commercial Food Waste Generators

Commercial businesses generate 40% of the total food waste in the United States (14). Examples of commercial generators include supermarkets, universities, restaurants, hospitals and hotels, where the main function is to provide food for customers. For generators, reducing food waste disposal costs is a beneficial way to decrease overall operating costs; however, food waste diversion will be more complex than just separation and collection of a third waste stream. The composition of food waste varies across generator types (15). Depending on the composition, waste generated could be incompatible for specific recycling technologies depending on the end products produced. Additionally, food safety regulations will limit some uses of food waste, adding further complexity to recycling decisions by promoting the need to split food waste disposal by characteristics at the source.

Unfortunately, no data is available from generators on the composition of their food waste, increasing the difficulty of allocation decisions for actors in food waste recycling networks. Lack of data also affects recycling decisions of seasonally variable food waste in terms of composition and quantity. Food sales increases during the holiday season (16), creating spikes of waste from specific products, such as summer sausages associated with holidays (17). These seasonal events would constitute food waste that the hauler is contractually obligated to bring to a recycling facility, but would be undesirable, resulting in increased tipping fees to compensate for recycling operational adjustments. Information collection and sharing efforts will be a paramount issue for the effective transition to food waste diversion. Spearheading information collection, the New York State Pollution Prevention Institute (NYSP2I) has created an interactive database that compiles information on food waste generators in New York State spanning many categories and included average estimations of weekly food waste generation quantities (18).

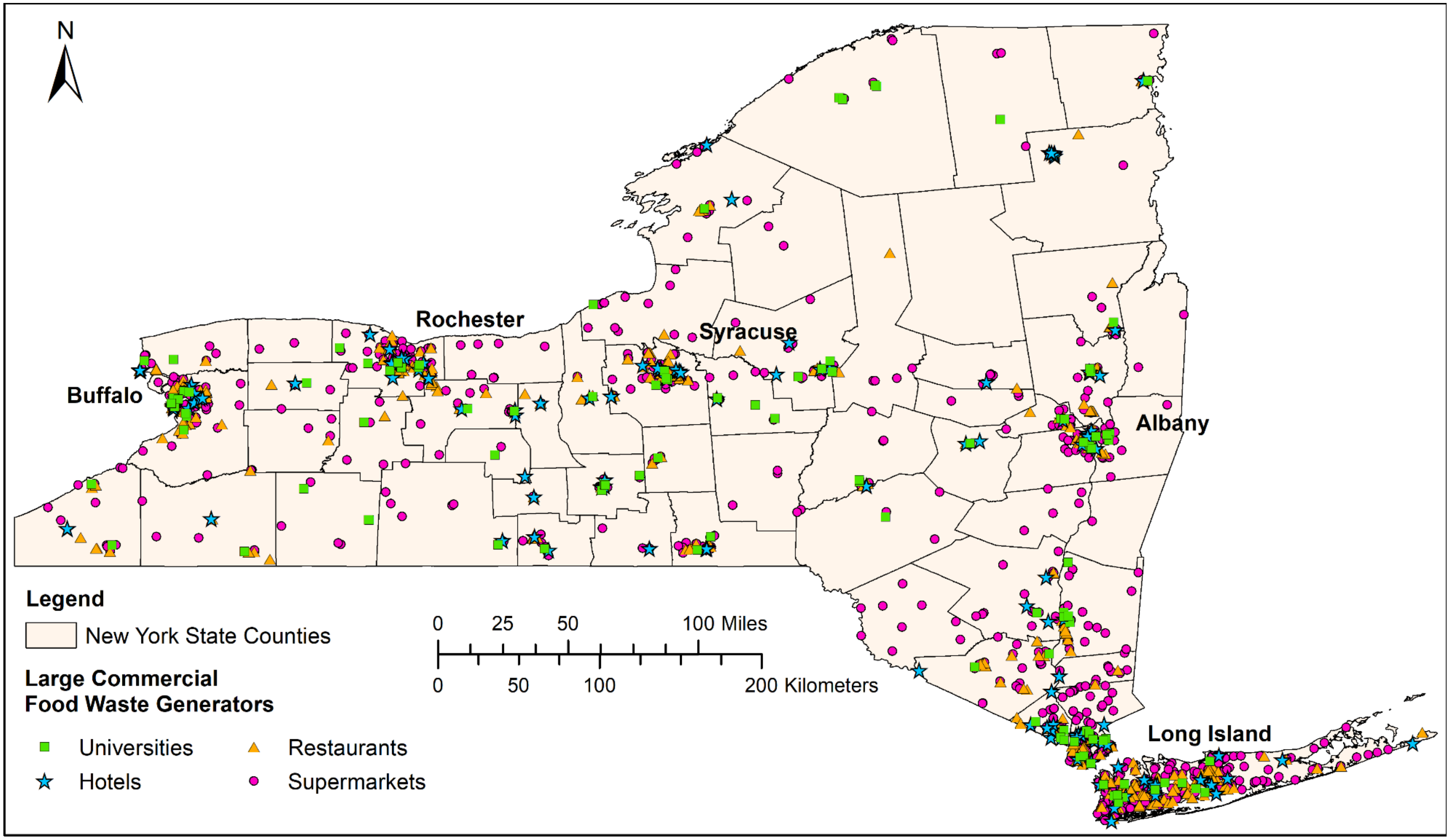

FIGURE 2 Map of Large Commercial Food Waste Generators in New York State.

Figure 2 shows the placement of large commercial food waste generators. Only four types are shown; however, additional food waste generators are located with a similar distribution to those shown.

Visually, large food waste generators are expectedly clustered around population centers throughout the NYS, allowing for efficient collection of food waste from many generators. However, this clustering could result in increased transportation costs due to long hauling distance between collection and delivery locations if recycling facilities are developed outside of populated areas. The spatial variability in food waste generation and availability of information will impact food hauling decisions companies face in NYS.

3.3 Destinations: Food Waste Recycling Technologies

Unlike landfills, recycling facilities are physically constrained by their design parameters limiting the flow of feedstock that can be accepted. Recycling facilities also charge a tipping fee to the waste generators for accepting waste since product sales do not generally cover the operating costs. However, the generated revenue from product sales could translate to lower tipping fees, making them a more economically attractive food waste management option (10).

Each type of food waste recycling technology has their own desired feedstock requirements for effective operation. No research exists that identifies the best recipe for any given technology; some conventions for prominent technologies exist.

- Composting requires solid organic material which is degrades in the presence of oxygen, requiring a balance of carbon, nitrogen, and moisture.
- Wet anaerobic digestion is a liquid process that degrades organic material without oxygen. This process must maintain a carbon to nitrogen balance, and consider operating parameters such as solids content, pH, volatile fatty acids, and alkalinity. Products include methane, electricity, heat, compost, fertilizer, water, animal bedding.
- Pyrolysis heats organic material to high temperatures without oxygen. Less moisture content in the feedstock translates to higher efficiencies, and products include heat, electricity, and soil amendment in the form of charcoal. The nutrient content of the feedstock can translate to the soil amendment, therefore
- Incineration combusts organic material in the presence of oxygen to generate heat and electricity. Less moisture content in the feedstock increases operating efficiency, but there are no recipes for incineration.
- Biofuel production is generally performed with agricultural products, however there has been some research into utilizing food waste. Where biodiesel needs high fat contents for transesterification, bioethanol requires higher sugar content for fermentation.

Research on feedstock recipes that maximize yield and product quality exist (19). Optimizing the feedstock recipe to produce superior products could generate higher revenue streams, consequently reducing tipping fees further. Giving haulers flexibility in allocation of food waste resources may complicate logistical solution, but provide the opportunity to optimize the delivery of the food waste to recycling facilities in their network to reduce service costs.

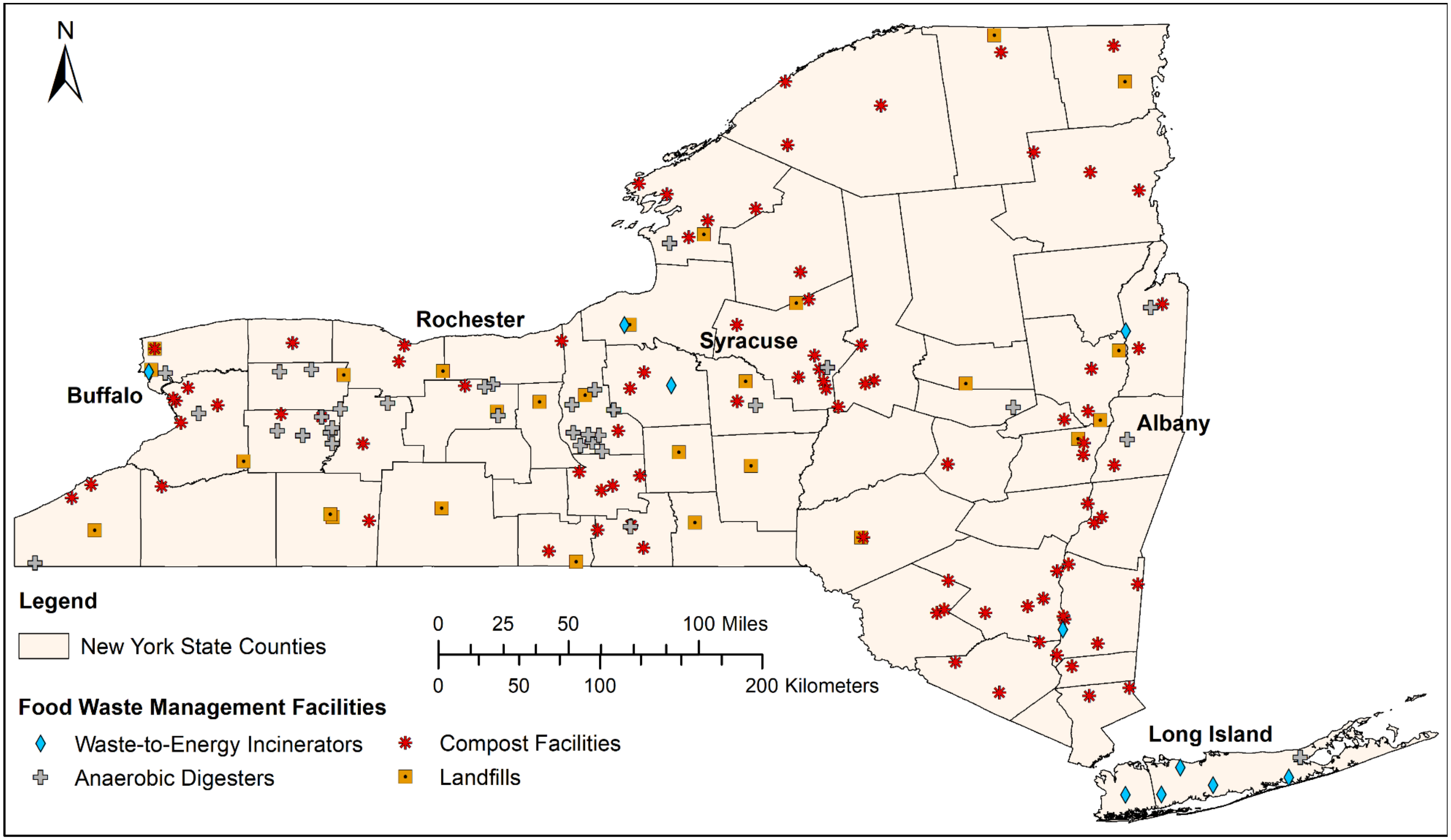

FIGURE 3 Map of Food Waste Management Facilities in New York State.
In New York State, the prominent available food waste management facilities include landfills, waste-to-energy incinerators, compost facilities, and anaerobic digesters, constituting 138 facilities in total.

Figure 3 shows a geographic pattern in the location of recycling facilities. Unlike food waste generators, recycling facilities are dispersed relatively evenly; however, geographic variations exist depending on type. While compost facilities are generally located throughout the state, anaerobic digesters are heavily located in Western NYS, where dairy farms are abundant and can provide cow manure that usually constitutes over 50% of input materials. Uneven distribution of technology types could limit the food waste management options available to haulers. This imbalance becomes a greater issue when policy requires generators to divert food waste if within a minimum distance of a recycling facility, but inputs are incompatible with available technologies.

4.0 SYNERGISTIC PERSPECTIVES

4.1 Freight Delivery

Food waste management can be viewed similarly to freight delivery where a single truck begins at the central depot, and is routed to many businesses. However, the flow of goods is reversed such that collections now occur at businesses and delivery occurs at the depot, i.e. a recycling facility. Just as freight orders within a single delivery truck are allocated to specific businesses, food waste collection from businesses might be allocated to specific recycling facilities.

Comparisons between cooperative versus peddle-run freight delivery strategies are similar to commercial food waste collection. Businesses could choose to bring their own food waste to a centralized facility for collection or continue with the conventional curbside collection strategies, mirroring goods delivery strategies. Tradeoffs between these two strategies exist within freight delivery and cost benefits are context specific (20, 21). A second issue encountered is collection scheduling. Since food waste decomposes, creating undesirable effects, businesses may want that portion of waste collected at specific times to minimize odors or pest problems. A dynamic collection time scheduling model could match service providers and clients according to preferred time slots daily and weekly (22). Dynamic scheduling might be more favorable than static scheduling for waste collection services given the variability in food waste generation. Just as capacitated freight networks can apply adaptive models to account for network disruptions (23), applying these models to food waste management could help haulers comply with food waste disposal regulations efficiently if faced with disruptions.

4.2 Supply Chains

Sourcing and hauling food waste can be considered as part of a supply chain from the perspective of the recycling facility, where the waste hauling companies facilitate the movement of resources. Therefore, viewing food waste management as a logistic system integrated with a larger supply chain offers benefits to waste hauling companies (24). Waste haulers can use supply chain models to allocate food waste to recycling facilities to minimize tipping fees while delivering material that matches the recipe demand of a recycling facility. Additionally, these methods can consider integrating other organic resources into the waste/resource transportation network to satisfy recycling facility material demands.

Deterministic, stochastic, economic, and simulation models exist for analysis of supply chains (25). Evaluating distribution effectiveness is especially important due to the variability of food waste and consistency required by industrial processes, therefore stochastic and simulation modeling are preferred due to their ability to describe systems while accounting for variability. Research in biofuel supply chains under uncertainty can grant insight into managing food waste management since both supply chains are sourcing organic materials as feedstocks (26, 27). One drawback in current literature, however, is that less emphasis is placed on individual routing and vehicle utilization on supply routes.

4.3 Reverse Logistics

Reverse logistics relates to the operations involved in recapturing value of waste throughout the manufacturing and end-use phases of goods. This concept arises often in consumer electronics to describe remanufacturing or refurbishing of non-functioning or outdated equipment. Transportation issues in reverse logistics include the efficient collection of consumer products and transferring to maintenance or recycling facilities. Parallel concepts can be applied to new food waste management strategies for collection and distribution of goods.

Waste hauling is usually performed by third-party logistic providers from the generator that handle material inputs for the creation of multiple recycling products (28). Hazardous waste management presents some similar issues to food waste management due to highly regulated and generally small quantities transported to larger treatment facilities. Reverse logistics costs have been used to reduce transportation and treatment costs (29). Even though there are similarities to consumer electronics reverse logistic models, food waste is fundamentally transformed into a different product than the material inputs that are supplied and not sold back the supplier of the waste. Consequently, this type of open-loop recycling system (8) is not well represented in reverse logistic research.

4.4 Milk Collection Routing and Blending

In the paper "A Milk Collection Problem with Blending" (30), the authors present the problem of blending three qualities of milk in a single vehicle compartment along a collection route alternative to blending at the processing facility. Blending milk qualities will result in lower revenue due to inferior product, but will also decrease transportation costs. A mixed integer linear program is proposed to solve problems of approximately 100 nodes, but combined with heuristics to solve real networks with larger node counts. When the formulation is applied to a real case of 500 farms distributed across a region approximately 9600km^2, system profit is increased from the current procedure by 120% and transportation costs are decreased by 46%. Even when a traditional vehicle routing problem (VRP) formulation is applied for separate collection of milk qualities, the blending scenario still maintains a 10% higher profit margin while decreasing transportation costs by 18% from VRP scenario. Clearly, blending of milk qualities is a favorable strategy for transportation companies to reduce costs without impacting revenue streams for producers.

This concept is highly applicable for food waste transportation in a very similar context. Blending food wastes of different characteristics for use at recycling technologies may have impact on the operations of industrial processes, positive or negative, but could also reduce transportation costs. Of course, waste hauling companies and recycling facility operators will have to build relationships with each other to ensure that materials transported are compatible with technology.

5.0 OPTIMIZING DECISIONS IN FOOD WASTE HAULING

Although existing models for freight systems provide a framework for evaluating food waste recycling networks, one critical difference is that cargo in conventional freight transport is discreet, conveying individual cargo units, while food waste is a blend of material collected from generators. Even with food waste separation into different components like meat or vegetables, collected material is still be blended within the vehicle container and delivered as a single resource for processing. Allocation and routing of food waste collection services must consider blending, but there is no current literature that confronts these three hauling issues concurrently in the context of waste management. As a first step to filling the literature gap, a simple mathematical formulation with similarities to a single stage supply chain are presented, examining the Western NYS for food waste management by combining allocation and blending.

5.1 Allocation and Blending in Western NYS

Typically, for bio-product supply chains, only a single type of product is considered for optimization, which makes sense for providing a useful functional unit in analysis for comparison to alternative decisions. However, from the hauling perspective, analysis in terms of a single product in a recycling network may not capture the least costly allocation decisions for available food waste. The availability of many types of recycling technologies allows many food waste delivery options and creation of various products from blended food waste supplies. Network models for hauling companies need to capture the technology diversity for allocation of food waste to minimize transportation costs by incorporating the blending of available food waste, but still deliver minimum material quotas to their clients.

A simple food waste allocation with blending formulation is presented that optimizes allocation of food waste to multiple recycling facility types. Four food waste generator types with specific food waste generation profiles and three food waste recycling facilities with specific process recipes comprise the network. The formulation is applied to small test network, then to Western New York to show transportation cost difference between allocation with and without blending.

TABLE 1 Set of Formulation Variables

w_{gm}	The quantity of waste delivered from generator g to facility m
V_m	The total quantity of waste delivered to facility m from generators
$(g,m) \in N$	Set of arcs from generators g to recycling facilities m in network N
$g \in G$	Generator g of set of generators G
$m \in M$	Recycling or disposal facility m set of facilities M
$t \in T$	Waste type t set of waste types T
q_g	Quantity of waste q generated by generator g
ε_g^t	Proportion of waste type t of total waste produced by generator G
$\varepsilon_m^{t(min,\max)}$	Minimum and maximum proportions of waste type t in recipe for facility m
$P_m^{(min,\max)}$	Min and max quantity of total waste that can be delivered to facility m
f_m	Tipping fee of waste at recycling facility m (*Decision Variable*)
C_{gm}	Cost of transporting waste from generator g to facility m (*Decision Variable*)
R_p	Unit revenue of products from disposal at facility (*Decision Variable*)

The Scenario 1 formulation for the food waste allocation problem is as follows:

$$Z = \text{Min} \sum_{(g,m)\in N} C_{gm} w_{gm}\, q_g + \sum_{m\in M} f_m\, V_m - \sum_{m\in M} R_p\, V_m \quad [1]$$

Subject to:

$$\sum_{m\in M} w_{gm} = 1 \; g \in G \quad [2]$$

$$\sum_{g\in G} w_{gm}\, q_g = V_m \;\; m \in M \quad [3]$$

$$V_m \geq P_m^{min} \; m \in M \quad [4]$$

$$V_m \leq P_m^{max} \; m \in M \quad [5]$$

$$\sum_{g\in G} w_{gm} q_g\, \varepsilon_g^t \geq V_m\, \varepsilon_m^{t(\min)} \;\; m \in M, t \in T \quad [6]$$

$$\sum_{g\in G} w_{gm} q_g\, \varepsilon_g^t \leq V_m\, \varepsilon_m^{t(\max)} \;\; m \in M, t \in T \quad [7]$$

Objective [1] minimizes the system cost by considering the transportation costs, tipping fees, and revenue generated by products sold on the market. Constraint [2] ensures that waste from a generator only goes to a single recycling facility and is binary. Constraint [3] tracks the amount of material that is delivered to each recycling facility. Constraints [4] and [5] ensure that the facility material quota is met and the capacity is not exceeded, respectively. Constraints [6] and [7] establish the technology recipe bounds for material characteristics delivered.

For Scenario 2, the formulation is modified to allow generators to split their food waste so that it can be sent to multiple generators. This forms the basis for blending food wastes in the network and utilizing resources as needed to improve system profit. These alterations keep the network constraints fundamentally the same, however rather and a binary allocation decision variable, *w* becomes a flow variable that depicts the quantity of waste allocated from generators to recycling facilities. q_g is removed from the objective function and Constraints 3, 6, and 7, but introduced on the left-hand side of Constraint 3.

The formulation scenarios are applied to a randomly generated test network of eight food waste generators and three food waste recycling facilities to understand the effects of splitting and blending food waste streams in a small network. The food waste generators g1-g6 are comprised of two supermarkets, two restaurants, one university, and one hotel. Quantities of generated waste are estimated based on NYSP2I generation factors (18), and compositions are estimated from WRAP UK audit information (15). Food waste recycling facilities are m1-m3 comprised of one landfill, one compost facility, and one anaerobic digester. Although the landfill is not a preferred food waste management facility, landfills were included to manage any overflow that is not physically compatible with the available technologies. Landfills and anaerobic digesters produce methane gas which is sold to the market, and compost facilities and anaerobic digesters produce compost that is also sold to the market, constituting revenues per ton of \$4.60, \$16.20, and \$24.40 per ton of food waste delivered for landfills, compost, and aerobic digesters, respectively. Tipping fees for these same facilities are \$45/ton, \$51/ton, and \$40/ton, and transportation costs are set at \$0.20/ton-mile, averages of Western New York facilities obtained from a NYS Energy and Research Development Authority report (10). Euclidean distances from generators to recycling facilities are used as transportation distances.

As expected, when splitting and blending of food waste is permitted in Scenario 2 for the example network, the system cost is reduced compared to Scenario 1, but only by 4%. In Scenario 1, out of 23 total tons of food waste generated, 20 tons of food waste are transported to the anaerobic digester, and 3 tons are transported to the compost facility, leaving the landfill unused. In Case 2, 22.3 tons of food waste go to the anaerobic digester, leaving the remaining 0.7 tons to the compost facility. Counterintuitively however, transportation costs increase by 9% between the two scenarios, attributed to the allocation from compost to anaerobic digester. This result sets the expectation that transport costs will also increase for a real network.

The formulation under both scenarios is applied to the food waste system in Western New York to estimate the distribution of food waste given the currently existing facilities. 403 food waste generators of the same four types as the example network that produce more than one ton of food waste per week are considered. 48 total landfills, compost facilities, and anaerobic digesters are considered for recycling facilities. Locations and capacity information for both generators and recycling facilities are gathered from NYSP2I's database (18), monetary costs and revenues used are the same as in the example network, and shortest path origin-destination transportation distances are obtained from the real regional road network.

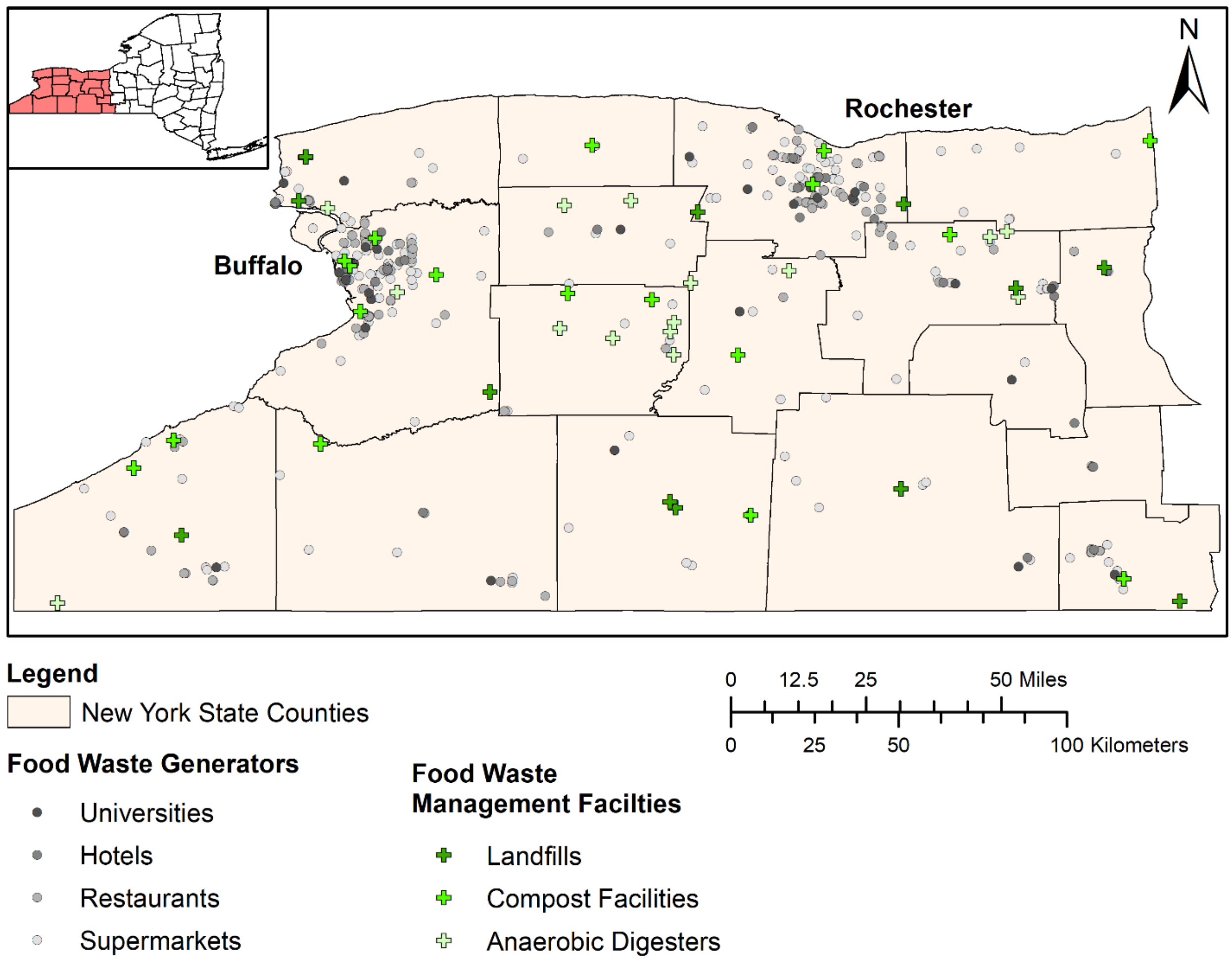

FIGURE 4 Map of Western New York Food Waste Diversion Network

Results indicate that splitting and blending of food waste in the Western New York region lowers the overall system cost by 4.1% over Scenario 1. Unlike the example network, transportation costs decrease by 1.8%, and the distribution changes from a small amount of food waste allocated to landfills and compost facilities to complete allocation of all 1340 tons of food waste to anaerobic digesters. The other 2.3% of cost decrease is attributed to the lower tipping fees and higher product sale price of products from anaerobic digesters. Although total network cost decreases are minimal in these scenarios, transportation costs comprise over 40% of cost decreases. Using customizable models allows hauling companies to assess cost changes when network conditions change. However, incorporating routing into the formulation is necessary to gain a complete picture of how costs will change. Likely, transportation costs will decrease due to combining trips to generators to utilize collection truck capacity.

6.0 CONCLUSIONS AND FUTURE RESEARCH

This paper draws attention to dilemmas that waste haulers will face when food waste becomes a third separate stream of municipal waste in addition to conventionally recycled materials and MSW. Increased interest in sustainability from businesses as well as food waste disposal bans by state governments will increase demand for these new collection services. Food waste, once transported and disposed of at landfills, will now be considered a resource for new recycling technologies that produce marketable products through industrialized processes. However, food waste recycling introduces considerable variability and complexity into the transportation logistics due to its variability in generation and recycling technology recipes. Waste hauling companies will need to alter current operations to take advantage of the service demand and maintain comparativeness with other waste service providers.

Research in other freight-related transportation fields can be leveraged to inspire methods for modeling network decisions to solve these dilemmas. Changing the view of food waste to resource allows for leveraging supply chain analysis to allocate food waste based on products made by recycling facilities and reduce transportation costs. Reverse logistics research characterizes the system in order to recapture value from waste, offering the most similar viewpoint from current research to food waste recycling. However, current freight transport research cannot adequately explain the food waste allocation, routing, and blending complexities that will become prevalent since conventional freight considers discrete units of cargo rather than a continuous resource.

Two models were presented to address issues relevant to emerging food waste recycling. A mathematical formulation is presented that combines allocation and blending; however, system and transportation costs only marginally decrease in the scenarios presented. Future research will focus on combining the allocation, routing, and food waste blending for collection services to understand potential network interactions and provide network information for making decisions.

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