Final Report

Innovative Methods for Delivering Fresh Foods to Underserved Populations

Hyeon-Shic Shin, Ph.D.
Morgan State University
hyeonshic.shin@morgan.edu

Paul M. Schonfeld, Ph.D.
University of Maryland, College Park
pschon@umd.edu

Young-Jae Lee, Ph.D.
Morgan State University
youngjae.lee@morgan.edu

Youngmin Choi
University of Maryland, College Park
cym@umd.edu

Nashid Khadem
Morgan State University
nakha3@morgan.edu

December 2019

1

ACKNOWLEDGMENT

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Innovative Methods for Delivering Fresh Foods to Underserved Populations		**5. Report Date** December 2019	
		6. Performing Organization Code	
7. Author(s) *Include ORCID #* Hyeon-Shic Shin https://orcid.org/0000-0003-2210-4911		**8. Performing Organization Report No.**	
9. Performing Organization Name and Address		**10. Work Unit No.**	
		11. Contract or Grant No. 69A43551747123	
12. Sponsoring Agency Name and Address US Department of Transportation Office of the Secretary-Research UTC Program, RDT-30 1200 New Jersey Ave., SE Washington, DC 20590		**13. Type of Report and Period Covered** Final	
		14. Sponsoring Agency Code	
15. Supplementary Notes			

16. Abstract:

Limited access to fresh food sources—ones within reasonable distances with reliable, affordable transportation—has become a public health concern. The negative associations between a lack of fresh food consumption and health are well known. Because certain demographic groups are disproportionately affected by the absence of stores selling healthy and affordable food, equity issues result. Many inner-city residents are left in neighborhoods devoid of such stores, and every day they are forced to trade off increased costs against healthy food consumption and health. This study aimed to develop a cost-effective last-mile fresh food delivery system to households in food deserts, which could help improve fresh food accessibility. Six alternative delivery modes—conventional trucks, e-bikes, shared-ride transit, parcel lockers, pop-up stores, and independently contracted drivers—were identified and optimized by employing Traveling Salesman Problem. Then we compared the results with the system's total costs. Sensitive analyses were conducted in terms of the time of delivery, zone size, user's value of time waiting for goods, the optimal number of lockers, costs associated with combined deliveries at lockers as well as customer addresses, and a second delivery attempt. Building on optimized modes, GIS network analyses were performed for randomly selected household locations in parts of poverty-prone West Baltimore. Numerical results showed that deliveries by trucks are the most cost-effective alternative, while the third-party deliveries ranked second. The two most expensive alternatives were shared-ride service and e-bike deliveries, based on the estimated costs of providing them.

17. Key Words: Food deserts, network optimization, network analysis		**18. Distribution Statement**	
19. Security Classif. (of this report): Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages**	**22. Price**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ABSTRACT

Limited access to fresh food sources—ones within reasonable distances with reliable, affordable transportation—has become a public health concern. The negative associations between a lack of fresh food consumption levels and health are well known. Because certain demographic groups are disproportionately affected by the absence of stores selling healthy and affordable food, equity issues result. Many inner-city residents are left in neighborhoods devoid of such stores, and every day they are forced to trade off increased costs against healthy food consumption and health. This study aimed to develop a cost-effective last-mile fresh food delivery system to households in food deserts, which could help improve fresh food accessibility. Six alternative delivery modes—conventional trucks, e-bikes, shared-ride transit, parcel lockers, pop-up stores, and independently contracted drivers—were identified and optimized by employing the Traveling Salesman Problem. Then we compared the results with the system's total costs. Sensitive analyses were conducted in terms of the time of delivery, zone size, user's value of time waiting for goods, the optimal number of lockers, costs associated with combined deliveries at lockers as well as customer addresses, and a second delivery attempt. Building on optimized modes, GIS network analyses were performed for randomly selected household locations in parts of poverty-prone West Baltimore. Numerical results showed that deliveries by trucks are the most cost-effective alternative, while the third-party deliveries ranked second. The two most expensive alternatives were shared-ride service and e-bike deliveries, based on the estimated costs of providing them.

1. INTRODUCTION

The limited access to fresh foods within a reasonable (physical and time) distance and at affordable prices for individuals living in underserved inner-city communities as well as remote rural areas, so-called "food deserts," has become a public concern. According to the Food and Nutrition Services (FNS) of the U.S. Department of Agriculture (USDA), a food desert is:

> "[A] low-income census tract where more than 20% of residents earn income at
> or below the federal poverty levels for family size, or at or below 80% of the
> surrounding area's median family income and where at least 500 persons or 33%
> of their population do not have a supermarket or large grocery store within one
> mile of their residence in urban areas or 10 miles in rural areas" (USDA 2017).

That is, household income, poverty, travel distance, and availability of supermarkets selling fresh foods are key contributing factors to food insecurity.

Public health researchers point out that fresh food insecurity contributes to unhealthy eating habits and chronic diseases like obesity (Bitler and Haider 2011, Hilmers, Hilmers and Dave 2012). People in food insecurity areas have better access to fast food, often within a few blocks, but no fresh food sources within a reasonable distance. The low reliability of and limited access to public transit in some neighborhoods as well as low vehicle ownership by individuals are often pointed out as barriers limiting fresh food access. Walking can be an alternative if fresh food sources are within walking distance. However, many elderly or disabled people cannot travel to grocery stores on foot. To address their limited mobility issues, delivering fresh food to their doorstep would be one of the best alternatives.

Because certain demographic groups are disproportionately affected by the lack of stores selling affordable healthy food, equity issues result. According to Feeding America (n.d.), in 2017, more than 40 million people (12.5%) in the United States faced food insecurity. Of concern is that more than one in six children (more than 12 million) lived in food-insecure households. In Baltimore City, in 2018, approximately 23.5% (146,000 people) lived in food deserts. Children accounted for 28.3% among all age groups. In addition, 31% of black residents had limited or no

access to fresh food sources, while only 8.9% of whites experienced the same issue (Misaszek, Buzogany and Freishtat 2018, 17).

While the profit-maximizing economic principle guides large grocers' location decisions, systemic inequity in low accessibility to fresh foods has emerged as an unintentional by-product. That is, a food desert is an example of market failure that warrants government involvement to improve equity—in other words, to reduce the social costs (e.g., health costs) associated with lower consumption of fresh foods.

Numerous studies in city logistics developed, piloted, and/or implemented solutions to last-mile issues. In addition, an increasing number of grocery chains and big box stores are providing fresh food delivery services. However, when it comes to addressing issues that cannot be solved by market principle, it is, indeed, the public sector's responsibility to mitigate mobility and accessibility issues for people in fresh food insecurity areas.

In this regard, this study aimed to develop cost-effective last-mile door-to-door fresh food delivery networks by examining six delivery alternatives. More specifically, the study's objectives were:
1. Design prototype system models for evaluating various alternatives;
2. Evaluate the developed models' sensitivity to various delivery operation conditions;
3. Conduct GIS network analysis using parts of West Baltimore as a case study; and
4. Make suggestions for further refinement of results for practical applications.

The following sections summarized the study process, results, implications, and suggestions. After discussing past studies, the following section presented the processes and results of modeling by discussing variable specifications, alternative delivery options, and their sensitivity to changes in operating conditions. Then, we elaborated upon the findings of the GIS network analysis for parts of West Baltimore as a case study area. Finally,this report discussed conclusions, suggestions, and future refinement of the study.

2. LITERATURE REVIEW

2.1 Past Studies on Food Deserts

Most food desert studies have focused on identifying and visualizing the food desert locations, compiling local food environment inventory, and conducting statistical analyses to examine socioeconomic characteristics (Moore, et al. 2008, Freedman and Bell 2009, Beaulac, Kristjansson and Cummins 2009, Gordon, et al. 2011). A few studies investigated the impact of supermarket closures on fresh food access (Guy, Clarke and Eyre 2004). Store closures left underserved individuals beleaguered and stuck in poverty-prone inner-city areas with no or limited fresh food options. Businesses follow where people (i.e., their customers) are moving. Continuing suburbanization has attracted larger grocery stores to automobility-dependent suburban communities (Furey, Strugnell and McIlveen 2001). A lack of accessible public transit within walking distance and low vehicle ownership have become barriers to residents traveling to large supermarkets in the suburbs (Weinberg 1995, Rose and Richards 2004).

Such barriers seem more likely to affect certain population groups. Indeed, quite a few studies pointed out accessibility disparities among different races and socioeconomic groups (Zenk, et al. 2005, Powell, et al. 2007, Hendrickson, Smith and Eikenberry 2006). Weinberg (1995) found that low-income neighborhoods have 52% fewer supermarkets for their needs while high-income neighborhoods have 156% more supermarkets. Predominantly black neighborhoods have less access to supermarkets than do white neighborhoods (Morland, et al. 2002). Similarly, the most underdeveloped black neighborhoods are approximately 1.1 miles farther from the nearest grocery store than are the most underdeveloped white neighborhoods (Zenk, et al. 2005).

Purchasing power is another contributing factor. With a void of grocery stores selling a variety of fresh foods at affordable prices, the most commonly available stores in food deserts are convenience stores or small corner stores. These stores tend to have fewer fresh food selections at generally higher prices (Kaufman 1998, Chung and Myers Jr. 1999, Hendrickson, Smith and Eikenberry 2006). People in food deserts have been forced to trade off increased costs against healthy food consumption and health. Food desert residents usually have no choice but to eat cheap and unhealthy processed items, which raises concerns about health issues such as obesity

and diabetes (A. M. Freedman 1991, Chung and Myers Jr. 1999, Lewis, et al. 2005, Block and Kouba 2006, Hilmers, Hilmers and Dave 2012).

2.2 Last-Mile Grocery Modes

An increasing number of large grocery chains and big box stores are providing online order and door-to-door delivery services. For example, Amazon.com launched Amazon Flex service in 2015 and since then has served more than 50 U.S. cities. The company hires independently contracted drivers. The drivers, with their cars, work around a three-hour time window covering small blocks of the compact delivery area and deliver an average of 40-50 packages (Amazon n.d.).

The most visible package delivery mode is straight trucks, vans, or often sedans. Depending on the built environment, however, non-motorized modes like cargo bikes have become a primary delivery mode, especially in European countries. While bikes have a smaller delivery coverage area than do cars, they have high potential in urban core areas with traffic congestion issues, limited spaces in loading zones, and narrow streets that are inappropriate for delivery vehicles. In Berlin, Germany, e-bikes cover two-thirds of delivery origins and destinations with an average delivery distance of 5.1 km (Gruber, Kihm and Lenz 2014). Moreover, 92% of e-bike delivery destinations were 10 km or less, compared to 56% of deliveries by conventional delivery vehicles.

In European countries, people's acceptance of both parcel lockers and package pick-up points has been increasing, primarily due to low delivery costs and low rates of missing items left on doorsteps (Morganti, Dablanc and Fortin 2014). A research team at the University of Washington evaluated the viability of providing parcel lockers near or at light rail stations in Seattle to examine the potential and transit users' acceptance, using a survey of 185 riders at three stations (Urban Freight Lab 2018). Approximately 67% of respondents at the University of Washington Station and nearly 50% at the other two stations would use or consider using lockers. More than 46% of the participants responded that 3-6 blocks to walk with packages could be bearable (i.e., about 0.68-1.37 kilometers), while at least one-fourth of the respondents were willing to walk a couple of more blocks.

2.3 Freshness of Goods and Delivery Frequency of Food Product Types

Freshness is particularly crucial in delivering fresh foods. Fancello et al. (2017) surveyed in Cagliari, Italy, the characteristics of food deliveries (e.g., delivery frequency, mode of transportation, etc.) and types of food. The study found fresh food items —such as fruits, vegetables, fish, and fresh baked goods—were more frequently delivered than other types of nonperishable products (e.g., dry goods or cured meat). In the private sector, for instance, Amazon.com has initiated a service called AmazonFresh that delivers items the same day with insulated packaging. In addition, a two-hour delivery service, including grocery deliveries, has been expanded recently for delivering items from Whole Foods Market, a supermarket chain that specializes in selling fresh and organic produce, meat, and everyday staples (Redman 2018). Similarly, meal-kit delivery companies have emerged since 2012, such as Blue Apron or Hello Fresh; the companies send customers pre-portioned food ingredients to prepare home-cooked meals in temperature-controlled packaging.

2.4 Value of Time Waiting for Groceries

The McKinsey & Company in 2016 surveyed 4,700 people in the U.S., Germany, and China to estimate their value of time on an unattended delivery (Joerss, et al. 2016). The survey found ambivalent, but provably apparent responses: The customers wanted a faster delivery, yet their willingness-to-pay was low. Approximately 50% of the U.S. consumers would generally pay extra for same-day delivery, but less than 15% would pay more than $1. Roughly 9% of consumers are willing to spend $5 on top of regular parcel delivery prices. Interestingly, people are willing to pay more for certain items. They would pay an extra $5 per fast delivery of groceries, small electronics, and automotive parts.Also, people preferred a direct home delivery to parcel lockers even at a lower price; about one-half respondents would use a locker service when a home delivery charges $3 more than a pick-up at lockers. The study estimated the user value of time is $0.6 per hour considering a working period of same-day delivery.

This section reviewed food deserts and related issues to be addressed. Also, attributes that may be relevant for this study's modeling were also reviewed—e.g., types of food, fast delivery, temperature control, delivery frequency, modes of transportation, workforce, and user

characteristics. Due to difficulties in modeling each one of produce items concerning the freshness over time, this study assumes insulated temperature-controlled packaging to deliver fresh goods.

3. ALTERNATIVE BUILDING AND EVALUATION

3.1 Alternative Descriptions

The study developed and considered six delivery alternatives: box trucks, e-bikes, shared-ride services, pop-up truck store deliveries, third-party car deliveries, and parcel lockers. Figure 1 presents conceptual drawings of the alternatives. Note that the study assumed that all deliveries start at the same depot, and there is only one depot where delivery items from other carriers are consolidated.
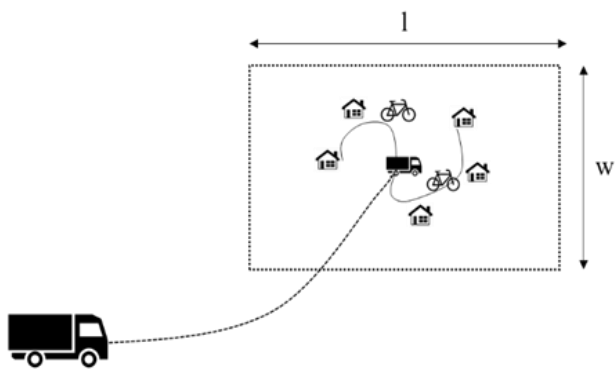
3.1.1 Truck Deliveries (Figure 1. a)

This alternative assumed that one delivery truck is assigned per each delivery tour with multiple destinations. The truck's maximum load is 2.5 tons of packages. A fully loaded truck can transport a total of 250 packages, each of which is 10 kilograms.

3.1.2 Electric Cargo Bike (e-bike) Deliveries (Figure 1. b)

In densely built inner-city areas with high traffic volume and narrow streets, deliveries by bikes—human-powered or electrically assisted cargo cycles—can be competitive. E-bikes are considered to be an environmentally friendly mode for urban parcel deliveries, due to their low emissions, reduced space requirements in loading zones or curbsides, and relatively low impact on roadway traffic. This type of delivery requires a micro-fulfillment center somewhere inside a service area (Conway, et al. 2012). Due to the e-bike's limited loading capacity (0.15 to 0.30 tons), frequent fulfillment trips to the depot may be necessary depending on the level of demand. In this study, we assumed that a stationed truck is a micro-depot where bikes replenish packages and complete the last legs of deliveries.

3.1.3 Shared-ride (SR) Deliveries (Figure 1. c)

Instead of delivering items to customers, this alternative considers collecting all the customers in service areas and bringing them to the nearest grocery stores. In this case, buses/vans travel from a terminal to the customer pick-up locations and bring them to the designated grocery store. After a certain amount of time, the buses bring those customers back to the original place.

(a) Truck deliveries
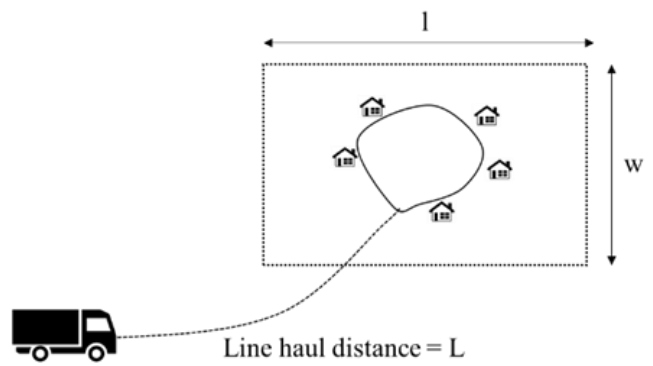
(b) e-bike deliveries
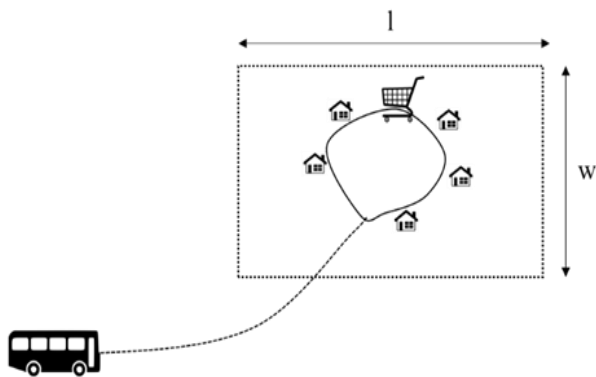
(c) Share-ride deliveries
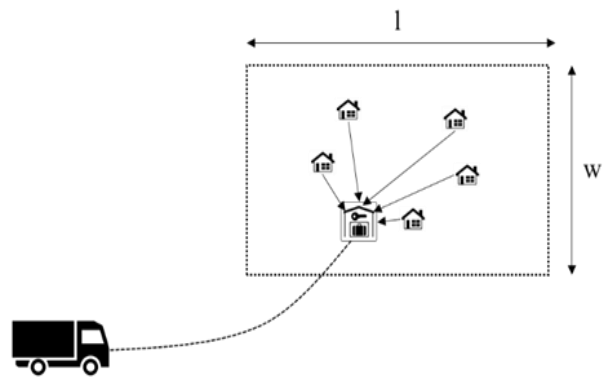
(d) Locker deliveries
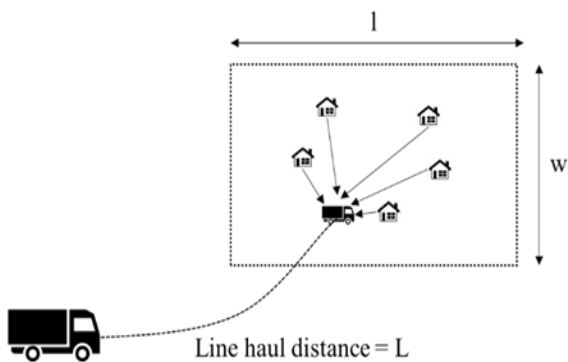
(e) Pop-up truck stores deliveries
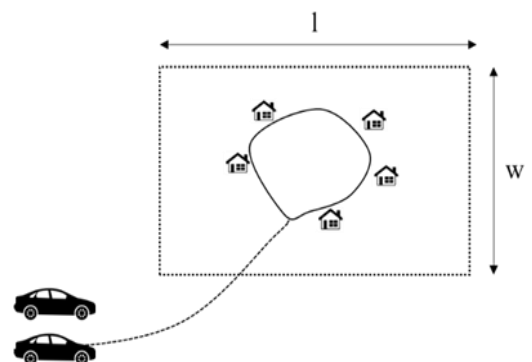
(f) Third party personal car deliveries

Figure 1 Types of delivery alternatives

3.1.4 Parcel Locker Deliveries (Figure 1. d)

A parcel locker is a self-service kiosk where customers scan their unique passcode to pick up packages at a time and place that is convenient for them. This type of delivery is regarded as an unattended delivery; deliveries are made when there is no one present, and users usually wait at home with little disruption to other activities. In this case, truck drivers drop off packages in lockers. Users then need to access the pick-up locations to receive their items. The costs related to the user's access to the locker were included in the cost function of this study's models.

3.1.5 Pop-up Truck Store (PTS) Deliveries (Figure 1. e)

Pick-up trucks stay at fixed locations for a certain amount of time and hand items over to users who come to receive groceries. After a certain amount of time, the trucks visit other locations and repeat the process. As discussed for the locker deliveries, the users' access costs were considered in the cost function of this study's models.

3.1.6 Third-party Delivery by Personal Car (TPC) Deliveries (Figure 1. f)

Service operators may serve the demands by using temporary drivers. The drivers receive assigned packages from a distribution center outside of a service area and deliver an average of 40-50 items during the shift.

3.2 Conceptual Network Model Building and Sensitivity Analysis

3.2.1 Assumptions for Delivery System

Conceptual networks were built based on six assumptions to mimic reality.

Assumption 1: The delivery demand is constant, independent of service quality variables (e.g., changes in vehicle operating speed, waiting time, etc.).

Assumption 2: The demand is uniformly distributed within the service area, and deliveries consist of one package per customer (i.e., per delivery point).

Assumption 3: From the depot (i.e., distribution center) to the demand points, delivery vehicles travel a round-trip line-haul distance and a Traveling Salesman Problem (TSP) tour at specified operating speeds.

Assumption 4: For e-bikes, travel time is not affected by either traffic or time of day.

Assumption 5: The number of stations in a service area is fixed for both parcel lockers and pop-up trucks, and the lockers are uniformly distributed within the service area.

Assumption 6: For parcel locker delivery, all deliveries are picked up by customers until the next scheduled delivery.

3.2.2 Baseline Numerical Values and Model Formulation

Table 1 Variable definitions and baseline values

Symbol	Variable	Units	Value	Range	Reference
		Decision Variables			
A	Size of Delivery Area	miles^2	-	-	
C_o	Operating Cost	$ / hr	-	-	
C_t	Total Cost	$ / hr	-	-	
C_w	Waiting Cost	$ / hr	-	-	
C_x	Access Cost	$ / hr	-	-	
h	Departure Interval	hr	-	-	
L	Average TSP Distance	miles	-	-	
N_{bike}	Number of Bikes	vehicles	-	-	
N_{bus}	Number of Buses	vehicles	-	-	
N_{locker}	Number of Lockers	stations	-	-	
$N_{station}$	Number of Bike Replenishment and Pick-up Truck Stations	stations	-	-	
N_{truck}	Number of Trucks	vehicles	-	-	
T_{rt}	Delivery Time	hrs	-	-	
		Input Variables			
B_{driver}	Driver Hourly Rate	$ / (truck · hr)	40	-	
D	Line-haul Distance	miles	10	-	
f	Overall Cost for TPC	$ / package	10.4	-	(Amazon (a) n.d.)
h_{min}	Min. Departure Interval	hrs	0.08	-	
l	Length of Service Area	miles	$\sqrt{Z}$	$\sqrt{5}$ - $\sqrt{50}$	
Q	Demand Density	packages / (mile^2 · hr)	20	$5-50$	
S_b	Bus Capacity	persons	40	-	(Colorado Department of

Symbol	Variable	Units	Value	Range	Reference
					Transportation n.d.)
S_{bk}	Bike Capacity	packages	20	-	(Amazon (b) n.d.)
S_l	Locker Capacity	packages	50	-	
S_p	Personal Car Capacity	packages	45	-	(Gruber, Kihm and Lenz 2014)
S_t	Truck Capacity	packages	250	-	
T_m	Dwell Time (Truck, Shared-ride, e-bike)	hrs / delivery point	0.05	-	(Siikavirta, et al. 2008, Boyer and Prud'homme 2009)
T_s	Dwell Time (Pick-up truck store)	hrs / delivery point	2	-	
T_w	Dwell Time (Bus, e-bike fulfillment, Locker)	hrs / delivery point	0.5	-	
T_x	Max. Allowable Access Time	hrs	0.17	-	(Chavis, et al. 2018)
V_d	Line-haul Speed	mile / hr	50	-	
V_k	Walking Speed	mile / hr	3	-	(FHWA 2006)
V_l	Local Speed	mile / hr	30	-	(Conway, et al. 2012)
v_x	User Value of Access Time	$ / (package · hr)	12	-	(Wardman 2001)
v_i	User Value of Riding Time	$ / (package · hr)	5	-	(Wardman 2001, Douglas and Wallis 2013)
v_u	User Value of Waiting Time	$ / (package · hr)	0.6	-	(Joerss, et al. 2016)
W	Working Hour	hrs / day	8	-	
w	Width of Study Area	miles	$\sqrt{Z}$	$\sqrt{5}$ - $\sqrt{50}$	
wgt	Average Package Weight	tons	0.01	-	
Z	Size of Service Area	miles^2	18	5 - 50	

Demands are determined as the product of demand density Q, service area Z, and vehicle departure interval h. The demands are served during regular shifts and assumed to be uniformly generated over time and space. A delivery area size per vehicle tour is estimated by dividing the size of the service area Z into the number of vehicles N_i, where i is a type of vehicles.

$$A = \frac{Z}{N_i}$$
Equation 1

Vehicles travel along a line-haul distance D to the first customer, and the remaining packages are delivered along a TSP route L at average line-haul speed V_d and local speed V_l, respectively. The vehicle returns to a depot along the same line-haul route after deliveries are completed. From these, vehicle round-trip delivery time T_{rt} is computed as follows. The configuration of delivery time is adjustable depending on delivery alternatives (shown in Figure 1) and will be discussed in a later section.

$$T_{rt} = \left(\frac{2D}{V_d} + \frac{L}{V_l}\right) + \frac{T_i(QZh)}{N_i}$$
Equation 2

The total number of vehicles serving the area, N_i, is an integer value estimated by incrementally adding a vehicle to the system until the delivery time is not exceeding the maximum working hours W or vehicle maximum capacity (i.e., S_b, S_{bk} S_l, S_p and S_t), and this results in a jump in cost. Dwell time per delivery point is the amount of time spent on last-mile deliveries and depends on delivery configuration. This estimation follows the same process for all delivery strategies.

The supply side of costs is modeled with cost functions associated with vehicle travel distance at various operating speeds, dwell times at delivery locations, and service frequencies, as well as the number and size of vehicles. For service alternatives that rely on single vehicles to serve multiple pick-ups or delivery points, the resulting tour lengths will be estimated with Stein's formula and its extensions. This formula approximates the length L of the shortest Traveling Salesman Problem (TSP) tour that connects n randomly located points in a zone whose area is A,

where k is a constant that depends on the local street pattern. For grid street networks, k is approximately 1.15 (Daganzo 1984). Stein's formula provides good approximations where the shape of the service area is "fairly compact and fairly convex." The delivery points are uniformly distributed, and the number of delivery points exceeds five.

The overall cost of the TPC delivery f includes packing, shipping, handling orders, customer service, and product returns; the exact cost per package is determined by package weight wgt (Amazon (a) n.d.).

3.2.3 System Constraints

For system constraints, each truck tour should be completed during the specified working hour W in constraint (Equation 3). The sum of the weights of packages (or passengers for shared-ride services) carried by vehicles should be within the vehicle's maximum capacity: constraint (Equation 4). Constraint (Equation 5) restricts user access time to at most a 10-min walk (Chavis, et al. 2018). Lastly, constraint (Equation 6) imposes that each alternative maintains a reasonable departure interval.

$$T_{rt} \leq W \qquad\qquad \textbf{Equation 3}$$

$$wgt \cdot (QhA) \leq S_i \qquad\qquad \textbf{Equation 4}$$

$$\frac{(w+l)}{4V_k\sqrt{N_i}} \leq T_x \qquad\qquad \textbf{Equation 5}$$

$$h > h_{min} \qquad\qquad \textbf{Equation 6}$$

where the subscription i denotes delivery alternatives. For shared-ride services, packages are replaced with bus passengers. Then, the average package weight wgt is no longer needed, which is set as one. The rest component QhA on the left-hand side of Equation 4 replaces with the number of passengers.

3.2.4 Cost Function

The cost function includes the supplier's and user's costs. Service provider cost considers the operation cost related to the number of operating trucks and drivers' hourly rate. The user cost can be represented as the cost of the time when users wait for deliveries C_w, in-vehicle riding C_r, or access to service facilities C_x. To sum up, the total cost is denoted as:

$$C_o = C_o + C_w + C_r + C_x \qquad\qquad \textbf{Equation 7}$$

It should be noted that the elements of the cost function are selectively applicable for each delivery alternative.

3.2.5 Truck Deliveries Formulation

User waiting cost is the only user cost in the truck deliveries alternative; therefore, the total cost C_t is the sum of service provider cost C_o and user waiting time C_w. The respective cost is found by:

$$C_o = \frac{B_{driver} \cdot N_{truck}\{T_{rt} + T_s(QhA)\}}{h} \qquad\qquad \textbf{Equation 8}$$

$$C_w = \frac{(QZh)v_u}{2} \qquad\qquad \textbf{Equation 9}$$

Equation 8 accounts for delivery costs as a multiplication of drivers' hourly charge, B_{driver}, and total delivery time spent over vehicle departure interval, $N_{truck}[T_{rt} + T_s(QhA)]$. The latter consists of travel time for each truck T_{rt}, and average unloading time per delivery point $T_s(QhA)$, denoted as T_m. Equation 9 explains the users' cost of unattended waiting time to receive packages.

3.2.6 e-bike as Last-mile Deliveries Formulation

In this alternative, deliveries are completed by deconsolidating packages from trucks and transshipping to e-bikes. Its total cost follows the same configuration as truck deliveries: $C_t =$

C_o+C_w. Since fulfillment for the bikes is conducted at the center of the service region, trucks travel back and forth between a center point and depot.

$$C_o = \frac{B_{driver}\left[N_{truck}\left(\frac{2D}{V_d}+Ts\right)+N_{bike}\left\{\frac{L}{V_l}+T_s(QhA)\right\}\right]}{h}$$

Equation 10

Cost elements follow the same process as the previous alternatives, and the user value of time of waiting is v_u.

3.2.7 Shared-ride Deliveries (SR) Formulation

The total cost of the shared-ride delivery alternative consists of user waiting time and in-vehicle riding time: $C_t = C_o+C_w+C_r$. Each demand point represents the user's pick-up location, and the size of user pick-up area A is governed by the number of the seats per bus S_b. Since the weight of passengers does not influence the bus capacity, the number of users in a study area determines the number of buses needed.

$$C_o = \frac{B_{driver}\left[N_{bus}\left\{\left(\frac{2D}{V_d}+\frac{2L}{V_l}\right)+T_w+T_s(QhA)\right\}\right]}{h}$$

Equation 11

$$C_r = v_i QZ\frac{L}{V_l}$$

Equation 12

In Equation 11, average TSP distance L is doubled due to returning users back to their origins, and two types of dwell time are used: T_s for pick-up and T_w for holding drivers at the stores (drivers waiting near supermarkets). The in-vehicle cost explains the average time spent by users, half the round-trip travel time in buses with a value of time for in-vehicle riding time v_i. Note that the value of time for bus waiting becomes v_{aw}. Although the value might be underestimated, users are waiting at convenient places without disruption to other activities.

3.2.8 Parcel Locker Deliveries Formulation

Users in locker deliveries need to access the nearest locker, which incurs additional user cost as follow: $C_t = C_c+C_o+C_w+C_x$.

$$C_o = \frac{B_{driver}\left[N_{truck}\left\{\left(\frac{2D}{V_d}+\frac{L}{V_l}\right)+T_m \cdot N_{locker}\right\}\right]}{h}$$

Equation 13

$$C_x = \frac{v_x(QZ)(w+l)}{2V_k\sqrt{N_{locker}}}$$

Equation 14

Average dwell time per locker T_m is set as a larger value than to other types of deliveries (Equation 15); a delivery person would place items in bulk in each locker. Also, notice that average TSP distance L is a distance for visiting all the lockers. The users' access distance is estimated by the length of the walk, which is a quarter of the width and length of a service area, divided by the square root of the number of lockers in a system. Then, user access cost is derived as user access time multiplied by the value of time for access. Unlike the truck delivery, the user value of time for locker deliveries becomes v_{aw} because a user's decision to access the locker is dependent on delivery completion.

3.2.9 Pick-up Truck Store (PTS) Formulation

Pick-up trucks have identical cost functions to locker delivery: $C_t = C_c + C_o + C_w + C_x$. Average TSP distance L for designated lots is a distance visiting all the stations.

$$C_o = \frac{N_{truck} \cdot B_{driver}\left\{\left(\frac{2D}{V_d}+\frac{L}{V_l}\right)+T_m\right\}}{h}$$

Equation 15

The user's value of waiting time becomes v_u.

3.2.10 Third-party Delivery by Personal Car (TPC) Formulation

Since a delivery person for the third-party deliveries does not get paid an hourly rate as discussed in the alternative descriptions, this type of service sums up all the cost elements first, and the cost may be divided by working hour for a comparison with other alternatives; the user's waiting and both fixed and variable costs associated with the delivery would be imposed.

$$C_o = \frac{fQZ}{W}\left(\frac{D}{2V_d} + \frac{L}{2V_l} + \frac{T_s(QhA)}{2}\right)$$

Equation 16

$$C_w = \frac{QZv_u}{W}\left(\frac{D}{2V_d} + \frac{L}{2V_l} + \frac{T_s(QhA)}{2}\right)$$

Equation 17

Note that the number of vehicles (or drivers) to be hired does not affect the operating cost.

3.2.11 Results

The vehicle departure intervals h, which minimizes the total cost function as well as meeting the imposed constraints, was found by differentiating the objective function C_t with respect to vehicle departure interval.

The results of the alternatives are specified by using the baseline inputs in Table 2. For truck delivery, one truck with a departure interval of 0.32 hours and delivery area of 18 mile^2 can optimize the system cost at \$1,023 per hour. Travel distance per vehicle tour is computed as 72.4 miles, by adding the average TSP distance to twice the line-haul distance. Travel time per vehicle tour is 7.9 hours. Note that average packages per vehicle indicates how many items or passengers are loaded per vehicle. In this h and A combination, the operating and user waiting costs consist of 96.6% and 3.4%, respectively, of the total cost. Although delivery by e-bikes needs a larger bike fleet size than by trucks, the service provider cost per delivery is smaller than that of trucks due to a large value of departure interval (e.g., consolidated shipping). Third-party delivery has the lowest total cost and cost per delivery among home deliveries. Note that a fleet size of 64 is not necessarily the number of drivers to be hired, but the total number of delivery tours that should be made during working hour W. Shared-ride service is the most expensive alternative per person due to its relatively large portion of a user's riding cost with the returning trips. The service provider cost per package for parcel lockers is the second-lowest, and the majority fraction of cost per delivery consists of user cost. The pop-up truck store ranks second-highest, but the service operator cost is the lowest. Note that user access cost C_x for the lockers and pop-up stores is identical from Equation 14.

Table 2 Results of alternatives

|	Home-delivery			In-store Service		User pick-ups and drop-offs	
	Truck	e-bike (bike & truck)		TPC	SR	Locker	PTS
Departure Interval, h (hr)	0.32	0.61		-	0.09	0.69	1.38
Delivery Area, A (mi^2)	18	18	1.64	0.28	18	18	9
Travel Distance (mi/vehicle tour)	72.4	-	20	24.1	47.8	29.8	26.9
Avg. TSP distance, L (hr/vehicle tour)	52.4	21.8	-	4.1	27.8	9.8	6.9
Travel Time, T_{rt} (hr/vehicle tour)	7.9	1.72	0.9	0.34	4.37	2.73	4.63
Number of vehicles, N_i	1	11	1	64	1	4/1 (locker/truck)	4/2 (PTS/truck)
Avg. Packages per vehicle	115	20	220	45	32 (persons)	248	248
Load factor (%)	46.1	100	87.8	100	81	99.4	99.4
Costs Elements (%) Operating, C_o	96.6	95.2		93.1	53.7	10.3	9.4
Costs Elements (%) Waiting, C_w	3.4	4.8		6.9	0.3	4.8	9.3
Costs Elements (%) Access, C_x	-	-		-	-	84.9	81.3
Costs Elements (%) Riding, C_r	-	-		-	46	-	-
Total Cost ($/hr)	1,023	1,369		640	3,619	1,542	1,611
Service Provider Cost ($/package)	8.57	5.93		1.68	59.97	0.64	0.31
Cost per delivery ($/package)	8.87	6.23		1.78	111.69 ($/person/round-trip)	6.21	3.24

Note: TPC = third-party deliveries by personal car, SR = shared ride services, PTS = pick-up truck store

3.3 Sensitivity Analyses

3.3.1 The Effects of Zone Size

This analysis found the adequate size of a service area Z and a relation between the zone size and associated costs. A zone size determines the number of packages generated in the service area. In Figure 2 (a), total cost increases with zone size. The jumps in cost correspond to the vehicles incrementally added to the system. More distinctive jumps are observed for the lockers and pick-up truck stores due to an increase in the number of lockers and stations; user riding cost decreases as more lockers and stations are deployed in a service region based on the constraints. The constant bike fleet size is detected beyond 23 mile^2 as shown in Figure 2 (c). Beyond this point, e-bikes begin delivery tours with shorter departure intervals. Since the vehicle fleet size for third-party delivery is not dependent on departure intervals, the vehicles linearly increase with zone size.

Thus, more vehicles and more frequent trips are required as zone size increases. Shared-ride services would not be a cost-effective option as the size of the service area increases since total cost increases faster than for the other alternatives.
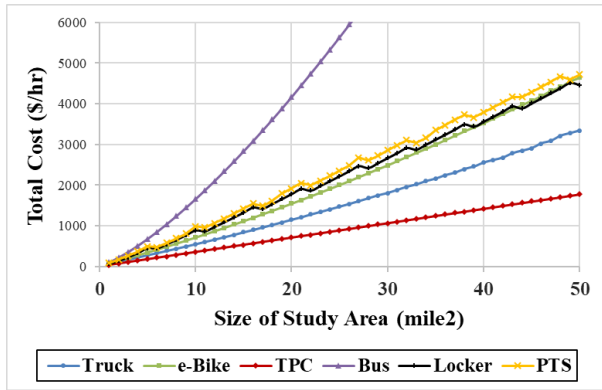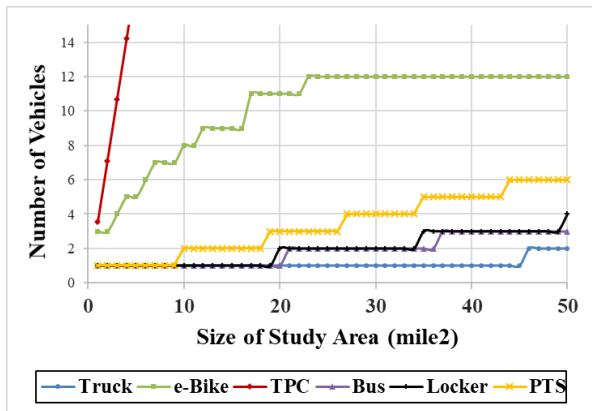
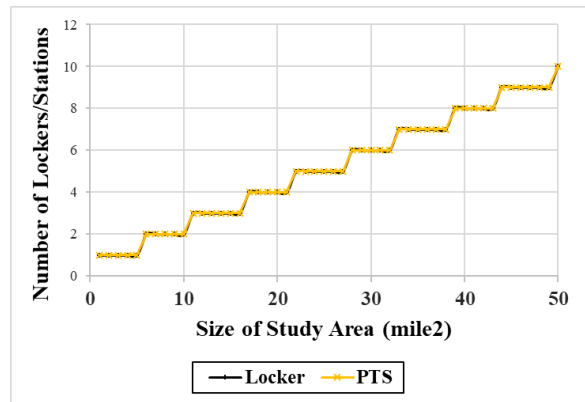*Total cost for buses increases up to $14,578/hr*

(a) Total cost
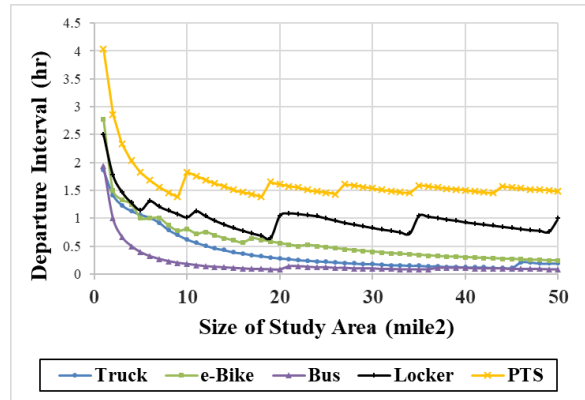
(b) Departure interval

*The number of vehicles for TPC increases up to 178*

(c) Number of vehicles

(d) Number of lockers & stations

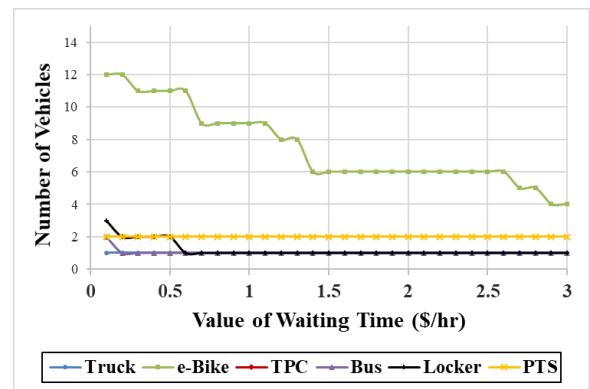**Figure 2 Cost functions for the differences in zone size**

3.3.2 User's Value of Time for Unattended Waiting

Customers value waiting times for goods differently (Joerss, et al. 2016). The number of vehicles needed generally decreases with user costs associated with the value of time as shown in Figure 3 (b). For the third-party delivery, the fleet size remains constant at 64 vehicles since the fleet is solely determined by the number of parcels generated in a system and vehicle capacity. A slight change in departure interval is observed in truck deliveries from 0.32 hours to 0.30 hours, but the truck fleet size stays unchanged in this range. Similarly, delivery trucks in pop-up truck stores remain constant since none of the constraints is violated at the given range of value of times. Unlike the changes in the truck fleet for parcel lockers, the fleet size for the pick-up stores remains constant

In summary, departure intervals decrease with a higher value of waiting time. Therefore, vehicles conduct frequent delivery tours.
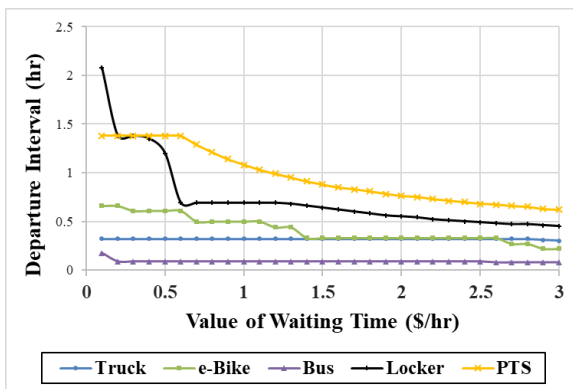
(a) Departure interval   (b) Number of vehicles

Figure 3 Cost functions for the differences in user's value of time

3.3.3 Combined Deliveries by Trucks

Trucks can deliver or fulfill items to other types of stations, parcel lockers or pick-up trucks on the way to customers' locations. This analysis is designed to explore trucks performing more than a single task in terms of cost-effectiveness, assuming that demands are equally divided by

the number of existing alternatives, while the baseline inputs remain unchanged. For instance, total demands for each delivery option would be assigned half the given two modes of transportation; the related delivery time and stops increase.

For scenario 2, trucks provide door-to-door services while delivering items to lockers. Scenario 3 is that trucks serve both door-to-door and pick-up store delivery services. The fourth scenario is that trucks deliver goods to parcel lockers and pick-up trucks. Note that the cost for operating each alternative is added up.

Table 3 Results of truck delivery

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
		T & L	T & PTS	L & PTS	T & L & PTS
Departure Interval (hr)		0.87	1.77	2.08	1.88
Area (mi^2)		6	4.5	6	2.6
Travel Distance (mi/vehicle tour)		70.2	81.8	28	68.3
Avg. TSP distance (mi/vehicle tour)		50.2	61.8	8	48.3
Travel Time (hr/vehicle tour)		8	4.9	4	4.8
Number of vehicles		3-Apr	4-Apr	3-Apr	4/4/2007
		(L / T)	(PTS / T)	(L / T)	(L / PTS / T)
Load factor (%)		41.8	63.7	99.8	38.7
Costs Elements (%)	Operating	59.5	32.3	13.1	52.5
	Waiting	5.1	15.3	12.7	9
	Access	35.4	52.4	74.2	38.5
Cost ($/hr)		1,192	594	1,765	1,392
Service Provider Cost ($/package)		3.81	0.3	0.31	1.08
Cost per Delivery ($/package)		2.26	0.93	2.36	2.06

* Note: T = truck deliveries, L = parcel lockers, PTS = pick-up truck stores

Departure intervals increase as trucks conduct more tasks. As a result, costs per delivery decrease with a large consolidation compared to the results in Table 2. In short, combined deliveries are beneficial compared to truck delivery with a single task.

3.3.4 Sensitivity for a Failure of Attempted Delivery for Door-to-door Services

In case customers are unable to receive items from a first delivery attempt—for instance, appropriate recipients are not home—service operators need to redeliver the packages. These attempts inevitably increase delivery costs, and this section explores how much each door-to-door alternative would cost. Unlike non-perishable goods that would be delivered on the next business day, fresh food delivery is time-sensitive to reduce food spoilage. Hence, the redelivery should occur on the same day, and the second attempt could be made with various options: a) either by trucks, e-bikes, or third-party deliveries in the next delivery schedule or b) by delivering the goods to lockers (Butrina, et al. 2017). For simplicity in analysis, a delivery person completes a tour and brings the items back to a depot; that is, the packages wait for the next delivery schedule. To do so, we increase demand density Q without adjusting the optimized departure interval h. That is, we maintain the current departure interval h to be unchanged at the optimal solution presented in Table 3. If the new solution violates any of the imposed constraints, we assign one more vehicle to serve the extra deliveries. Although a recent finding reports that the failure rate is up to 15% in metropolitan areas (Urban Freight Lab 2018), the failed first delivery rates in this section range from 0% (baseline) to 100% by 20%.

(a) Total Cost   (b) Number of Vehicles
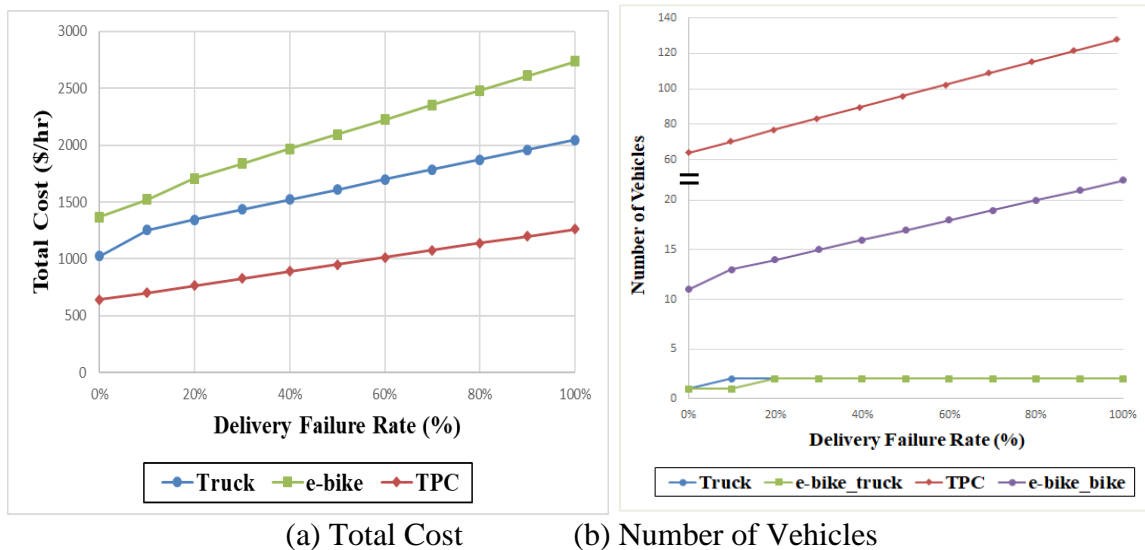
* Note: TPC = third-party personal car

Figure 4 Cost functions in response to delivery failure rate

Total system cost increases as the failure rate rises (Figure 4) This results in allocating additional vehicle fleets in a system. The rates of increase for truck and e-bike deliveries are fast, below at 20% of the failed first delivery rates since the delivering trucks should be deployed accordingly. Beyond that point, total costs for all the alternatives grow linearly with redelivery.
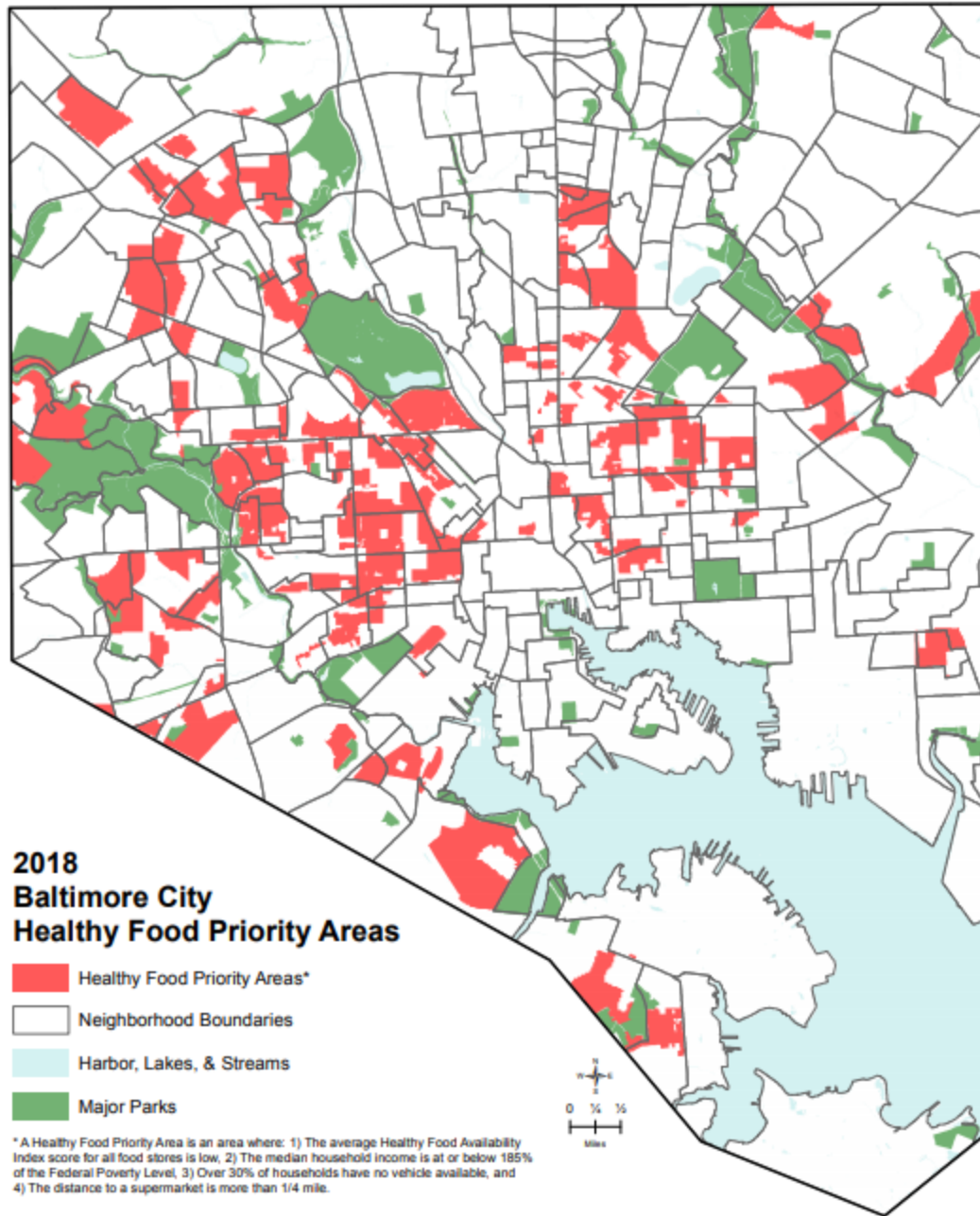
5. CASE STUDY: CITY OF BALTIMORE

This case study was built on assumptions and results presented in Chapter **3. ALTERNATIVE BUILDING AND EVALUATION**This case study compared delivery performances by trucks, e-bikes, pick-up buses, lockers, pop-up trucks, and third-party personal car delivery.

5.1 Study Area

Baltimore City replaced the term "food desert" with Healthy Food Priority Area (HFPA). The rationale is that the lack of food access is a structural inequity issue, not a natural phenomenon (Misaszek, Buzogany and Freishtat 2018). With that said, in this case study, HFPA is referring to a food desert.

While the definition of HFPA is similar to the USDA's or other public entities, HFPA was further refined by adding the Healthy Food Availability Index (HFAI) that reflects the availability of fresh food in stores across Baltimore City (Misaszek, Buzogany and Freishtat 2018). The HFPA is defined as "an area where the distance to a supermarket or supermarket alternative is more than a ¼ mile, the median household income is at or below 185% of the Federal Poverty Level, over 30% of households have no vehicle available, and the average Healthy Food Availability Index (HFAI) score for all food stores is low" (Misaszek, Buzogany and Freishtat 2018). Figure 5 shows the locations of HFAI in 2018. In the map, the areas in red are HFAI. According to the latest report (Misaszek, Buzogany and Freishtat 2018) estimated that in 2018 approximately 23.5% (146,000 people) of Baltimoreans live in a HFPA. The report revealed the most vulnerable groups disproportionately affected by low fresh food access (Misaszek, Buzogany and Freishtat 2018, 17). First, children are the most vulnerable age groups, accounting for 28.3% among all age groups. Second, among all race/ethnic groups, blacks are the most likely to live in a HFPA.

2018
Baltimore City
Healthy Food Priority Areas

🟥 Healthy Food Priority Areas*

⬜ Neighborhood Boundaries

🟦 Harbor, Lakes, & Streams

🟩 Major Parks

* A Healthy Food Priority Area is an area where: 1) The average Healthy Food Availability Index score for all food stores is low, 2) The median household income is at or below 185% of the Federal Poverty Level, 3) Over 30% of households have no vehicle available, and 4) The distance to a supermarket is more than 1/4 mile.

0 ¼ ½
Miles

Source: Johns Hopkins Baltimore City Food Desert Map 2018
Figure 5 Healthy Food Priority Areas in Baltimore

This study took a one square kilometer area in West Baltimore as a study area (**Error! Not a valid bookmark self-reference.**). The blue dots in the map represent the locations of households that were randomly sampled. This area consists of Dickeyville, Purnell, West Forest Avenue, Wakefield, Windsor Hills, and a part of Franklintown. Dickeyville is an area in West Baltimore City with a population of 47,848 of whom 21,881 are male and 25,967 are female. Purnell has a population of 849, West Forest Park 2,408, Wakefield 1,772, Windsor Hills 1,552, and Franklintown 1,282. These areas are predominantly black with a declining economy.
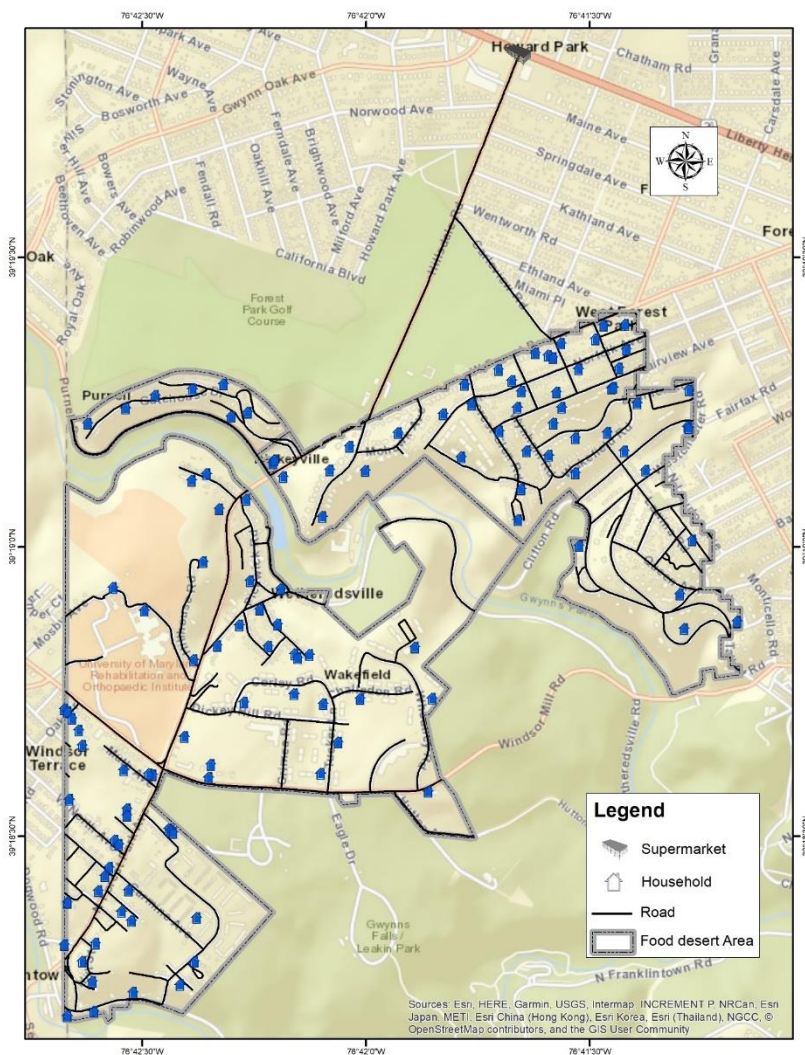

Figure 6 Study area map

5.2 Calculating Travel-time and Distance

As stated earlier, assumptions and base objective functions and constraints discussed in Chapter **3. ALTERNATIVE BUILDING AND EVALUATION**were also utilized for the case study. We calculated the travel time and distance by employing "Traveling Salesman Problem." The optimized outputs were obtained from network analyses using the Network Analyst, an extension for ArcGIS. This extension enabled us to conduct network-based spatial analysis to find the most efficient routes by delivery alternative. Using a GIS road network obtained from Open Baltimore (data.baltimorecity.gov), we created a network dataset to meet the requirements of the Network Analyst. The analyses were performed assuming typical Monday 10 AM traffic conditions. The delivery points' sequential numbering was automatically generated from the "New Route" tool once the point locations were uploaded. Figure 7 presents the analyses results by six alternatives.

In the truck delivery system, the delivery truck visits each delivery point. It is assumed that each truck can load up to 120 packages. Trucks travel from the depot a line-haul distance L at an average speed of V to a corner of the delivery area shown in Figure 7 (a). Then, the truck drivers drop off groceries at each doorstep. The e-bike delivery needs a micro-fulfillment center inside the service area. One stationed truck is used as a micro-depot, and frequent fulfillment trips to the truck are generated. E-bikes serve only last-mile deliveries (Figure 7 (b)). The third-party service operators may serve the demands by using temporary drivers. The drivers receive assigned packages from a distribution center outside of a service area and deliver an average of 40-50 items during their shift (Figure 7 (c)).In a pick-up bus system, a pick-up bus collects all customers from designated stops and brings them to the nearest grocery (Figure 7 (d)). In this case, buses travel from the terminal a line-haul distance L at an average speed of V to a corner of the customer pick-up locations. Each vehicle completes its tour by connecting to a local store. After a certain amount of time, the buses bring those customers back to the original place. Parcel lockers are available for unattended parcels; the customer can scan their unique passcode and pick up packages. In this case, a truck driver drops off all the items in designated lockers (Figure 7 (e)). The costs related to the user's access to the locker are included in the cost function. Pop-up trucks stay at fixed locations for a certain amount of time and hand items to users who come to receive groceries (Figure 7 (f)). After a certain amount of time, the trucks visit other locations and repeat the process.
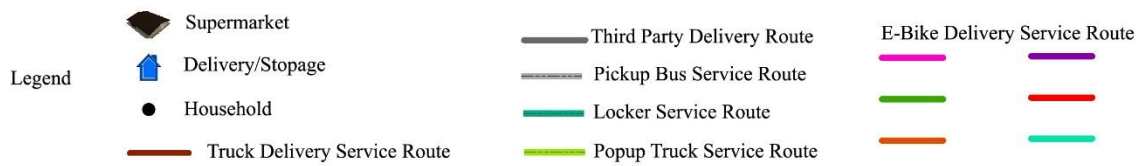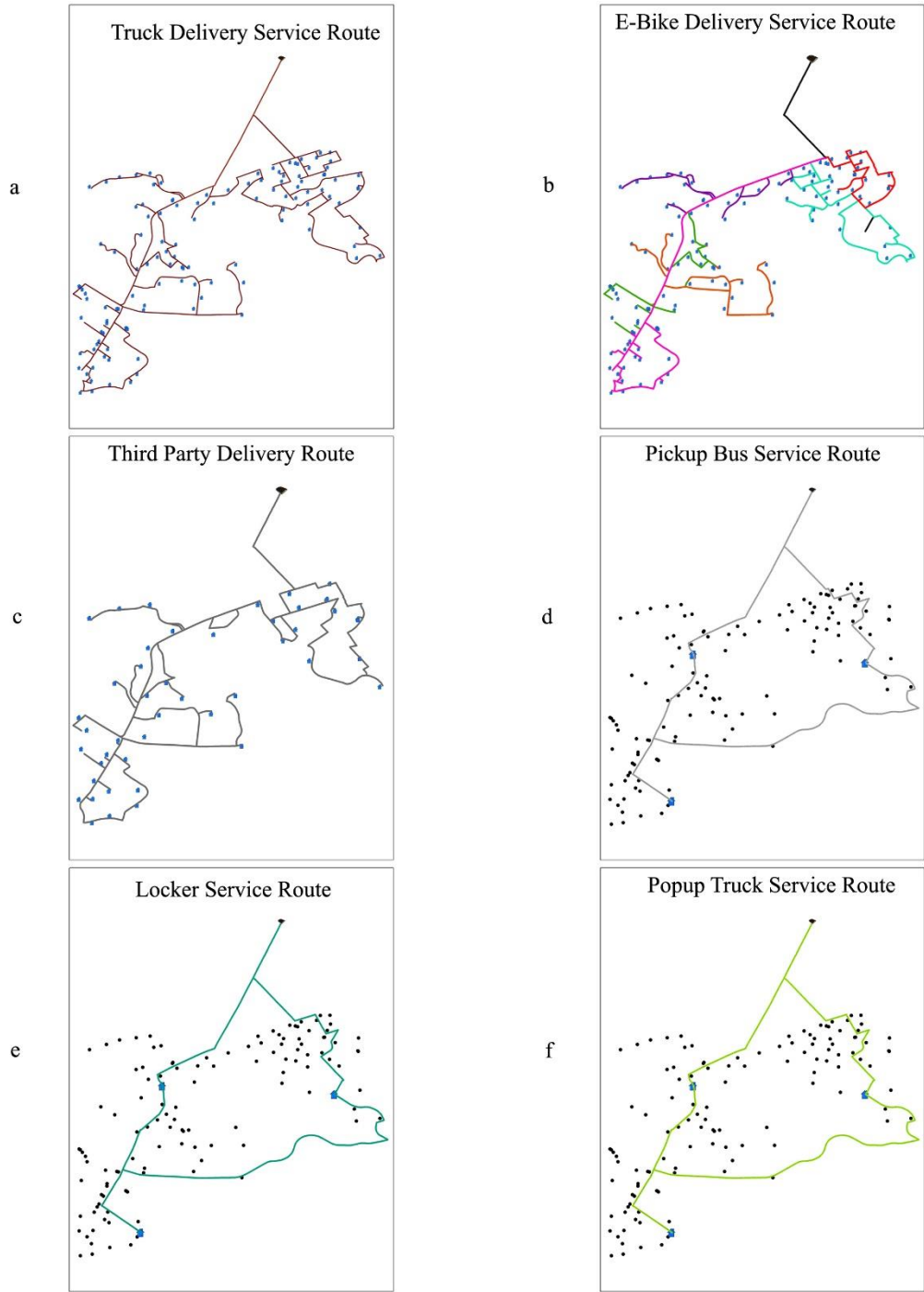
Figure 7 Types of mode with travel routes

5.2 Results

The results of the alternatives are summarized in Table 4. For truck delivery, one truck with a departure interval of an hour and delivery area of one square mile can optimize the system cost of $1,831.26 in almost six hours, that is $325/hr or $15.26 per package. Travel distance per vehicle tour was calculated as 15.24 miles with 6.5-hour travel time. E-bike also costs $1,382/hr as it has truck cost as well as bike cost. One bike needed six rounds to deliver all 120 packages, which required $27.79 for each package. Here the shared vehicle/pick-up bus is the most expensive, which is $2,132 per hour. The second-most-expensive option is the locker, which costs $44.79 per package. However, the third-party appears to be the less expensive mode at $12.41 per package, but the pop-up truck has the lowest operating cost, which is $104.63.

Table 4 Cost calculation of fresh food delivery

Variables	Home delivery				In-store Pickup & Drop off	User Pick up & drop off	
	Truck	E-bike truck	e-bike	3rd party	Pick-up Bus/shared a ride	Locker	Pop-up Truck
Departure Interval, h (hr)	1	1	-	-	1	1	1
Delivery Area, A (mi2)	1	1	1	1	1	1	1
Travel Distance (mi/tour)	14.98	0.99	24.76	13.59	5.75	5.74	5.75
Avg. TSP distance, L (mi/tour)	15.54	-	19.22	12.58	4.36	4.97	4.97
Travel Time, Trt (hr/tour)	5.64	0.04	8.69	3.45	0.82	5.23	6.23
Number of vehicles, Ni	1	1	1	1	1	4/1	4/1
Avg. Packages per vehicle	120	120	20	45	32	120	120
Load factor (%)	-	-	-	-	-	-	-
Operating, Co	1825.20		3323.13	528.06	1727.60	110	104.63
Capital cost, Cc	-	-	-	-	-	5349.89	3979.45
Waiting Cost, Cw	6		12	30.46	6	6	6
Access Cost, Cx	-	-	-	-	-	20	20
Riding Cost, Cr	-	-	-	-	14.53	-	-
Cost ($/hr)	325		382	161.89	2,132	1,049	660
Cost per package ($/hr)	15.26	27.79	-	12.41	54.63	44.80	34.25

6. CONCLUSIONS

Limited access to fresh food sources within reasonable distances with reliable, affordable transportation has become a public health concern. Past studies found negative associations between lower fresh food consumption levels and health—e.g., obesity. Moreover, the studies pointed out areas with a paucity of fresh food—a so-called food desert—are clustered in minority neighborhoods. Certain age groups, races, and ethnic populations living in food deserts are disproportionally affected by the lack of access to fresh foods.

Location decisions of businesses are made based on the economic principle of profit maximization; thus, they have relocated where most people live because of continuing suburbanization. However, many inner-city neighborhoods have been left devoid of accessible stores that sell fresh foods. People in food deserts must make trade-offs between their health and costly fresh foods available in convenience stores and small corner stores.

This study aimed to develop a cost-effective last-mile fresh food delivery system that addresses the lack of mobility and mitigates issues associated with food deserts. Six alternative combinations of delivery modes—conventional trucks, e-bikes, shared-ride transit, parcel lockers, pop-up stores, and independently contracted drivers—were identified and optimized by employing the Traveling Salesman Problem. Then we compared the results with the system's total costs—i.e., the user's and services provider's. Sensitive analyses were conducted in terms of 1) time of delivery, 2) zone size, 3) user's value of time waiting for goods, 4) the optimal number of lockers, costs associated with, 5) combined deliveries at lockers as well as customer addresses, and 6) re-delivery resulting from the failure of the first attempt. Building on optimized modes, GIS network analyses were performed for randomly selected household locations in parts of poverty-prone West Baltimore.

Numerical results show that delivery by truck is the most cost-effective option for delivering fresh items, while the third-party delivery ranks second. Shared-ride services and electric cargo bicycles are far more expensive than truck delivery. For delivering items late at night, a driver's hourly rate is a significant factor in determining operating costs, while other variables associated with a delivery time have less impact on total costs. Cost per delivery decreases as service

operators either cover the large size of a zone or densely populated areas; the numbers of parcel lockers and fulfillment centers should be increased with zone size. A vehicle departure interval is relatively insensitive to a change in the user's value of waiting time since the operator's cost contributes a large share of total costs. The study also examines whether truck delivery can perform multiple tasks—i.e., delivering items to customers and fulfillment centers in a single delivery tour—and the benefits from consolidation are presented. The cost for redelivery by e-bike increases faster than the other home deliveries that include truck and third-party delivery.

Further extension of this study may include the following. By applying real-world inputs to the suggested model, more specific variables may be considered such as the effects of roadway network configuration or dividing service areas into several sub-areas. In addition, sensitivity to changes in public policy variables such as tax incentives to participating grocers needs to be considered to identify a practical business model that public agencies can manage in collaboration with carriers and grocers. Although the study assumes that all packages are insulated with appropriate temperature-controlled packaging similar to private meal-kit delivery services, researchers may consider deliveries without the packaging. Then, the mandatory completion time for a delivery tour can be imposed in the model. Finally, the user's value of time for unattended waiting may be explored.

REFERENCES

Alwitt, L.F., and T. D. Donley. 1997. "REtail stores in poor urban neighborhoods." *Journal of Consumer Affairs* 31 (1): 139-164.

Amazon (a). n.d. *Fulfillment by Amazon.* https://services.amazon.com/fulfillment-by-amazon/pricing.html.

Amazon (b). n.d. *Deliver smiles with Amazon Flex.* https://flex.amazon.com/.

Amazon. n.d. *Amazon Flex.* https://flex.amazon.com.

Beaulac, J., E. Kristjansson, and S. Cummins. 2009. "Peer reviewed: A systematic review of food deserts, 1966-2007." *Preventing Chronic Disease* 6 (3).

Bitler, M., and S. J. Haider. 2011. "An economic view of food deserts in the United States." *Journal of Policy Analysis and Management* 30 (1): 153-176.

Block, D., and J. Kouba. 2006. "A comparison of the availability and affordability of a market basket in two communities in the Chicago area." *Public Health Nutrition* 9 (7): 837-845.

Boyer, K. K., and A.M. Prud'homme. 2009. "The last mile challenge: Evaluating the effects of customer density and delivery window patterns." *Journal of Business Logistics* 30 (1).

Butrina, P., G. Girón-Valderrama, J. Machado-León, A. Goodchild, and P. Avvalasomavaiula. 2017. "From the last mile to the last 800 ft: Key factors in urban pickup and delivery of goods." *Transportation Research Record: Journal of the Transportation Research Board* 2609: 85-92.

Centers for Disease Control and Prevention. 2017. *A look inside food deserts.* cdc.gov/features/fooddeserts.

Chavis, C., T. Davis, T. Norris, and A. Jones. 2018. "An analysis of food accessibility using the USDA Food Acquisition and Purchase Survey." *Transportation Research Board 97th Annual Meeting*.

Chung, C., and S. L. Myers Jr. 1999. "Do the poor pay more for food? An analysis of grocery store availability and food price disparities." *JOurnal of Consumer Affairs* 33 (2): 276-296.

Colorado Department of Transportation. n.d. "Overview of transit vehicles." *Colorado Department of Transportation.* https://www.codot.gov/programs/commuterchoices/documents/trandir_transit.pdf.

Conway, A., P. Fatisson, P. Eickemever, J. Cheng, and D. Peters. 2012. "Urban micro-consolidation and last midle goods delivery by freight-tricycle in Manhattan: Opportuniteis and challenges." *Transportation Research Board 91st Annual Meeting.* Washington, D.C.

Daganzo, C. F. 1984. "The length of tour in zones of different shapes." *Transportation Research Part B* 18 (2): 135-145.

Douglas, N. J., and I. P. Wallis. 2013. "Predicting the value of public transport in-vehicle time." *Australasian Transport Research Forum.* Brisbane, Australia: Australasian Transport Research Forum.

Fancello, G., D. Paddeu, and P. Fadda. 2017. "Investigating last food mile deliveries: A case study approach to identify needs of food delivery demand." *Research in Transportation Economics* 63: 56-66.

Feeding America. 2019. "Child food insecurity." https://www.feedingamerica.org/sites/default/files/2019-05/2017-map-the-meal-gap-child-food-insecurity_0.pdf.

—. n.d. *Food insecurity in the United States.* https://map.feedingamerica.org/.

FHWA. 2006. *Federal Highway Administration university course on bicycle and pedestrian transportation.* Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/safety/pedbike/05085/pdf/lesson8lo.pdf.

Freedman, A. M. 1991. "The poor pay more for food in New York, survey finds." *The Wall Street Journal*, B1.

Freedman, D. A., and B. A. Bell. 2009. "Access to healthful foods among an urban food insecure population: Perceptions versus reality." *Journal of Urban Health* 86 (6): 825-838.

Furey, S., C. Strugnell, and M. H. McIlveen. 2001. "An investigation of the potential existence of "food deserts" in rural and urban areas of Nothern Ireland." *Agriculture and Human Values* 18 (4): 447-457.

Gordon, C., M. Purciel-Hill, N. R. Ghai, L. Kaufman, R. Graham, and G. Van Wye. 2011. "Measuring food deserts in New York City's low-income neighborhoods." *Health & Place* 17 (2): 696-700.

Gruber, J., A. Kihm, and B. Lenz. 2014. "A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services." *Research in Transportation Business & Management* 11: 53-62.

Guy, C., G. Clarke, and H. Eyre. 2004. "Food retail change and the growth of food deserts: A case study of Cardiff." *International Journal of Retail & Distribution Management* 32 (2): 72-88.

Hendrickson, D., C. Smith, and N. Eikenberry. 2006. "Fruit and vegetable access in four low-income food deserts communities in Minnesota." *Agriculture and Human Values* 23 (3): 371-383.

Hilmers, A., D. C. Hilmers, and J. Dave. 2012. "Neighborhood disparities in access to healthy foods and their effects on environmental justice." *American Journal of Public Health* 102 (9): 1644-1654.

Joerss, M., J. Schröder, F. Meuhaus, C. Klink, and F. Mann. 2016. "Parcel delivery: The future of last mile." *Travel, Transport and Logistics.*

Johns Hopkins Ceter for a Livable Future. 2018. *Report: 'Food desert' gets a name change in response to Baltimore community feedback.* https://www.jhsph.edu/news/news-releases/2018/report-food-desert-gets-a-name-change-in-response-to-baltimore-community-feedback.html.

Kaufman, P. R. 1998. "Rural poor have less access to supermarkets, large grocery stores." *Rural America/Rucal Development Perpectives* 13: 19-26.

Lewis, L. B., D. C. Sloane, L. M. Nascimento, A. L. Diamant, J. J. Guinyard, A. K. Yancey, and G. Flynn. 2005. "African Americans' access to healthy food options in South Los Angeles restaurants." *American Journal of Public Health* 95 (4): 668-673.

Misaszek, Caitlin, Sarah Buzogany, and Holly Freishtat. 2018. *Baltimore City's food environment: 2018 Report.* Baltimore: Johns Hopkins Center for a Livable Future; City of Baltimore. https://clf.jhsph.edu/sites/default/files/2019-01/baltimore-city-food-environment-2018-report.pdf.

Misiaszek, C., S. Buzogany, and H. Freishtat. 2018. *Baltimore City's food environment report.* MD, Baltimore: John's Hopkins Center for a Livable Future.

Moore, L. V., A. V. Diez Roux, J. A. Nettleton, and D. R. Jacobs, Jr. 2008. "Associations of the Local Food Environment with Diet Quality—A Comparison of Assessments based on

Surveys and Geographic Information Systems." *American Journal of Epidemiology* 167 (8): 917-924.

Morganti, E., L. Dablanc, and F. Fortin. 2014. "Final deliveries for online shopping: The deployment of pickup point networks in urban and suburban areas." *Research in Transportation Business & Management* 11: 23-31.

Morland, K., S. Wing, A. D. Roux, and C. Poole. 2002. "Neighborhood characteristics associated with the location of food stores and food servicre places." *American Journal of Preventive Medicine* 22 (1): 23-29.

Powell, S. M., S. Slater, D. Mirtcheva, Y. Bao, and F. J. Chaloupka. 2007. "Food store availability and neighborhood characteristics in the United States." *Preventive Medicine* 44 (3): 189-195.

Redman, R. 2018. "Prime Now delivery from Whole Foods hits more cities." *Supermarket News*, June 27. https://www.supermarketnews.com/online-retail/prime-now-delivery-whole-foods-hits-more-cities.

Rose, D., and R. Richards. 2004. "Food store access and household fruit and vegetalbe use among participants in the US Food Stamp Program." *PUblic Health Nutrition* 7 (8): 1081-1088.

Schliwa, G., R. Armitage, S. Aziz, J. Evans, and J. Rhoades. 2015. "Sustainable city logisticw - Making cargo cycles viable for urban freight transport." *Research in Transportation Business & Management* 15: 50-57.

Siikavirta, H., M. Punakivi, M. Ka"rkka"inen, and L. Linnanen. 2008. "Effects of e-commerce on greenhouse gas emissions: A case study of grocery home delivery in Finland." *Journal*

of Industrial Ecology 6 (2).

    https://onlinelibrary.wiley.com/doi/abs/10.1162/108819802763471807.

Smith, R. 2017. *Food access in D.C is deeply connected to poverty and transportation.*

    Washington, D.C.: D.C. Policy Center.

Song, B., and Y. A. Ko. 2016. "Vehicle routing problem of both refrigerated- and general-type

    vehicles for perishable food products delivery." *Journal of Food Engineering* 169: 61-71.

Suel, E., and J. Polak. 2017. "Development of joint models for channel, store, and travel mode

    choice: Grocery shopping in London." *Transportation Research Part A* 99: 147-162.

U.S. Department of Agriculture. n.d. *Definition of a food desert.*

    https://www.ers.usda.gov/webdocs/DataFiles/80591/archived_documentation.pdf?v=413

    32.

Urban Freight Lab. 2018. *Evaluation of sound transit train stations and transit oriented*

    development areas for common carrier locker systems. Technical Report, Seattle:

    University of Washington.

    https://depts.washington.edu/sctlctr/research/publications/evaluation-sound-transit-train-

    stations-and-transit-oriented-development-areas.

Urban Freight Lab. 2018. *Evaluation of sound transit train stations and transit oriented*

    development areas for common carrier locker systems: Phase I research projects.

    Seattle: University of Washington.

USDA. 2017. "U.S. Department of Agriculture, Food and Nutrition Services. Food desert

    locator. June 2, 2017. http://www.fns.usda.gov/tags/food-desert-locator." *USDA*

    Economic Research Service.

Wardman, M. 2001. *Public transport values of time.* Working paper, Leeds, UK: University of Leeds.

Weinberg, Z. 1995. *No place to shop: The lack of supermarkets in low-income neighborhoods: Analysis of a University of Connectitcut Study on low-income communities and households receiving public assistance in 21 metropolitan areas.* Public Voice for Food and Health Policy.

Zenk, S. N., A. J. Schutz, B. A. Israel, S. A. James, S. Bao, and M. L. Wilson. 2005. "Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit." *American Journal of Public Health* 95 (4): 660-667.