Research Project Number:
RES2016-31

FINAL REPORT
Alternative Vehicles for Last Mile Freight

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May 2019

DISCLAIMER

This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under RES #: 2016-31, Research Project Title: Alternative Vehicles for Last Mile Freight

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Technical Report Documentation Page

1. Report No. RES 2016-31	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Alternative Vehicles for Last Mile Freight*		5. Report Date December 2019 6. Performing Organization Code
7. Author(s) Christopher R. Cherry, Mojdeh Azad, William J. Rose, John MacArthur		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Tennessee, Knoxville 851 Neyland Drive Knoxville, TN 37996		10. Work Unit No. (TRAIS) 11. Contract or Grant No. RES2016-31
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered Final Report October 1, 2016 to September 30, 2019 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This research addresses alternative vehicle use for last mile freight. To overcome the limitation in data availability, an e-trike delivery company was visited, and GPS data were collected during October and November 2017. We used different data analysis approaches to understand the characteristics of the delivery system including, speed, travel distances, travel times, stop locations and durations. Next, we constructed two simulations to evaluate the costs of the system and estimate the costs if the company utilized vans (all or a mixed fleet) for deliveries for the same e-bike delivery company and a test in Nashville. We present the results in different sections. Overall, the associated total costs of a LEV-based delivery system are not dramatically higher than traditional systems. The main factor in cost trade-offs was found to be labor cost. However, along with sustainability initiatives of the system, emissions cost reduces at a large scale. Availability of bike infrastructure, location of distributing center, and density of delivery area are important factors that contribute in competitiveness of a LEV delivery company. With the increase in world population living in urban areas, innovative sustainable solutions are required to address last mile delivery issues in urban cores where there is more traffic congestion and emissions. E-cargo cycles can effectively solve some of these issues by providing less pollutant and reliable modes of transportation for urban logistics. Cities need to evaluate their transportation network and parking policies and investigate the required infrastructure enhancements in their urban cores to provide sufficient space for this type of vehicles.

17. Key Words	18. Distribution Statement
LAST-MILE DELIVERY, E-TRIKE, CARGO CYCLE, URBAN FREIGHT, E-BIKE, E-CARGO	No restriction. This document is available to the public from the sponsoring agency at the website https://www.tn.gov/

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	50	

Acknowledgement

This project was completed with the generous assistance of B-line Urban Delivery, a last mile freight company in Portland, Oregon. This work done here would not be possible without their expert insight and contributions, specifically Franklin Jones, Dan Bravin, and Sam Appelbaum.

Executive Summary

While little research into the use of Light Electric Vehicles (LEVs) as a tool for urban freight delivery exists, several companies are currently employing LEVs or other emerging vehicles to fulfill urban freight delivery needs. Moreover, several innovative international companies have developed vehicles (e.g., Twizy Cargo and Arcimoto Deliverator) and operating procedures in urban contexts. For example, Gnewt has focused solely on serving last-mile freight needs in Europe using innovative electric vehicles along with innovative techniques, like micro-hubs and mobile-crossdock facilities. B-Line Urban Delivery in Portland, Oregon uses electric trikes and makes over 35,000 deliveries, avoids 82 metric tons of CO2 emissions, and substitutes over 90,000 delivery miles since its founding in 2009. Other delivery companies around the United States such as UPS and Sol Chariots are employing bicycles, electric trikes, and golf carts to assist in delivery of packages, especially during peak delivery seasons.

Extensive additional research into the role of light electric vehicles as tools for urban freight delivery is still needed. Foremost among these is the need to investigate the benefit of using LEVs as opposed to traditional delivery vehicles in terms of cost, safety, reliability, efficiency, and environmental impact. Investigation into the role of public policy to promote LEV usage, ensure safety, provide adequate facilities for larger LEVs, include LEVs in urban freight planning, and provide incentives for using LEVs as an alternate to replace heavier trucks is required. Feasibility studies are also critical in order to determine the optimum land use, roadway design, density, and consumer demand requirements for different urban freight delivery models, including studying the scenarios that are best for traditional delivery vehicles and which are best for LEVs.

This research started by reviewing the literature to understand similar system in different countries, vehicle sizes, markets, and operating performances. Next, an e-bike delivery company was used as a case study, and GPS data were collected during October and November 2017. We used different data analysis approaches to understand the characteristics of the delivery system including, speed, travel distances, travel times, stop locations and durations. We constructed a simulation to evaluate the costs of the system and estimate the costs if the company utilized vans (all or a mixed fleet) for deliveries. Overall, the associated total costs of a LEV-based delivery system are not dramatically different than traditional systems. The main factor in cost trade-offs was found to be labor cost. However, along with sustainability initiatives of the system, emissions reductions are large. Availability of bike infrastructure, location of distribution center, and density of delivery area are important factors that contribute in competitiveness of a LEV delivery company.

With the increase in world population living in urban areas, innovative sustainable solutions are required to address last mile delivery issues in urban cores where there is more traffic congestion and emissions. E-cargo cycles can effectively solve some of these issues by providing less pollutant and reliable modes of transportation for urban logistics. Cities need to evaluate their transportation network and parking policies and investigate the required infrastructure enhancements in their urban cores to provide sufficient space for these types of vehicles.

List of Acronyms

GIS- Geographic Information System

GPS- Global Positioning System

LEV- Light Electric Vehicles

TDOT- Tennessee Department of Transportation

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Chapter 1: Introduction

1.1. Overview

Today, over 50% of the world's population is living in urban areas and it is expected to increase up to 70% in 30 years [1]. Followed by changes in land use, environment, demographics, and consumer behavior, this phenomenon would magnify the challenges of city logistics. Notably, last-mile delivery services in dense urban cores need to consider traffic congestion, energy consumption, emissions, and transportation infrastructure in their solutions to maximize their operating performance and profits. Due to the growing interest and importance of innovative and sustainable solutions for city logistics, light electric vehicles (LEVs) deployment is becoming popular in different cities [2, 3]. In addition, several studies and projects such as the European Union (EU)'s Cyclelogistics have started tackling the last-mile urban freight challenges through the implementation of electric (e-)cargo bikes in urban areas [4].

At the intersection of LEVs and cycle logistics, e-trikes can be considered a sustainable alternative for urban core deliveries. Similar to cargo bikes, e-trikes are relatively small, require less parking space, can make use of bike infrastructure to maneuver through the city, and can work from distribution centers that are close to customers compared to delivery vans. Additionally, they remove the barriers associated with human power such as changes in grade, range, or low average speed. These factors make e-trikes a suitable means of transportation for urban logistics, which are particularly well-suited for food logistics due to the associated time constraints [2, 5]. While a large number of studies and projects have been conducted in European countries, the limitation of data in the context of the U.S. is a critical information gap in understanding the characteristics of freight which adds uncertainty to cost and emission models [6].

1.2. Scopes and Report Organization

The main objectives of this projects are to:

- inventory vehicle types that are appropriate for urban delivery,
- identify compatible land use and built environment characteristics for urban freight,
- conduct an empirical case study to evaluate performance of LEV urban freight operations, and
- provide guidance on urban freight delivery policies on operations in Tennessee.

The remainder of this report is organized as follows. Chapter 2 presents a review of literature on (e-)cargo cycles and cost analysis. Chapter 3 is devoted to the data description and methods used in this study. Chapter 4 presents the results of the analyses and discussions. Chapter 5 concludes the report by providing a summary of all analyses, concluding remarks, limitations, and recommendations.

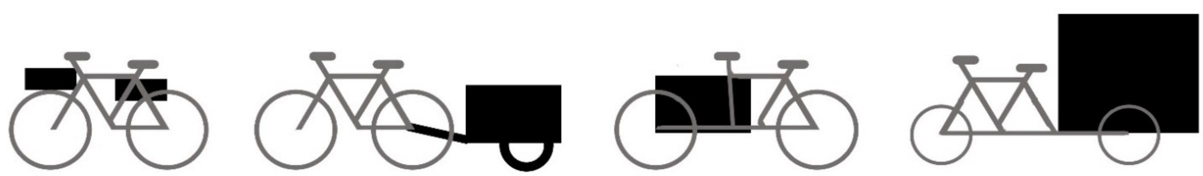
Chapter 2: Background and Literature Review

2.1. Emerging vehicle types, capabilities, and markets

According to Federal Highway Administration (FHWA)'s data on annual vehicle distance traveled in 2016, truck traffic share of VMT on urban interstates and other urban roadways was about 11 and 6 percent, respectively [7]. These values are expected to increase and would magnify challenges related to safety, environment, and traffic congestion in urban areas [6]. In order to address the urban freight problems and minimize the negative impacts of increased truck traffic share in cities, different strategies have been proposed by National Cooperative Freight Research Program (NCFRP) in three main categories: last-mile delivery, environment, and trade node strategies. Focus of last-mile strategies is on reducing traffic congestion related to local deliveries or pickups in urban areas. The focus of environmental strategies is to reduce noise and emissions from delivery vans/trucks. Trade node strategies focus on problems related to metropolitan areas that serve as hubs for trades [6].

To reduce the negative environmental impacts of city logistics, several innovative solutions have been introduced including light goods vehicles and cargo cycles [3]. Using a light electric cargo bike lies in both categories of last-mile related and environmental solutions. Yet, they are argued to have low effectiveness and applicability in the U.S. from solely the environmental point of view. Additionally, light electric vehicles (i.e. e-scooters and e-cargo bikes) have been piloted by most of the large delivery companies [8].

Table 2-1 presents a summary of selected research studies related to e-cargo bikes. Differences in European and other countries' city logistics environment have resulted in a large number of studies and projects related to this topic in Europe [3]. A series of European study projects called *CycleLogistics*, *CycleLogistics ahead*, and *City Changer Cargo Bike* have been undergone since 2011 to investigate and enhance the cargo cycle use in urban logistics in order to tackle some of urban mobility challenges. Their reports stated that generally about one-third of motorized trips for goods transport have the potential to be shifted to the cargo cycles [4]. These cycles can be categorized into four groups: standard bicycle with panniers or shoulder bag, standard bicycle with a trailer, cargo bike, and cargo trike (illustrated from left to right in Figure 2-1) The main services are last mile delivery, mail, and point-to-point deliveries [9].



a) standard bicycle with panniers or shoulder bag | b) standard bicycle with a trailer | c) cargo bike | d) cargo trike

Figure 2-1: Four general categories of cargo cycles

Several studies have discussed the potential market segments that can benefit from cargo cycles and found that cargo cycles are most cost-effective if used in dense urban cores and especially for the postal, parcel, or food deliveries [2, 10]. Different studies showed that overall efficiency of the delivery systems will not change if they replace up to about 10-48% of their van trips with cargo cycles [11-13]. The competition between e-trikes and traditional vans however is sensitive to the city urban policies, parking availability, and speed limits and is greatly affected by drivers' costs [14]. In general, studies agree on cost saving from implementing e-cargo cycles for delivery activities in dense urban cores with distributing center being close to the customers [5, 14-17].

From the environmental perspective, the fuel consumption effects were found to be small on e-trikes compared to vans on a per-mile basis, while the carbon emission reduction of using e-trikes could be from 51% to 72%, compared to the traditional system [14, 18]. Results from a study based on GPS data collected from two local cargo cycle operators also confirms positive environmental impacts of cargo cycles in congested areas [19]. Life cycle analysis can further investigate the battery-related emissions of e-cargo cycles.

One of the important advantages of cargo cycles compared to delivery vans is the ability to park on sidewalk, often in the furniture zone of the pedestrian space. As a result, cargo cycles would be closer to customers while limiting time cruising for parking or associated citation costs. Additionally, they maintain similar or faster speed as delivery vans in urban cores. As an example, the inner-city last mile speed in Nashville, TN is around 16 mph [20]. In general, parking limitations, restrictions, and costs have resulted in Americans spending $72.7 billion cruising for a parking space in urban core areas [21]. That is equivalent to 6-15 minutes search time for on-street parking per each trip in the US largest cities.

In summary, the advantages of e-cargo cycles in city logistics are lower vehicle price, lower running and parking costs, increased speed in traffic congestion, less driver training requirements, and lower negative environmental impacts. The disadvantages are security issues, limited range, seasonality, managing trailer locations, route scheduling, and labor cost [22, 23]. There is large gap in study locations of the e-cargo delivery systems. Note that the majority of studies have been conducted in European countries with a different cycling environment than the US.

Table 2-1: Main findings from selected relevant literature

Author, year	Location	Methods	Key findings
Lenz, B. and Riehle, E., 2013. [12]	Europe, 38 companies in several countries	Interviews and survey	• Main services are courier, express, and parcel and delivery of basic products in catering. • Parking prices is a motivation to shift from car to cargo bikes. • Availability of city center hubs are important spatial factor. • Cargo freight has the potential to reduce emissions and noise pollution.
Schliwa, G., et al., 2015. [24]	Europe, several countries	Thorough review and interview	• Cycle logistics coherently defined as "the use of human-powered or electrically-assisted standard bicycles, cargo bikes and cargo tricycles for the transport of goods between A and B, primarily in urban areas", covering first/last mile and express services. • Perceptions of important (potential) customers can adversely affect the small companies in integrating cargos in their system. • The viability of cargo logistics depends on the geography of cities. Potential areas are urban cores with high density, historical centers with narrow roads, or areas with regulated traffic measures (e.g. orders for reduced traffic during day). • Local authorities can play an important role in providing conditions that helps integrating cargo cycles in delivery services companies. Examples are "measures affecting material infrastructure (transport infrastructure, e.g. dropped curbs and cycle lanes), non-material infrastructure (incentivize the integration of sustainable last mile operators in the supply chain across different companies), equipment (e-assist deregulation) as well as urban governance (such as zero-emission zones, reducing drive-through traffic, pavement parking enforcement)."
Koning, M. and Conway, A., 2016. [25]	Europe, France	Survey	• Most of the shifted volumes to cargo cycles were from motorized two-wheels and vans. • Largest externality savings from implementing cargo cycles were in reduced pollutants and impacts on congestion whereas the smallest savings were in reduced CO_2 emissions and noise.

Maes, J. and Vanelslander, T., 2012. [26]	Europe, Belgium	Market study and cost estimation	• Using bike messenger service can contribute in meeting CO2 emission requirements, even though it is not enough to solve the urban transport emission problem. • Short run employment possibilities are limited. • Policy initiatives can help boost the bike courier market. • Limitations in emission savings if the warehouse is not in the city.
Gruber, J., Kihm, A. and Lenz, B., 2014. [27]	Europe, Germany	Spatial analysis, cost estimations, and survey	• Electric cargo bikes lie between bikes and cars in terms of cost, payload, and range. • Messengers' attributes such as demographics, attitude and values have significant impacts on their willingness to use e-cargo bikes. • Important factors in implementation of e-cargo bikes are their range, price, and publicly available information.
Tipagornwong, C. and Figliozzi, M., 2014. [14]	USA, Portland, OR	Cost analysis	• Cargo cycles competitiveness to diesel vans is sensitive to urban policies, road design variables (e.g. speed limit, parking availability), and drivers' cost, but not fuel cost. • Cargo cycle services perform better in denser urban areas with depots being located close to the customers.
Nocerino, R., et al., 2016. [28]	Europe, Italy	Pilot project costs and environmental analysis	• Battery duration and reliability are among the main concerns of deploying e-scooters and e-bikes for logistics for logistic companies. • Pilots demonstrated that capacity, battery, and reliability should be less of a concern if enough and accurate choice of cycles are chosen.
Melo, S. and Baptista, P., 2017. [11]	Europe, Portugal	Cost analysis	• Cargo cycles can replace up to 10% vans without affecting the overall network efficiency in areas that distance is smaller than 2 km. • About 25% of external cost reduction can be reached by introducing e-cargo cycles in urban logistic activities.

Saenz, J., et al., 2016. [18]	USA, Portland, OR	Emission assessment	• Total greenhouse gas emissions reduced between 51-72% if diesel vans are replaced by electric tricycles. • E-cargo cycles' competitiveness and benefits maximized in dense congested areas.
Conway, Aet al., 2017. [19]	USA, New York city, NY	Case studies using GPS data	• Speed distributions varies on different road infrastructure. • Service time with cargo cycle deliveries is shorter than truck deliveries. • More space and emission savings can be observed in congested urban cores.
Melo, S. and Baptista, P., 2017. [11]	Europe, Portugal	Cost analysis	• Cargo cycles can replace up to 10% vans without affecting the overall network efficiency in areas that distance is smaller than 2 km. • About 25% of external cost reduction can be reached by introducing e-cargo cycles in urban logistic activities.
Figliozzi, M., et al., 2018. [29]	USA, Portland, OR	Lifecycle emissions minimization model	• Lifecycle emission rates per customer were at least six times smaller when e-trikes are utilized compared to a diesel cargo van. • Lifecycle CO_2e emission rates per customer were at least four times smaller when e-trikes are utilized compared to a diesel cargo van.

2.2. Cost analysis model

Relevant literature relies on defining mathematical models to optimize the network and evaluate the cost-effectiveness of the cargo cycle delivery systems. Figure 2-2 presents the main attributes used in cost analysis of (e-)cargo cycles in the literature [14-17]. These attributes can be categorized into main four classes: system operator decisions, distribution center (DC) location, rider (employee) behaviors, and transportation road network. Several attributes are related to more than one category. For instance, duration of stops depends on rider's speed in opening the cargo and delivering the product to the customer as well as the time required to find a stop location.

Results of mathematical models for cost or emissions trade-offs analysis of using cargo cycles from these studies revealed similar overall effects with lower costs and emissions values when compared to traditional modes of logistics transport. However, they vary in magnitude which can be a result of the limitation of data, relying on the operator's estimations of their vehicles' performance, or make assumptions from various general resources [15, 30, 31].

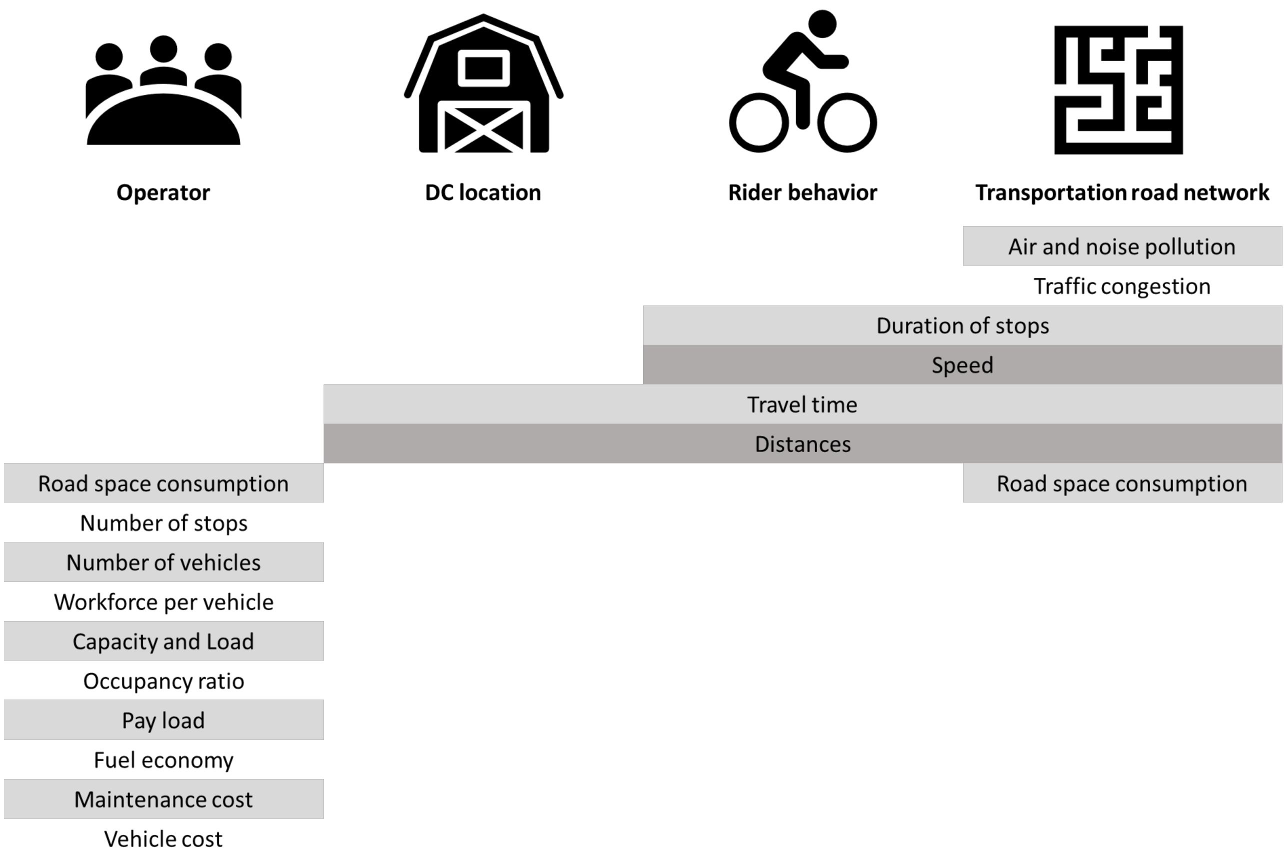


Figure 2-2: Main attributes in cost analysis

Chapter 3: Methodology

We performed three sets of analyses to explore the study questions. First, we evaluated GPS data from B-Line Urban Delivery in Portland to understand the characteristics of the e-trike delivery system and its performance. Second, using the data from the first step, we developed a simulation model and calculate the costs. Last, we evaluated the judgment of experts from the state of Tennessee. Below, we explain each analysis in detail.

3.1. GPS data analysis

This section relies on data collected from the fleet of B-line Urban Delivery vehicles in Portland, Oregon. At the time of data collection, B-line Urban Delivery used five e-trikes to deliver goods to shops, retail stores, and restaurants, mainly distributed in the urban core of Portland. They have since expanded their fleet to eight trikes. The trikes are operated by a rider that pedals the trike. Each trike has an electric motor to provide assistance. The company operated seven days a week, with the greatest numbers of daily tours on Wednesdays and Thursdays. Based on company's information, the carrying capacity of e-trikes ranges from 800-1300 pounds with the average speed estimation from 13-19 km/h, the average range of 19-24 km, and the vehicle width from 48-50 inches (Figure 3-1).

GPS data at 1 Hz resolution was collected using G-Log GPS Recorders installed on each e-trike during October and November 2017 (approximately 55 days of data collection). The dataset includes several variables such as daily time-stamped geographic location, speed, and headings for each e-trike. Data points of an e-trike which were less than 1,000 points in a day have been dropped (with some exceptions). This data was later cleaned for the next steps.

3.1.1. Data cleaning

To ensure data quality, we conducted the following pre-processing and cleaning steps using R programming software: (i) remove duplicate or missing observations, (ii) remove redundant variables collected by the GPS recorder, (iii) assign a unique id for each tour, and (iv) merge all data to a single database. Next, we calculated the travel time (seconds) and distance (meters) between consecutive GPS points for each trike in each day. The average speed between each two points was then calculated by dividing the distance by time. Records with a calculated speed of more than the defined threshold of 40 km/h were removed from the database. To decrease discrepancy between calculated and recorded speed, we compared these values and removed the inconsistent points by applying two-dimensional kernel density estimation function to speed values. Table 3-1 presents a summary of data features for this study.

Table 3-1: Summary of GPS data

Delivery Characteristics	
Number of e-trikes	5
Number of GPS point records	2.5 million
Data resolution	1 point per second
Collection period	Oct 4- Dec 1, 2017
Total number of tours	192
Total distance traveled	4,504 km

3.1.2. Stop detection

The next step is to identify the location and duration of stops for each tour. Theoretically, stops can be defined as the records with the speed of zero. However, due to the errors associated with GPS data collection, the recorded longitude and latitude might vary over the duration of stop period and hence introduce positive values of speed in data. As e-trikes are human-powered, the speed range is smaller than other vehicle types in logistics and supply chain studies, resulting in a smaller threshold to unambiguously identify stops. To address this issue, we created a 15-meter buffer around all the points with speed lower than 2 km/h in ArcGIS. Then, we dissolved them based on the tour id to create different polygons for each tour. Next, we conducted a spatial join of points to each polygon and counted the total number of points in each polygon with an assumption of no more than one delivery to one location per day. Polygons with more than 200 points (i.e., 200 seconds) were considered as stop locations.

In addition to the previous steps, we defined four boundaries in the city of Portland for comparison purposes: (1) Northwest (NW) (mostly commercial, general employment, and high-density multi-dwelling zones), (2) Southwest (SW) (downtown and mostly commercial zone), (3) Northeast (NE) (mostly residential and some commercial), and (4) Southeast (SE) (mostly residential and some employment) (Figure 3-1). The B-line warehouse is located in the SE, so this boundary includes at least a portion of all tours. Also, more than 75% of delivery tours passed through SW while only 17% passed through NE.

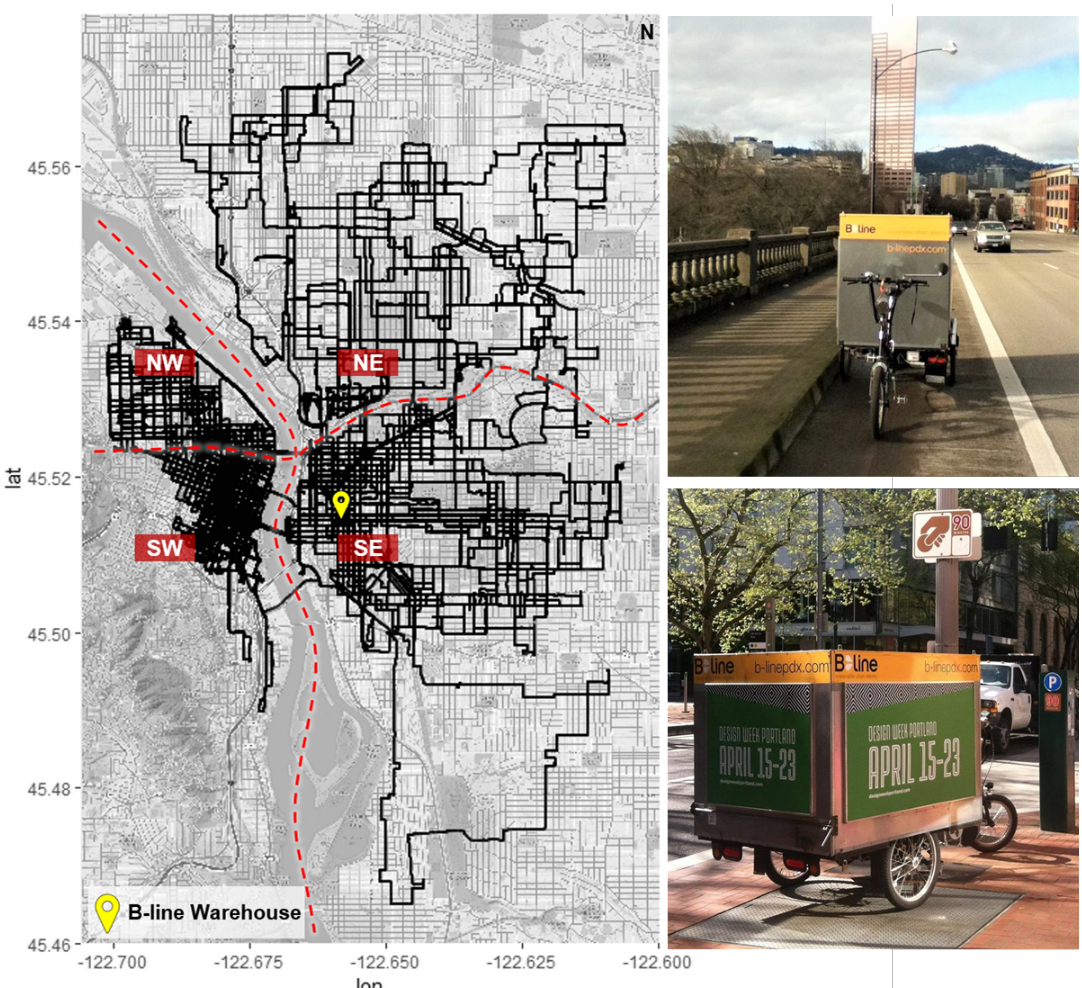


Figure 3-1: Distribution of data in Portland and the boundaries (left), Delivery e-trikes adapted from the company's Facebook page at facebook.com/pg/blinedelivers (right)

3.2. Cost analysis

3.2.1. Simulation model

Different simulation software programs have been developed to help simulating various behaviors in manufacturing, supply chain, logistics, healthcare, and other industries. In this study, we created a simulation model in AnyLogic software which has the ability to simulate multimethod behaviors such as discrete, continuous, and agent-based methodologies [32]. AnyLogic software has a focus on business simulation and been used in these main domains: supply chain, logistics, retail, manufacturing, market and competition, business process, project and asset management, and traffic simulation [33].

The simulation model used one week of B-line Urban Delivery data as an input, including customer locations and routes. The simulation parameters are presented in Table 3-2. The simulation ran for 5 simulated days, with 20 replications for each parameter combination. Following the initial run, the output, total cost calculations, service level, and total labor hours were analyzed against recommendations from Law [34] and 20 replications were found to be appropriate. To examine the potential of replacing multiple LEV routes with a single cargo van, we included 16 potential fleet mix options in the simulation (Table 3-3).

In each replication, vehicles moved from one stop to the next, following the routing order provided by B-line Urban Delivery. The LEVs followed exact routes extracted from GPS data while vans traveled from one stop to the next following the shortest route recommendation from Open Street Map (as provided by AnyLogic). Each vehicle followed the same sequence of activities repeatedly throughout the route:

1) Vehicles begin at the depot
2) Vehicles drive to the next stop on the route found from the GPS data.
3) On reaching the customer location:
   a) As LEVs are able to park on the street or sidewalks, it is assumed that LEVs immediately park and begin serving the customer.
   b) Vans require space for parking and loading/unloading. As a result, vans cruise for parking. Let p be the percentage of parking availability and the vehicle finding an available parking space while reaching the destination follows a Bernoulli trial. Therefore, number of trials until the first success would follow a geometric distribution with a mean of $1/p$ [35]. Hence, parking utilization data from Portland Bureau of Transportation have been used to set up the probabilities for finding an available parking spot [36] (see Appendix-B). This parking utilization data has been collected during typical mid-week days in 2015 and includes parking supply and occupancy for both on-street and off-street parking spaces in five study areas.
      i) Along with additional time spent cruising for parking, it was assumed that serving the customer required a single trip to and from the parked vehicle at a walking speed of 3 miles per hour.
4) Service times at each customer location were provided by B-line.
5) Once all customers were served, drivers of both LEVs and vans returned to the depot.
6) The vehicles were given a 13-hour time window to complete all deliveries. If stops are incomplete 13-hours after the day begins, the driver returns to the depot and customer service levels are reduced.

Table 3-2: Simulation parameters

	Vehicle Type	
Parameter	Freight Tricycle	Diesel Van
Driving Speed	Varied based on time of day	Varied based on time of day, location, and direction of travel
Cruising Distance	0	Geometric (p determined by Portland “Centers & Corridors” parking studies from 2015)
Service Time	Provided by B-line	Provided by firm
Customer Locations	Provided by B-line	Provided by firm
Fleet Mix	0-5	1-5

Table 3-3: Fleet Mix Options

Fleet Mix	Van	LEV
0	0	5
1	1	4
2	1	3
3	1	2
4	1	1
5	1	0
6	2	3
7	2	2
8	2	1
9	2	0
10	3	2
11	3	1
12	3	0
13	4	1
14	4	0
15	5	0

In scenarios with the total number of vehicles less than five, cargo van routes were combined based on average distance per stop or number of stops. To capitalize on the strengths of both vans and LEVs, cargo vans with a single route were assigned the route with the longest distance per stop. If a single van covered two separate routes, the two routes with the fewest stops were combined. When more than one van combined two routes, one van covered the route with the most and fewest stops and the other van covered the routes with the second and third fewest stops to balance out the workload.

3.2.2. Cost function

The cost function was derived from Tipagornwong and Figliozzi study [14] and changed to reflect the attributes that were collected through GPS data. This cost function has a specific focus on cargo cycles as well as competing vehicles – vans. There are many different alternative vehicle cost functions, but based on discussions with LEV operators, for the type of cargo used, maneuverability, and size, vans are the likely most competitive alternative. In a simulation environment, other vehicles and cost parameters could be estimated. We also are aiming to extend the results of the former study [14] and present comparable analytical approaches. Table 3-4 presents the cost model parameters and the following function was used in the simulation:

Total Cost (per vehicle type) = energy cost + emission cost + maintenance cost (c_m) + labor cost

or

$$C_{tot} = [c_e](er) + [c_{CO2}][lerr_{CO2}] + [c_m](l) + [c_l](t)$$

Where:
C_{tot} = total cost for vehicle type i ($),
c_e = unit energy cost for vehicle i [$/gal or $/ikW-h],
er = per mile fuel or electricity consumption rate of type i vehicles (gal/mi or kW-h/mi),
c_{CO2} = unit CO_2 emissions cost ($/ton), referenced to carbon taxes in the European cap and trade system as of 2013 [37],
l = per tour distance traveled to serve route of vehicle i (mi/tour),
r_{CO2} = CO_2 emission rate of vehicle type i (kg/gal or kg/kW-h),
c_m = per mile maintenance cost for vehicle i ($/mi),
c_l = unit labor cost for vehicle i ($/h), and
t = total tour time of vehicle i (h).

Table 3-4: Cost model parameters

	Vehicle Type		
Parameter	Freight Tricycle	Diesel Van	Source
Model	Cycle Maximus	Dodge ProMaster City	[14]
c_e	8.45 cents/kW-h	$2.993/gal	[38], [39]
c_m ($/mi)	.02	.20	[14]
c_l ($/h)	14,15,16	16.46	[40], [41]
c_{CO2} ($/ton)	18	18	[14], [37]
er	29 watt-h mi	12-21 mi/gal	[14], [42]
r_{CO2}	0 kg/kW-h	10.180 kg/gal	[14], [43]
l	Simulation Output		
t	Simulation Output		

The simulation model included varying parameters associated with labor costs for LEV drivers based on B-Line's website. B-Line drivers are paid between $14 to $16 per hour, and so replications were conducted at $14, $15, and $16 per hour as the LEV driver pay rate. The labor cost for van drivers was defined based on the average delivery driver pay acquired from an online employment-related search engine [41].

Additionally, data from online sources stated city fuel consumption for a Dodge ProMaster Cargo Van at 15 mpg and for a Dodge ProMaster City van (not released until 2015) at 21 mpg. Consumption rates were therefore set at 12, 15, 18, 21 mpg to include this range as well as rate of 12 mpg used in Tipagornwong and Figliozzi study [14]. As the Dodge ProMaster City provides a carrying capacity (131.7 cubic feet) more than twice that of the average LEV (67.2 cubic feet), consolidating the fleet to fewer than three cargo vans would require the larger Dodge ProMaster Cargo Van (carrying capacity of 309.5 cubic feet). As a result, consumption and emission data were simulated for both van types. Fuel costs implemented in the original model were based on average diesel fuel costs the week of Oct 9, 2017 similar to the date of LEV GPS data used in simulation.

To analyze the operation of this system in Nashville, we relied on results from Portland study for defining the characteristics of the system. We randomly generated points on defined zones in the city urban core using ArcGIS, relative to the average number of stops we found from the previous part. These points correspond to potential customers. Next, using Open Street Maps (OSM), we created a road network in ArcGIS Network Analyst and generated LEV routes using Vehicle Routing Problem tool on OSM predefined cycle network. Having LEV routes for one day, we followed the same procedure to calculate the costs for the city of Nashville.

3.3. Pairwise comparison

We derived top five criteria defined from the literature related to the use e-cargo in urban freight and last mile delivery: Emissions, noise, congestion, costs, and safety. To assess the importance of each criteria in the context of the state of Tennessee, we carried out a survey of 5 persons who have expertise and work in freight and last mile delivery in TN. Each expert evaluated the importance of each criteria through pairwise comparisons between each two elements using a scale of 1 to 9 with 1 being equal importance, 3 being moderate importance, 5 being strong importance, 7 being very strong importance, and 9 being extreme importance. We relied on Pairwise comparison method developed by Saaty [44] as a part of Analytical Hierarchy Process (AHP) to analyze the results. The following steps are used to calculate the weights of each factor using the geometric mean of responses, followed by calculating the consistency index [44, 45]. Factors with higher weights indicate that they are the most important factors according to each expert's evaluations. A geometric mean of all evaluation weights would result in finding the most important factors among all experts.

Step 1: Develop comparison matrix A

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

Where:

$a_{ij} = \left(\prod_{n=1}^{n} a'_{ij-n}\right)^{1/n}$ and

a'_{ij-n} = pair-wise score given by each expert n

Step 2: Calculate eigenvalues

$W = [w_1 \quad w_2 \quad \dots \quad w_n]^T$

The weight matrix: $w_i = \frac{\sum a'_{ij}}{n}$,

With normalized elements of the comparison matrix A: $a'_{ij} = \frac{a_{ij}}{\sum a_{ij}}$, and

Largest eigenvalue: $\lambda_{max} = \frac{1}{n}\sum\frac{(AW)_i}{w_i}$

Step 3: Calculate Consistency Index (CI) and Consistency Rate (CR)

$CI = (\lambda_{max} - n)/(n-1)$,

$CR = \frac{CI}{Randm\ Index\ (here\ 1.12)}$.

A CR of equal or less than 0.1 is considered acceptable [44].

Chapter 4: Results and discussions

4.1. Characteristics of LEVs in US-based urban logistics

First, we describe the characteristics of the urban freight delivery operation that were obtained solely from the GPS data in Portland. Based on the data cleaning criteria, we removed 4.2% of the data as outliers. In the next sections, we summarize speed, distance, and travel time profiles in the whole dataset, explore spatial speed patterns, and analyze the delivery and stop characteristics in detail.

Speed, distance, and travel time profiles

Delivery speed is one of the main factors affecting the cost estimation and the overall performance of a logistics system. Its effects become more prominent in combination with time-constraint delivery types in which the food must be delivered within a certain period of time. To exclude stops from calculating the moving speed profiles, we considered a minimum speed value of 2.0 km/h for calculations. Based on summary descriptive statistics, the average speed excluding stops is 13.2 km/h (SD= 4.75, 95% CI= 0.01), average daily travel distance per e-trike is 23.5 km (SD= 8.44, 95% CI = 1.20), and average daily travel time per e-trike is 3.57 h (SD= 1.42, 95% CI = 0.20) (Figure 4-1). We use the empirical analysis from Portland's transportation system and there are possible reasons that these figures could over- or under-estimate the performance of these vehicles in other markets. These include (but are not limited to) road network density, congestion levels, dedicated infrastructure, signal coordination, terrain, and others.

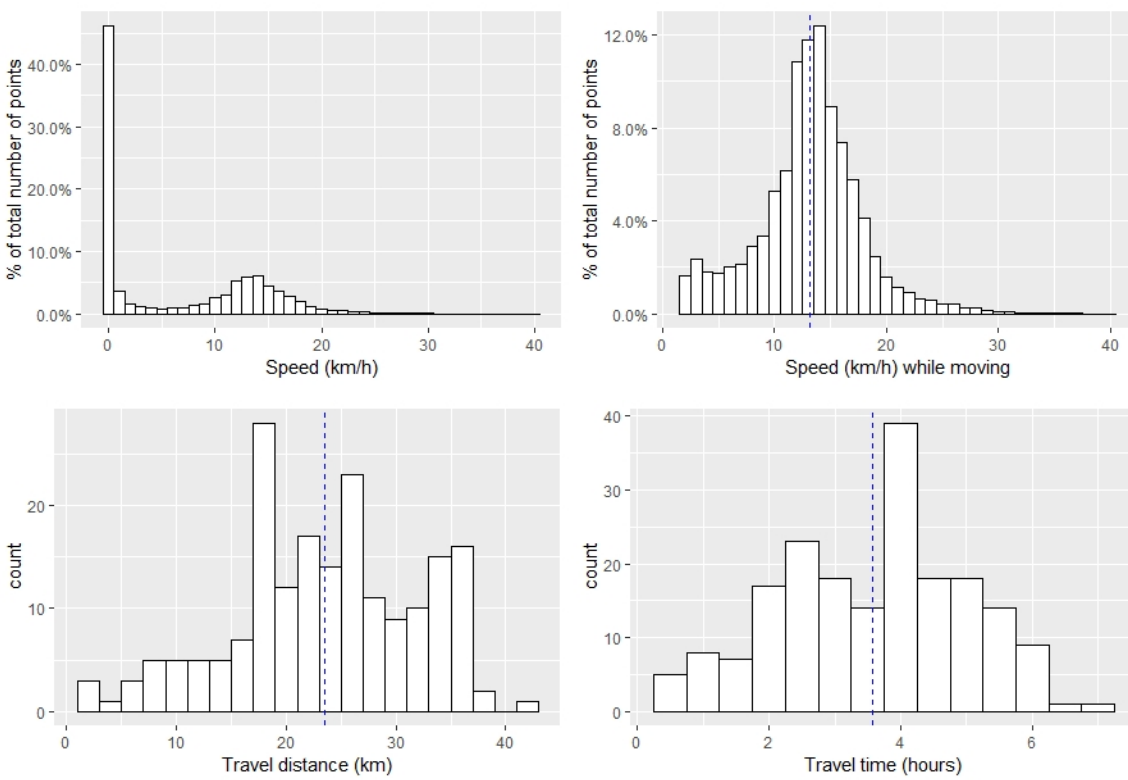


Figure 4-1: Speed, travel distance, and travel time per e-trike per day

The average speed of e-trikes is significantly different between the four areas, indicating the effect of the built environment. SW and NW (more dense) being generally lower than SE and NE (less dense). We observe a mean of 12.0 km/h (SD = 5.62) and 12.8 km/h (SD = 4.42) for SW and NW, respectively. The average speed in SE and NE is 13.8 km/h (SD = 4.4) and 14.0 km/h (SD = 4.58), respectively. This can be due to different road densities on the western versus eastern part of the city. The average speed is also significantly different within days of a week (Figure 4-2). Note that all regions were not served every day.

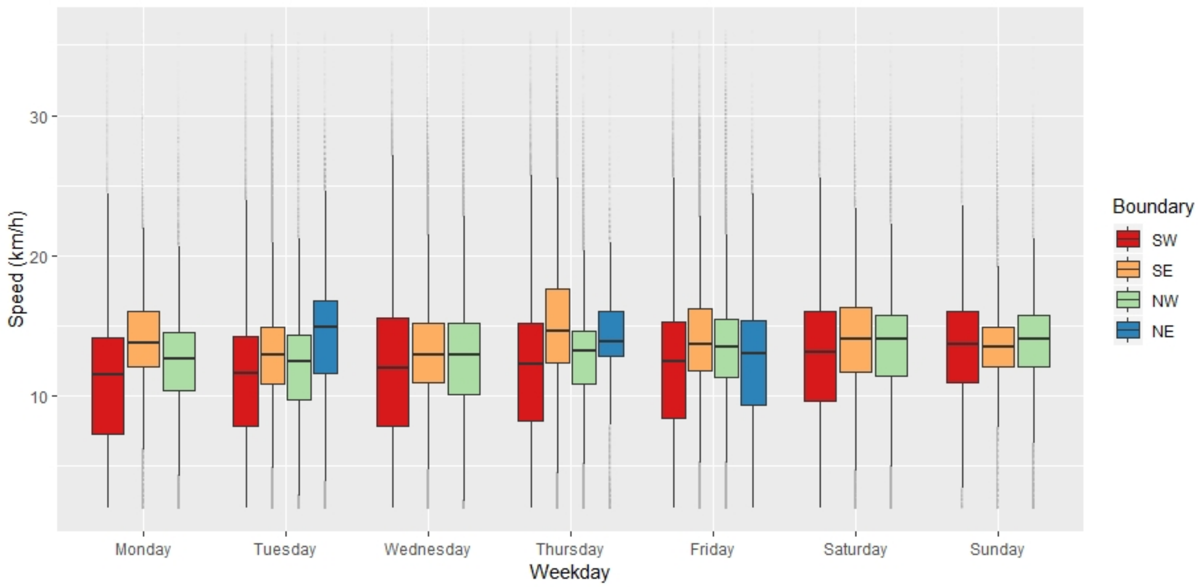


Figure 4-2: Average speed profiles by day of the week and boundary

We also analyzed speed segments with more than 300 points (i.e., 300 seconds) considering bike facility type. The results show that the average speed is higher on 'off-street path/trail' and 'bike lanes'. Additionally, average speed on 'neighborhood greenways' and 'off-street path/trail' were significantly higher than other busy bike facilities (0.2 to 1.1 km/h higher) (

Table 4-1). Note that while choosing a different threshold than 300 points would slightly change the average speed values, however, the order of the facility types sorted by speed would not change.

These results imply that the disparities among different days, hours, and bike infrastructure should all be accounted to fully understand the effects of the built environment and traffic conditions on the operating performance of the service. It is noteworthy that while the distance and time to find parking for e-trikes is assumed to be minimal in the previous studies [14, 15], the actual traces of e-trikes in downtown area showed patterns of cruising around some blocks before making a stop. This can be observed on busy one-way segments on which the e-trikes need to stop at a location on their left. Freight operators can use the GPS tracks and speed analysis to improve their routing performances considering vehicular and pedestrian traffic networks and meet their goals accordingly.

Table 4-1: Descriptive statistics of the average speed (km/h) on busy road segments based on bike facility type

Facility	n[1]	mean	sd	median	min	max	Q0.25	Q0.75
Buffered Bike Lane	24707	13.23	4.08	13.74	2.00	38.65	11.19	15.64
Enhanced Shared Roadway [2]	4662	13.41	4.36	13.71	2.01	33.15	10.94	15.98
Protected Bike Lane	7839	13.76	4.80	14.16	2.04	37.62	11.1	16.27
Neighborhood Greenstreet *[3]	84095	13.91	3.97	13.96	2.00	39.84	11.76	16.21
Bike Lane	110759	14.08	4.83	14.09	2.00	39.99	11.5	16.45
Off-Street Path/Trail *	29312	14.32	3.82	14.43	2.01	38.67	12.05	16.41

[1] number of GPS points

**Significantly different than all other bike facilities.*

Definitions below are adapted from Portland Bicycle Plan For 2030 adapted from portlandoregon.gov

[2] "Roadways where bicycles are not given priority, but bikeway signage and markings are used to increase driver awareness of bicycles on the roadway and traffic calming devices and/or intersection crossing treatments enhance bicycle travel."

[3] "Manages stormwater on site through use of vegetated facilities, creates attractive streetscapes that enhance neighborhood livability by helping to calm traffic by introducing park-like elements into neighborhoods, serves as an urban greenway segment that connects neighborhoods, parks, recreation facilities, schools and main streets."

4.1.1. Speed Spatial patterns

Geographical distribution of the e-trikes can also provide valuable information on the system performance. In a small-sized e-cargo system, this distribution could be largely affected by the customers' locations and road segments directions. While presenting the average speed on road segments provides a general overview of traffic condition and road capacity, we wanted to identify the segments with high GPS-spot speed. Therefore, we illustrated daily geographic positions of e-trikes according to their speed (Figure 4-3). Points with the spot speed of 15 km/h or more are shown in red and weighted by the speed value. As expected, we observe more high-speed segments in NE and SE areas. During weekdays, speed is more consistent in western areas, however, different traces of speeds can be observed on the same road segments in eastern areas. This can be a result of different times for deliveries, vehicular traffic condition, or using different e-trikes in those areas (e.g., different volumes, ranges).

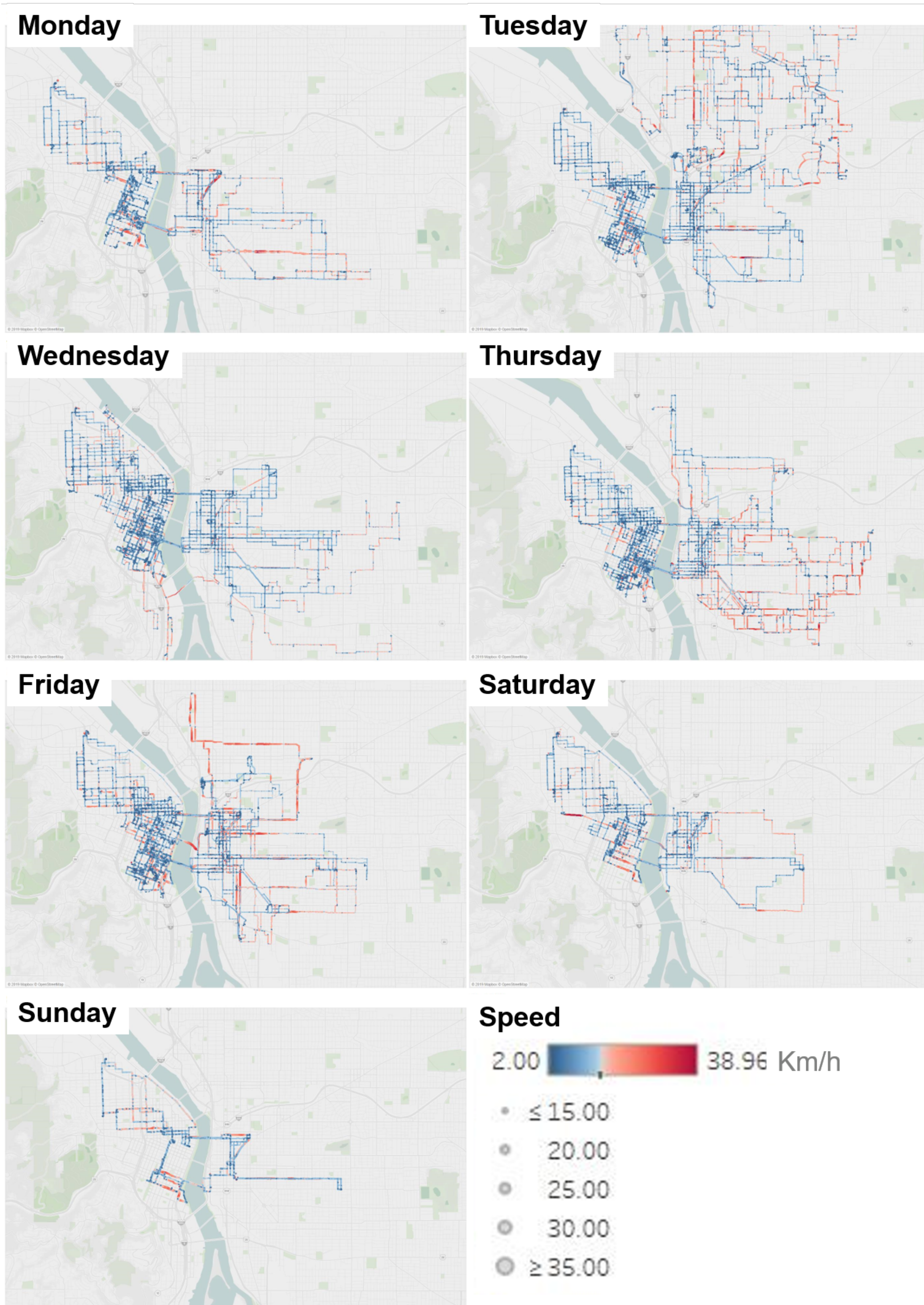


Figure 4-3: GPS spot-speed by day of the week

Next, we counted the number of GPS points in each hour, day and week and limited the data to the hours in which the number of points was larger than 600. This value is equivalent to 10 minutes of service with one e-trike operating in the system. Figure 4-4 illustrates the average of speed values per hour, per day, and per week. The size of the circles is weighted by the number of GPS points during that time period, and the color of the circles represent the average speed of those points. No e-trikes were working during Thursday on week 47 due to Thanksgiving. In addition, some observations were lost due to GPS failure. We observe more activities and smaller speed values during early weekdays and morning peak hours. However, the speed generally varies substantially during different hours, days, and weeks. Categorizing and considering the speed variation in routing and scheduling can increase the performance of the system. Specifically understanding how these speeds vary related to built-environment factors and traffic operations factors is an important element to consider. It is important to note that there are a few patterns in the data, specifically slower speeds during peak afternoon hours and slower speeds earlier in the week (perhaps depending on tour characteristics). In addition, larger systems might benefit from similar graphs for optimizing their battery charging schedules.

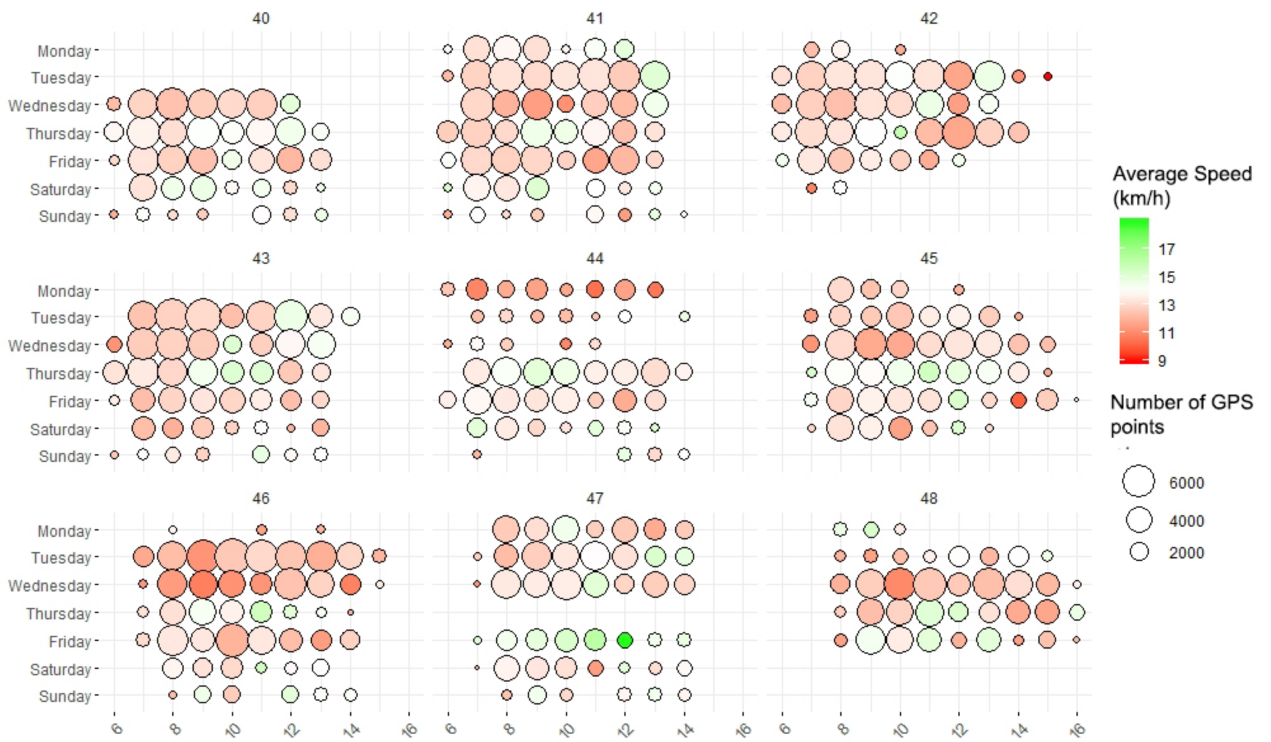


Figure 4-4: GPS spot-speed average by day, hour, and week number

4.1.2. Stop characteristics

We identified the stops relying only on the GPS data. Therefore, it is difficult to distinguish delivery stops and non-delivery stops, such as the e-trike riders' personal reasons for needing to stop. We aimed to use basic heuristics to filter out traffic-oriented stops. Having delivery information data from the service providers can validate the results, for example known delivery addresses. In the urban core, the GPS data was less precise that caused coordinate drift, and moving speeds were generally lower. These two factors combined make identifying stops in urban cores solely from GPS data more challenging. Acknowledging this limitation, the average number of stops per e-trike in a day was found to be around 13, with a range of

1 to 27 daily stops and an average stop duration of 7.67 minutes (SD= 4.32, 95% CI=0.19, median=6.35). This is consistent with the operator's operation schedule. The distribution of daily stop counts and stop durations are illustrated in Figure 4-5**.**

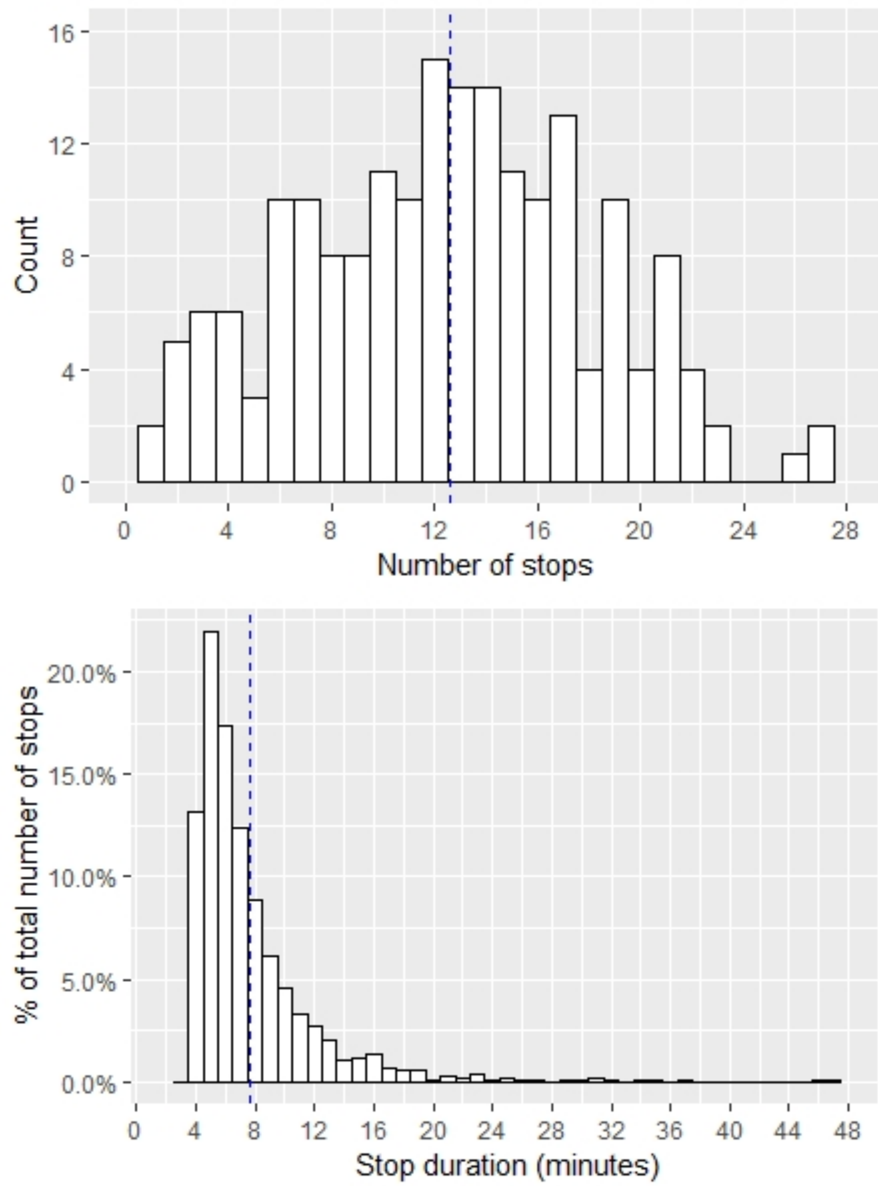


Figure 4-5: Daily number of stops (top) and stop duration (bottom) with dashed lines showing the mean value

4.2. Cost analysis

4.2.1. Portland case study

In the first part, we performed the simulation with deliveries being conducted solely by LEVs or by vans. We applied the cost function and compared the energy, labor, emission, and total cost along with total time. The characteristics of the total cost with regard to labor, pay load, and van fuel consumption can be seen in Figure 4-6. As expected, labor cost is the main driver for cost differences in the model. If an LEV driver's pay is $14 per hour, using LEVs are more cost efficient in this system. However, increasing the LEV driver's pay would increase total cost for LEVs and result in the total cost being greater than vans.

However, the total cost percentage difference is small. For instance, assuming an average $15 per hour pay for LEV drivers, the increase in total cost of utilizing LEVs comparing to vans is 2-4% with a 10% increase in labor cost. However, the energy cost decreases by 98-99% (Table 4-2).

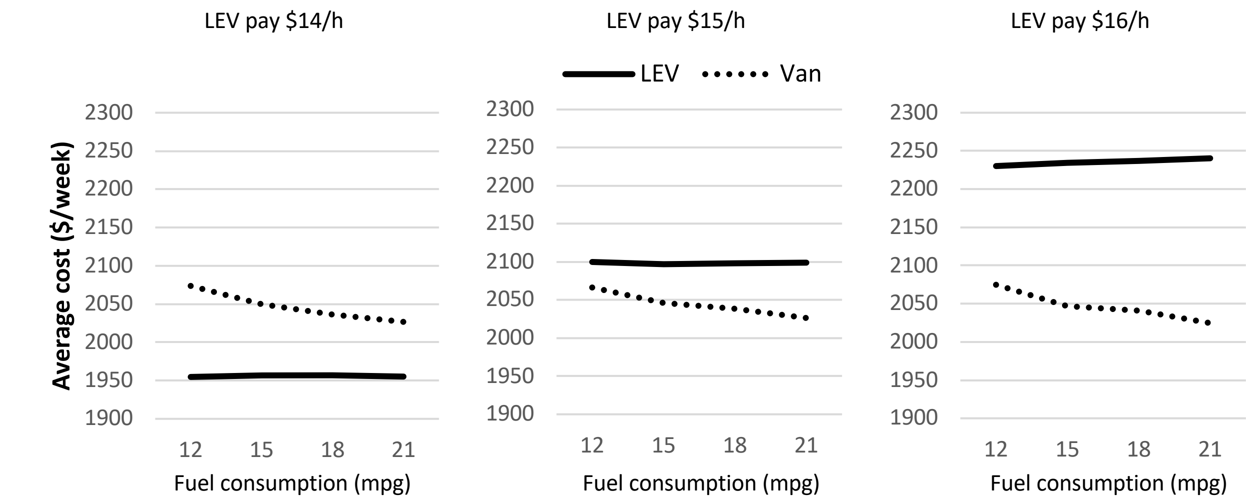


Figure 4-6: Average total cost for LEV and van by LEV pay and van fuel consumption

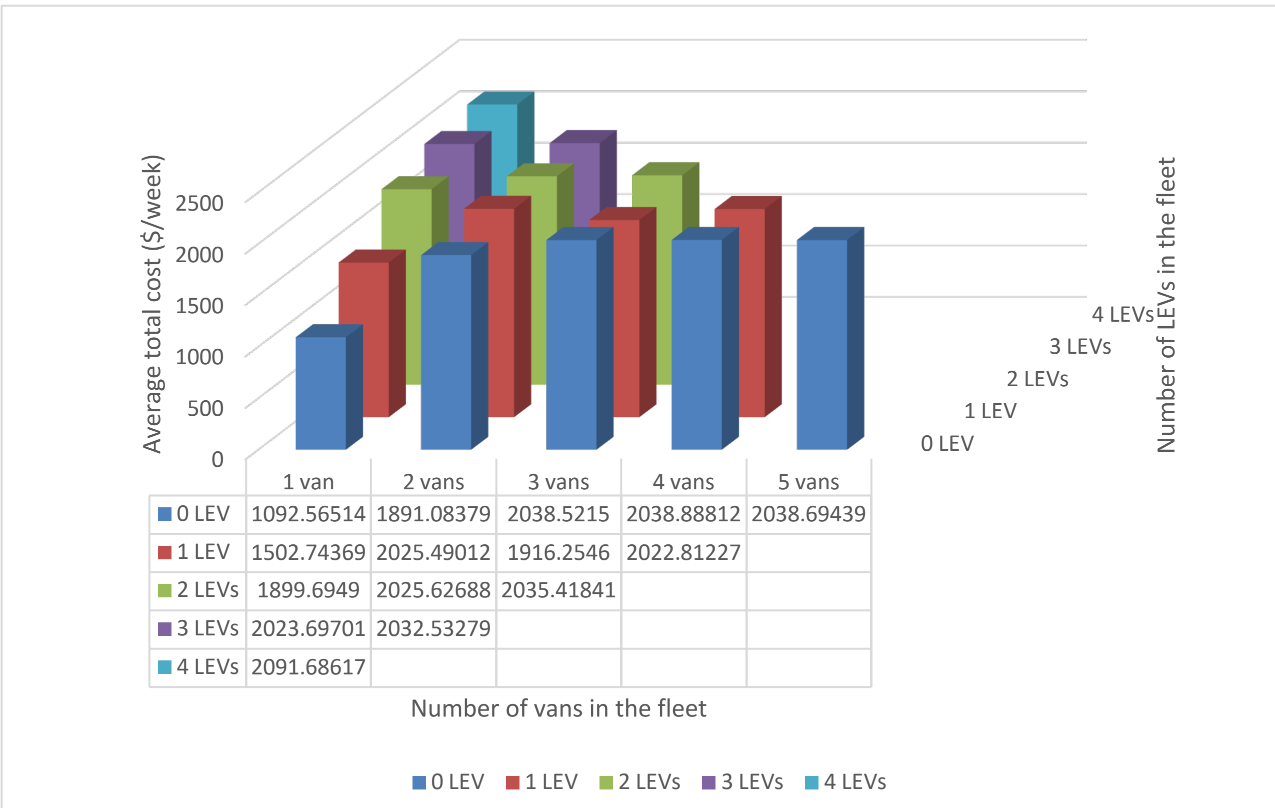
Table 4-2: Cost analysis detail for LEV and van

		Only LEVs (*average values)				**Only vans (*average values)**							
LEV pay ($/h)	Consumption (mpg)	Total Cost	Energy Cost	Labor Cost	Total Time	Total Cost	Energy Cost	Labor Cost	Total Time	Emissions Cost	% changes in total cost	% changes in energy cost	% changes in labor cost
14	12	1954.7	0.9	1946.4	139.0	2073.7	87.8	1909.5	116.0	5.9	-6%	-99%	2%
	15	1956.8	0.9	1948.4	139.2	2050.0	70.3	1904.5	115.7	4.7	-5%	-99%	2%
	18	1956.5	0.9	1948.1	139.1	2036.4	58.5	1903.6	115.6	3.9	-4%	-98%	2%
	21	1955.3	0.9	1946.9	139.1	2026.7	50.2	1902.7	115.6	3.4	-4%	-98%	2%
15	12	2099.9	0.9	2091.5	139.4	2066.4	87.8	1902.3	115.6	5.9	2%	-99%	10%
	15	2097.0	0.9	2088.6	139.2	2046.2	70.2	1900.8	115.5	4.7	2%	-99%	10%
	18	2098.2	0.9	2089.8	139.3	2038.7	58.5	1905.8	115.8	3.9	3%	-98%	10%
	21	2098.6	0.9	2090.2	139.3	2026.4	50.2	1902.5	115.6	3.4	4%	-98%	10%
16	12	2230.2	0.9	2221.8	138.9	2074.8	87.8	1910.7	116.1	5.9	7%	-99%	16%
	15	2234.3	0.9	2225.9	139.1	2046.6	70.2	1901.3	115.5	4.7	9%	-99%	17%
	18	2237.3	0.9	2228.8	139.3	2041.2	58.5	1908.4	115.9	3.9	10%	-98%	17%
	21	2240.3	0.9	2231.9	139.5	2024.6	50.2	1900.7	115.5	3.4	11%	-98%	17%

Integration of fleet mix added an element of complexity to the problem. The interaction of fuel consumption and LEV driver pay altered the results of the fleet mix problem. As cargo vans were removed from the problem, the service level metric became important. As we expected, the costs of running fewer vehicles overall were lower. At the same time, vehicles were given 13 hours to complete their deliveries. If time windows were tightened, it may result in a more dramatic reduction in service levels and alter the cost equation.

Figure 4-7 presents the cost analysis result for LEV pay of $15 per hour and 18 mpg fuel consumption for vans, using the cost function defined in the methodology section. In scenarios with one van, the cost increases by adding each LEV to the fleet. Note that running with a single van cuts the cost significantly, but it also cuts the service level by the same margin. Additionally, in two scenarios the fleet did not cover all customers in the proposed time period: one van and one LEV (82%) and one van and no LEVs (50%). Therefore, while the cost is reduced in calculations, about half of the deliveries were not made.

In scenarios with two vans, adding an LEV to the fleet did not dramatically increase the costs. In scenarios with three vans, adding one LEV decreased the costs compared to having only vans in the fleet. Overall, the fleet mix choice is determined by a company's initiatives towards sustainability and other business opportunities. In most scenarios, the total cost to ensure 100% service levels did not change dramatically with fleet mix. Even with a full fleet of cargo vans with the most efficient fuel consumption, the difference in total costs was less than $100 in the week.



	1 van	2 vans	3 vans	4 vans	5 vans
0 LEV	1092.56514	1891.08379	2038.5215	2038.88812	2038.69439
1 LEV	1502.74369	2025.49012	1916.2546	2022.81227	
2 LEVs	1899.6949	2025.62688	2035.41841		
3 LEVs	2023.69701	2032.53279			
4 LEVs	2091.68617				

Figure 4-7: Mixed fleet cost analysis

4.2.2. Nashville

In the previous section, we tested our proposed approach using real data from the B-Line Urban Delivery company in Portland. The Portland study has a unique characteristic in terms of the routing choices due to the commercial business landscape, which requires the e-trikes to pass through busy corridors and for a minimum period of time, largely due to the sector focusing (primarily) on the food industry. This is a niche area that requires in-time delivery and logistics solutions with relatively small and frequent deliveries. The routes are not completely optimized in terms of the shortest distance or time for deliveries. Additionally, Portland has a more complete bike infrastructure compared to many cities in the US. Nevertheless, the proposed approach was extended to analyze an e-trike based delivery system in Nashville, relying on some general findings from Portland study (e.g. average number of stops per day). The purpose of this analysis is to investigate the performance of a similar delivery service in Nashville with a different transportation infrastructure and characteristics from Portland and understand how much the prediction can be extended in a different city context.

To populate our Nashville case, we rely on performance characteristics and scenario development from the Portland system. Assuming each e-trike serves the average number of 13 stops per day, we randomly generated 39 stops in three zones in the city of Nashville for five e-trikes running 2-3 times a day (AM and PM shift). The total number of stops in downtown is approximately 50% of total stops to meet the goal of serving the urban core in the city. Figure 4-8 presents the routing for each e-trike in one sample day. The routes are generated using ArcGIS Network Analyst and are optimized on an OSM network generated for bicycle routing. Other scenarios can easily be developed, for example, serving West Nashville.

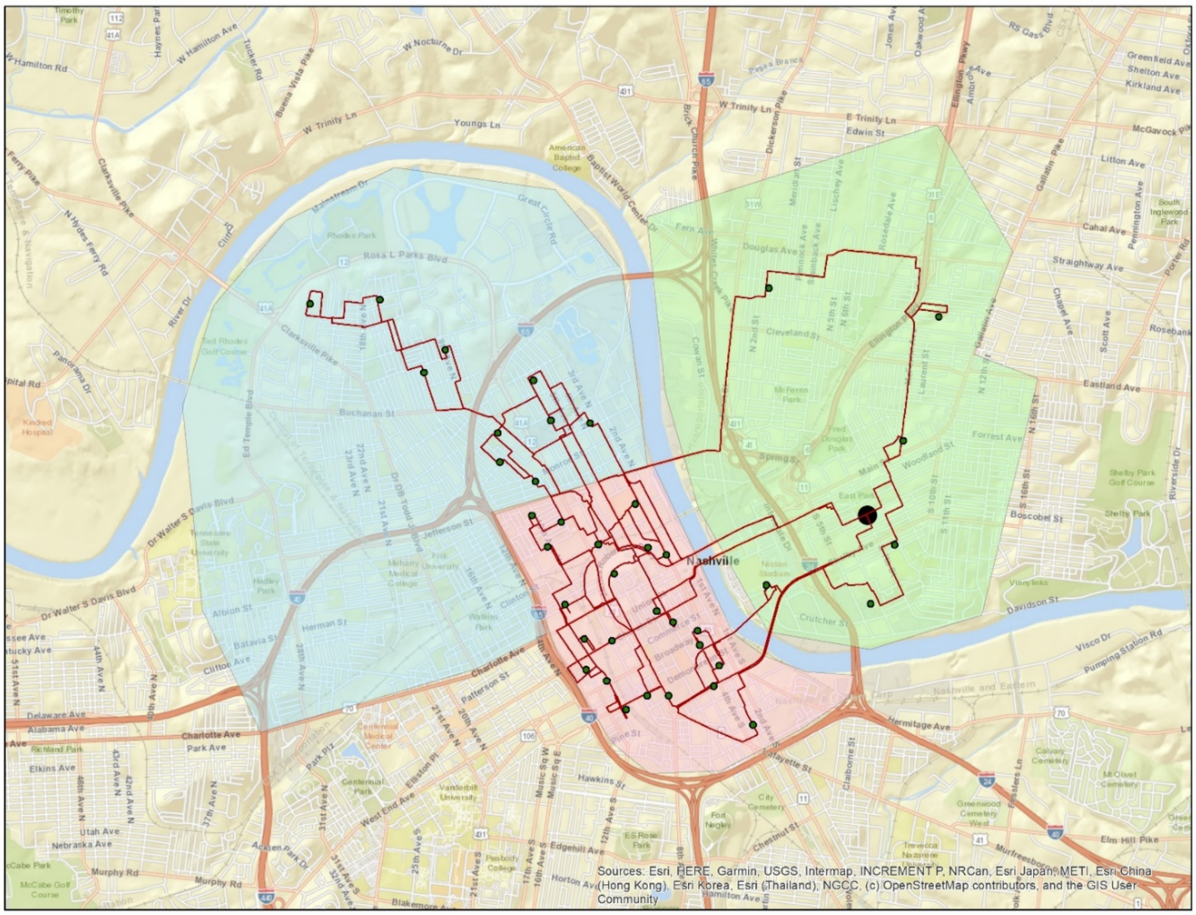


Figure 4-8: Zone and route assumptions in Nashville, TN

Following the same process as Portland, we used similar fuel consumption rates and LEV cost functions. The fleet options to estimate the costs in AnyLogic software were 5 LEVs, 3 vans, 4 vans, or 5 vans (no mixed fleet). Additionally, we created two factors ‘time constraint’ and ‘parking utilization rate’ for the Nashville simulation. Time constraint is defined as the hours allotted for deliveries. To get a variety of outcomes, we included a range of 3 hours to 15 hours limit per route. Parking availability rates have been defined from 0 (100% of parking spaces are occupied, and the drivers have to spend more time seeking an open space) to 1 (all parking spaces are available). Using average values of all utilization rates with no time constraint, LEV costs are lower than vans in all simulated scenarios (Figure 4-9). However, this relationship changes significantly with different parking utilization or time constraints. For a detailed comparison, please see the appendix.

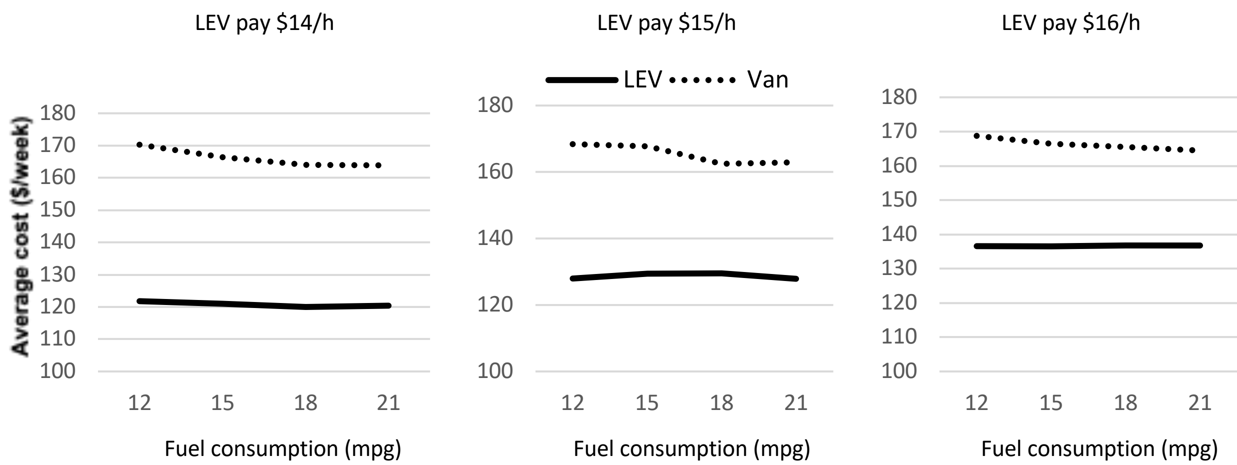


Figure 4-9: Cost analysis for Nashville, TN

Figure 4-10 presents the fleet cost analysis by parking utilization rate. Note that the analysis scenarios are all vans (3,4, and 5, with 0 LEV) or all LEVs (0 van). Note that p=0 and p=1 does not reflect real situations because of the assumption made for the distribution function, explained in section 3.2.1. Choosing these values would result in zero failures for finding a parking spot using $F(x) = 1 – (1\text{-}p)^k$. Fleet cost analysis shows that parking utilization rate plays an important role in the final cost when the fleet is all vans.

Note that the size of the market simulation in Nashville was smaller than the real market in Portland. In Portland, we had the same set of routes in every simulation. For Nashville, we defined 5 routes and randomly selected between 3 and 5 per day, which likely contributed to the differences across costs in Nashville. For the entire week, Portland customers required 79.0 hours per week for service (not including travel between customers). However, for the Nashville scenario, if all five routes are executed all five days, the total service time requirement adds up to 41.3 hours per week. Additionally, the number of customers served highlights a potential difference. The Portland simulation included 508 customers with travel times between each for one week. However, all five routes in Nashville combined to 59 customers per day.

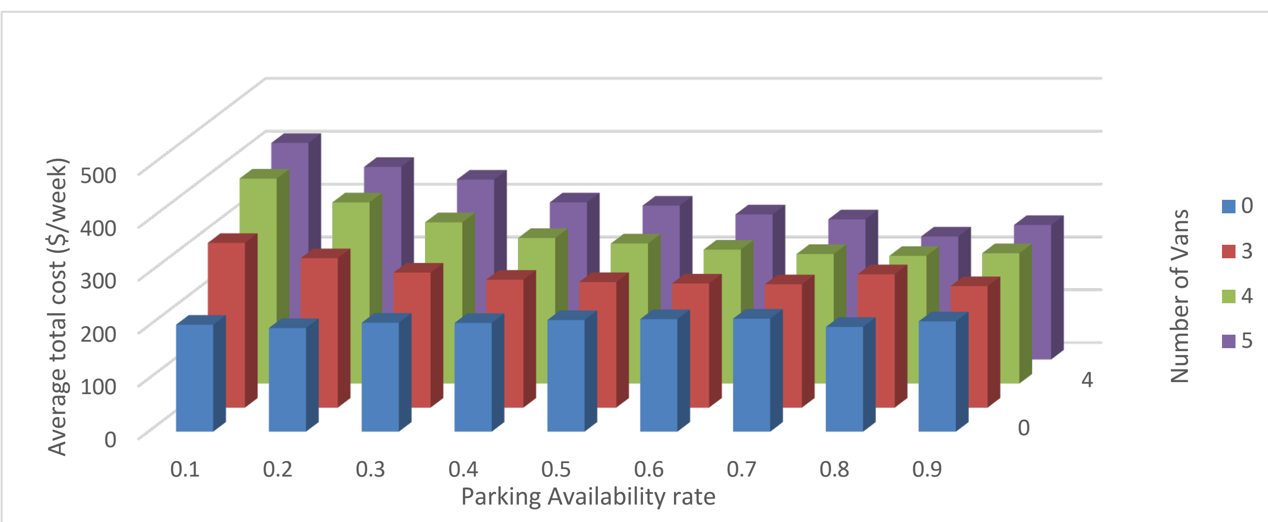


Figure 4-10: Fleet cost analysis for Nashville by different parking utilization rates ($/week of simulation)

4.3. Review by Experts

To get an overview of main factors related to deployment of LEVs in urban deliveries compared to vans, five experts from TN completed the online survey. The experts were freight-oriented engineers and planners from the cities of Nashville, Memphis, Knoxville, and Chattanooga. The outcomes of experts' judgements are presented in Figure 4-11. All experts evaluated safety as the most important factor while noise has the least importance. More comparison studies should be conducted to examine more experts' judgments and understand the factors.

Calculating the factor weights considering pairwise comparisons, we conclude that the ranking of the factors' importance is as follows: safety, congestion, emissions, costs, and noise (Table 4-3). The operator's main goal, however, is to reduce emissions with a fast and sustainable delivery system within city core areas. This is somehow consistent with previous studies that argued authorities focus on regulatory rules and therefore, more integration is required among different stakeholders (shippers, customers, authorities, operators) [46]. Therefore, all stakeholders should be involved in the decision-making process to maximize the impacts of different policies [47].

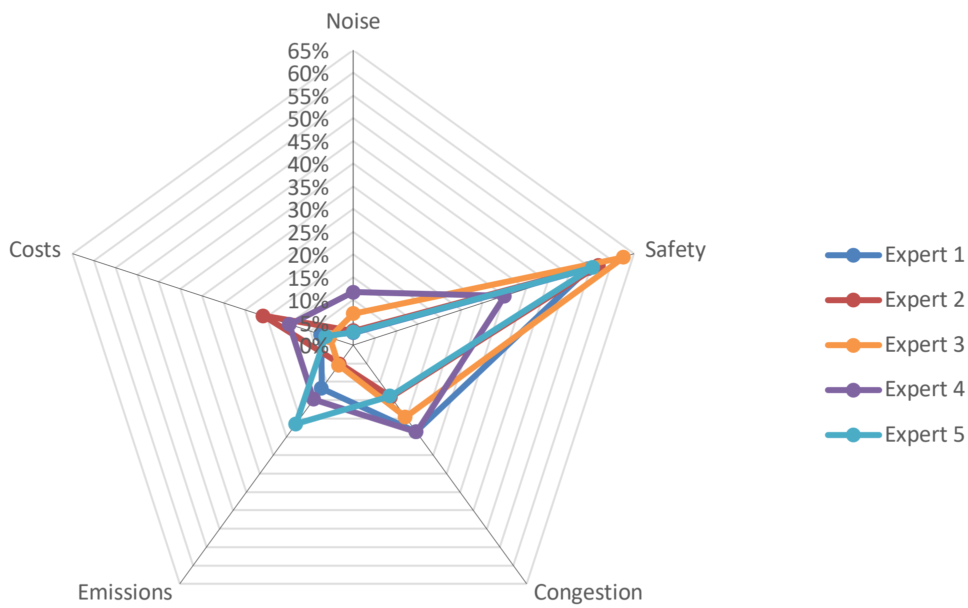


Figure 4-11: Weights of each expert on each factor regarding using LEVs in urban freight

Table 4-3: Pair-wise comparison matrix, with factor weights and consistency rate

	Emissions	Noise	Congestion	Costs	Safety	Weight
Emissions	1	2.713085	0.408231	1.312094	0.145549	0.098
Noise	0.368584	1	0.249757	0.355953	0.137582	0.047
Congestion	2.449592	4.003899	1	2.329511	0.172427	0.173
Costs	0.76214	2.809361	0.429275	1	0.138415	0.090
Safety	6.870516	7.224674	5.799546	7.224674	1	0.592
CI=	0.051133					
RI=	1.12					
CR=	*0.045654*					

Chapter 5: Conclusion/Recommendations

5.1. Importance of data

In recent years, electric-assisted cargo cycles have been proposed as an innovative and sustainable city logistics solution. However, lack of data collection on emergent systems has resulted in little analysis on the operating performance of the system at a micro-scale. This study conducted analyses on an e-trike urban freight delivery system using the GPS data collected over the span of two months in Portland, OR. Using the bike-friendly city of Portland as a case study could have improved operational performance due to better-dedicated bike infrastructure and network connectivity than most American cities. We described the data cleaning process and methods to explore the GIS data collected from the e-trikes and analyzed the transportation performance of the system in details. Through our analyses, we showed that even within one system, many factors including traffic conditions and infrastructure could lead to lead to varying levels of effectiveness in system performance. Therefore, different factors should be categorized and considered appropriately for evaluating the feasibility and calculating the costs of e-trike implementation in last-mile deliveries.

We recommend the development of a framework to systematically generate and collect data using various sources (e.g., rider/e-trike travel log and GPS, phone application) from public and private delivery sectors to overcome the huge current gap in data and information. Collected GPS data can reveal valuable information of the operation performance of LEVs to all stakeholders. This information can help improving the routings, policies, and business plans to maximize the opportunities towards achieving various initiatives. Authorities can benefit from partnership with operators to evaluate city policies and enhance them towards achieving more safety to the citizens, reduce congestion in urban core areas, and reduce emissions and noise. The main limitations associated with GPS data collection are possible data loss due to GPS recorder dead battery and data location accuracy reduction near tall buildings, bridges, or large trees. Using advanced, embedded GPS recorders can help to reduce these issues.

5.2. Evaluation of LEV-based delivery system for urban cores

Our proposed cost analysis framework considered various cost factors related to the system. We carried out computational tests using real data from a case study as well as transportation network data (e.g. speed, travel time) for the city of Nashville. Our results yielded that a mixed fleet of vans and e-trikes can affect the associated costs, while the services avoid heavy congestion in urban cores. There is a significant decrease in emissions and energy costs when e-tikes replace the vans for delivery purposes in urban cores.

Different types of e-cargo cycles can contribute in urban deliveries. Main factors in categorizing and choosing the cargo cycles are their volume, range, and the delivery purposes. Additionally, the size of the vehicle affects the effectiveness of the system as they can use bike infrastructures instead of roads when possible and therefore experience less vehicular congestion and parking constraints. Additionally, e-cargo cycles can overcome several physical barriers that conventional cargo cycles might experience (e.g. speed, slope, range). An LEV-based delivery system is competitive in urban core areas where the density is high with heavy traffic and with a distributing center close to the urban core.

Cities can evaluate the existing standard cargo sizes and compare with bike infrastructure policies (e.g. lane width). In this study, the maximum vehicle width (50”) which is slightly less than the minimum width of a bike lane proposed by FHWA (60”). In order to provide sufficient space for cargo delivery systems, it is important for cities to consider other potential purposes of bike lanes within urban cores. This study is limited to one operator in a single city. While the methods can be applied to other systems, the results should be generalized cautiously with other systems. Methods presented in this study can provide input for TDOT to create a framework of sustainable last-mile delivery requirements and identify the stakeholders and policies that contribute in moving towards introducing green and competitive delivery systems in urban cores.

Future research can evaluate the existing bike infrastructure in urban core areas, evaluate operators' cargo cycles delivery system compatibility considering different cargo sizes, bike infrastructure width, slope changes in infrastructure, sidewalk width, connectedness of bike infrastructure, land use, and signal timing. This would result in a fine geographic map of the city and help in determining the best areas for distribution centers, bike infrastructures, and public spaces that will be utilized to serve deliveries and play important roles in the effectiveness of cargo delivery systems. Additionally, a large number of crashes between delivery vehicles and pedestrians or bicyclists in urban cores can be prevented if the delivery vehicles are replaced by e-trikes. Further studies are necessary to evaluate safety by analyzing delivery vehicles' crash data and find the main factors that contribute in these crashes. Having the factors, we would be able to model the potential changes in safety by replacing delivery vehicles with e-trikes.

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Appendices

Appendix A- Speed distribution in Portland

Historical average speed in Portland has been used to build a speed distribution for the network simulation in AnyLogic. The average speed and travel time data have been adopted from Oregon's Department of Transportation iPeMS (Iteris Performance Measurement System). Vertical, horizontal, and diagonal routes were defined manually for the four regions in Portland (SW, SE, NE, and NW) and the 15-minutes average speed for the month of October 2017 has been used to build the speed distribution for the system to be assigned to the vans in the simulation.

Speed distribution in Portland- Vertical

	SW	SE (EW)	SE (WE)	NE (NS)	NE (SN)	NW (NS)	NW (SN)
6	weibull(4.29779,3.08982,7)	beta(3.028,1.25739,13,17.06)	beta(3.028,1.25739,13,17.06)	beta(2.81998,.660656,15,24.83)	beta(4.8502,1.89592,20.17,25.67)	triangular(7.3491,8.82357,8.46021)	cauchy(.0398999,7.31615)
p	0.86	0.0768	0.0768	0.172	0.355	0.113	0.138
KS	0.0456	0.0993	0.0993	0.116	0.0971	0.126	0.121
7	beta(7.31099,6.40273,6,11.6454)	weibull(2.43605,4.49645,10)	weibull(2.43605,4.49645,10)	triangular(12.2868,24.7184,17.612)	beta(2.65093,2.72524,12,24.46)	beta(2.14432,1.95178,6,8.49)	beta(2.14432,1.95178,6,8.49)
p	0.895	0.699	0.699	0.969	0.946	0.0538	0.0538
KS	0.0435	0.0534	0.0534	0.0364	0.0397	0.103	0.103
8-15	beta(6.80519,8.80325,5,11.5779)	beta(3.50123,3.05231,9.84,20.01)	gamma(29.286,.264682,7.57699)	logistic(.797702,15.6574)	logistic(.797702,15.6574)	Empirical(too consistent for distribution)	Empirical (too consistent for distribution)
p	0.636	0.391	0.876	0.815	0.815		
KS	0.0202	0.0337	0.0221	0.0169	0.0169		
16-18	weibull(3.64917,3.52482,4)	gamma(3.81692,1.0644,7)	gamma(3.81692,1.0644,7)	beta(4.84355,6.9069,9,19.9536)	beta(4.72757,6.74231,9,19.9447)	Emipirical	Empirical
p	0.999	0.0771	0.0771	0.882	0.89		
KS	0.0166	0.0565	0.0565	0.0252	0.0602		
19	logistic(.434917,7.69992)	erlang(.873039,2,12.6784)	lognormal(1.0459,.39992,12.131)	logistic(15.6316,.647067)	logistic(15.6316,.647067)	logistic(6.49344,.107722)	logistic(6.49344,.107722)
p	0.646	0.555	0.995	0.915	0.915	0.717	0.717
KS	0.0558	0.0828	0.0429	0.0421	0.0421	0.0526	0.0526
20	lognormal(1.22353,.196683,4.75702)	lognormal(.760159,.308943,8.4837)	lognormal(.760159,.308943,8.4837)	erlang(.360704,7,14.274)	erlang(.360704,7,14.274)	lognormal(-1.0638,.511276,6.19541)	lognormal(-1.0638,.511276,6.19541)
p	0.962	0.223	0.223	0.762	0.762	0.316	0.316
KS	0.038	0.082	0.082	0.0509	0.0509	0.0734	0.0734

Speed distribution in Portland- Horizontal

	SW	SE	NE	NW
6	beta(1.44466,2.66304,6.46,16.28)	beta(2.05645,1.87902,16.06,22.98)	weibull(8.20602,7.52448,16)	logistic(.557286,12.6923)
p	0.171	0.945	0.188	0.699
KS	0.0512	0.0397	0.083	0.0535

7	weibull(2.97831,4.34693,4.9203)	weibull(3.7596,7.35662,10.6617)	beta(1.99878,1.75576,14.33,22.68)	weibull(5.72587,5.24864,6.2479)
p	0.789	0.658	0.595	0.972
KS	0.0298	0.0553	0.0581	0.0367
8-15	beta(6.77837,8.64474,4.83779,12.1611)	beta(4.57707,4.06803,9.84,20.17)	logistic(.551539,15.1325)	beta(9.19424,134.639,5,60.1441)
p	1	0.532	0.561	0.0632
KS	0.013	0.0219	0.0214	0.0357
16-18	weibull(3.15591,3.75786,4)	beta(2.99517,2.68457,10.17,19.36)	normal(14.7245,.996665)	beta(3.73335,4.02684,4.31,12.02)
p	0.964	0.719	0.739	0.992
KS	0.0303	0.0306	0.0301	0.019
19	erlang(.947121,3.5.03299)	weibull(2.78555,2.45082,12.6863)	gamma(3.1776,.447613,14.2834)	lognormal(1.57488,.225898,3.50665)
p	0.196	0.86	0.376	0.984
KS	0.0511	0.0456	0.0689	0.0348
20	gamma(3.7971,.830799,5.11116)	laplace(.903333,15.21)	lognormal(.370202,.422377,14.5748)	beta(5.98373,693.709,6.2,328.69)
p	0.568	0.632	0.475	0.81
KS	0.036	0.0564	0.0637	0.0482

Speed distribution in Portland- Diagonal

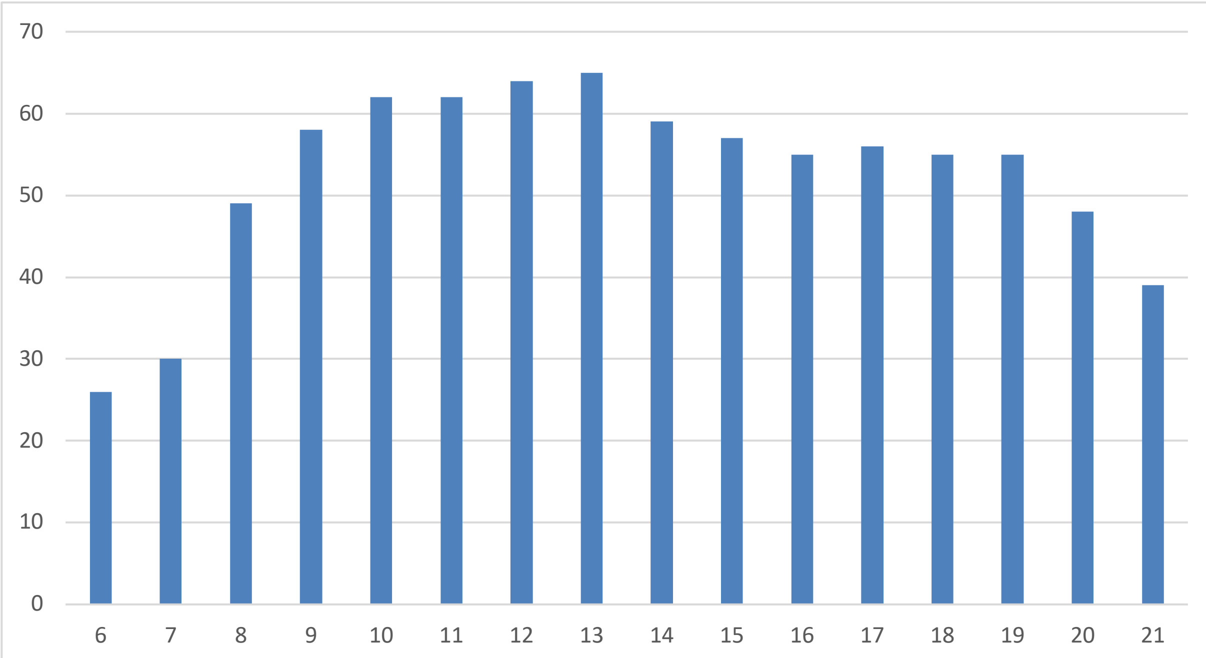
	SW(SENW,NWSE)	SW (SWNE)	SW (NESW)	SE (SENW)	SE (NWSE)	SE (SWNE)	SE (NESW)	NE	NW
6	erlang(.600672,4,9.28044)	erlang(.600672,4,9.28044)	erlang(.600672,4,9.28044)	lognormal(2.3426,.141557,7.5158)	lognormal(2.3426,.141557,7.5158)	lognormal(2.3426,.141557,7.5158)	lognormal(2.3426,.141557,7.5158)	weibull(5.72151,5.93385,16.1799)	beta(2.3154,2.02866,10.7663,16.69)
p	0.0951	0.0951	0.0951	0.853	0.853	0.853	0.853	0.796	0.762
KS	0.0669	0.0669	0.0669	0.0327	0.0327	0.0327	0.0327	0.0348	0.036
7	lognormal(1.63636,.215518,5.30478)	lognormal(1.63636,.215518,5.30478)	lognormal(1.63636,.215518,5.30478)	lognormal(2.66811,.114812,.740719)	lognormal(2.66811,.114812,.740719)	lognormal(2.66811,.114812,.740719)	lognormal(2.66811,.114812,.740719)	beta(1.99372,2.15224,14.24,21.92)	weibull(3.49861,4.76245,7.80762)
p	0.209	0.209	0.209	0.583	0.583	0.583	0.583	0.05	0.822
KS	0.0576	0.0576	0.0576	0.0417	0.0417	0.0417	0.0417	0.833	0.0339
8-15	beta(3.57078,4.47813,6.67,10.3222)	erlang(.137094,21,6)	logistic(.310722,10.8087)	weibull(6.24851,4.7377,8.76975)	beta(2.09143,5.21145,10.18,17.6167)	lognormal(1.59826,.12337,6.36491)	logistic(.532848,14.4709)	erlang(.118732,70,6.55552)	beta(2.29342,2.78986,6.14,13.59)
p	0.661	0.225	0.661	0.67	0.116	0.457	0.853	0.23	0.227
KS	0.0194	0.0393	0.0273	0.0271	0.0449	0.032	0.0227	0.02	0.0201
16-18	weibull(3.39246,2.85551,5)	weibull(3.5573,3.50784,4.65134)	weibull(3.48178,10.7235,7.01729)	beta(2.61021,4.88171,9.24,18.77)	beta(2.61021,4.88171,9.24,18.77)	beta(2.61021,4.88171,9.24,18.77)	beta(2.61021,4.88171,9.24,18.77)	normal(13.9523,.908226)	beta(4.99695,8.3864,3.97,15.9921)
p	0.49	0.992	0.642	0.113	0.113	0.113	0.113	0.991	0.937
KS	0.0359	0.0262	0.045	0.0376	0.0376	0.0376	0.0376	0.0137	0.0167

19	triangular(6.98492,12.3132,8.13042)	triangular(6.98492,12.3132,8.13042)	triangular(6.98492,12.3132,8.13042)	lognormal(.849784,.24972,8.81063)	beta(41.6525,28.8812,7.73402,17.6584)	lognormal(1.44344,.114497,7.0975)	gamma(13.5473,.171161,11.8459)	gamma(9.61589,.26645,12.3885)	weibull(2.45569,3.42026,6.52173)
p	0.247	0.247	0.247	0.864	0.984	0.476	0.931	0.995	0.95
KS	0.0554	0.0554	0.0554	0.0622	0.0473	0.088	0.0559	0.0224	0.0279
20	beta(5.23526,7.86563,7.12387,11.4052)	gamma(13.5728,.156897,7.24244)	lognormal(.656851,.198113,9.18027)	laplace(.339318,11.38)	weibull(2.55493,1.68191,12.9602)	lognormal(1.44344,.114497,7.0975)	erlang(.210951,11,12.2204)	lognormal(1.13103,.260814,12.4068)	logistic(.726059,9.92863)
p	0.993	0.998	0.998	0.82	0.993	0.476	0.917	0.426	0.0381
KS	0.0317	0.0406	0.0393	0.0656	0.0438	0.088	0.0575	0.0471	0.697

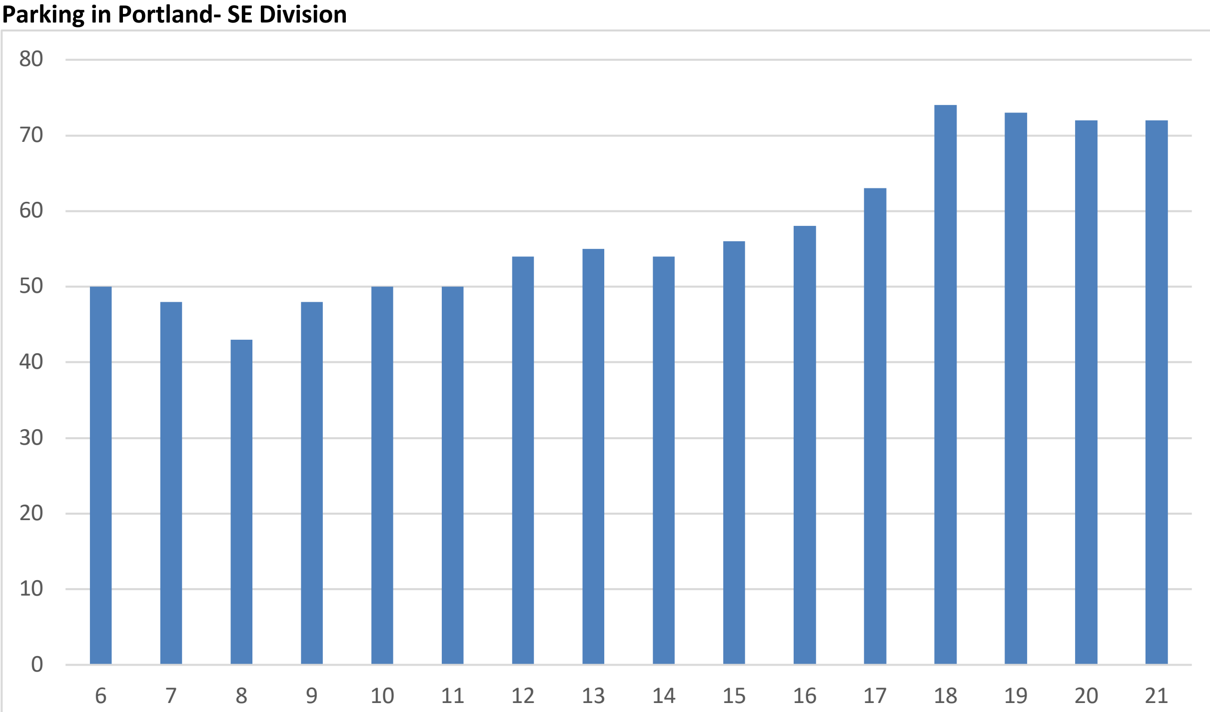
Appendix B- Parking data in Portland

The following data has been adopted from [36].

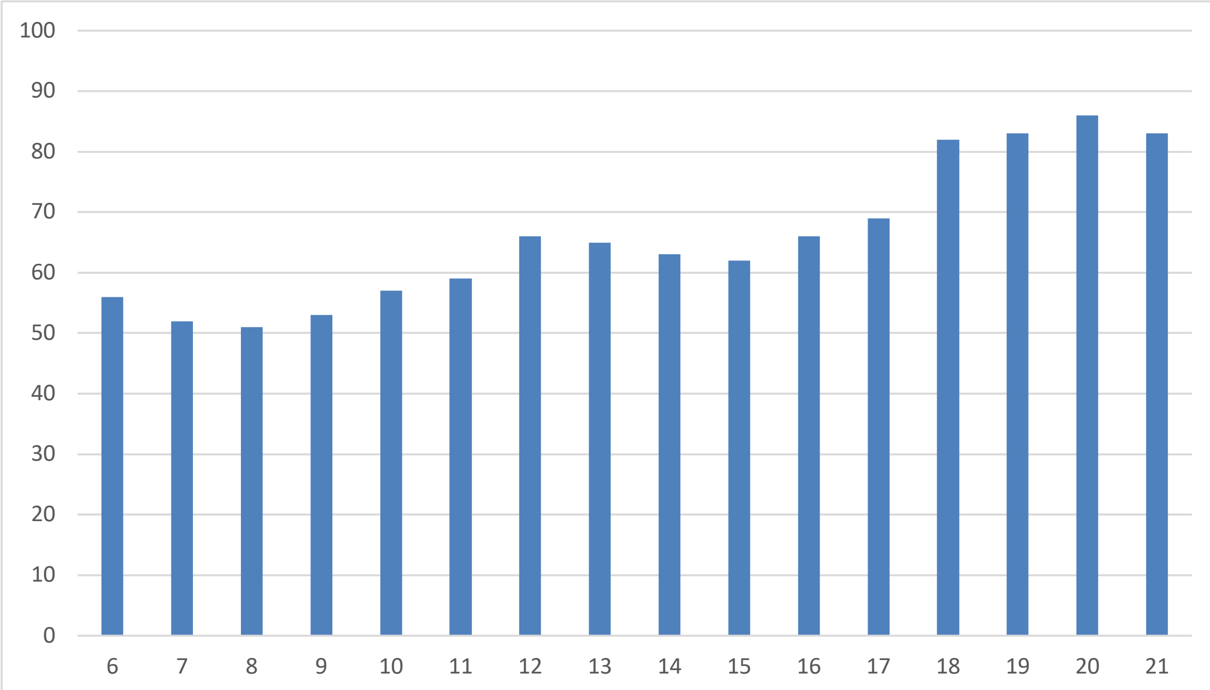
Parking in Portland- Hollywood



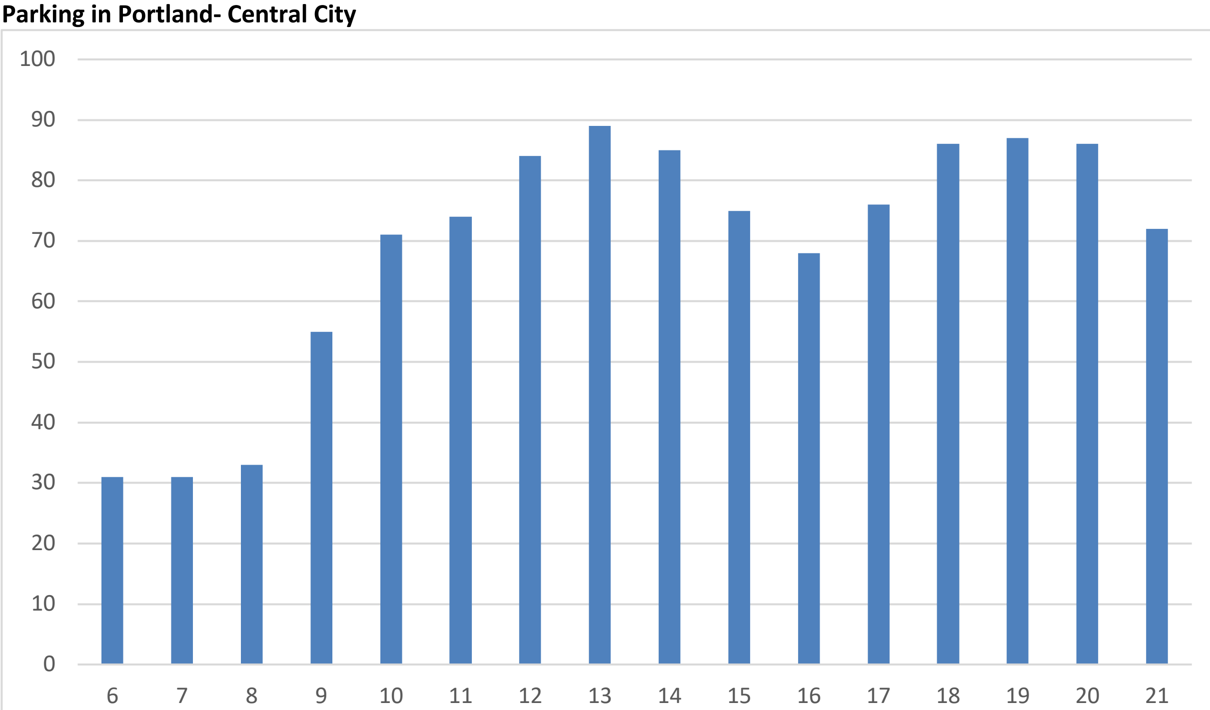
Parking in Portland- SE Division



Parking in Portland- N Mississippi

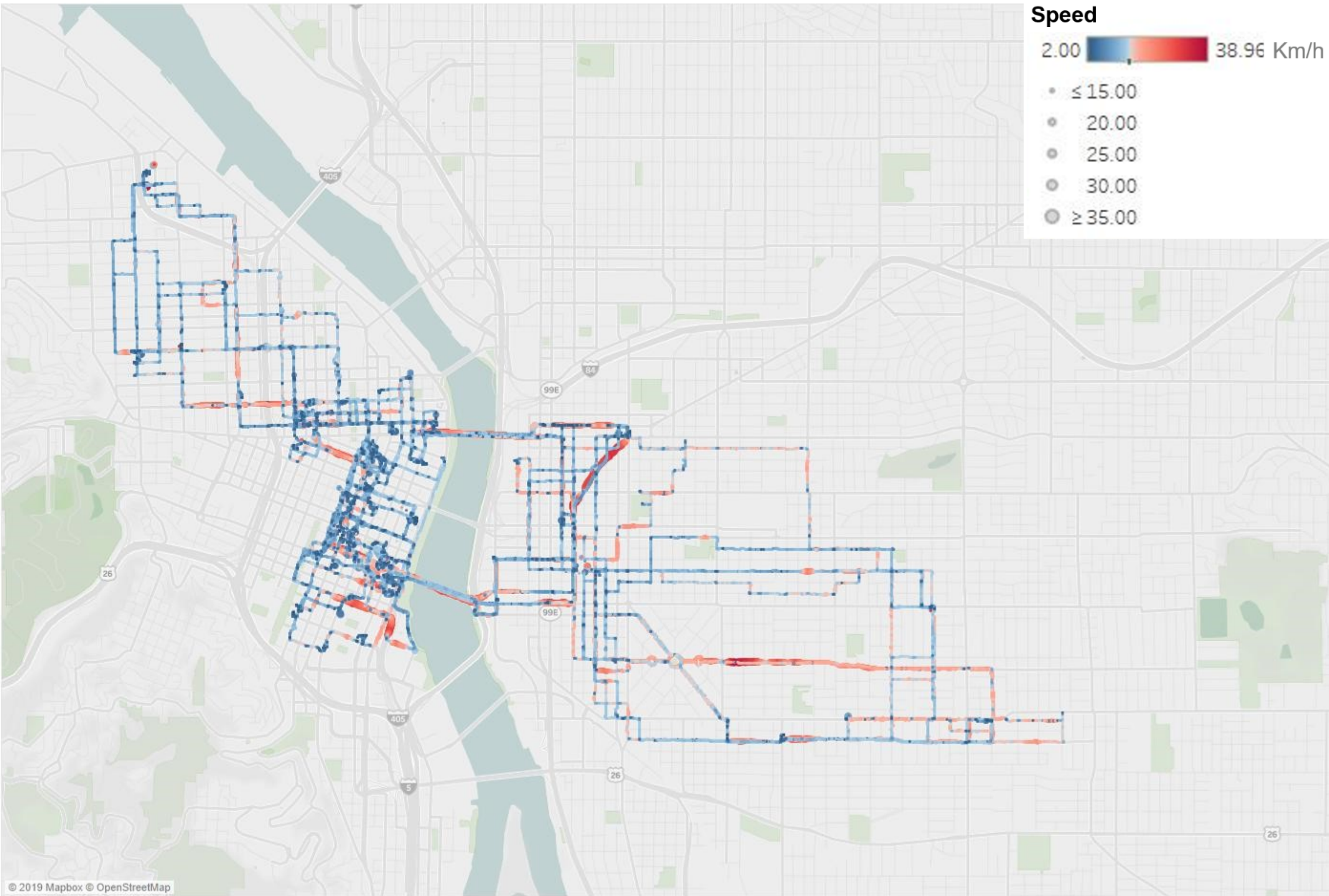


Parking in Portland- Central City

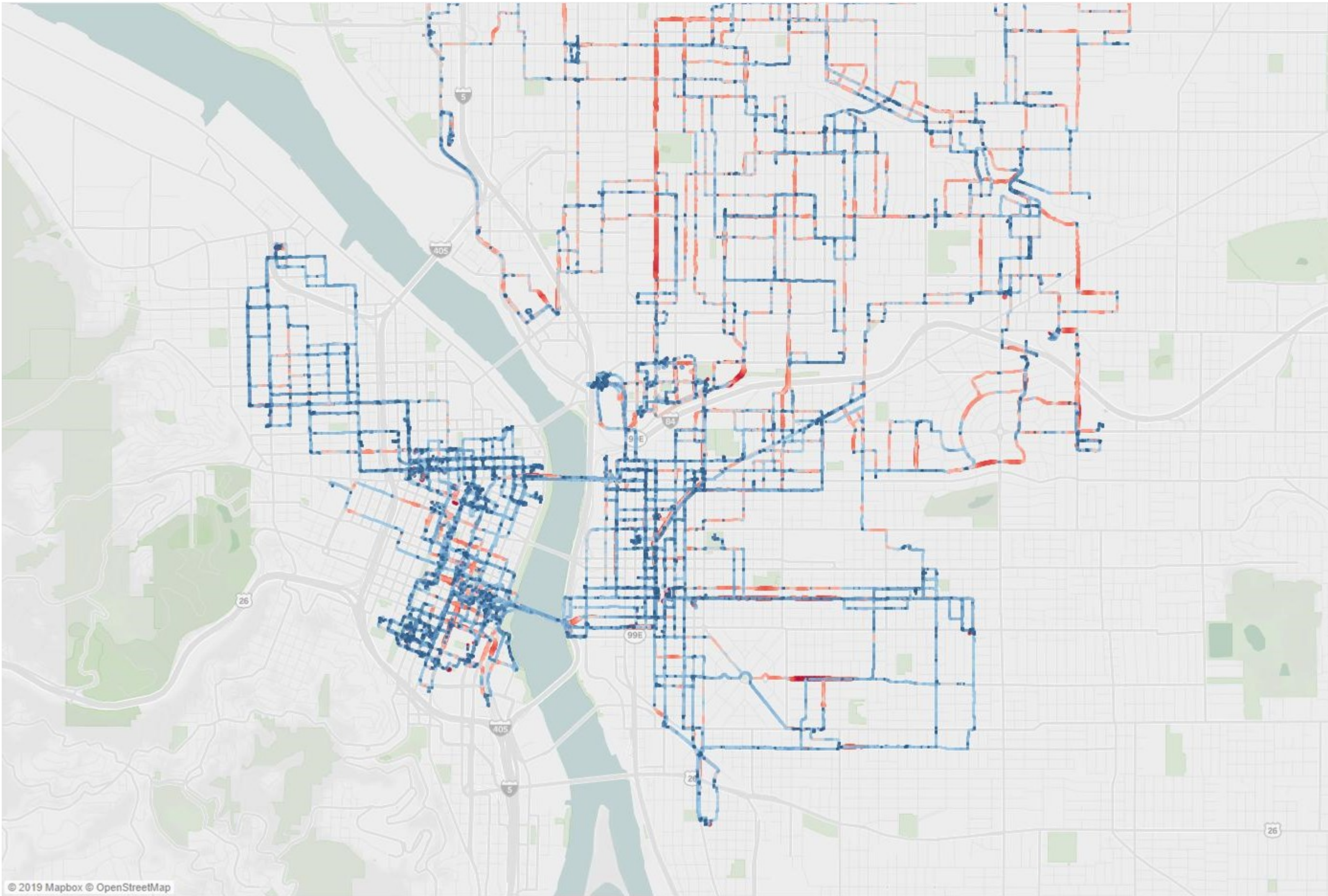


Appendix C- Speed maps by day

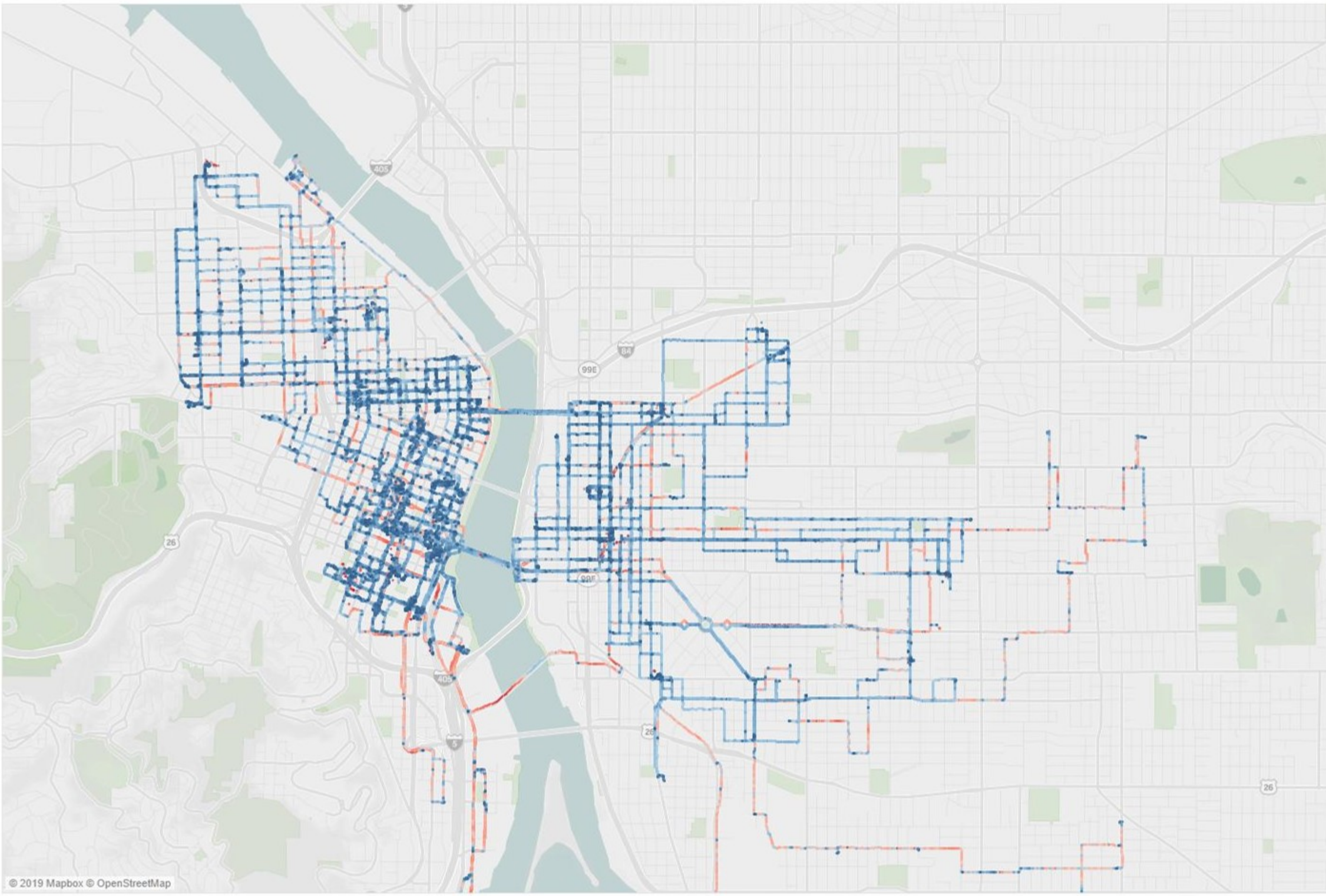
Monday



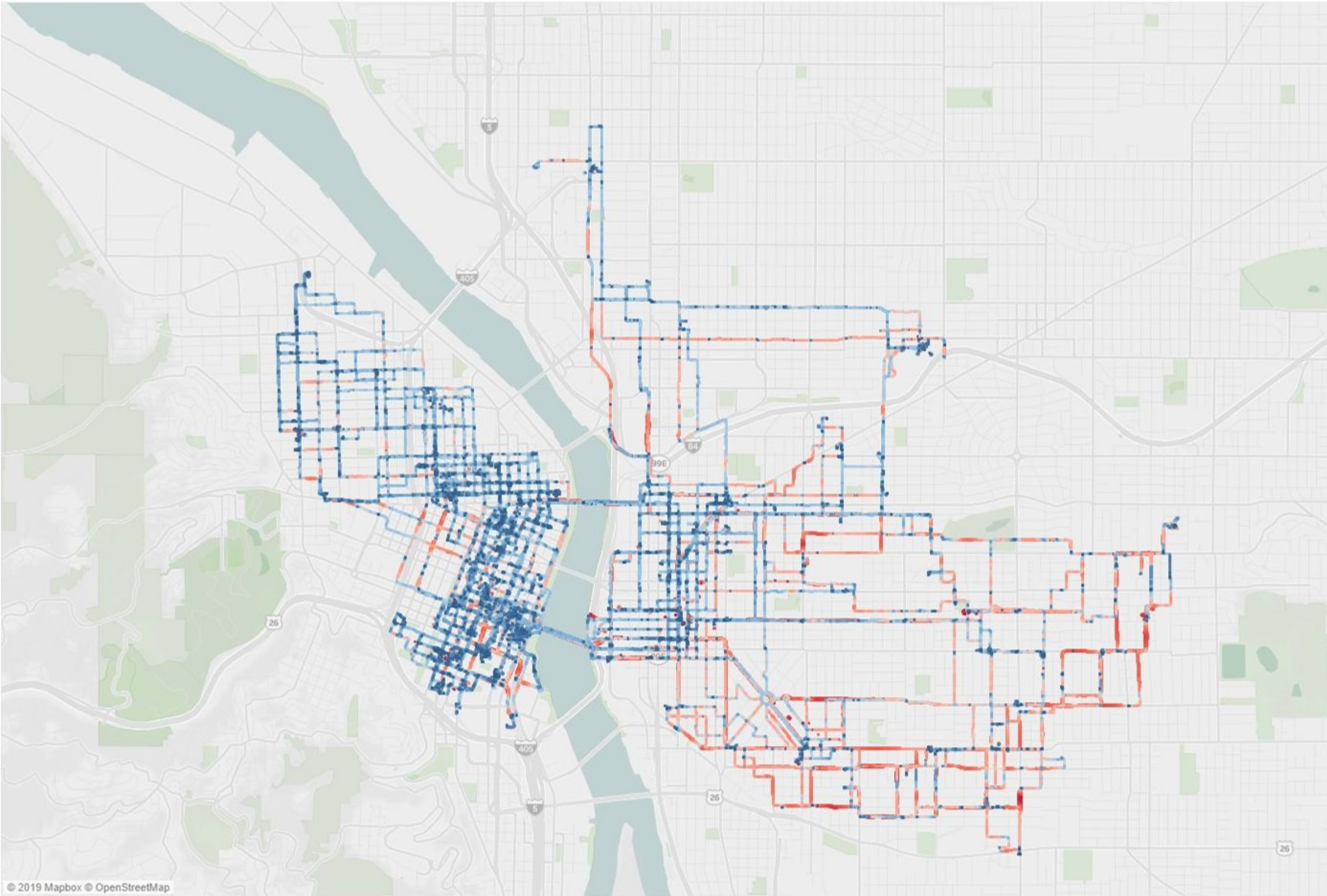
Tuesday



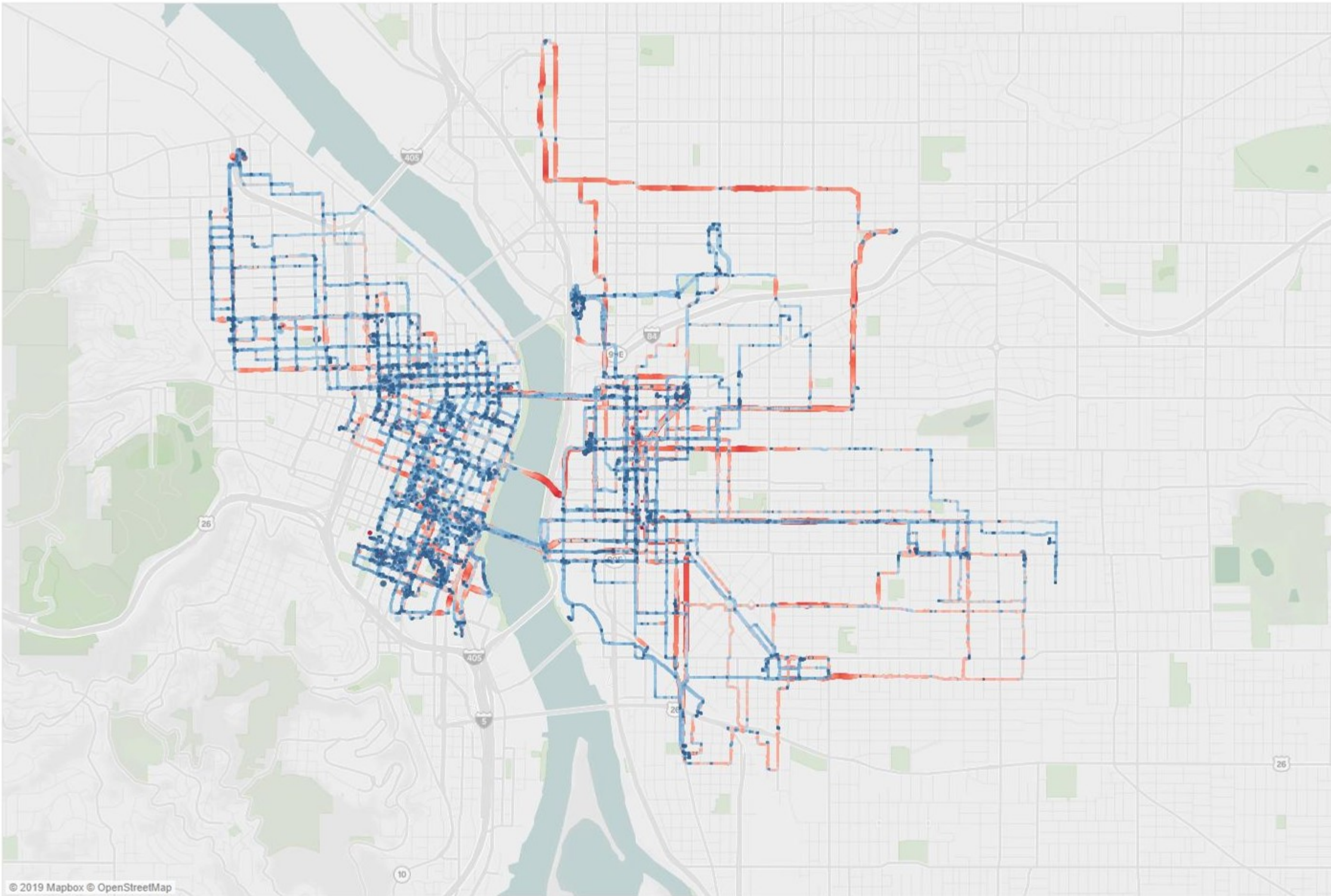
Wednesday



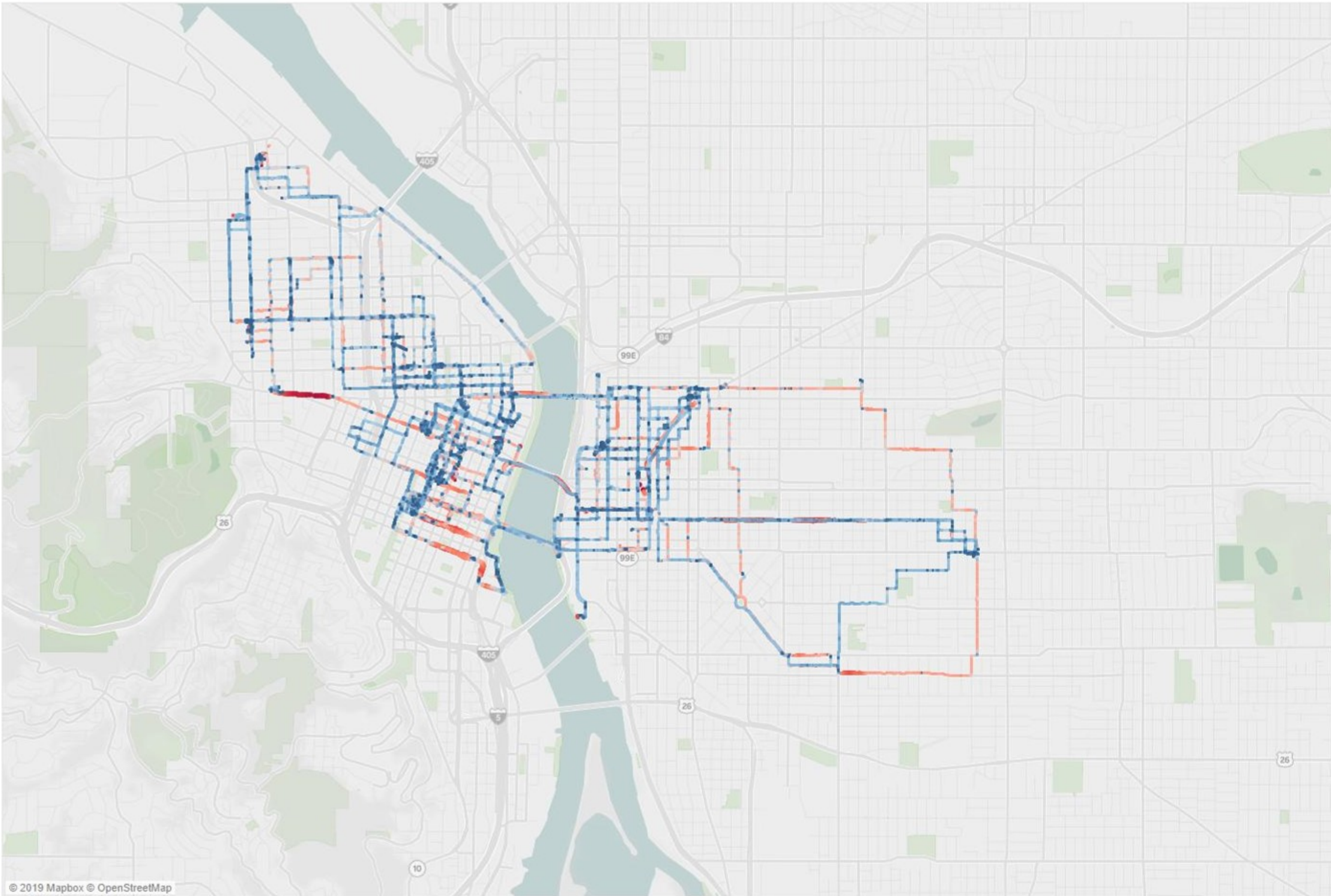
Thursday



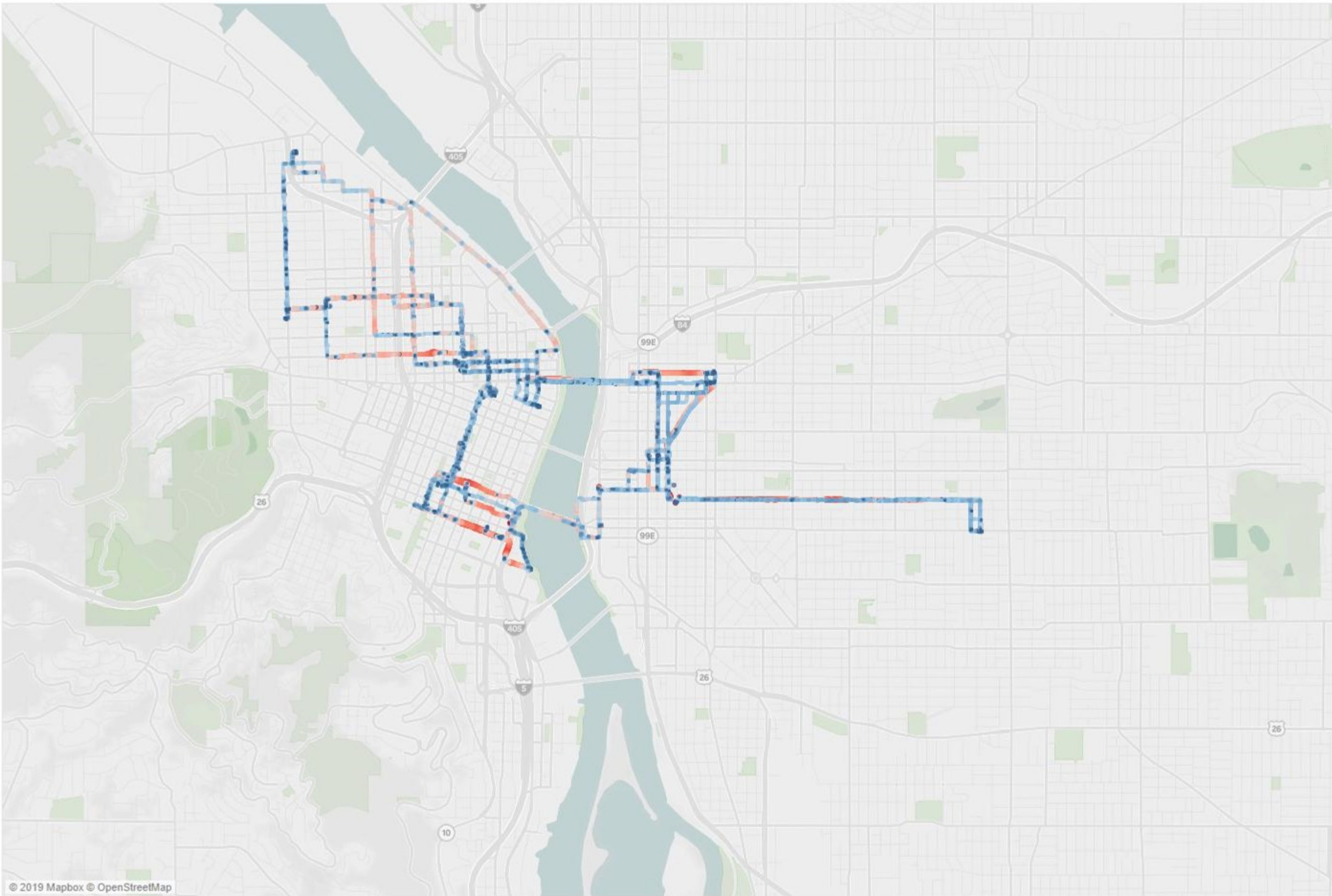
Friday



Saturday



Sunday



Appendix D- Portland results

Cost analysis in Portland

Row Labels (pay-consumption- # of LEV- # of Vans)	Average of TotalCost	StdDev of TotalCost	Average of TotalTime	StdDev of TotalTime	Average of EmissionsCost	StdDev of EmissionsCost
$14/h	**1880.119**	**241.5071**	**116.5654**	**17.76487**	**2.594941**	**1.484144**
12 mpg	**1893.577**	**242.6329**	**116.5966**	**17.77111**	**3.415519**	**1.777163**
0 LEV	1847.214	375.6857	103.7898	20.93223	5.273098	1.017843
1 Van	1109.182	4.726705	62.60738	0.426328	3.291224	0.061102
2 Vans	1918.403	10.50099	108.1823	0.662571	5.37191	0.051939
3 Vans	2064.722	10.83607	116.1763	0.682568	5.866555	0.022406
4 Vans	2070.074	9.985698	115.9745	0.588005	5.9085	0.011635
5 Vans	2073.689	17.24522	116.0088	1.047457	5.927301	0.003199
1 LEVs	1856.316	218.4286	111.4566	12.14948	3.877053	0.550011
1 Van	1488.035	6.397322	91.04561	0.586165	2.952238	0.049482
2 Vans	2016.222	9.511998	121.0169	0.70373	4.194957	0.01852
3 Vans	1909.393	9.112086	114.1811	0.579813	4.019718	0.004793
4 Vans	2011.614	11.21199	119.583	0.706182	4.341298	0.00524
2 LEVs	1939.918	67.82973	122.3022	3.357465	2.879604	0.196778
1 Van	1846.014	5.878718	117.6867	0.423876	2.605031	0.013125
2 Vans	1980.11	9.749222	124.3015	0.656123	2.999006	0.005955
3 Vans	1993.631	11.74622	124.9183	0.747265	3.034775	0.017939
3 LEVs	1945.475	10.88531	128.8221	0.663325	1.755558	0.052878
1 Van	1940.059	8.917773	128.6477	0.602068	1.704106	0.006925
2 Vans	1950.891	10.09663	128.9965	0.69038	1.80701	0.010862
4 LEVs	1970.449	13.84058	137.1933	0.98522	0.624679	0.00129
1 Van	1970.449	13.84058	137.1933	0.98522	0.624679	0.00129
5 LEVs	1954.748	11.26542	139.0257	0.804612	0	0
0 Van	1954.748	11.26542	139.0257	0.804612	0	0
15 mpg	**1882.005**	**241.7986**	**116.5461**	**17.79563**	**2.73409**	**1.422877**
0 LEV	1828.785	372.5426	103.6911	20.9339	4.223409	0.810221
1 Van	1096.169	4.22431	62.46356	0.478149	2.644714	0.041643
2 Vans	1903.814	10.5193	108.3686	0.75093	4.307766	0.052444
3 Vans	2046.427	8.061709	116.1573	0.542314	4.695866	0.010948
4 Vans	2047.489	11.117	115.7584	0.702216	4.725534	0.010798
5 Vans	2050.023	14.41786	115.7078	0.866925	4.743163	0.01035
1 LEVs	1843.53	216.4308	111.4034	12.14464	3.104577	0.436839
1 Van	1478.976	7.061263	91.01347	0.54021	2.369843	0.040003
2 Vans	2000.753	11.21633	120.8579	0.762828	3.359419	0.008827
3 Vans	1894.308	9.435811	114.0256	0.623112	3.217724	0.009339

4 Vans	2000.081	8.610721	119.7167	0.53562	3.471322	0.003479
2 LEVs	1929.709	68.02799	122.2172	3.422009	2.300993	0.159495
1 Van	1835.504	8.425497	117.5086	0.586057	2.078495	0.011309
2 Vans	1970.777	11.34846	124.3357	0.750681	2.397822	0.003704
3 Vans	1982.846	9.038278	124.8074	0.575597	2.426662	0.015739
3 LEVs	1942.337	10.56857	129.0004	0.697066	1.403887	0.041423
1 Van	1938.638	10.30827	128.9314	0.737447	1.363368	0.007981
2 Vans	1946.037	9.705325	129.0695	0.665967	1.444406	0.001351
4 LEVs	1963.471	10.556	136.8467	0.746712	0.499332	0.000939
1 Van	1963.471	10.556	136.8467	0.746712	0.499332	0.000939
5 LEVs	1956.765	11.33591	139.1688	0.809047	0	0
0 Van	1956.765	11.33591	139.1688	0.809047	0	0
18 mpg	**1875.486**	**241.555**	**116.5923**	**17.7827**	**2.277973**	**1.185857**
0 LEV	1818.572	371.3272	103.7215	20.99553	3.520511	0.673543
1 Van	1088.534	4.408555	62.3936	0.439286	2.20733	0.037956
2 Vans	1892.219	8.257147	108.2722	0.620701	3.594506	0.041744
3 Vans	2036.829	12.56488	116.3011	0.797729	3.91415	0.011309
4 Vans	2038.844	10.58394	115.9921	0.650431	3.937323	0.006792
5 Vans	2036.433	14.02004	115.6487	0.851021	3.949245	0.003025
1 LEVs	1836.865	215.4268	111.5407	12.09494	2.58352	0.370271
1 Van	1473.894	6.694481	91.23985	0.540533	1.960496	0.027068
2 Vans	1994.802	10.80996	121.0697	0.811691	2.798017	0.009901
3 Vans	1888.474	12.39675	114.1923	0.76489	2.680472	0.004311
4 Vans	1990.288	11.27839	119.661	0.711452	2.895094	0.009991
2 LEVs	1925.124	66.96269	122.3247	3.39609	1.918054	0.129914
1 Van	1832.26	8.259791	117.6381	0.541568	1.7364	0.008921
2 Vans	1964.878	8.714475	124.3626	0.595895	1.998958	0.003568
3 Vans	1978.235	8.325106	124.9735	0.536901	2.018806	0.002692
3 LEVs	1937.694	12.22346	128.9318	0.762286	1.170189	0.034098
1 Van	1931.736	10.4649	128.6942	0.707763	1.136807	0.006086
2 Vans	1943.652	11.06511	129.1695	0.756913	1.203572	0.00187
4 LEVs	1960.185	11.95228	136.7187	0.850173	0.416391	0.000865
1 Van	1960.185	11.95228	136.7187	0.850173	0.416391	0.000865
5 LEVs	1956.504	12.01605	139.1498	0.85843	0	0
0 Van	1956.504	12.01605	139.1498	0.85843	0	0
21 mpg	**1869.41**	**240.5062**	**116.5266**	**17.79342**	**1.952183**	**1.015974**
0 LEV	1809.252	368.2762	103.6194	20.93516	3.016298	0.578071
1 Van	1085.577	5.031128	62.4275	0.376371	1.891216	0.039295
2 Vans	1881.246	9.11127	108.125	0.648367	3.070603	0.032966
3 Vans	2025.259	11.99446	116.1245	0.845397	3.35626	0.010133
4 Vans	2027.453	15.58491	115.8221	0.934298	3.377036	0.008622

5 Vans	2026.724	21.31693	115.5981	1.298828	3.386376	0.005747
1 LEVs	1828.725	213.4099	111.3876	12.06887	2.214301	0.314712
1 Van	1469.091	6.963917	91.1155	0.575375	1.684827	0.024895
2 Vans	1982.942	9.032666	120.7599	0.58363	2.394895	0.013088
3 Vans	1879.969	10.99469	114.0556	0.663344	2.297696	0.006136
4 Vans	1982.898	12.35274	119.6195	0.802649	2.479787	0.006517
2 LEVs	1921.435	68.6095	122.3601	3.513264	1.644745	0.112193
1 Van	1826.403	7.816808	117.5251	0.550636	1.487999	0.006123
2 Vans	1962.702	10.73152	124.5197	0.740085	1.713214	0.003459
3 Vans	1975.201	9.954603	125.0354	0.653412	1.733023	0.00606
3 LEVs	1934.587	9.460839	128.9164	0.576153	1.00246	0.02973
1 Van	1929.446	6.509828	128.7296	0.462885	0.973269	0.00405
2 Vans	1939.728	9.25763	129.1032	0.62741	1.031651	0.001967
4 LEVs	1960.665	9.249349	136.804	0.65697	0.357072	0.000939
1 Van	1960.665	9.249349	136.804	0.65697	0.357072	0.000939
5 LEVs	1955.263	13.51334	139.0608	0.964193	0	0
0 Van	1955.263	13.51334	139.0608	0.964193	0	0
$15/h	**1928.045**	**254.3207**	**116.5595**	**17.77201**	**2.594371**	**1.48369**
12 mpg	**1940.595**	**254.5708**	**116.5239**	**17.83107**	**3.414803**	**1.776599**
0 LEV	1843.713	374.4289	103.5578	20.87371	5.27246	1.012807
1 Van	1107.812	6.062605	62.4685	0.379784	3.303392	0.069991
2 Vans	1917.278	11.13421	108.1272	0.775823	5.355395	0.030904
3 Vans	2061.929	6.881584	115.9378	0.383255	5.869044	0.014325
4 Vans	2065.124	12.58074	115.6871	0.735322	5.907952	0.011305
5 Vans	2066.42	21.14457	115.5685	1.281673	5.926516	0.008398
1 LEVs	1889.185	219.285	111.4489	12.23902	3.876878	0.552168
1 Van	1520.302	5.967675	90.92062	0.456277	2.948251	0.04522
2 Vans	2049.95	11.07688	121.0201	0.74668	4.19862	0.017798
3 Vans	1938.289	9.196114	113.992	0.565328	4.019278	0.005406
4 Vans	2048.199	9.830345	119.863	0.624255	4.341365	0.012514
2 LEVs	2001.516	65.90031	122.2377	3.36437	2.878749	0.19909
1 Van	1910.338	7.483658	117.601	0.472952	2.601037	0.013742
2 Vans	2038.602	8.343818	124.1408	0.537818	2.999248	0.006926
3 Vans	2055.609	9.020905	124.9714	0.571216	3.035962	0.019005
3 LEVs	2037.97	9.925006	128.8525	0.589638	1.752993	0.052977
1 Van	2034.154	10.16649	128.8061	0.661154	1.700756	0.002823
2 Vans	2041.787	8.257016	128.8989	0.521521	1.80523	0.002886
4 LEVs	2093.803	11.46331	136.9442	0.765445	0.624805	0.001563
1 Van	2093.803	11.46331	136.9442	0.765445	0.624805	0.001563
5 LEVs	2099.919	12.96416	139.4351	0.863881	0	0
0 Van	2099.919	12.96416	139.4351	0.863881	0	0

15 mpg	**1930.189**	**254.2545**	**116.5573**	**17.77654**	**2.732283**	**1.422222**
0 LEV	1828.676	371.659	103.6779	20.91167	4.22165	0.808166
1 Van	1098.567	4.355277	62.53109	0.40779	2.648318	0.064096
2 Vans	1898.778	7.987562	108.1021	0.597816	4.300923	0.043854
3 Vans	2047.504	8.925884	116.2256	0.505768	4.691983	0.013861
4 Vans	2052.373	11.94915	116.0497	0.708288	4.728383	0.012392
5 Vans	2046.157	16.49676	115.4813	0.999067	4.738643	0.003647
1 LEVs	1876.256	216.3041	111.4154	12.07403	3.099067	0.447352
1 Van	1511.839	6.761422	91.12599	0.57999	2.344861	0.02321
2 Vans	2033.699	8.617364	120.7326	0.529018	3.358082	0.011183
3 Vans	1927.413	9.517858	114.0956	0.600884	3.221826	0.012771
4 Vans	2032.073	11.53632	119.7075	0.723813	3.471498	0.003896
2 LEVs	1993.796	63.89765	122.3474	3.277873	2.3012	0.156468
1 Van	1905.518	8.403966	117.8418	0.52196	2.082394	0.008615
2 Vans	2030.615	9.61404	124.2667	0.625551	2.398227	0.004967
3 Vans	2045.255	9.896547	124.9337	0.642947	2.42298	0.002839
3 LEVs	2032.325	10.58522	128.8268	0.607688	1.40434	0.041584
1 Van	2025.612	6.944615	128.5599	0.496892	1.363719	0.008425
2 Vans	2039.037	9.32237	129.0938	0.600895	1.44496	0.002185
4 LEVs	2091.606	10.30427	136.9313	0.682783	0.499728	0.000956
1 Van	2091.606	10.30427	136.9313	0.682783	0.499728	0.000956
5 LEVs	2096.982	12.02067	139.2387	0.802231	0	0
0 Van	2096.982	12.02067	139.2387	0.802231	0	0
18 mpg	**1923.368**	**254.6917**	**116.5739**	**17.79988**	**2.279252**	**1.186556**
0 LEV	1819.951	370.1437	103.7766	20.94994	3.521953	0.676723
1 Van	1092.565	5.221319	62.55156	0.264501	2.200393	0.047988
2 Vans	1891.084	7.310732	108.2036	0.529082	3.609008	0.042274
3 Vans	2038.522	9.4232	116.3609	0.667599	3.9131	0.011597
4 Vans	2038.888	12.35747	115.9813	0.749881	3.937806	0.007079
5 Vans	2038.694	13.37749	115.7857	0.812095	3.949456	0.00485
1 LEVs	1866.825	216.3354	111.3626	12.19578	2.585517	0.365007
1 Van	1502.744	7.005379	90.9027	0.494104	1.97149	0.029042
2 Vans	2025.49	10.23714	120.9031	0.74138	2.798172	0.011254
3 Vans	1916.255	9.419205	113.9315	0.570243	2.6801	0.002469
4 Vans	2022.812	11.62702	119.7129	0.71936	2.892305	0.004014
2 LEVs	1986.913	63.08569	122.3072	3.214026	1.920184	0.129031
1 Van	1899.695	7.867437	117.8926	0.557972	1.739749	0.006402
2 Vans	2025.627	8.716028	124.3283	0.543468	2.001075	0.007449
3 Vans	2035.418	12.60383	124.7008	0.790951	2.019727	0.003795
3 LEVs	2028.115	10.40266	128.7899	0.623039	1.169666	0.036574
1 Van	2023.697	8.133335	128.6676	0.540905	1.134165	0.006033

2 Vans	2032.533	10.71844	128.9122	0.687556	1.205167	0.007482
4 LEVs	2091.686	12.31513	137.0295	0.81379	0.416319	0.00088
1 Van	2091.686	12.31513	137.0295	0.81379	0.416319	0.00088
5 LEVs	2098.176	17.49135	139.3186	1.165108	0	0
0 Van	2098.176	17.49135	139.3186	1.165108	0	0
21 mpg	**1918.026**	**254.4005**	**116.5827**	**17.76393**	**1.951146**	**1.014973**
0 LEV	1808.879	367.7822	103.6456	20.8657	3.013134	0.577934
1 Van	1086.082	5.913566	62.57324	0.559524	1.890048	0.041486
2 Vans	1880.667	8.906223	108.1976	0.589374	3.058892	0.026851
3 Vans	2024.966	9.09006	116.1225	0.589103	3.353308	0.008871
4 Vans	2026.264	11.30885	115.7539	0.604544	3.377742	0.008519
5 Vans	2026.414	20.18134	115.5809	1.222972	3.38568	0.003333
1 LEVs	1863.942	214.6347	111.5468	12.13035	2.21429	0.315932
1 Van	1502.198	6.723026	91.15942	0.581632	1.682779	0.02163
2 Vans	2021.068	7.050179	121.0132	0.44559	2.394999	0.007515
3 Vans	1915.209	10.82622	114.2608	0.676225	2.297478	0.005707
4 Vans	2017.295	8.87627	119.7536	0.565952	2.481902	0.006159
2 LEVs	1983.363	62.88839	122.3704	3.239405	1.643939	0.112214
1 Van	1896.394	10.16527	117.9239	0.734949	1.487062	0.00741
2 Vans	2022.48	9.437945	124.4468	0.596063	1.714287	0.006498
3 Vans	2031.216	10.29109	124.7406	0.653181	1.730467	0.00283
3 LEVs	2027.079	11.89161	128.8872	0.666642	1.00346	0.032197
1 Van	2019.727	9.421652	128.5697	0.582542	0.972696	0.005518
2 Vans	2034.432	9.364175	129.2048	0.60049	1.034225	0.010241
4 LEVs	2085.378	13.17573	136.6734	0.873747	0.356762	0.000783
1 Van	2085.378	13.17573	136.6734	0.873747	0.356762	0.000783
5 LEVs	2098.632	13.06594	139.3492	0.871036	0	0
0 Van	2098.632	13.06594	139.3492	0.871036	0	0
$16/h	**1976.906**	**274.1201**	**116.6009**	**17.77264**	**2.594915**	**1.484945**
12 mpg	**1990.392**	**272.9926**	**116.628**	**17.76868**	**3.418013**	**1.777788**
0 LEV	1848.621	376.7029	103.8412	21.04162	5.282022	1.003273
1 Van	1109.127	5.046423	62.46705	0.457421	3.32944	0.054579
2 Vans	1916.46	7.85481	108.1158	0.51892	5.374789	0.057542
3 Vans	2072.362	10.3027	116.5672	0.705879	5.868245	0.020509
4 Vans	2070.365	13.23084	115.9766	0.85403	5.91264	0.01139
5 Vans	2074.789	16.01634	116.0795	0.973988	5.924994	0.005018
1 LEVs	1925.304	219.1659	111.6565	12.22572	3.876917	0.551908
1 Van	1556.577	7.463587	91.13474	0.524714	2.948731	0.045968
2 Vans	2088.802	10.70912	121.2861	0.778689	4.197786	0.01445
3 Vans	1975.097	11.74117	114.325	0.753321	4.019445	0.006024
4 Vans	2080.74	10.72228	119.8803	0.648908	4.341707	0.010619

2 LEVs	2064.671	65.59855	122.3129	3.444275	2.879031	0.194489
1 Van	1973.748	10.75501	117.5622	0.697751	2.607762	0.024936
2 Vans	2107.214	9.567006	124.6275	0.619522	2.999638	0.012364
3 Vans	2113.052	9.168554	124.7491	0.568389	3.029694	0.004353
3 LEVs	2127.041	10.6625	128.6402	0.611479	1.754391	0.051789
1 Van	2122.605	8.344115	128.5652	0.537013	1.703795	0.01034
2 Vans	2131.476	11.05971	128.7153	0.683558	1.804988	0.002998
4 LEVs	2223.698	14.9877	137.1369	0.936002	0.624553	0.00137
1 Van	2223.698	14.9877	137.1369	0.936002	0.624553	0.00137
5 LEVs	2230.165	11.17844	138.8602	0.6987	0	0
0 Van	2230.165	11.17844	138.8602	0.6987	0	0
15 mpg	**1977.945**	**274.3306**	**116.5191**	**17.81502**	**2.733557**	**1.423465**
0 LEV	1829.408	373.3349	103.6868	21.0084	4.223784	0.814933
1 Van	1095.587	5.169494	62.33973	0.347368	2.633911	0.048128
2 Vans	1902.336	9.448913	108.1904	0.626468	4.319566	0.052613
3 Vans	2050.917	7.779084	116.4074	0.505456	4.69722	0.012316
4 Vans	2051.553	9.87442	115.9849	0.582651	4.72977	0.022062
5 Vans	2046.648	16.08839	115.5115	0.974093	4.738455	0.004696
1 LEVs	1907.8	216.1593	111.3051	12.16925	3.100425	0.438846
1 Van	1543.933	5.483082	90.86609	0.342245	2.362026	0.035247
2 Vans	2066.601	8.186574	120.7597	0.498517	3.352917	0.012379
3 Vans	1957.005	7.38076	113.9132	0.420701	3.216296	0.005808
4 Vans	2063.66	9.68112	119.6815	0.591645	3.470463	0.00433
2 LEVs	2055.956	61.43535	122.3453	3.210208	2.302781	0.154847
1 Van	1970.766	7.987703	117.9068	0.52718	2.086222	0.00578
2 Vans	2093.014	6.914454	124.3422	0.435988	2.398216	0.003096
3 Vans	2104.089	9.214999	124.787	0.568086	2.423904	0.004194
3 LEVs	2125.21	9.446604	128.8484	0.509689	1.404127	0.043191
1 Van	2119.703	7.813984	128.6821	0.503432	1.362065	0.006213
2 Vans	2130.718	7.632636	129.0147	0.470732	1.446189	0.008117
4 LEVs	2216.247	16.89326	136.7975	1.053187	0.499686	0.001206
1 Van	2216.247	16.89326	136.7975	1.053187	0.499686	0.001206
5 LEVs	2234.347	11.57899	139.1214	0.723664	0	0
0 Van	2234.347	11.57899	139.1214	0.723664	0	0
18 mpg	**1972.319**	**274.5841**	**116.6288**	**17.79367**	**2.276586**	**1.184485**
0 LEV	1820.306	370.9857	103.8272	21.01505	3.515753	0.675566
1 Van	1090.859	4.421795	62.44891	0.307146	2.200126	0.046389
2 Vans	1895.008	9.644898	108.4956	0.749844	3.583233	0.038374
3 Vans	2035.011	12.98801	116.2299	0.860468	3.909908	0.011211
4 Vans	2039.464	9.885518	116.0227	0.623881	3.93684	0.006609
5 Vans	2041.186	18.38055	115.9387	1.114335	3.94866	0.004048

1 LEVs	1902.231	214.3578	111.4971	12.15724	2.584786	0.364406
1 Van	1540.826	8.835942	91.06154	0.722939	1.972383	0.036419
2 Vans	2061.848	6.094838	121.1259	0.438007	2.793656	0.014459
3 Vans	1954.191	9.716553	114.2718	0.610576	2.679374	0.002361
4 Vans	2052.058	8.0475	119.5291	0.496058	2.893731	0.002508
2 LEVs	2050.61	63.9562	122.3868	3.39871	1.917814	0.130598
1 Van	1962.29	7.472717	117.7089	0.538645	1.735278	0.008815
2 Vans	2086.395	8.350515	124.3261	0.51543	1.998165	0.004399
3 Vans	2103.147	10.58209	125.1253	0.653307	2.019999	0.002289
3 LEVs	2120.9	11.80783	128.8133	0.691622	1.16894	0.034785
1 Van	2117.148	9.651018	128.7421	0.586728	1.134738	0.004231
2 Vans	2124.652	12.78321	128.8845	0.791793	1.203141	0.001798
4 LEVs	2215.769	12.76099	136.8471	0.796785	0.416151	0.000928
1 Van	2215.769	12.76099	136.8471	0.796785	0.416151	0.000928
5 LEVs	2237.251	11.33448	139.3029	0.707839	0	0
0 Van	2237.251	11.33448	139.3029	0.707839	0	0
21 mpg	**1966.968**	**275.3026**	**116.6277**	**17.79645**	**1.951504**	**1.017536**
0 LEV	1809.345	368.3991	103.6568	20.90653	3.015857	0.584538
1 Van	1084.882	4.387673	62.48669	0.280911	1.875289	0.029686
2 Vans	1883.452	7.033076	108.2887	0.401699	3.0846	0.035756
3 Vans	2026.077	11.20706	116.2189	0.754453	3.35431	0.00789
4 Vans	2027.707	11.53702	115.817	0.704547	3.38019	0.011129
5 Vans	2024.606	13.08304	115.4727	0.792853	3.384897	0.002994
1 LEVs	1897.382	213.3314	111.5791	12.07457	2.21329	0.320149
1 Van	1538.711	8.339618	91.32956	0.506743	1.674014	0.016695
2 Vans	2055.831	6.746867	121.0761	0.467708	2.397036	0.007993
3 Vans	1944.392	8.428102	114.0763	0.512194	2.299858	0.008304
4 Vans	2050.595	12.70865	119.8344	0.773484	2.482253	0.007257
2 LEVs	2046.765	61.34421	122.4094	3.27315	1.643918	0.112957
1 Van	1962.02	6.545556	117.8928	0.384652	1.485995	0.007458
2 Vans	2081.555	9.005068	124.3239	0.527087	1.714701	0.006168
3 Vans	2096.72	10.04403	125.0114	0.619283	1.731058	0.002857
3 LEVs	2119.48	11.6034	128.9096	0.655407	1.001591	0.030252
1 Van	2113.706	9.68034	128.7338	0.619034	0.971793	0.002732
2 Vans	2125.254	10.60514	129.0854	0.658375	1.031389	0.001328
4 LEVs	2215.629	9.266209	136.8989	0.57999	0.356682	0.001032
1 Van	2215.629	9.266209	136.8989	0.57999	0.356682	0.001032
5 LEVs	2240.344	8.941136	139.4968	0.559004	0	0
0 Van	2240.344	8.941136	139.4968	0.559004	0	0
Grand Total	**1928.357**	**259.9541**	**116.5753**	**17.76522**	**2.594742**	**1.483873**

Appendix E- Nashville results

Nashville Cost analysis data

Row Labels	Average of TotalCost	StdDev of TotalCost	Average of TotalTime	StdDev of TotalTime	Average of EmissionsCost	StdDev of EmissionsCost
Parking utilization 0 %	**123.9285027**	**91.36915265**	**7.064028135**	**5.078949395**	**0.400072456**	**0.432033479**
$14/h	**122.3902224**	**90.68433465**	**7.093738086**	**5.115765787**	**0.402789112**	**0.436110953**
12 mpg	125.5289251	92.89514793	7.164968619	5.177023893	0.533488315	0.553417677
5 LEVs	123.2463114	83.74431619	8.720391032	5.940600766	0	0
3 vans	120.6279851	94.92150764	6.340974768	4.772390014	0.675262463	0.527465285
4 vans	127.9589805	95.23870786	6.731698578	4.748630085	0.726227047	0.528425949
5 vans	130.2824236	97.85193848	6.866810099	4.882279783	0.73246375	0.538994748
15 mpg	123.3551821	91.35954325	7.145410611	5.18005997	0.421900874	0.439817295
5 LEVs	123.9803172	84.45860809	8.772389211	5.991097491	0	0
3 vans	115.1052532	90.39185695	6.164250257	4.642037134	0.522382239	0.408986479
4 vans	125.2644367	94.60440395	6.714913391	4.798790693	0.574259683	0.427125148
5 vans	129.0707214	96.06586517	6.930089585	4.861966262	0.590961573	0.432325078
18 mpg	118.2891653	88.12217963	6.890498522	4.970855676	0.345828525	0.360771469
5 LEVs	114.1875109	77.91134286	8.079520482	5.527104885	0	0
3 vans	112.5836394	88.75963476	6.10354101	4.606776451	0.432588726	0.339916691
4 vans	122.2328232	92.52819411	6.624213171	4.764791756	0.474024963	0.35203049
5 vans	124.1526878	92.95118071	6.754719426	4.777172717	0.476700411	0.349745606
21 mpg	122.3876171	90.4145187	7.17407459	5.142174659	0.309938736	0.320431083
5 LEVs	119.548206	81.46982182	8.458983598	5.779192834	0	0
3 vans	117.5217847	92.27703666	6.42419839	4.822907452	0.391072496	0.304054494
4 vans	124.3425841	92.78048236	6.792096465	4.808006053	0.41950507	0.305887919
5 vans	128.1378935	95.22151524	7.021019907	4.922325072	0.42917738	0.311873796
$15/h	**123.7672387**	**90.93887752**	**7.055857465**	**5.062040985**	**0.39876319**	**0.429434264**
12 mpg	125.6052936	92.63605889	7.056264765	5.100542889	0.519676518	0.539725654
5 LEVs	130.5921234	88.78368471	8.629694463	5.881139596	0	0
3 vans	115.7828662	90.74405674	6.102099578	4.567081436	0.639200848	0.499338199
4 vans	126.2357078	93.86330511	6.658895107	4.694271648	0.708167332	0.514395534
5 vans	129.810477	97.29066028	6.83436991	4.856655958	0.731337891	0.539167287
15 mpg	125.7812388	92.12471832	7.144597349	5.099857024	0.429004362	0.441317583
5 LEVs	128.8325996	87.34434702	8.51327646	5.785721704	0	0
3 vans	118.7967826	92.48370369	6.366988276	4.736299953	0.539716739	0.417175049
4 vans	128.5416381	95.05863348	6.8905765	4.820926254	0.591698757	0.426352469
5 vans	126.9539352	94.16549779	6.807548158	4.778855048	0.584601953	0.423050245
18 mpg	121.1097249	88.62037881	6.940588961	4.93420408	0.34659904	0.357867309
5 LEVs	124.0527084	83.34698602	8.196988092	5.521521356	0	0
3 vans	111.7817235	86.5418295	6.058449467	4.486209691	0.42419212	0.326384201
4 vans	123.2592216	92.35575865	6.689490015	4.737735659	0.479474336	0.352773369
5 vans	125.3452463	92.30011488	6.817428268	4.739253678	0.482729704	0.347491905

21 mpg	122.5726973	90.50583384	7.081978788	5.124329441	0.29977284	0.310674868
5 LEVs	130.7022196	90.12521276	8.637427742	5.969219523	0	0
3 vans	111.4806399	87.04810878	6.102589444	4.552127529	0.367458956	0.287034093
4 vans	122.8523532	91.77699639	6.721884543	4.753811272	0.414336477	0.302093392
5 vans	125.2555766	92.96490482	6.866013424	4.809836821	0.417295928	0.303975473
$16/h	**125.628047**	**92.49057935**	**7.042488855**	**5.061250525**	**0.398665066**	**0.430729493**
12 mpg	127.9754987	95.03403289	7.060434232	5.138619895	0.526305851	0.546709682
5 LEVs	138.1466981	95.93696224	8.563830962	5.959293143	0	0
3 vans	119.8811807	94.5859349	6.310432368	4.767619555	0.671170463	0.525730689
4 vans	122.8463787	91.54306042	6.47580624	4.559667482	0.694160714	0.505710786
5 vans	131.0277373	98.01834463	6.891667361	4.899778912	0.739892227	0.543952925
15 mpg	125.087847	91.4050453	6.994897821	4.972050455	0.417321768	0.431122332
5 LEVs	134.1925772	89.36162082	8.317503588	5.551520045	0	0
3 vans	121.5824715	95.51046217	6.526798038	4.902268061	0.549416782	0.43042887
4 vans	120.5255547	88.49899893	6.488993629	4.482587268	0.552141091	0.396063191
5 vans	124.0507847	92.54093734	6.646296029	4.708849012	0.567729198	0.414183697
18 mpg	126.0243313	92.69015792	7.106168461	5.102104171	0.35399545	0.366074302
5 LEVs	137.9920444	93.64260479	8.553530806	5.817429934	0	0
3 vans	118.7537527	93.75253551	6.434854774	4.869222347	0.456563553	0.357706945
4 vans	121.2752214	90.60939797	6.590747828	4.657304427	0.471786333	0.344850711
5 vans	126.0763068	92.65405392	6.845540435	4.755106289	0.487631914	0.3514111
21 mpg	123.4245109	90.99894095	7.008454904	5.045101578	0.297037195	0.308928408
5 LEVs	137.5175999	92.39306432	8.523793174	5.739994771	0	0
3 vans	112.9973131	89.05256042	6.182359317	4.657284676	0.374935078	0.294627666
4 vans	115.3638816	85.80641373	6.333862529	4.443417548	0.386111352	0.282374468
5 vans	127.819249	95.38975972	6.993804596	4.958279183	0.427102351	0.312096109
Parking utilization 20 %	**171.3185902**	**140.5677864**	**10.02893202**	**7.815098762**	**0.387023141**	**0.436923596**
$14/h	**169.8939864**	**140.5363182**	**10.07177251**	**7.828829269**	**0.388676433**	**0.44069691**
12 mpg	173.5944264	145.1679982	10.1613374	7.968178097	0.516890979	0.565257104
5 LEVs	120.4513323	81.06529701	8.522828626	5.750382976	0	0
3 vans	167.4655814	139.346387	9.374749758	7.567521533	0.602209485	0.5027614
4 vans	196.6013787	158.0260492	11.01365086	8.56118098	0.711230906	0.552950512
5 vans	209.8594132	170.5855669	11.73412035	9.236854043	0.754123524	0.596485274
15 mpg	169.6057324	140.5625314	10.03276893	7.813147249	0.408936381	0.442484579
5 LEVs	118.8024973	81.5222874	8.406936471	5.78269824	0	0
3 vans	167.42603	141.1877836	9.521133778	7.804198345	0.482553457	0.401108134
4 vans	193.2848769	155.17607	10.94398666	8.497662538	0.56961284	0.437955027
5 vans	198.9095254	157.5195008	11.25901881	8.591928943	0.583579227	0.452109506
18 mpg	169.2458773	139.0814323	10.09373533	7.808836746	0.338651514	0.367153805
5 LEVs	124.9800456	84.78993902	8.8434593	6.013831639	0	0
3 vans	163.5866156	136.4328525	9.348487883	7.55997922	0.401693361	0.331955446
4 vans	189.3485972	152.7684919	10.80416183	8.417248259	0.468706394	0.366192301
5 vans	199.0682508	159.3412229	11.37883231	8.769734027	0.4842063	0.374371476

21 mpg	167.1299092	137.5626006	9.99924839	7.745990699	0.290226859	0.314340768
5 LEVs	121.3407871	82.24810009	8.585760398	5.834341259	0	0
3 vans	162.1716076	133.3297346	9.320452306	7.435855398	0.341352184	0.278431592
4 vans	187.9098939	152.4792512	10.78561227	8.449136847	0.399350847	0.311449038
5 vans	197.0973485	157.738065	11.30516859	8.71278577	0.420204403	0.326383377
$15/h	**170.1716551**	**139.558638**	**9.957850854**	**7.756737586**	**0.385067375**	**0.433867488**
12 mpg	170.8624573	139.5912736	9.89356259	7.665079615	0.501484782	0.544036276
5 LEVs	127.7144715	86.10314059	8.439673182	5.703359889	0	0
3 vans	165.1710816	137.1779938	9.2674254	7.490371169	0.585809243	0.480486902
4 vans	190.8899476	152.290354	10.68064105	8.22354169	0.693602424	0.537573647
5 vans	199.6743283	160.7477822	11.18651073	8.679797732	0.726527459	0.567685609
15 mpg	170.480577	141.6128814	9.94392397	7.840958117	0.408943356	0.44576899
5 LEVs	122.6136787	82.86702676	8.102177957	5.489777385	0	0
3 vans	165.4327249	138.449839	9.403871698	7.644563436	0.474749444	0.390190643
4 vans	193.2434336	155.7933503	10.92470768	8.51620278	0.573362548	0.444966978
5 vans	200.6324707	163.1592672	11.34493854	8.924430409	0.587661432	0.465837961
18 mpg	170.3191226	139.0778856	10.00789886	7.768060645	0.340810349	0.36888973
5 LEVs	129.2409035	87.21995504	8.539972804	5.777414926	0	0
3 vans	162.448926	134.2491981	9.283506331	7.448653104	0.395957353	0.322510648
4 vans	187.8908326	151.1687212	10.70998607	8.305887757	0.46858504	0.362691361
5 vans	201.6958285	162.1397253	11.49813025	8.918827335	0.498699005	0.387699135
21 mpg	169.0244635	138.3439309	9.986017994	7.774648607	0.289031013	0.31300982
5 LEVs	127.2396642	85.64961498	8.408606337	5.672975445	0	0
3 vans	161.8119036	133.6921979	9.310212076	7.465243017	0.338298782	0.274934104
4 vans	184.4445824	147.8645754	10.59505977	8.202219909	0.388235301	0.301428937
5 vans	202.6017038	163.5760065	11.63019379	9.054633216	0.42958997	0.333655913
$16/h	**173.8901291**	**141.6356029**	**10.05717269**	**7.862771609**	**0.387325616**	**0.43639004**
12 mpg	175.697723	141.7073563	10.06449926	7.780825921	0.50494671	0.544618442
5 LEVs	139.5871667	94.17254588	8.652421721	5.850240321	0	0
3 vans	164.0705484	136.7831416	9.207192906	7.456041131	0.584602561	0.478496309
4 vans	198.0774049	158.4391185	11.11074779	8.585568408	0.712208337	0.550400537
5 vans	201.0557719	159.7648384	11.28763464	8.645075829	0.722975943	0.554135369
15 mpg	173.8038085	142.4826284	10.02316313	7.882080269	0.410608488	0.447769408
5 LEVs	133.9349697	90.53212132	8.301984836	5.623819269	0	0
3 vans	165.0720248	137.4468758	9.354401031	7.56941425	0.482508859	0.396447745
4 vans	193.7443066	156.3190555	10.97980899	8.557699913	0.569652139	0.441722567
5 vans	202.4639328	165.1209957	11.45645765	9.023501784	0.590272955	0.470469983
18 mpg	172.3016775	141.3352855	10.00604623	7.875060557	0.339608879	0.370880363
5 LEVs	133.7298239	89.60102187	8.289459402	5.566774285	0	0
3 vans	158.0763505	129.6868048	9.052933224	7.208295412	0.382949019	0.308534446
4 vans	190.7757358	155.7322148	10.89412125	8.59223045	0.467071504	0.368481613
5 vans	206.6247996	167.4843339	11.78767104	9.214704899	0.508414992	0.399128775
21 mpg	173.7573076	141.4192939	10.13498215	7.935330707	0.294138387	0.32069098
5 LEVs	140.5284046	96.36988518	8.711159911	5.986164215	0	0

3 vans	163.9032683	137.0149234	9.429822429	7.661885752	0.341599114	0.280005141
4 vans	190.8592658	153.8827105	10.95202589	8.517275834	0.40875751	0.319115664
5 vans	199.7382915	162.9575114	11.44692037	9.020300457	0.426196923	0.336618295
Parking utilization 40 %	**150.4674676**	**116.769064**	**8.742600162**	**6.453849765**	**0.396078637**	**0.436925209**
$14/h	**148.8917214**	**115.915332**	**8.782665008**	**6.459052981**	**0.396069661**	**0.435797027**
12 mpg	152.2369215	119.2737583	8.862748587	6.539584843	0.525614644	0.555268929
5 LEVs	123.7373329	84.1216773	8.75519755	5.967287098	0	0
3 vans	148.7109576	122.4501061	8.172467902	6.477431719	0.643306105	0.51918968
4 vans	164.910683	129.907967	9.067536111	6.8380572	0.71659462	0.547545813
5 vans	171.5887123	130.12223	9.455792787	6.847326294	0.742557851	0.542877804
15 mpg	148.0625047	114.9056724	8.707381579	6.374623398	0.416477411	0.437990054
5 LEVs	120.1593038	82.36722473	8.502255408	5.843048438	0	0
3 vans	145.051907	118.2796789	8.08160814	6.355645112	0.507468402	0.408219464
4 vans	160.4775323	123.2926253	8.949757074	6.558440668	0.5712796	0.427205917
5 vans	166.5612755	125.9477314	9.295905695	6.718057368	0.587161643	0.431405716
18 mpg	147.6300895	114.63811	8.766711167	6.454265089	0.342496661	0.362077539
5 LEVs	125.3699419	85.50839596	8.871192423	6.065253704	0	0
3 vans	147.2213454	121.0934767	8.285629711	6.562119519	0.430430829	0.351173618
4 vans	155.0852885	121.1215226	8.732628525	6.516812683	0.461050335	0.346146496
5 vans	162.843782	124.3011067	9.177394009	6.701114136	0.478505482	0.354360564
21 mpg	147.6373702	115.0639998	8.793818699	6.48508006	0.299689929	0.316453231
5 LEVs	121.9787199	83.84188764	8.63102039	5.947167246	0	0
3 vans	143.3199893	116.6449037	8.124339924	6.361398728	0.362326287	0.289504493
4 vans	159.6926179	123.5378372	9.036995878	6.692365832	0.413673108	0.31016506
5 vans	165.5581536	127.3946936	9.382918605	6.908734219	0.42276032	0.316416587
$15/h	**150.3018692**	**116.697711**	**8.731123155**	**6.455374906**	**0.394841939**	**0.435315715**
12 mpg	151.2799668	117.5696565	8.671440944	6.392274014	0.518347536	0.549537217
5 LEVs	127.292603	85.6055361	8.411077063	5.670666664	0	0
3 vans	145.4775887	119.5165241	8.00203774	6.335627809	0.621435679	0.502467446
4 vans	162.3186407	125.3994509	8.920511246	6.592235297	0.715402949	0.537015245
5 vans	170.0310348	131.1340505	9.352137728	6.901403266	0.736551515	0.552907909
15 mpg	149.7442469	115.4149063	8.694239653	6.410961718	0.40999357	0.433360608
5 LEVs	134.778482	93.05538065	8.906694806	6.163261943	0	0
3 vans	140.0306007	113.9770475	7.800806861	6.091622457	0.495385676	0.399836054
4 vans	157.1505641	120.4614183	8.754403846	6.415544352	0.558594616	0.413243517
5 vans	167.0173405	129.4862636	9.315053099	6.92104671	0.585993987	0.441387492
18 mpg	153.8727089	119.7133627	8.978360394	6.648848785	0.357067481	0.379836431
5 LEVs	133.0008705	90.1602626	8.788638222	5.971902059	0	0
3 vans	146.9590236	121.1470284	8.267494663	6.564400311	0.429483835	0.351606103
4 vans	166.5003463	129.079087	9.366526774	6.930830145	0.49641759	0.370739369
5 vans	169.0305953	131.6256302	9.490781917	7.081288411	0.502368499	0.380590803
21 mpg	146.3105544	114.2399832	8.580451627	6.378109217	0.29395917	0.312935057
5 LEVs	125.2723796	84.62043462	8.277735211	5.605233853	0	0

3 vans	141.5277931	115.8833523	8.008368813	6.319380475	0.359584498	0.290479877
4 vans	159.6217932	125.3226126	9.036116342	6.788925423	0.41045657	0.310934948
5 vans	158.8202515	124.168865	8.999586142	6.741950378	0.405795612	0.308680912
$16/h	**152.2088121**	**117.7217881**	**8.714012323**	**6.450148628**	**0.397324311**	**0.439863629**
12 mpg	155.4680211	120.6881724	8.781362358	6.512309647	0.529325499	0.56111506
5 LEVs	136.5188054	93.45688166	8.462109968	5.805488995	0	0
3 vans	152.6007037	126.427984	8.385467473	6.693705798	0.660391619	0.536822331
4 vans	167.305603	130.8376313	9.186134735	6.872708008	0.732357884	0.55374514
5 vans	165.4469722	127.146873	9.091737257	6.663349991	0.724552492	0.540803521
15 mpg	150.892495	116.9755125	8.618543991	6.391708235	0.414346387	0.438953979
5 LEVs	131.5109904	90.12413372	8.151474134	5.598734671	0	0
3 vans	147.0663448	120.8038766	8.203325398	6.495165301	0.509408368	0.412452888
4 vans	162.6446114	127.8296351	9.064477324	6.815079901	0.574368657	0.43740988
5 vans	162.3480332	123.866194	9.054899109	6.60603588	0.573608522	0.424711055
18 mpg	151.8573096	117.3555231	8.742512791	6.477447262	0.347666426	0.370147544
5 LEVs	136.8761733	94.02786299	8.484482236	5.840891261	0	0
3 vans	144.9278987	118.3414178	8.153782733	6.410660112	0.424546481	0.342648821
4 vans	161.8047641	127.5345388	9.109021429	6.863709328	0.481313611	0.368757282
5 vans	163.8204024	125.6694859	9.222764767	6.762904722	0.484805611	0.364954849
21 mpg	150.6174226	116.1065421	8.71363015	6.436759301	0.297958931	0.316906402
5 LEVs	135.9794205	91.83685191	8.428485934	5.705150468	0	0
3 vans	141.7661555	116.1533918	8.030721245	6.326373546	0.359402528	0.29139734
4 vans	157.2373213	123.0732693	8.905780286	6.663563217	0.403371676	0.306688226
5 vans	167.4867929	128.6483298	9.489533137	6.968418606	0.429061521	0.321479601
Parking utilization 60 %	**141.3379535**	**107.5226917**	**8.197610907**	**5.952244103**	**0.393330125**	**0.431438136**
$14/h	**139.584509**	**107.0071049**	**8.217603428**	**5.970878584**	**0.394536147**	**0.432855787**
12 mpg	141.7723731	109.3670301	8.222164491	6.008131903	0.522715287	0.549889661
5 LEVs	118.8596878	83.0625171	8.410725693	5.892203711	0	0
3 vans	135.6489487	108.7797935	7.417831876	5.709902251	0.623656785	0.495662586
4 vans	156.0032558	120.0274036	8.507224484	6.248545328	0.733727984	0.550889619
5 vans	156.5776001	118.3335603	8.552875911	6.165904809	0.733476381	0.540647189
15 mpg	139.21644	106.5045274	8.179192809	5.934252432	0.412825899	0.433798532
5 LEVs	119.8301346	81.96466887	8.478621323	5.813950329	0	0
3 vans	138.7953249	112.0221019	7.683446707	5.944657468	0.523718247	0.41743272
4 vans	148.3958803	114.8191358	8.238403965	6.074094825	0.559154348	0.423919823
5 vans	149.8444203	112.3336675	8.316299242	5.942826146	0.568430999	0.416089577
18 mpg	138.7271257	105.8707407	8.224075389	5.957397987	0.344182705	0.362752293
5 LEVs	121.962757	82.24567563	8.629566111	5.834546334	0	0
3 vans	134.154703	107.6852757	7.517975254	5.785178208	0.421534396	0.336872739
4 vans	145.1258917	112.1012618	8.132309094	5.982075293	0.463194635	0.350066677
5 vans	153.665151	116.6527481	8.616451096	6.220412176	0.492001788	0.362983786
21 mpg	138.6220971	106.5427175	8.244981024	6.001168006	0.298420698	0.315972609
5 LEVs	119.3309766	80.33594463	8.443469207	5.699064509	0	0

3 vans	132.6613411	107.1055619	7.477896204	5.791162862	0.361163973	0.290625142
4 vans	146.3378533	111.2350069	8.26107243	5.970726866	0.40490967	0.300163743
5 vans	156.1582173	120.8319733	8.797486257	6.50538463	0.42760915	0.324363682
$15/h	**141.2071645**	**107.4301276**	**8.191972713**	**5.957280738**	**0.392168739**	**0.430647881**
12 mpg	143.4233649	109.2360718	8.203551655	5.948398054	0.519215565	0.545162711
5 LEVs	127.0148338	86.36185631	8.393263765	5.720406959	0	0
3 vans	139.0259882	112.9901551	7.60981081	5.93322719	0.63910168	0.515708931
4 vans	153.5075696	116.2946282	8.393115789	6.050042309	0.717165134	0.528499354
5 vans	154.1450679	117.3025334	8.418016256	6.11443485	0.720595445	0.533014294
15 mpg	142.1640655	108.4227906	8.228740038	6.002151347	0.414803869	0.437397479
5 LEVs	129.6926776	89.74151844	8.570500316	5.943669171	0	0
3 vans	133.4978035	107.0833312	7.408581755	5.688958373	0.498691661	0.398546666
4 vans	144.4177745	111.2239242	8.016632379	5.876930433	0.547612332	0.411105826
5 vans	161.0480064	121.7299196	8.919245701	6.436092892	0.612911482	0.451840876
18 mpg	140.327306	106.3263617	8.191969285	5.948650407	0.341772324	0.35941218
5 LEVs	132.0698332	90.2342727	8.727372393	5.97636569	0	0
3 vans	131.9268498	105.0525924	7.389184163	5.634082557	0.417765483	0.329846582
4 vans	145.7069982	112.1073655	8.162846573	5.978453688	0.465731929	0.347543564
5 vans	151.6055428	115.9788431	8.488474013	6.178352542	0.483591886	0.361817177
21 mpg	138.9139218	105.9675197	8.143629872	5.947319111	0.292883198	0.310065211
5 LEVs	128.4821047	87.79228753	8.490113586	5.815075326	0	0
3 vans	128.4518888	103.2068581	7.23913522	5.575493844	0.349427918	0.279804292
4 vans	146.5797579	112.4006796	8.267116163	6.052721389	0.403036107	0.301514494
5 vans	152.1419357	117.2152349	8.578154521	6.296829079	0.419068766	0.315765937
$16/h	**143.222187**	**108.1506194**	**8.183256581**	**5.93142932**	**0.393285488**	**0.431020058**
12 mpg	145.1389511	109.6155659	8.180839096	5.912160789	0.518764266	0.544311128
5 LEVs	134.4766486	90.96063487	8.335157503	5.651493465	0	0
3 vans	140.0878878	114.1179709	7.656119825	5.972608921	0.648152802	0.521775728
4 vans	147.078017	111.5194361	8.039079386	5.811139009	0.683456778	0.507313609
5 vans	158.913251	119.5168744	8.692999671	6.22038765	0.743447485	0.544292431
15 mpg	145.1143428	109.5060143	8.277492321	6.016357963	0.415267695	0.437271518
5 LEVs	140.9486302	96.11613819	8.736994079	5.970489176	0	0
3 vans	136.8491224	110.8957995	7.592694624	5.914280548	0.511823162	0.412576659
4 vans	151.3529986	114.6340455	8.394479854	6.051372306	0.579550689	0.426774306
5 vans	151.3066202	115.8230821	8.385800727	6.140538866	0.569696929	0.427331606
18 mpg	141.7755915	107.8280503	8.136986152	5.936035985	0.344834884	0.365306751
5 LEVs	135.2802314	92.08313525	8.385632595	5.720560545	0	0
3 vans	132.4220271	107.5424058	7.414536842	5.762308742	0.418109419	0.339056051
4 vans	148.445292	114.0528497	8.287652084	6.082453007	0.477619828	0.358015397
5 vans	150.9548154	116.0845298	8.460123085	6.177113499	0.483610289	0.36251923
21 mpg	140.8598626	105.8657668	8.137708755	5.876994955	0.294275105	0.30800086
5 LEVs	136.2463177	92.4593017	8.444998657	5.74363769	0	0
3 vans	130.0397263	103.5793054	7.336569696	5.600465051	0.354913583	0.279611931
4 vans	148.7633236	113.791384	8.39378491	6.111698066	0.413856616	0.305883522

5 vans	148.3900829	112.3205815	8.375481758	6.034830681	0.408330223	0.302447096
Parking utilization 80 %	**137.314592**	**103.1267817**	**7.952371023**	**5.722528384**	**0.392779213**	**0.427639735**
$14/h	**135.0257495**	**101.8551995**	**7.940731085**	**5.7094763**	**0.392532266**	**0.428062779**
12 mpg	138.2307121	104.3748143	8.017168508	5.763568249	0.518370157	0.544062653
5 LEVs	122.5986358	82.5875994	8.674690874	5.858596137	0	0
3 vans	128.9794	103.4889088	7.009493078	5.384863687	0.614658385	0.494444299
4 vans	147.5976731	111.793485	8.021178401	5.799725991	0.713553468	0.529198981
5 vans	153.7471395	114.6637135	8.36331168	5.928035843	0.745268776	0.544177006
15 mpg	134.3076943	100.9232738	7.881881955	5.64160874	0.410282728	0.427915311
5 LEVs	119.9130906	80.72697959	8.48438826	5.726923412	0	0
3 vans	121.4169127	93.64880845	6.706604721	4.936922241	0.476616503	0.365462213
4 vans	147.4059674	111.5520105	8.12891911	5.852140816	0.58310162	0.430960688
5 vans	148.4948066	111.8276489	8.207615728	5.893707055	0.58141279	0.428756857
18 mpg	135.0721258	102.3354339	7.980501177	5.776246103	0.347581149	0.363749529
5 LEVs	120.8171051	83.09281633	8.548749925	5.893284367	0	0
3 vans	129.2693058	102.7408997	7.198854882	5.487721362	0.427014921	0.33530898
4 vans	138.8614207	104.8132312	7.748459673	5.573643061	0.461786743	0.341432514
5 vans	151.3406715	114.7934966	8.425940228	6.095917375	0.501522931	0.371837191
21 mpg	132.4924656	99.95452291	7.883372702	5.67122262	0.293895031	0.307680231
5 LEVs	119.1392047	80.44317656	8.430075389	5.706655247	0	0
3 vans	127.4778228	101.8528943	7.161749979	5.47905729	0.363031341	0.28856136
4 vans	137.8751217	104.8812845	7.761332369	5.613109348	0.394814481	0.29323358
5 vans	145.4777135	109.3428617	8.180333069	5.865668963	0.417734299	0.306739783
$15/h	**138.0827681**	**103.5780764**	**7.996324676**	**5.750999652**	**0.39460789**	**0.429399298**
12 mpg	139.8078452	105.3271672	7.980819446	5.760275707	0.519071602	0.542007767
5 LEVs	128.5054317	88.6422705	8.492278848	5.87079063	0	0
3 vans	129.9325366	103.9982528	7.068323514	5.425526915	0.621906908	0.494289016
4 vans	147.1999438	110.4778011	8.006428379	5.734239542	0.709850611	0.520770722
5 vans	153.5934688	115.2886434	8.356247044	5.957854465	0.744528889	0.544493942
15 mpg	137.717045	103.2288161	7.957509877	5.72958557	0.413779069	0.433025705
5 LEVs	130.4171322	88.23793484	8.618116056	5.84453398	0	0
3 vans	135.9797453	109.7804317	7.515562634	5.808352249	0.527969444	0.425329277
4 vans	140.9127115	107.3004969	7.770697887	5.639639823	0.559291779	0.416871531
5 vans	143.5585909	106.9113533	7.92566293	5.63318268	0.567855054	0.410950983
18 mpg	137.1367659	102.9969464	7.984292654	5.738650074	0.345908289	0.363544129
5 LEVs	130.0319283	86.41112765	8.592512968	5.72403635	0	0
3 vans	131.5092362	105.1510364	7.326505493	5.605413539	0.434265167	0.343629882
4 vans	141.1558504	108.6480975	7.875075654	5.758503077	0.467469801	0.353525745
5 vans	145.8500485	110.3923835	8.143076502	5.859438845	0.481898188	0.356043206
21 mpg	137.6694162	103.0321103	8.062676726	5.792019595	0.299672599	0.312886287
5 LEVs	130.4556901	88.44427994	8.620863416	5.858433689	0	0
3 vans	130.2765022	104.8004035	7.307492183	5.637220637	0.372278892	0.296835144
4 vans	145.7777077	110.6236649	8.190411908	5.913934903	0.419478808	0.310223671

5 vans	144.1677649	107.0503848	8.131939397	5.746059269	0.406932697	0.296143739
$16/h	**138.8352585**	**103.9470771**	**7.920057308**	**5.709599572**	**0.391197482**	**0.425655714**
12 mpg	139.5425925	104.5891068	7.856415998	5.667559348	0.509243779	0.532686883
5 LEVs	135.7701361	93.60310691	8.415340902	5.815140091	0	0
3 vans	132.947478	106.4601023	7.226930966	5.539741009	0.640237484	0.509725187
4 vans	143.1312909	108.6473979	7.801732639	5.62799546	0.692320265	0.514804512
5 vans	146.3214651	109.558772	7.981659485	5.687700288	0.704417365	0.515884977
15 mpg	141.4995595	105.7557735	8.055232453	5.801272217	0.41808107	0.436237103
5 LEVs	139.1969406	95.62247283	8.628592717	5.9404209	0	0
3 vans	134.3383841	108.2134685	7.416198505	5.719976432	0.52095403	0.418867919
4 vans	145.3796263	110.2242363	8.031617806	5.795316873	0.57483874	0.424819973
5 vans	147.083287	109.0911595	8.144520785	5.752320161	0.57653151	0.415864476
18 mpg	138.7008843	104.0115761	7.949350348	5.750502603	0.345211121	0.362351257
5 LEVs	140.1824128	95.45025664	8.68893605	5.929658928	0	0
3 vans	124.5604493	98.20864752	6.940243954	5.221501939	0.412619778	0.323052943
4 vans	140.6725827	108.1919247	7.841139058	5.742489809	0.470189422	0.352305563
5 vans	149.3880924	112.9218824	8.327082331	5.994872049	0.498035283	0.368627776
21 mpg	135.5979976	101.6131553	7.81923043	5.631732968	0.29225396	0.306346882
5 LEVs	132.1785229	89.96273263	8.192956286	5.588664104	0	0
3 vans	129.9633457	103.7449531	7.310467547	5.581869711	0.367449536	0.292329384
4 vans	139.3617085	106.3666265	7.843380217	5.705080371	0.398558381	0.297393161
5 vans	140.8884132	106.2745651	7.930117671	5.681541343	0.403007923	0.296996171
Parking utilization 100 %	**135.1205316**	**101.4301709**	**7.804257597**	**5.620953785**	**0.394710556**	**0.43092661**
$14/h	**132.6868757**	**99.92064516**	**7.782197604**	**5.587875568**	**0.394002303**	**0.430157424**
12 mpg	134.1982036	101.4510189	7.75080709	5.5699363	0.517346928	0.543607275
5 LEVs	117.1276132	79.44125372	8.286605879	5.63581801	0	0
3 vans	131.7963874	105.4805067	7.112486387	5.455877458	0.650828335	0.52102341
4 vans	143.1396298	107.7914843	7.749823476	5.557733594	0.708618324	0.524047639
5 vans	144.729184	108.9505858	7.854312617	5.631959259	0.709941054	0.530146092
15 mpg	134.5517854	101.6741701	7.875995678	5.687195879	0.418476212	0.439285413
5 LEVs	121.5436569	82.69456435	8.600085077	5.866146824	0	0
3 vans	135.3998467	109.3876881	7.428511093	5.753687872	0.540479847	0.435648646
4 vans	137.1948721	103.2579389	7.552139222	5.397465643	0.554620824	0.407509557
5 vans	144.0687659	108.9254135	7.923247321	5.715916381	0.578804176	0.429610115
18 mpg	131.1937419	98.806009	7.740522993	5.56841926	0.342944514	0.35952121
5 LEVs	118.6363824	80.89222728	8.394024541	5.738205894	0	0
3 vans	126.9873066	100.8224417	7.064809034	5.360286346	0.4234877	0.336168428
4 vans	137.587693	103.7109684	7.637551368	5.480759721	0.468071093	0.345371755
5 vans	141.5635857	107.217588	7.865707027	5.671303112	0.480219264	0.357743069
21 mpg	130.8037718	97.94096189	7.761464656	5.540530715	0.297241558	0.309321753
5 LEVs	118.192786	79.96169379	8.362673413	5.672487155	0	0
3 vans	126.4088081	101.5331418	7.06651894	5.421962109	0.368189326	0.295718979
4 vans	139.2840612	104.9677897	7.799345865	5.584931963	0.411817425	0.30172171

5 vans	139.329432	102.7382863	7.817320405	5.469054028	0.40895948	0.294269661
$15/h	**135.2531538**	**101.6126742**	**7.810163421**	**5.636663384**	**0.39572208**	**0.432377752**
12 mpg	137.6215917	103.2463748	7.831486612	5.646911878	0.521603352	0.545673958
5 LEVs	129.1909076	89.16657873	8.537075801	5.90572194	0	0
3 vans	130.6979712	104.6557674	7.052971489	5.414680283	0.641630988	0.515592847
4 vans	146.6981197	110.1829393	7.931263518	5.664108427	0.732485073	0.537432446
5 vans	143.8993684	107.7525734	7.804635638	5.560565072	0.712297346	0.522781356
15 mpg	137.0041614	103.0585164	7.890454944	5.705018772	0.420633899	0.440685833
5 LEVs	129.8870745	89.29930035	8.583329228	5.914869237	0	0
3 vans	128.4297559	103.2836273	7.045228955	5.430884598	0.512454264	0.410877897
4 vans	141.8872265	107.8134518	7.812923482	5.631783905	0.569888129	0.422689906
5 vans	147.8125889	110.4925501	8.120338113	5.789280412	0.600193201	0.438417993
18 mpg	133.2695821	100.6849614	7.729153718	5.597254538	0.346995122	0.364580839
5 LEVs	124.5836954	85.76922241	8.232801832	5.680894638	0	0
3 vans	130.2407931	104.2215663	7.23141455	5.528478606	0.439649327	0.350651386
4 vans	137.7551713	105.9874809	7.644497736	5.606088658	0.47083713	0.353853801
5 vans	140.4986685	105.7591697	7.807900753	5.593854212	0.477494034	0.352228815
21 mpg	133.11728	99.63472086	7.789558409	5.612564708	0.293655946	0.307775294
5 LEVs	129.9850167	89.48315759	8.589896332	5.926811803	0	0
3 vans	123.8155626	98.59515886	6.932847158	5.277326894	0.35765055	0.284365716
4 vans	139.8649691	105.8316499	7.842587033	5.631997465	0.410012529	0.304161393
5 vans	138.8035716	104.1359669	7.792903114	5.539002637	0.406960706	0.300281764
$16/h	**137.4215652**	**102.7327619**	**7.820411766**	**5.640909941**	**0.394407286**	**0.430454961**
12 mpg	139.5992327	104.6771438	7.830071365	5.658834634	0.521208331	0.544819091
5 LEVs	137.5802523	95.88935349	8.528392122	5.956517533	0	0
3 vans	131.1795989	104.5737268	7.096423106	5.405628883	0.645494775	0.511810508
4 vans	145.4528284	110.2684024	7.879739859	5.669296948	0.724391337	0.535285591
5 vans	144.1842513	108.0437728	7.815730373	5.566476589	0.714947213	0.526438694
15 mpg	137.8923559	102.795547	7.822302592	5.608743349	0.419391603	0.438982689
5 LEVs	135.705795	91.62838836	8.411434671	5.692305477	0	0
3 vans	124.9202857	99.55933405	6.870164291	5.224519725	0.49795752	0.397378624
4 vans	144.8834403	110.0732593	7.962601156	5.75149361	0.587770737	0.43625012
5 vans	146.0599025	108.6666318	8.045010251	5.699286503	0.591838154	0.430317945
18 mpg	136.6722733	102.1265841	7.829774851	5.667971047	0.341814846	0.357673268
5 LEVs	143.8612452	99.44949177	8.917567129	6.177249341	0	0
3 vans	126.043086	100.238239	7.003833548	5.308906453	0.4253782	0.338246929
4 vans	134.6914593	101.7862406	7.497215581	5.369684284	0.460887716	0.339171841
5 vans	142.0933026	107.1157228	7.900483146	5.666336857	0.480993467	0.355989975
21 mpg	135.5223988	101.5692571	7.799498257	5.644805692	0.295214363	0.30894887
5 LEVs	138.0862445	96.35546105	8.559628452	5.984807118	0	0
3 vans	124.940516	99.11989451	6.998369942	5.298231467	0.360651233	0.286255759
4 vans	134.6328996	101.6844184	7.559834268	5.410757128	0.394269629	0.29062759
5 vans	144.429935	108.929829	8.080160366	5.804654186	0.425936592	0.313706976
Grand Total	**143.2479396**	**112.2014104**	**8.298299974**	**6.23636603**	**0.393999021**	**0.43264833**