Impacts of Urban and Invisible Freight

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Executive Summary

Urban freight represents the transportation of goods usually in the first or last mile of a delivery cycle in urban settings. Traditional urban freight involves pick-up and delivery to and from businesses and residents by commercial freight carriers using efficient transport methods. However, the introduction of e-commerce has brought invisible freight services which are often gig-based and operate out of unmarked passenger vehicles, vans, or personal micromobility devices. Together, these services bridge the gap between business and consumer.

This report aims to gain an initial understanding of the urban freight sector and its impacts from a local government transportation perspective. The key goals of this report are to detail who the entities are responsible for urban and invisible freight movement in an urban context, what modes they rely on, and what impacts they have on other road users. To capture the full extent and impact of Metro Vancouver's urban freight, a comprehensive list of companies operating in the area was compiled. Additionally, open-source data were collected for the municipalities in which the study would occur to inform the specific site selection for manual data collections as well as the statistical models detailing the behavior and impacts of urban freight. Finally, manual data collection of parking events and site characteristics occurred at nine locations across five municipalities in Metro Vancouver. Each of these sites included collections from 11:00 am-1:00 pm and 4:00 pm-6:00 pm on a weekday and a weekend for a total of four parking activity collections per site. The municipalities included the City of Vancouver, City of North Vancouver, City of Richmond, City of Coquitlam, and Electoral Area A University of British Columbia.

Through this research, we found that invisible freight had a higher share of on-street freight parking activity, primarily food delivery drop-off and pick-up from passenger vehicles in Metro Vancouver. This freight activity was higher during the weekdays as opposed to the weekends and slightly higher from 4 pm- 6 pm over 11 am- 1 pm, likely due to the increase in food delivery demand. Delivery drop-off parking durations were 53% longer than delivery pick-up durations. From our modeling, the probability of a freight vehicle leaving an illegal curb space (including "no parking", "no stopping", and "bus only" curb designations) at any given time was 3.36 times higher than freight vehicles parked in alleys/lots, keeping every other variable constant. Consistent with the literature, this finding suggests drivers who parked illegally in such spaces tend to occupy the curb for a shorter time compared to when they park in an alley, commercial lane, or parking lot. We found that 29% of freight vehicles were illegally parked (most frequently observed to be passenger vehicles). Note, however, that we were unable to confidently collect information about compliance with paid parking as some of the drivers likely made payments by their phones. Therefore, transaction data can help address this issue (not available for this study). Almost all freight delivery, ridehailing, and taxi events were short-duration parking events (15 minutes or less)

and occurred in metered parking spots, including 1-hour and 2-hour parking locations. This may represent a mismatch between curb demand and current curb typology. Finally, the average emission factor for freight passenger vehicles (mostly involved in invisible freight) in CO_2/km was lower than the value for personal passenger vehicles, indicating that freight vehicles were more efficient than the sample personal vehicles.

Key Takeaways:

1. Lower parking activity occurred on weekends for all parking activities
2. Invisible freight had a higher share of on-street freight parking activity than traditional freight
3. Smaller freight vehicles had shorter parking durations, with delivery drop-off activities having longer durations than delivery pick-up
4. Restaurant food delivery represented the highest share of goods delivered
5. All on-street parking activities included events in no stopping/no parking zones
6. All on-street parking activities included illegal parking, with passenger pick-up and drop-off having the highest proportion of illegal parking
7. Parking in on-street loading zones was primarily less than 25 minutes for all activities
8. Food delivery companies were overrepresented in freight companies observed
9. Food deliveries took less time than package and mail deliveries
10. At the sites observed, passenger vehicles used in invisible freight tend to be slightly more efficient vehicles

Keywords: urban freight, last-mile delivery, parking behavior, data analysis

Introduction

Goods movement is an essential part of life in Metro Vancouver that connects people to goods and services on the local, regional, and global scale. This project aims to gain an initial understanding of the urban freight sector and its impacts from a local government transportation perspective. The key research questions in this project were:

1. Who the entities are responsible for urban freight (including traditional and invisible freight)
2. What is the overall freight behavior (including modes being used across traditional and invisible freight, their parking behavior, their compliance with curb designations, etc.)
3. What is the impact of urban freight on other users (including conflicts with other road users and the environmental efficiency of freight passenger vehicles)

In the Background section, we introduce various types of urban freight along with their parking behavior and impacts. A list of curb management strategies was compiled to address challenges due to increased demand for curb space caused by competing needs. Metro Vancouver's context was investigated by obtaining details of urban freight operators within the region along with parking bylaws designed by municipalities. In the Methodology section, we described the adopted method to answer the research questions. We benefited from open-source data to inform the site selection by developing a measure consisting of relevant urban freight variables. A detailed data collection plan and variables are described along with descriptive statistics. A parking duration model was developed controlling for potential dependence between sites. Finally, our data allowed us to investigate the efficiency of passenger vehicles involved in urban freight. We concluded our report by summarizing findings and putting forward recommendations for policy and research.

Background

This section describes urban freight logistics with a focus on last-mile deliveries. We looked into a recent form of urban freight, “invisible freight”, enabled by e-commerce in addition to traditional freight services. Parking behavior studies are reviewed and summarized in the next section. Urban freight externalities and solutions are discussed. We concluded this section by shifting the focus to Metro Vancouver, describing what types of last-miles deliveries are taking place in the region and what guidelines municipalities designed to manage curb space.

Urban Freight

Urban freight represents the transportation of goods usually in the first or last mile of a delivery cycle in urban settings. Traditional urban freight involves pick-up and delivery to and from businesses and residents by commercial freight carriers using efficient transport methods. However, the introduction of e-commerce has brought about a new entity to urban settings: invisible freight. Invisible freight services are often gig-based and operate out of unmarked passenger vehicles, vans, or personal micromobility devices. Together, these services bridge the gap between business and consumer. Especially in light of the COVID-19 pandemic, e-commerce continues to increase year after year, with Canada seeing a 47% increase in e-commerce spending from 2018 to 2020 (1). Due to continued expected growth in e-commerce, last-mile deliveries are estimated to increase by 78% by 2030 which in turn will give rise to a 36% growth in the number of delivery vehicles on the road globally (2).

Traditional Freight

Traditional freight involves the pick-up and delivery of goods by standard means such as national postal services and private delivery and courier companies. Globally, the share of urban freight is large and growing. In Canada, freight deliveries increased 26% from 2016 to 2018, and 29-62% of those originated and ended in the same metropolitan area (3). In Metro Vancouver, there are four freight market sectors: regional, inter-regional, gateway, and cascade (*4*). These encompass the freight activity occurring from all modal ports in the area. In the UK, vans are the primary mode of delivery services and the number of vans increased by 82% from 1993 to 2015 (*5*). In London, one of these vans "typically delivers 118 shipments to 72 customers in 37 delivery stops" (*6*). In Australia, an estimated 56% of retailers in Melbourne receive 2-7 deliveries per week (*6*). In the urban context, these services are most often involved in the first or last mile of delivery which refers to the first and last segments in a transportation journey. The last mile segment, for example, can represent the final segment between a regional distribution center and the customer, a regional center to a local distribution center, a local center to a central customer pick-up location, or many other final segment definitions. Most of the freight transportation cycle is characterized by efficient bulk goods movement, but first and last-mile logistics represent expensive and inefficient transportation due to the spread of businesses and residents (*7*).

Delivery services are also falling victim to the "Amazon Effect" which describes how Amazon, and e-commerce as a whole, have changed the expectations of consumers (*8*). In this, consumers are increasingly expecting 1-2 day shipping, and businesses are changing their freight practices to accommodate this competition. The result is more urban freight and inefficient last-mile deliveries. Contrary to the growing demand for it, first- and last-mile logistics represent between 13-75% of supply chain costs for companies (*9*, *10*). The increase in e-commerce as a whole and the need for companies to reduce their delivery times means these costs are felt more and more by companies. Additionally, as this segment of freight delivery is often completed with light commercial vehicles or light trucks, last-mile delivery represents a sector of transport emissions that need to be reduced (*11*). Because of this, many studies seek to improve the efficiency, sustainability, or cost-effectiveness of urban or first-/last-mile delivery. Common solutions range from more efficient routing of delivery trucks and vans (e.g., Toth & Vigo, 2001; Wang et al., 2021), increased use of central consumer pick-up locations (e.g., Deutsch & Golany, 2018), and novel delivery methods like passenger-freight combination deliveries (*9*), among others. For a broader list of urban freight solutions, see Appendix A. In all studies, the motivation is clear: urban freight volume is increasing and delivery strategies need to evolve to keep up.

Invisible Freight

Invisible freight involves the pick-up and delivery of goods by individuals working for a delivery service, but using personal means of transportation, including light duty vehicles, bicycles, and scooters. Often, these delivery services operate on a gig-based system, where the deliverers are contracted and paid on a per-delivery basis. Some delivery services may have drivers operating on prescheduled shifts while others may have drivers choose which deliveries in particular they will complete (*15*). Invisible freight can include deliveries of groceries, restaurant take-out, alcohol, and general packages. Invisible freight shares many of the challenges of traditional freight but often includes greater inefficiencies when deliveries are made on a per-customer basis. For example, while traditional freight may attempt to combine deliveries to similar drop-off locations into one vehicle for more efficient last-mile trips, invisible gig-based delivery services may deliver from one business to one customer at a time, especially with hot food restaurant deliveries.

The number of workers involved in invisible freight delivery is, by nature, constantly changing. The gig-based system allows deliverers to have flexible schedules and for companies to contract delivery services on a need basis (*15*). In Canada, 14% of transportation and warehousing businesses reported hiring gig-based workers. Similarly, in British Columbia 16.5% of the same businesses hired gig-based workers (*16*, *17*). Because invisible freight operates out of passenger vehicles and other personal means of transportation (e.g. biking, walking), it is difficult to quantify behavior and impacts and thus few studies exist on the true nature of invisible freight. This report hopes to address this by offering insight into the sizes and behaviors of invisible freight in the Metro Vancouver area.

Parking Behavior

A substantial portion of last-mile deliveries is spent in parking. More than 50% of the time on delivery rounds (*18*) to 80% of commercial vehicles' operating time (*19*) takes place in parking with 74%- 80% of vehicles occupying on-street parking (*18*, *19*). One of the most important elements of parking activity, and one of the critical research questions that this report aims to address, is parking duration (also known as service or dwell time (*20*)). There is a positive and linear relationship between parking duration and curb occupancy rates (*21*). Average dwell time reported in different studies ranges between 8 to 45 minutes (with distributions ranging from 1.5 to 240 minutes) (*22*–*26*). Most commercial vehicles require short-term parking (15-30 minutes) consistent with parking restrictions (*27*).

Estimation of parking dwell time requires parking activity data which can be collected using different methods and data sources. Dey et al. (*28*) conducted a review of parking occupancy data collection methods and compared them (see Appendix B). In addition to the emerging technologies in data collection such as CCTV cameras, parking activity can be captured using freight vehicles' GPS trajectories (for example, see Dalla Chiara et al., 2021; Wise et al., 2019) and ridealongs (for example, see Dalla Chiara et al., 2021). Manual data collection is one of the most common methods employed in parking behavior literature, where researchers observe and note specific information from chosen locations (*20*, *22*, *27*, *29*, *30*).

Other data sources can help analysts infer parking activity behavior. For instance, building frontage is used to measure curb space supply (*21*, *31*) while freight trip generation model outputs are employed as a surrogate measure of parking demand (*21*, *31*). Some studies take advantage of such data to complement their manual data collection efforts. For instance, Dixit et al. (*32*) used traffic cordon counts along with drivers' and retailers' interviews.

Parking violations can serve as a proxy for parking demand by illustrating the times when legal parking may not be available for delivery pick-up and drop-offs. It has been shown that parking demand, and consequently parking behavior, varies by time of day and land use (*27*). Chen et al. (*31*) reported that parking violations peak in the morning within commercial land use. Schmid et al. (*25*) had similar observations, finding that high conflict periods occur between 7 am-1 pm within commercial neighborhoods while conflicts distribute over 8 am-4 pm in residential areas. Therefore, strategies for curb space management must differentiate between land uses. For instance, the presence of loading/unloading bays in commercial areas can make freight transportation more efficient and reduce emissions by up to 10% while the same strategy causes negative impacts in residential and mixed-use areas (*33*).

Parking violations can also be utilized to inform curb space management strategies (*34*). Illegal behavior seems to be more prevalent in trucks compared to passenger vehicles (*35*), with a study in Manhattan by Jaller et al. (*21*) observing that 25% of commercial vehicles (out of 374 surveyed) parked illegally with the most common violation being expired or unpaid parking meters.

Most parking infractions are related to illegal parking in unauthorized curbside parking (*27*, *36*). However, unauthorized parking is associated with shorter parking durations (*19*, *25*). In Manhattan a quarter of zip codes would face a commercial parking supply shortage in peak hours even if all curb space is used for commercial vehicle parking (*21*). Together, these points suggest a need for increased short-term commercial parking space in cities.

There are other important variables besides land use and lawful parking behavior that correlate with parking duration. Freight trips are undertaken by a range of transportation modes and each demonstrates a different parking duration. Dixit et al. (*32*) observed that the majority of freight trips (74%) are made by light commercial vehicles in Gothenburg, while in Delhi smaller vehicles undertake most of the trips (34% by mini light commercial vehicles and 28% by passenger vehicles). Smaller vehicles appear to exhibit shorter parking durations (*20*, *26*). The type of trip also influences parking dwell time. In Gothenburg, while service vehicles constitute a small segment of freight trips (14.5%), they occupy loading bays the most (*32*). In downtown Seattle, 20-40% of all parking events observed were related to service vehicles, but they had the largest share of parking events of 30 minutes or longer (*27*). Off-street parking tends to be associated with a longer parking duration than on-street parking (*20*). The number of deliveries per stop and frequency of stops within a freight tour also correlate with parking duration (*21*, *37*). Table 1 illustrates other variables collected in studies of freight parking behaviors.

Table 1 variables collected in parking studies

Variables	**Studies**
Parking duration	Girón-Valderrama et al., 2019; Schmid et al., 2018; Kim et al., 2021; Zou et al., 2016, Jaller et al., 2013, Wise et al., 2019; Campbell et al., 2018; Amer & Chow, 2017; Dalla Chiara et al., 2021;Fehr & Peers, 2018; Fehr & Peers, 2019
Curb typology	Girón-Valderrama et al. 2019; Jaller et al., 2013, Dixit et al., 2022, Wise et al., 2019; Dalla Chiara & Goodchild 2020; Dalla Chiara et al., 2021; Fehr & Peers, 2018; Fehr & Peers, 2019
Parking typology (on-off street)	Kim et al., 2021; van den Bossche et al., 2017; Dalla Chiara & Goodchild 2020; Fehr & Peers, 2018; Fehr & Peers, 2019
Transportation mode	Girón-Valderrama et al. 2019; Schmid et al., 2018; Kim et al., 2021; Zou et al 2016; Dixit et al, 2022; van den Bossche et al., 2017; Dalla Chiara et al., 2021; Fehr & Peers, 2018; Fehr & Peers, 2019
Illegal behavior	Girón-Valderrama et al. 2019; Schmid et al., 2018; Jaller et al 2013; van den Bossche et al., 2017; Dalla Chiara et al., 2021

Variables	Studies
Delivery vs service	Girón-Valderrama et al. 2019; Schmid et al., 2018, Dixit et al, 2022
Goods typology	Schmid et al., 2018; Kim et al., 2021; Kim et al., 2021; Zou et al 2016 ; Dalla Chiara et al., 2021; Fehr & Peers, 2018; Fehr & Peers, 2019
Walking distance	Schmid et al., 2018, Wise et al, 2019; Dalla Chiara et al., 2021
Vertical delivery	Kim et al., 2021; Dalla Chiara et al., 2021
Day	Kim et al., 2021, Dixit et al, 2022
Time	Kim et al., 2021; Zou et al 2016, Dixit et al, 2022; van den Bossche et al., 2017; Campbell et al, 2018; Fehr & Peers, 2018; Fehr & Peers, 2019
Site-specific characteristics	Kim et al., 2021; Zou et al 2016, Dixit et al, 2022, Dalla Chiara & Goodchild 2020; Dalla Chiara et al., 2021; Fehr & Peers, 2018; Fehr & Peers, 2019
# delivery workers	Kim et al., 2021, Fehr & Peers, 2018; Fehr & Peers, 2019
Company info	Zou et al 2016, Dixit et al, 2022
Tour (or trips)	Zou et al 2016, Jaller et al 2013, Dalla Chiara & Goodchild 2020; Dalla Chiara et al., 2021
# delivery stop	Zou et al 2016, Jaller et al 2013; Dalla Chiara et al., 2021
# tasks while parking	van den Bossche et al., 2017
Receptionist	Kim et al., 2021
Ancillary activity for delivery	Dalla Chiara et al., 2021
Availability of loading zone	Fehr & Peers, 2018; Fehr & Peers, 2019

Urban Freight Impacts

Congestion, emission, noise, and safety are considered negative externalities concerning goods movement in the context of Metro Vancouver (TransLink, 2017, 2022). A recent review reveals that the environmental impacts of last-mile deliveries have gotten more attention than other impacts (*38*). The transportation sector is the largest contributor to greenhouse gas (GHG) emissions in Metro Vancouver (responsible for 31% of GHG emissions in 2015 in Lower Fraser

Valley) (*39*). Heavy commercial vehicles constitute 5% of Vehicle Kilometers Traveled (VKT) and represent 5% of total GHG emissions in Metro Vancouver (*39*). However, their contribution to local air pollutants is much more significant (in the context of the United States, heavy vehicles contribute to 9% of VKT while generating approximately 50% of NOx and PM10 (*40*, *41*)). It's worth noting that the light-duty vehicle market has been accelerating the transition to Zero emission vehicles while heavy-duty vehicles lag behind (*42*). Emissions and congestion are expected to increase by 32% and 21%, respectively, by 2030 due to increased last-mile deliveries (2).

Freight-involved conflicts and collisions are another adverse externality of freight transport. While overall fatality rates have not changed significantly, fatality rates for urban freight collisions indicate concerning trends. Adjusted for VKT, fatality rates of urban freight-related collisions in the U.S. increased by 17% between 2009 and 2015 while the fatality rates of overall collisions only increased by 3% for the same period (*43*).

The negative externalities are not independent, for instance, a shortage in supply of curb space aggravates congestion and emissions due to searching for parking. Similarly, it increases safety risks due to the increased likelihood of illegal behavior such as double parking (*33*, *44*). Increased cargo trips are positively correlated with both emission and congestion (*45*). Additionally, the negative impacts of freight transportation can go beyond well-known externalities. Freight transportation also has implications for social equity and community severance (*46*), which is defined as "physical or psychological separation of neighborhoods with possible effects on the health and wellbeing of local residents" by Anciaes et al. (*47*). Much freight infrastructure is located in the neighborhoods where communities of color are predominant which in turn exacerbates local air quality and leads to health implications for these communities (*48*).

With the recent growth in the e-commerce market, the negative consequences of last-mile deliveries are also expected to grow. It is established that the e-commerce channel consumes less energy than the conventional supply chains with regard to transportation because the consumed energy by passenger transportation (i.e., shopping trips) exceeds the added energy in e-commerce freight transportation due to bulk efficiencies in freight transport (*49*). However, the shopping behavior of e-commerce shoppers and increased last-mile deliveries suggest detrimental environmental impacts as this is the least efficient segment in freight transport (*38*, *50*). Despite the challenges associated with last-mile deliveries, they present cities with opportunities and benefits (see Figure 1).

Sustainability pillar	Urban last-mile freight	
	Externalities and costs	Opportunities and benefits
Social (also termed 'Equity' in some freight literature)	• Noise and disturbance • Traffic annoyance • Urban severance • Impact on other modes • Public health impacts	• Supports consumer choice, convenience • Essential for local amenity (waste removal, servicing) • Supports employment
Economic	• Contributes to traffic congestion • Crash costs • Inconvenience for shipper and receiver • Impacts on local markets • Delivery often not directly charged to end-users	• Supports enterprise, economic growth • Reduced freight costs (which flow to consumer prices) • Taxation/sunk cost recovery opportunities (e.g. road, rail, port pricing)
Environmental	• Vehicle emissions • Noise and visual impacts • Severance • Land consumption (parking, roads, warehousing) • Fuel and resource consumption	• Supports separation of incompatible land uses • Enables importation of more efficient products • Required for management of environmentally damaging substances
Governance	• Immediate problems often drive policy • Politicisation of issues; perverse influences of lobby groups • Conflicting interests and wicked problem structures • Regulations may have unintended outcomes	• Freight policy can achieve related policy goals • Opportunities for more efficient resource allocation for all parties • Sharing/pooling of resources, fixed costs (e.g. consolidation) • Cooperation needed to realise mutual benefits

Figure 1 opportunities and challenges of urban freight, from (*46*)

Curb Space Management Strategies

Curb space is a vital segment of the street that serves many purposes such as on-street parking, pick-up/drop-off of passengers, freight loading/unloading, and transit stops among others. Growing demand for e-commerce deliveries, ride-hailing services, and micro-mobility modes has escalated the competition for the limited curb space in cities (*33*). In addition to competing demand for curb space, there is a desire to repurpose general purpose travel lanes for higher value public priorities, such as transit priority lanes, bike lanes, or patio seating (*complete street approach* (*51*)) which in turn affects the curb space. In this section, we focus on the strategies that specifically target curb space use by freight vehicles. Curb space management strategies include (but are not limited to):

1. **Off-peak deliveries** are a commitment to delivering outside of peak times of the day. This strategy has been implemented in many places including Zaragoza, Spain, Eindhoven, Netherlands, and New York City, USA to address congestion and parking demand (Pembina Institute, 2021, (Diehl et al., 2021). Moreover, a pilot study in Ontario revealed that off-peak deliveries were faster, and generated less GHG emissions and air pollutants (*48*). A simulation study concluded that off-peak deliveries are most

influential compared to other strategies as they can reduce parking demand by 80% in peak hours (*52*). Off-hour deliveries encourage deliveries outside regular business hours. The strategy seemed to decrease parking duration in off-hours (10 pm-6 am) in New York City (*21*). One potential issue of off-peak/off-hour deliveries is that a large shift to these hours could negatively impact parking availability in the new hours (*21*). Other challenges to this strategy include receivers' willingness to participate in such deliveries, noise impacts, safety, and regulatory concern (*53–55*).

2. **Commercial loading zone pricing** is a system in which commercial vehicles pay per dwell time to use loading zones. This has been implemented in Washington, D.C. and led to a drop in double-parking and non-truck parking in loading zones (*48*). New York City similarly has developed a pricing scheme to encourage shorter stops which led to decreased curb space occupancy from 140% (double-parking included) to 95% (*34*, *56*). Dynamic pricing along with reduced target parking occupancy rates of 70%-90% is another example of a success story in managing curb space (33, 45). This strategy coupled with smaller and low-emission vehicles for last-mile deliveries decreases the demand from large vehicles competing for scarce curb space (*44*, *46*, *48*, *57*).

3. **Courier loading zone** is a designated curb space that accommodates short-stop deliveries and has been implemented in Toronto (*48*). Reducing the parking time limit has also proved to increase turnover (*44*). Fifteen-minute loading zones have been proposed in the San Francisco curb space management plan (*34*).

4. **Curbside priority access** for freight vehicles. This is when freight vehicles are prioritized over other transportation modes in commercial and industrial land uses when loading/unloading demand is significant (*44*, *58*).

5. **Staging zones** are designated waiting zones for delivery vehicles to access off-street loading zones (*44*).

6. **Flex zones** allow the curb space to be used dynamically serving various purposes. Thus, it provides flexible designations for curb space (see Figure 2) (*29*, *30*, *44*, *57*). By permitting e-cargo bikes to park in commercial loading zones, New York City also benefited from shared zones (*48*).

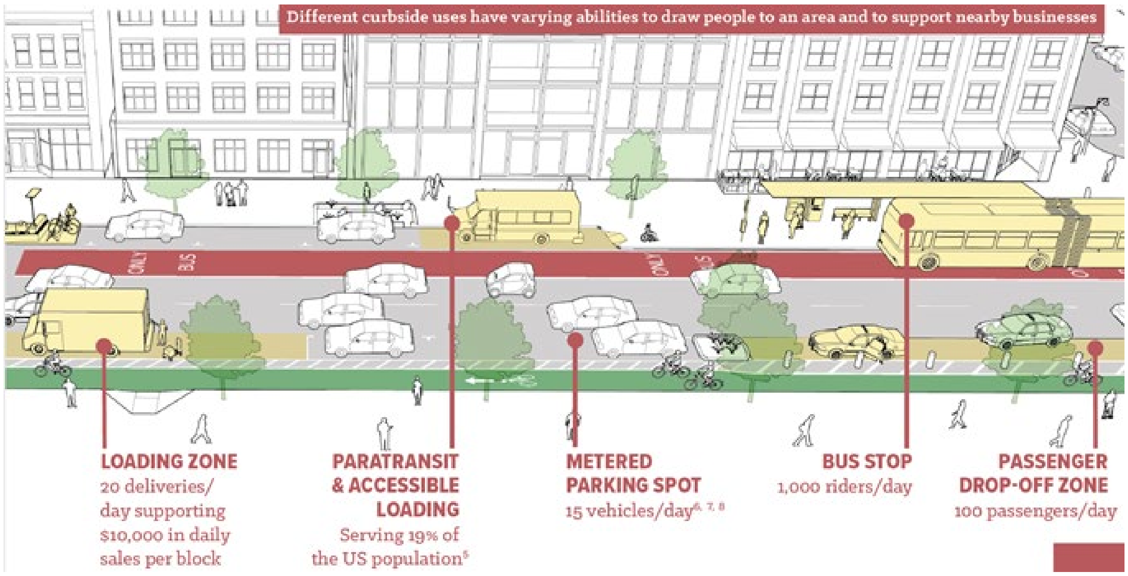


Figure 2 Flex zones, from (*59*)

7. **Relocating and modifying loading zones**; loading zones should be relocated out of the main street and consolidated at midblock locations (*44*). Seattle has extended, relocated, and merged loading zones with pick-up/drop-off zones (*34*). New York City has provided additional commercial vehicle parking and parking meters. The project has led to favorable impacts for stakeholders (*58*, *60*).

Furthermore, National Cooperative Research Program published a comprehensive report and supplemental interactive web service[1] that discusses 54 initiatives to improve freight system performance in metropolitan areas (*60*). The web service output for the "peak-hour clearway" initiative is given in Appendix C. More recently, the National Cooperative Highway Research Program published a report that provides guidance for effective freight transportation (*58*). From these guides, the following strategies are specific to on-street parking management:

1. Loading and parking restrictions. Restrictions are developed for a specific user (for instance truck-only loading zones) or time of day (shared or flex zones) (*58*, *60*).
2. Peak-hour clearways. This initiative prevents parking or stopping during peak hours. London has implemented this strategy and limited stopping to designated locations (Holguín-Veras et al., 2015).

[1] https://cite.rpi.edu/iselector/

3. Parking reservation systems. This initiative is supported by Intelligent Transportation Systems. In Japan, a pilot study showed on-street parked vehicles for loading/unloading decreased by 56% following the implementation of parking reservations (*58*, *60*).

4. Preferential parking for freight vehicles. This strategy gives priority to freight vehicles to access curb space (*58*). Further information on this strategy is provided in Appendix D.

Study Site Criteria

Urban freight behavior has been studied extensively in cities across the world and in time, increasingly so since the 1960s (*61*). The selection of the sites for study forms the basis of the claims from any results. While many studies collected site information from automatic collection methods such as transactional data (*29*, *30*, *62*, *63*), in-ground sensors (*30*), CCTV cameras, and fixed cameras (*29*, *30*, *64*), the collection method of interest to this study is manual data collection (in line with (*20*, *22*, *27*, *29*, *30*)).

Of the manual collections, most were collected between one and five sites. While some studies did not explain how the site locations were chosen, those that did were based on land use profiles. The site locations were chosen to either represent a specific land use of interest or to capture a representative sample of land uses across the city. Urban Freight Lab (*65*) in their study of last-mile delivery in Seattle, selected candidate establishments based on their land-use profile. They further studied each establishment with respect to site-specific conditions and freight characteristics and conducted site visits. The final candidate set was selected through internal voting and whether they could obtain the building manager's permission (*65*). Similarly, a study in San Francisco on ridesharing behaviors described that the “[five] case study locations were identified for a range of different land-use mixes, street characters, and functional roadway classifications. The common element at all five locations was moderate to high levels of ridesharing passenger loading activity relative to other parts of the City (based on data provided by Uber)”(*30*). Characteristics of the manual data collection studies surveyed are captured in Table 2. Most studies were conducted at peak traffic hours, both in the morning and in the afternoon. Some studies included collection hours in the middle of the day when traffic may be lower (Urban Freight Labs, 2018), while others included evening to night collection times (Fehr & Peers, 2019).

Table 2 Characteristics of manual data collection studies

Number of Sites	Collection time	Temporal profile	Study
5 establishments	3 days per study area	8:00-13:00, 8:00-12:00, and 8:30-16:30	Urban Freight Lab, 2018

1 location	Average weekday	Morning	Jaller et al, 2013
76 locations			Zou et al, 2016
5 locations	Average weekday	7:00-10:00 and 15:00-19:00	Fehr & Peers, 2018*
3 locations	Evening/Night Events	18:00-23:59	Fehr & Peers, 2019*

*Prepared for Uber Technologies.

Metro Vancouver Context

In this section, we detail the current status of urban freight in the Metro Vancouver area by outlining the operations of traditional and invisible freight companies as well as the parking guidelines.

Company Operation

To capture the full extent and impact of Metro Vancouver's urban freight, a comprehensive list of companies operating in the area was compiled. Urban freight in the area includes general package delivery by courier or delivery service, restaurant, grocery, and alcohol delivery.

The full list is included in Appendix E, but a summary of the delivery services is included in Table 3. All delivery services include a vehicle component, including cars, vans, and light-duty trucks. Some general courier delivery services utilize only hybrid, electric, or ultra-low emission vehicles, as well as bike service for downtown Vancouver deliveries. Additionally, some restaurant food delivery services allow bike or scooter deliveries in downtown Vancouver. Outside of downtown Vancouver, general courier and restaurant delivery services utilize cars, vans, or light-duty trucks. Grocery or alcohol services exclusively use cars or vans for deliveries, likely due to the weight and size of these deliveries.

Of the companies surveyed to date, general courier services, including Canada Post and Amazon Delivery, were employee-based delivery services, as well as grocery and alcohol deliveries. Restaurant delivery services were 100% gig-based. Finally, general courier and grocery delivery services tended to run only during business hours, but food delivery services were observed at all hours and days. Restaurant delivery services only ran during restaurant hours, but a number of Metro Vancouver restaurants, especially fast-food places, are open and available for delivery 24 hours.

Table 3 Summary of urban freight characteristics in Metro Vancouver

Delivery Type	Mode	Deliverer Type	Hours of Operation
General Courier	Bike, Car Downtown Vancouver Car, Van, Truck Elsewhere	100% (35/35)* Employee	Generally 8a-6p M-F, Five (5) services offer weekend delivery
Grocery, Alcohol	Car, Van Everywhere	96%^ (56/58)* Employee, 4%^ (3/58)* Gig-Based	Generally 8a-10p M-Su, Six (6) services closed weekends
Restaurant	Bike, Scooter, Vehicle Downtown Vancouver Car Elsewhere	100% (8/8)* Gig-Based	24/7

*This list is non-exhaustive and should continue to be updated
^Does not capture the size of the fleet

Parking Guidelines

Parking guidelines of Metro Vancouver municipalities were reviewed to determine illegal behavior and further flag such behavior in our data observations. Parking guidelines are included in traffic bylaws (bylaw 13007 for the City of Surrey, bylaw 5870 for the City of Richmond, and bylaw 2849 for the City of Vancouver among other municipalities). Borrowing from these bylaws, general on-street parking (and stopping) violations are listed below (consistent with BC Motor Vehicle Act[2]):

- Parking in unauthorized curb spaces, "no parking" areas where vehicles are allowed to stop only (and not park), "no stopping" zones (with or without time restrictions) where vehicles are not allowed to cease motion.
- Parking in lanes where traffic (drivers and pedestrians) is obstructed. Besides traffic, where driveways, garage doors, waste containers, and fire escapes are blocked.
- Parking where visibility and access to property and fire hydrants are compromised.
- Exceeding time limit in a parking spot with restricted parking signage.
- Parking or stopping in bus zones/stops.

[2] http://www.bclaws.ca/civix/document/id/complete/statreg/96318_00

- Angle parking, unless a sign indicates otherwise.

The City of Vancouver classifies commercial loading zones as lanes next to commercial properties where stopping is only permitted with a valid permit. Commercial vehicles can stop in commercial loading zones for up to 30 minutes. The City of Vancouver further specifies in its bylaw that commercial vehicles can stop in passenger zones for up to 30 minutes until noon and in a metered space for free until 10:30 am. Loading zones must be used only for loading passengers (up to 3 minutes in the City of Vancouver and up to 5 minutes in the City of Richmond) and goods (up to 30 minutes). There are exceptions to the above rules such as people with disabilities (owning a valid SPARC permit) that can park in passenger zones for up to 30 minutes while loading/unloading. In addition to general guidelines, the City of Vancouver has put forward specific guidelines for app-based delivery drivers (see Figure 3).

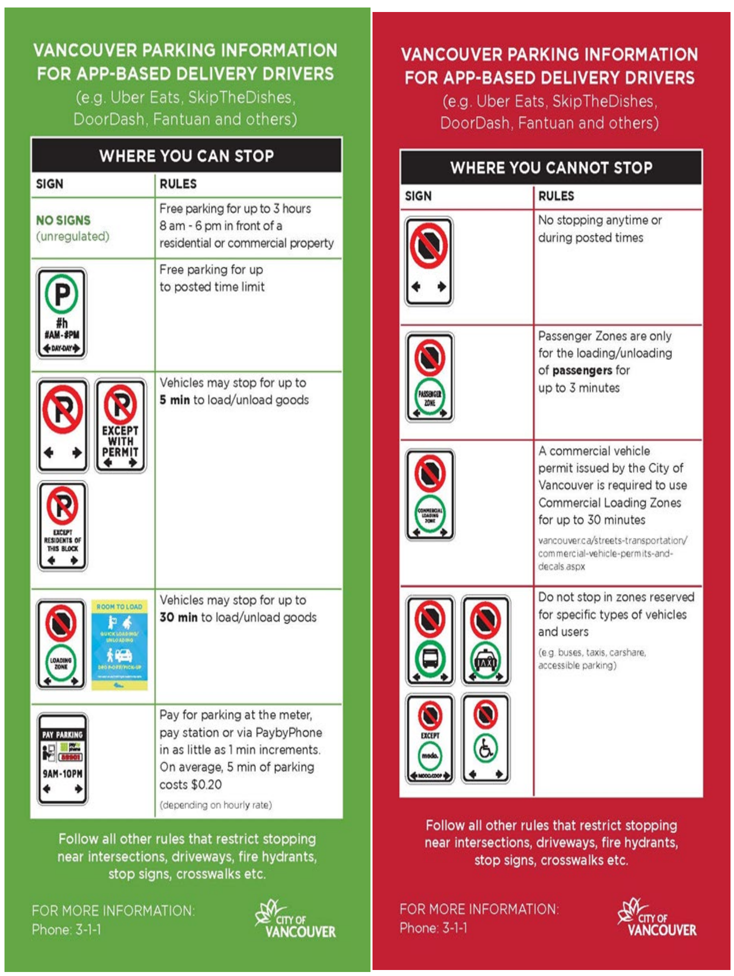


Figure 3 City of Vancouver guidelines for app-based delivery services

Methodology

Figure 4 demonstrates the methodology developed to answer the research questions proposed in this study. In the following sections, we detail each step of the methodology.

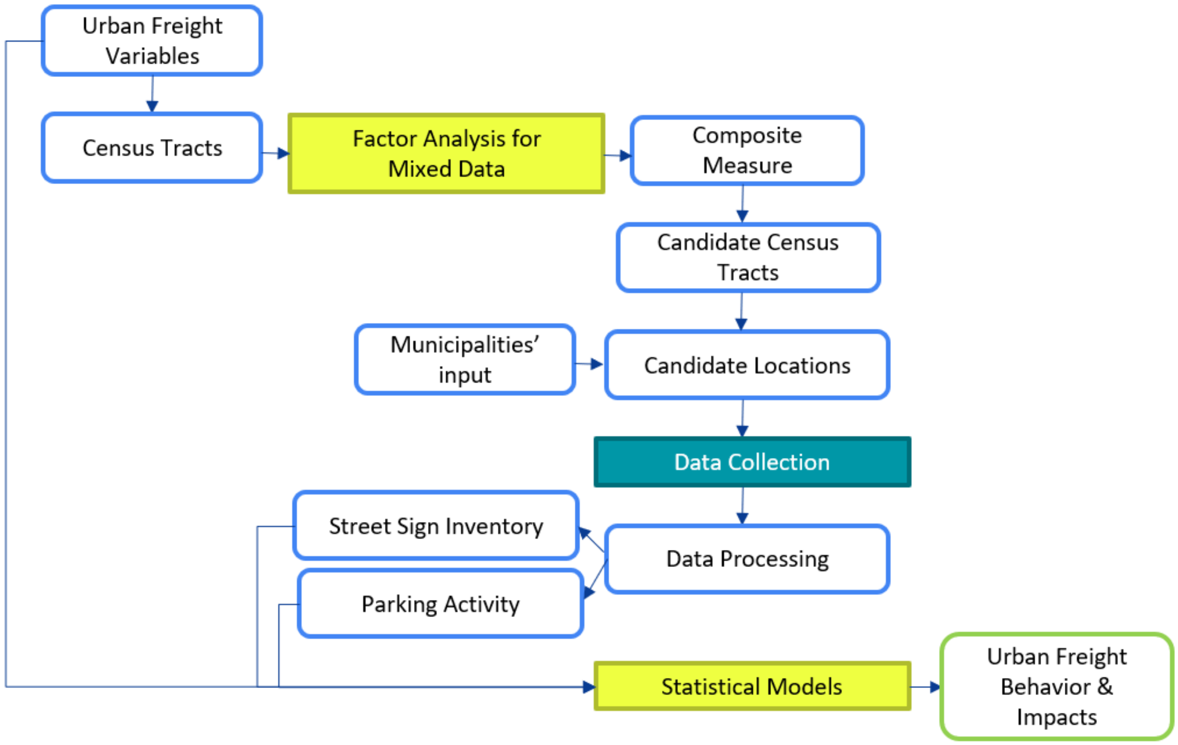


Figure 4 Methodology flowchart.

Data

To understand the behaviors and impacts of urban freight, a variety of data was collected from open data sources, expert input, and observational surveys. Each of these sources is detailed below.

Urban Freight Variables

Open-source data were collected for the municipalities in which the study would occur. These data were used to both inform the specific site selection for observational collections as well as the statistical models detailing the behavior and impacts of urban freight. For both, it was important to capture the variables that impact parking behavior for freight vehicles of all services and, particularly for the site selection, to ensure that these datasets have encompassing spatial extent and consistent temporal scales. For the site selection, data sets were only included if they covered the whole spatial extent of the municipality under study, and within datasets, only temporally overlapped collections. Based on municipalities' feedback, the most recent datasets available were included (when available). Details of the open-source datasets used for either the site selection or the resulting statistical analysis are included below.

Census Tract Boundaries - The physical boundaries of the 2021 census tracts within each municipality are collected and maintained by Statistics Canada and formed the basis of the site selection (*66*). Each of the other variables was mapped to these boundaries.

Population Density - For each census tract, the population counts, and therefore density, are collected through the 2021 census and maintained by Statistics Canada (*67*). The population counts for each census tract can be acquired through a variety of scripting languages, including R and Python, by using the census tract IDs (from the above boundaries) to request the relevant population values. This was done through the GET function in R or the urllib package in python. Population density may influence the parking behavior of urban freight vehicles in that multiple deliveries may be made from one parking location in denser areas.

Land Use Categories - Metro Vancouver maintains spatial maps of land use zoning for 2016 (*53*). The land-use categories for the Metro Vancouver area were aggregated into more general categories, with some of the categories excluded based on their relevance to the project. Some of these categories include undeveloped land, unclassified transit, lakes, and cemeteries. These category mappings are seen in Table 4.

Table 4 Mapping of land use categories to aggregated values for analysis

Aggregated Category	Land Use Categories
Commercial	Hotels, Motels, Rooming Houses
	Industrial
	Industrial - Extractive
	Office
	Retail and Other Commercial
Residential	Residential - Institutional and Non-Market Housing
	Residential - Low-rise Apartment
	Residential - Mobile Homes
	Residential - Rural
	Residential - Single Detached with No Secondary Unit
	Residential - Mid/High-rise Apartment
	Residential - Townhouse
Mixed	Mixed Residential (Low-rise Apartment) Commercial
	Mixed Residential (Mid/High-Rise Apartment) Commercial
Other	Recreation, Open Space and Protected Natural Areas
	Civic and Other Institutional
	Exhibition, Religious and Other Assembly
	Health and Education

Truck Routes- A spatial map shows the routes available with and without restrictions for trucks of varying sizes and weights (*68*). Some of these routes include restrictions or advisories based on the weight or height of the truck. For traditional freight, this can dictate the locations for parking large trucks and can influence the selection of sites for the observational study.

Truck, Passenger, Bus Volumes- As part of the Regional Travel Model (RTM) for Metro Vancouver, traffic volumes of various designations are recorded (*69*). The Annual Average Daily Traffic (AADT) of single-occupancy passenger, light goods, heavy goods vehicles, and transit bus is recorded for road segments across the region for 2017.

Urban Center Boundaries- Metro Vancouver maintains a spatial map of areas designated as urban centers from 2018 (*70*). This designation signifies areas with diverse populations and land uses which are expected to grow in the near future.

Vehicle Collision Locations- The Insurance Corporation of British Columbia (ICBC) maintains a database of vehicle collisions for 2020 (*71*). For each collision, the location, date, time, and details of the crash are recorded. Because of the potential for collisions caused by freight vehicles looking for parking or illegally parking, this dataset is included in the site selection.

Parking Ticket Locations- The City of Vancouver collects and maintains an open-source dataset of parking tickets issued (*72*). The 2021-issued tickets were extracted and tickets irrelevant to parking bylaws (such as water conservation) were discarded. As urban freight vehicles may have to park illegally due to lack of available commercial, loading, or other relevant parking designations, this data may indicate areas of particular importance for further observational study. The parking ticket locations are recorded as street crossroads or midblock information and had to be geocoded. This process was done through the Open Street Map (OSM) API in R. However, because of the imprecise nature of using crossroad or midblock designators, the ticket locations have some positional errors.

Parking Meter Locations- The City of Vancouver and the City of Coquitlam collect and report the locations of parking meters (*73*, *74*). In conjunction with parking tickets, the availability of parking meters indicates the ability of drivers to find safe and legal parking while making deliveries.

Bus Stops Locations – Translink maintains a transit system map with geolocated bus stops (*75*). The competition for curb space between freight vehicles and buses renders this variable relevant to the study of freight parking behavior.

Frequent Transit Development Areas – Metro Vancouver maintains a spatial map of areas along frequent transit corridors that, similar to bus stop locations, are deemed important to capture with respect to freight behavior (*76*).

Bike Routes- An open-source spatial map of bike routes was recently developed by Winter et al. (*77*) and is accessible online[3]. *Non-conforming* cycling facilities were removed so that bike routes only comprise facilities meeting national guidelines. Considering the emergence of micromobility in the freight sector, this variable is relevant for studying curb use behavior for freight deliveries.

Parking lots- OSM has an amenity tag equal to parking which was used to tag parking lot facilities. The polygons with such a tag were extracted from OSM using the osmdata package in R (*78*).

Road Closures- Current Road closures and construction locations are maintained by the municipalities (*79*). The presence of a road closure can change the parking and travel behavior of urban freight. For roads that are closed, the parking behavior may decrease from normal activity, while roads around the closed segment may see an increase in parking and travel. This variable was not included in the site selection itself, but is recorded as a potential influence on parking behaviors for the sites chosen.

Traffic Camera Locations- The City of Vancouver and the City of Richmond collect and maintain an open-source feed of intersection traffic cameras (*80*, *81*). The presence of these cameras allows for analysis of parking behaviors outside of the observational collection times and the ability to validate the data collection. This variable was not included in the site selection itself, but if available for the chosen site, allows for more collection periods without requiring an observer to be present at the site.

Municipal Input

Representatives from each municipality in the study offered expert input into the selection of the observational study sites. The candidate sites were sent to each municipality along with the spatial map of finer resolution freight variables to help inform their feedback. During a presentation to municipal staff, collision/near-miss events involving a freight vehicle were identified as important and added to the observational data.

Observational Data

For each observational study site, data were collected on both the location as well as the parking behavior of vehicles that entered and exited the site during the study period. For each site location, the cross streets of the collection, date and time, nearby road closures, and the relational location of the observer were recorded. Road closure near or in the collection site indicates a potential deviation from normal parking behavior, either increased or decreased depending on the rerouting necessary from the closure. Finally, the relational location of the observer was recorded as mid-block or at the intersection to determine the sight catchment area from the observer's

[3] https://www.arcgis.com/home/item.html?id=c6d2917c4a7d4fb4a8e7a615369b68d5

location. In addition to parking events, curb regulatory signs were collected by annotating curb signs on maps printed from Field Papers[4] consistent with a similar approach employed in Portland[5]. To ensure a better representation of the locations of curb signs, we used the closest addresses and further georeferenced addresses using the geocode_OSM function in R (*82*). The Field Papers maps can be uploaded in any GIS software as the maps are georeferenced. Upon uploading annotated Field Paper maps in ArcGIS pro, curb signs were created as line features containing the regulation of the curb as an attribute. Curb inventory data along with other contextual urban freight variables were further used in the statistical analysis. For each parking event, the collected variables are summarized in Table 5.

Table 5 Variables from the observation data collection

Parking Behavior Collected Data	Possible Values
Parking Start Time	HH:mm
Parking End Time	HH:mm
Curb Location Zone	Integer values
Passenger or Freight Vehicle	Passenger / Freight
Vehicle Typology	For freight: e.g., box truck, cargo van, passenger vehicle For passenger: e.g., personal vehicle, taxi, ridehail
Company Name, if applicable	e.g., UPS, DoorDash
Vehicle make and model	e.g., Hyundai Elantra, Honda CRV
Commercial Label	Yes / No
Curb Type Where Parked	e.g., Bus Stop, Loading Zone, No Stopping, Meter
Conflict with Surroundings	Vehicle typology of other person involved in conflict
Illegal Type	e.g., No Stopping, Parking in Bus Zone
Loading Zone Available at Time of Parking	Yes / No
Vehicle Task	e.g., delivery pickup/dropoff, Service, passenger pickup/dropoff
Goods Type, if delivery	e.g., Food (meal), Groceries, Packages, Mail, Parcel, Flowers, Alcohol
Number of Goods, if delivery	Integer values
Number of Workers	Integer values
Engine Combustion Type	ICV, PHEV, BEV

Collection of the parking duration and location zone code offer information on the parking behavior. The passenger or freight vehicle designation, company name, vehicle classification, and commercial label indicate the stakeholders of urban freight in Metro Vancouver. As denoted in the

[4] http://fieldpapers.org/

[5] https://github.com/curblr/curblr-spec/tree/master/conversions/Portland

study from the Urban Freight Lab (*65*), the freight and passenger vehicles were broken down by a vehicle typology. This typology is used in our study to categorize both passenger and freight parked vehicles. The curb type where the vehicle parked, illegal behavior type, loading zone availability, and the commercial vehicle task detailed the activities behind urban freight parking behavior. Finally, the number of people performing the freight task and the presence of a receptionist at the delivery location showed the scaling of urban freight by the number of deliverers and how far into the building they must travel to complete the delivery, as detailed by Kim et al. (*20*).

Site Selection

To inform our site selection, various data sources described in the Data section were utilized to construct a single composite measure. As the census tract was selected as the spatial study unit, the urban freight variables were scaled with respect to census tracts area. Scaling renders the comparison between variables feasible as the distributions become independent of the census tract size, however at the cost of losing finer-resolution information due to spatial aggregation. To address this shortcoming, we returned to finer-resolution variables when zooming in census tracts to choose data collection points. Table 6 describes the variables used in developing the composite measure along with their type.

Table 6 Variables employed to construct the composite measure

Urban Freight Variable	Type	Definition
Population density	Numerical	Population per land area of a given census tract
Dominant Land-use	Categorical	Land-use category with maximum coverage in a given census tract (values: residential, commercial, mixed, other)
Truck Route Density	Numerical	Length of truck routes within a given census tract per land area
Urban Center	Binary	If a given census tract contains an urban center (values: yes, no)
Parking Meter Density	Numerical	Number of metered parking stations within a given census tract per land area
Collision Density	Numerical	Sum of collisions within a given census tract per land area
Parking Tickets Density	Numerical	Sum of tickets issued within a given census tract per land area
Passenger Volume Density	Numerical	Total AADT volumes of single-occupancy passenger vehicles within a given census tract per land area
Freight Volume Density	Numerical	Total AADT volumes of heavy and light goods vehicles within a given census tract per land area
Bus Volume Density	Numerical	Total AADT volumes of bus services within a given census tract per land area
Bus Stops Density	Numerical	Total number of bus stops within a given census tract per land area
Frequent Transit Development Area	Binary	If a given census tract contains a frequent transit development area (values: yes, no)
Bike Route Density	Numerical	Length of cycling facilities within a given census tract per land area
Parking Proportion	Numerical	Total areas of parking lots within a given census tract per land area

Composite Measure

The composite measure aims to maximize the variation observed in the urban freight variables (Table 6) and convey their information by one single measure for each census tract. Due to the nature of variables (including numerical (e.g., freight volume density) and categorical (e.g., dominant land-use), the appropriate method to construct a composite measure was factor analysis for mixed data (FAMD). FAMD is a generalization of principal component analysis (PCA) method. PCA is used to reduce the dimensionality and address multicollinearity by finding the best linear expression of the numerical variables (*83*); FAMD extends PCA to categorical variables by encoding them into numerical variables while preserving the same weight for both numerical and categorical variables in finding the principal components (for more information, see (*84*)). The composite measure was yielded by the FAMD function in FactoMiner package in R (*84*). Percentage variance in data captured by the composite measure and each variable's contribution to the composite measure are outputs of interest. Only variables with significant association (p-value<0.05) with the composite measure are maintained.

Neighborhood Selection

The distribution of the composite measure across census tracts within a city can be communicated by using Jenks Natural Breaks. Jenks Natural Breaks splits the composite measure distribution into five contiguous classes so that values within each class have the least squared deviation. Thus the boundaries of the classes are located where there are relatively big differences in composite measure values (for more information, see univariate classification schemes in De Smith et al. (*85*). ArcGIS was used to generate Jenks Natural Breaks for the composite measure. From the top three classes with the highest composite measure value, the census tract with the maximum value within the class was selected as a potential site for data collection. Finer-resolution variables (i.e., restricted/unrestricted truck routes, traffic volumes, collisions, parking tickets, and parking meter stations) were plotted in each candidate census tract to inform the transition from the census tract to a data collection point within the census tract (see Figure 5 for illustration). The potential data collection point is visually selected along streets with higher collision counts, higher counts of parking tickets issued, higher traffic volumes, and along designated truck routes. The data collection point was further optimized by consulting with partner cities to account for locations that the available freight variables cannot capture (e.g., a significant freight generator building). We expanded our candidate sites to go beyond points within the three candidate census tracts by including a site that partner cities deem to be important but missing in the candidates or a neighborhood with an event that disrupts the normal traffic (such as a road closure), should either of these cases occur.

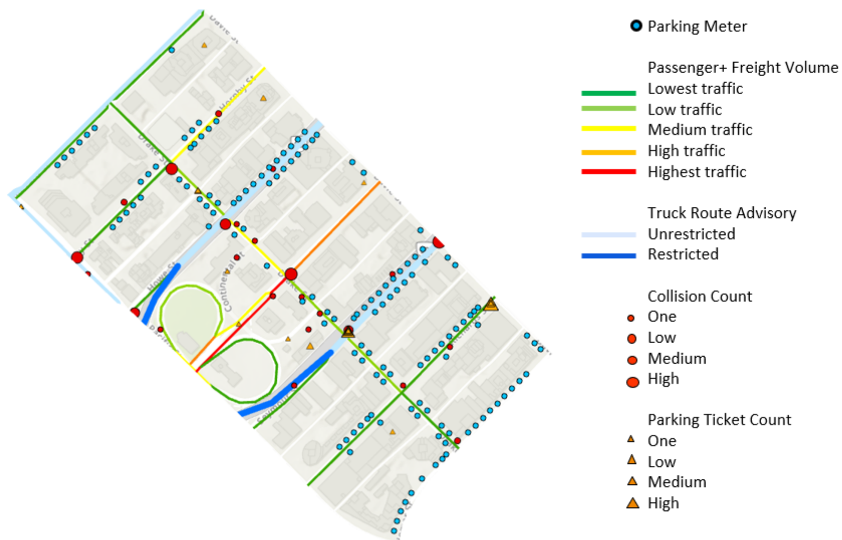
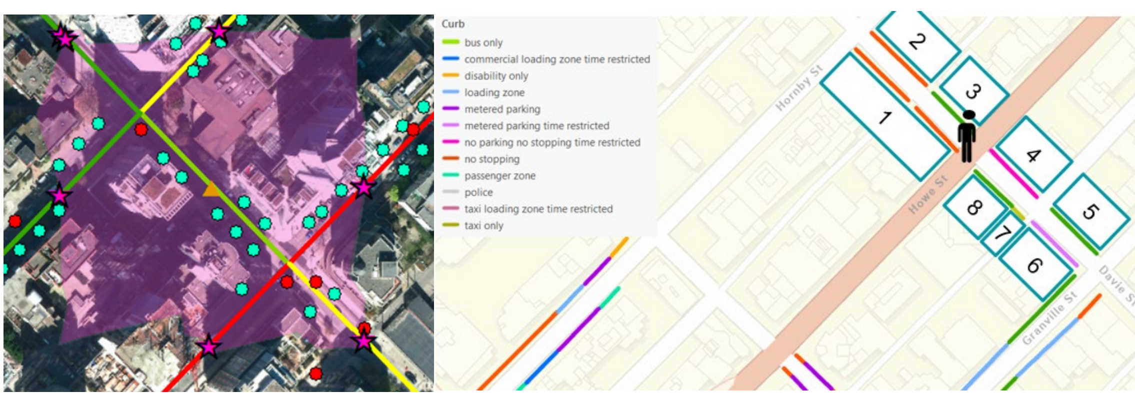


Figure 5 Candidate census tract with finer resolution variables (census tract with mixed land-use).

Informed by literature (*25*, *27*, *36*, *65*), a 100-meter catchment area was generated around data collection points. The catchment area was assumed to capture the activity of drivers with destinations within the catchment area (even if parked vehicles are not in eyesight). To develop a catchment area, service area analysis in ArcGIS software was employed. The catchment area is a polygon obtained by walking 100 meters in all directions on the local streets network (obtained from Open Street Map[6]) (see Figure 6 a). The catchment area determines the extent of each data collection effort. The catchment area is further divided into zones to capture the location of parked vehicles along the street without the need to measure them precisely. The zoning is based on the curb regulation along the street where boundaries indicate changes in the curb regulation (see Figure 6 b).



a b

Figure 6 a. Catchment area. b. Zoning along a street informed by curb regulation.

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[6] https://www.openstreetmap.org/#map=2/71.3/-96.8

Study Design

Data Collection Plan

First, a pilot collection was undertaken with two collectors to test collection strategies and methodology. In this collection, paper-based and app-based parking activity collection methods were tested for ease of use and accuracy. From the pilot collection, it was determined that both collection methods were accessible and accurate, and it was a personal preference for each collector. Additionally, it was determined that two collectors were needed for each intersection to best collect all parking activity along the four streets leading away from it. Finally, due to time constraints of the collectors, only two collections per collection day would be possible and early morning collection was ruled out due to lack of on-street freight activity. This information was used to refine the collection methodology and carried through the subsequent collections.

For the full collections at each selected site, two observers were present to manually conduct a street sign inventory and record parking activity. To capture both traditional and invisible freight, each site included collections from 11:00 am-1:00 pm and 4:00 pm-6:00 pm on a weekday and a weekend for a total of four collections per site. This temporal profile was informed by the literature review (see Table 2). The inclusion of two observers allowed for the collection of parking data along two roads around an intersection. Five of the nine sites included volunteer collectors from the municipal offices. These volunteers offered help with the data collection ranging from one study period to all four study periods for a given site (two days, two collection times). At the collection sites, locational zoning maps were created to help geospatially locate the parking events without actual GPS locators as well as keep track of the curb type in the whole catchment. Each collector was given a zoning map denoting the catchment area of collection. An example of one of these zoning maps is shown in Figure 7.

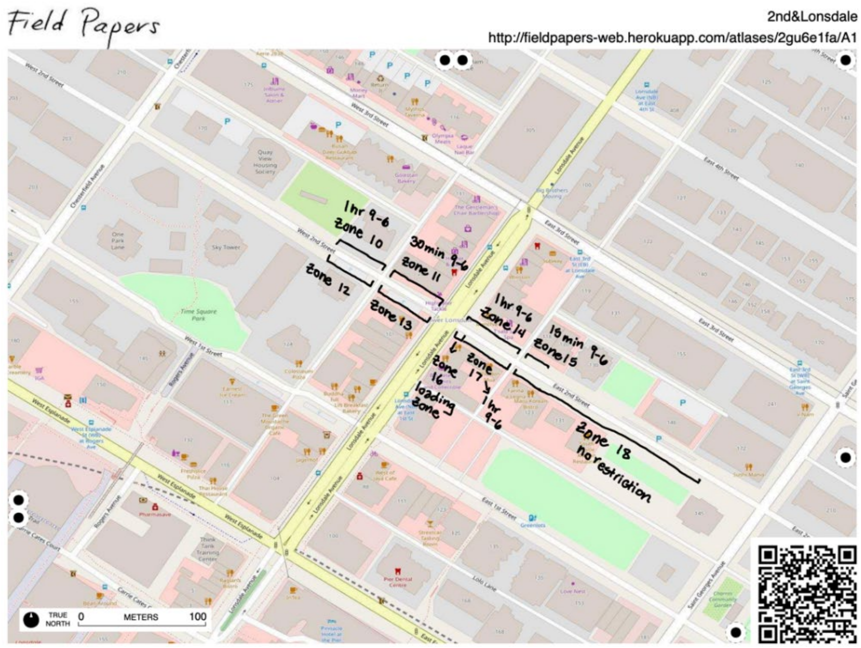

Figure 7 Locational zoning map for one collector at one of the collection sites.

Statistical Methods

Parking Duration Analysis

To further investigate the factors affecting curb usage by freight, a parking duration model was developed with a set of exogenous variables. Variables were either collected in the data collection or elicited from urban freight variables for each site. To account for contextual urban freight variables, a buffer of 100 meters was constructed around each collector standing position in line with Figure 6a, however, to control for different shapes of networks (think a sparse suburban street network compared to a dense grid network in downtown), we opted to look into finer-resolution urban freight variables (explained in the Data section) and curb typology (generated from the curb inventory) in a 100-meter buffer rather than a catchment area, thus all sites have the same spatial unit. All contextual variables were extracted from the 100-meter buffer for each site and added to data collection variables. Note that data collection variables varied between each parking event observation (variation within each site) while site variables were the same for each site (variation between sites). These variables allow us to map the parking duration not only to specific parking events but, to a larger extent, to the characteristics of a site and city. Table 7 summarizes the variables along with their definition.

Table 7 Variables for parking duration analysis.

Variable	Definition
	Data collection variables
Curb type where parking takes place	The type of curb (collapsed into **paid parking** (consists of meter or pay parking), **loading zone** (consists of commercial loading/parking), **passenger zone** (consists of passenger loading zone, tour bus zone, and taxi), **no curb** (consists of no stop, no parking, or bus zone regulations), **alley/lot** (consists of commercial lane, alleys, and parking lots), **other** (consists of carshare only, disability parking, authorized parking, sidewalk, travel lane, and driveway), **time parking** (any free parking with/without a time constraint such as 15 min parking or paid parking on Mon-Sat where the data collection was on Sunday))
Freight Typology	**Micro mobility** (consists of (e-)bike, (e-) scooter, cargo bike, and motorcycle), **Heavy duty** (consists of box truck, garbage truck, construction, and truck with trailer), **Light duty** (consists of Service vehicle, van, cargo van), **passenger vehicle** (consists of passenger vehicle[1])
Loading zone availability	If a commercial loading zone was available during the parking event
Visible freight	if the vehicle has a visible commercial label on the vehicle
Task	If the operator is performing a delivery pick-up or drop-off, or a service. If the task could not be identified, the observation is assigned other as task.
Good type	Food, package/parcel/mail, service, other
Number of goods	Number of goods being delivered
Number of workers	Number of workers (including any other person except driver in the car)
Illegal parking behavior	If an illegal behavior is taking place while parking
Weekday	If the observation was collected on a weekday as opposed to weekend
TimePeriod	If the observation was collected in 11-1 period as opposed to 4-6
	Site variables
Collision	Number of collisions collected in a 100-meter buffer around the collector standing position
Dominant land use	The most dominant land-use category in a 100-meter buffer around the collector standing position (residential, mixed, commercial, and other)
Truck routes	Length of truck routes (meter) in a 100-meter buffer around the collector standing position
Parking lots	Area of parking lots (squared meters) in a 100-meter buffer around the collector standing position
Passenger volume	AADT single occupancy passenger vehicles in a 100-meter buffer around the collector standing position
Freight volume	AADT light and heavy goods vehicles in a 100-meter buffer around the collector standing position
Bus volume	AADT bus volume in a 100-meter buffer around the collector standing position
Bus stop	Number of bus stops in a 100-meter buffer around the collector standing position

Bike routes	Length of bike routes (meter) in a 100-meter buffer around the collector standing position
Dominant curb type[2]	What curb typology has the highest length within the curb inventory for the site of interest.
Dominant available curb type	What *legal* curb typology (available to freight vehicles) has the highest length within the curb inventory
Curb diversity	Number of different legal curbs (available to freight vehicles) within the curb inventory of the site of interest

[1] during data collection, an invisible freight operator was observed to use a carsharing vehicle which is grouped into passenger vehicle
[2] for curb variables, if a curb has multiple regulations during different times and days, the one with the most overlap with collection times and days is considered.

The freight parking duration model was specified using Cox proportional-hazards model (consistent with (*26*)). Cox proportional-hazards is a common type of survival model in which the time elapsed before a hazard (here, the vehicle leaves its parking spot) terminates an event (here, parking) is predicted (*25*, *26*). Survival models allow for *censoring* (*86*). Censored observations are freight vehicles that did not leave the parking spot prior to the completion of data collection. Survival function S(t) defines the probability of parking duration T of a freight vehicle exceeds t minutes (*26*):

$$S(t) = P(T > t)$$

And hazard function h(t) defines the conditional probability that the freight variable leaves the parking spot at a time between t and t+dt (*26*):

$$h(t) = \frac{\frac{d}{dt}(1 - S(t))}{S(t)}$$

Cox proportional-hazard model specifies the hazard function as (*26*):

$$h(t) = h_0(t)\exp(\beta_1 x_1 + \cdots + \beta_n x_n)$$

where h_0 denotes a baseline hazard and x are explanatory variables with their corresponding coefficients β. A hazard ratio can be then estimated showing the relative effect of an explanatory variable on the parking duration. Hazard ratios greater than 1 correspond to variables that are associated with shorter parking durations. The modeling is implemented in R by coxph function in survival package(*87*).

To investigate if the duration times vary significantly across sites (and cities), a mixed effects cox proportional-hazards model (also known as the frailty model) was developed with explanatory variables being assigned a fixed effect and each site (or city) being assigned a random intercept.

We further tested random intercepts for each site within a city to see if there were any systematic changes in sites due to the parent city. The inclusion of random intercepts per site (or city) accounts for within-site homogeneity in the duration (*86*). The hazard function with random intercepts can be expressed by:

$$h(t) = h_0(t)\exp(\beta_1 x_1 + \cdots + \beta_n x_n + \alpha_j)$$

where α_j denotes the random intercept associated with j-th site. The random intercept modifies the linear model accounting for any site-specific characteristics that may increase or decrease parking duration. The models were implemented in R by coxme function in coxme package (*88*). All models were developed using backward selection by including all variables and iteratively removing the least contributing variables (with a confidence level of 95%). To test if the mixed effect models offer a better explanation, we compared them to models without random intercepts using an ANOVA test.

Emission Impacts of Invisible Freight

The environmental impact of urban freight is well documented, however, less is known about the environmental impact of invisible freight. To have a better understanding of the emission impacts of invisible freight, we need to know what vehicles are used and freight operator travel behavior. In our research, we only collected data on vehicles and not on travel behavior, thus we could only argue about the efficiency of invisible freight vehicles compared to personal passenger vehicles. During the data collection, license plate information was collected. The API of https://licenseplatedata.com/ was purchased and license plates were passed to the website which returns the make, model, year, and fuel type among other characteristics of the vehicle. The year, make, and model information was used to extract average emission factors per km traveled distance (available at (*89*)). When the license plates were not found, we used the recorded make and model from the data collection, however, the model-year could not be recorded in the data collection as such information was not visible. To estimate the age of vehicles, we employed 2021 passenger vehicle population data (available at (*90*)) for cities (and UBC) that we collected data. We estimated weights for each year based on the vehicle population manufactured in that year divided by the total vehicle population. Note that fuel consumption rates were only available for the year 1995 onward, thus we discarded any year before that. This assumption is limiting but only 7% of cars within data collection cities were manufactured before 1995 (*90*). These weights were used to estimate a weighted average of emission factors for observations with a missing model-year. This method represents the distribution of vehicle age across cities realistically. The distribution of emission factors for freight operated out of passenger vehicles was compared to personal passenger vehicles collected during the data collection.

Results

Selected Sites

Composite measures were developed for cities based on the available data. Across all cities, the composite measure was found to be positively related to the underlying variables. Interestingly, however, the magnitude of associations varied across cities (see Appendix F). Census tracts in the top three Jenks Natural Breaks were selected as potential sites. The finer-resolution data (such as bus stops, freight volumes, etc.) were plotted on the candidate census tracts along with a candidate position within each census tract. The distribution of contextual variables employed in composite measure, composite measure distribution, and candidate sites were sent to each municipality. Based on the municipal staff feedback, the candidate sites were finalized. Figure 8 demonstrates a candidate census tract for the city of Vancouver.

Figure 8 Candidate data collection site (displayed by red X) for the City of Vancouver.

Overall, nine locations were chosen across five municipalities in Metro Vancouver. Each of these sites included collections from 11:00 am-1:00 pm and 4:00 pm-6:00 pm on a weekday and a weekend for a total of four parking activity collections. The municipalities included City of Vancouver, City of North Vancouver, City of Richmond, City of Coquitlam, and Electoral Area A University of British Columbia. The collection schedule is detailed in Table 8.

Table 8 Collection schedule for the nine selected sites across Metro Vancouver.

Municipality	Site Intersection	Collection Dates
City of Vancouver	Cambie St & W Cordova St	July 8, 2022 (Fri) July 17, 2022 (Sun)

	Ash St & 8th Ave	July 5, 2022 (Tue)
		July 10, 2022 (Sun)
City of North Vancouver	Lonsdale Ave & 2nd St	July 7, 2022 (Thu)
		July 9, 2022 (Sat)
	Lonsdale Ave & 14th St	June 30, 2022 (Thu)
		July 9 2022 (Sat)
City of Coquitlam	Glen St and The High St	July 13, 2022 (Wed)
		August 7, 2022 (Sun)
	Glen St and Pinetree Way	July 21, 2022 (Thu)
		July 23, 2022 (Sat)
City of Richmond	Saba Rd & Buswell St	July 19, 2022 (Tue)
		August 6, 2022 (Sat)
	Cambie Rd & Hazelbridge Way	July 22, 2022 (Fri)
		July 24, 2022 (Sun)
University of British Columbia	Wesbrook Mall & Birney Ave	June 24, 2022 (Fri)
		July 16, 2022 (Sat)

At each site, in addition to recording parking events, a curb inventory was taken for the catchment area. The method used by researchers is shown to generate approximately reliable georeferenced curb inventories considering no measurement was taken on the site. Figure 9 displays the proximity of the annotated meter parking locations along Ash street in the City of Vancouver, shown as black dots, to the georeferenced meter parking locations accessible online via the City's Open Data Catalogue, shown as red circles (*73*). Detailed maps of the curb inventories for each site can be found in Appendix G.

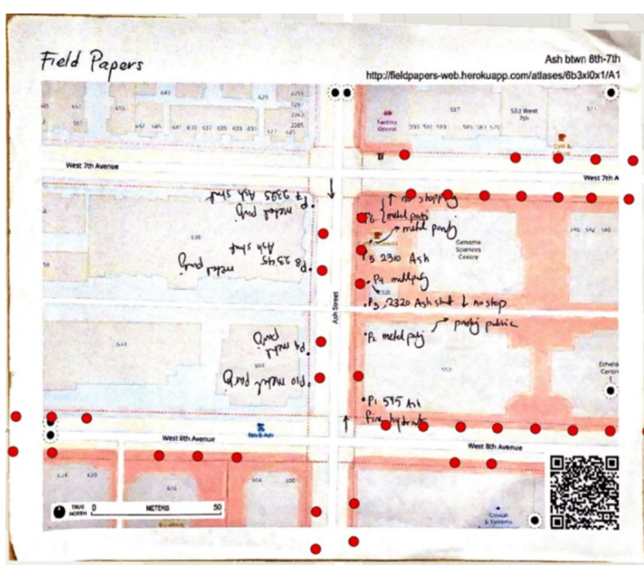

Figure 9 The annotated locations of meter parking and the geocoded locations provided by the city.

Descriptive Statistics of Data Collected

To begin, for each site, the number of parking events was broken down into four tasks: passenger parking, ridehail parking, traditional freight parking, and invisible freight parking as shown in Figure 10.

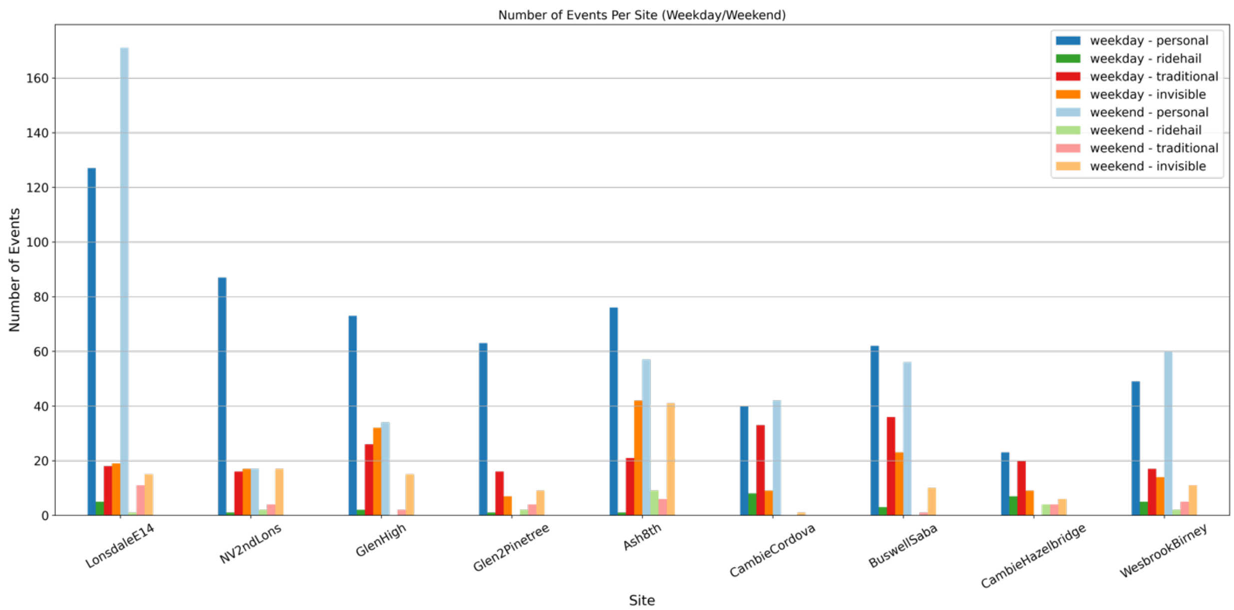

Figure 10 The number of parking events per site, by weekday/weekend collection and activity type.

Key Takeaway 1: Lower parking activity was observed on weekends.

At every site, the weekend collections recorded lower parking activity across almost all categories. Across all sites, there was as 15% decrease in passenger parking activity, 27% decrease in invisible freight activity, 76% decrease in traditional freight activity, but a 36% increase in ridehailing activity.

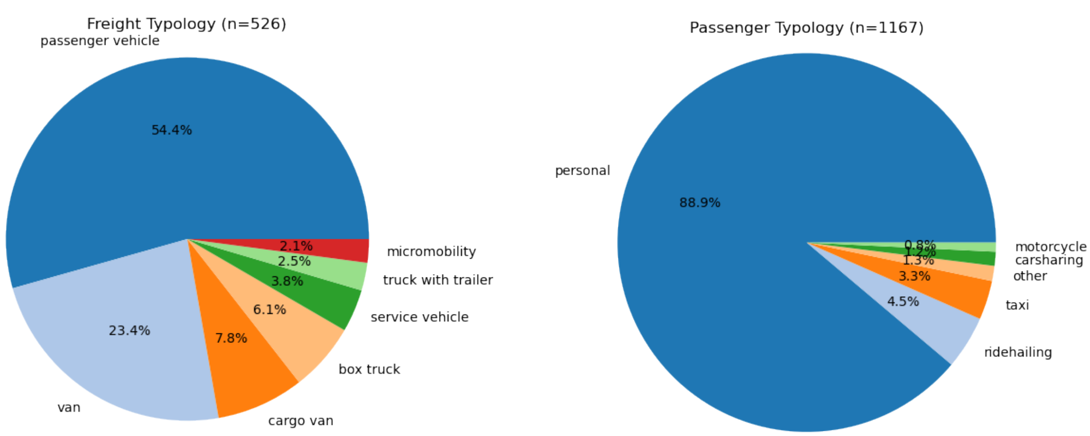

Figure 11 Freight and Passenger Typologies.

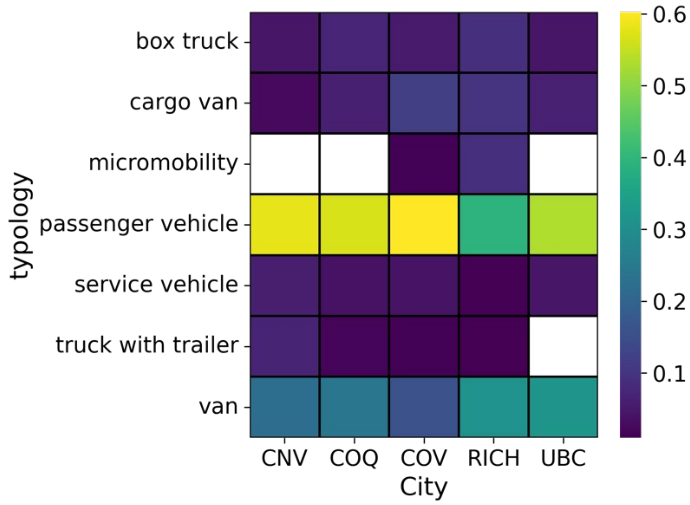

Figure 12 Percentage of freight vehicle modes observed by the city.

Figure 12 shows the distribution of freight modes observed by the municipality in which the sites sat. Across the region, passenger vehicles were overrepresented with the percentage of vehicles observed between 39% (Richmond) and 60% (Vancouver). Overall, the trends are consistent across the municipalities, with only slight differences in percentages for each mode.

Key Takeaway 2: Invisible freight had a higher share of on-street freight parking activity than traditional freight.

Across all collections, passenger vehicles accounted for the majority of on-street freight parking activity (54.4%) (Figure 11). Here, we note that while every effort was made to accurately record the parking events, invisible freight from passenger vehicles is by nature difficult to identify. Some of the passenger vehicle freight events may have been for personal purposes. Traditional freight, represented by all other typologies except micromobility, made up 45.6% of all recorded on-street freight activity. This study did not focus on alley or off-street loading bay locations, and this may account for the low amount of larger vehicle presence, such as trucks with trailers, box trucks, and cargo vans. Unsurprisingly, passenger vehicles for personal use dominated non-freight activity. Ridehailing and taxi services together made up only 7.8% of non-freight recorded events.

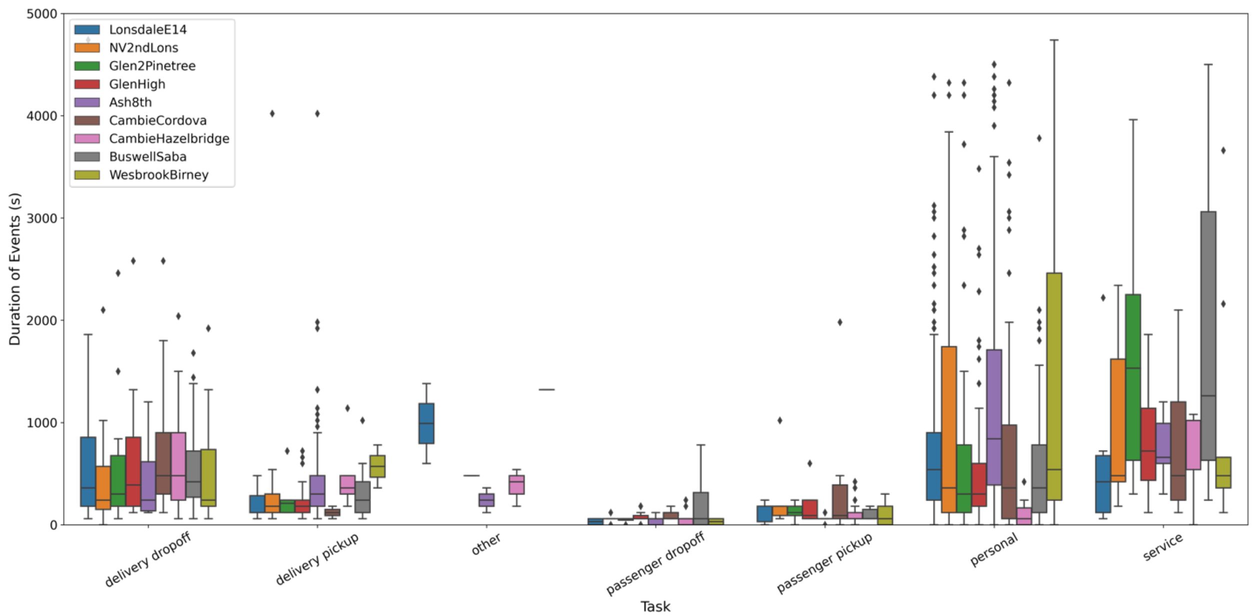

Figure 13 Duration (in seconds) of parking events by the task performed at each site.

Key Takeaway 3: Smaller freight vehicles had shorter parking durations, with delivery drop-off activities having higher durations than pick-up.

For each site, in addition to the parking data recorded as shown in Table 6, the duration of the parking event is recorded as the number of seconds between the end time and the start time. Figure 13 illustrates that by task, duration times were consistent across the nine sites. For delivery tasks, drop-off events lasted longer than pick-up events. Consistent with literature findings, smaller vehicles had shorter parking durations than larger vehicles (19, 25). Micromobility and passenger vehicles had an average duration of 5 minutes, while traditional freight vehicles such as vans, cargo vans, box trucks, and large trucks had average durations between 11 and 15 minutes. For passenger drop-off and pick-up events, dominated by ridehailing and taxi vehicles, the parking durations were short and not significantly different. Parking for personal use (e.g., dropping off family, picking up food or groceries for self) and service (e.g., construction, building service) represented the longest durations as well as the largest deviations between sites. This may be explained by the curb typology of the area as well as potential differences in the collection habits of volunteers across the sites.

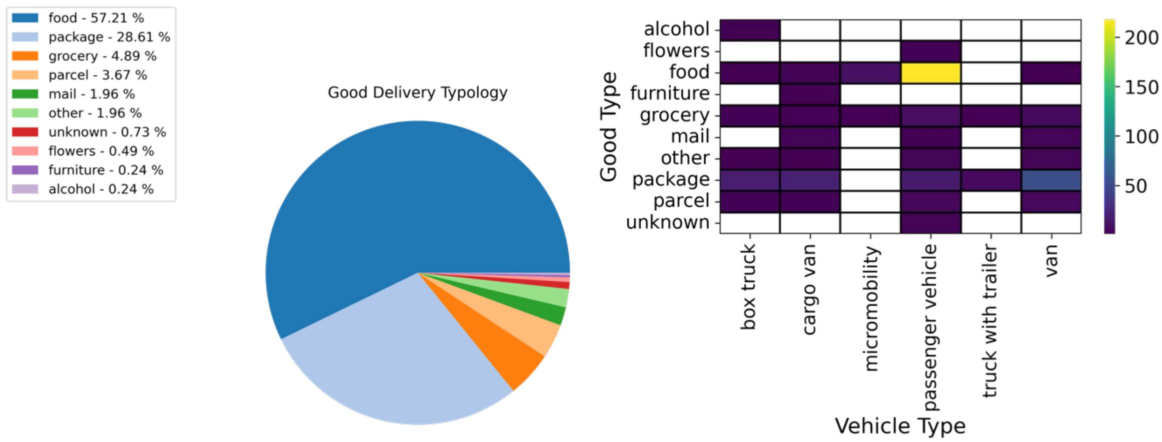

Figure 14 a. Typology of goods delivery; b. Typology of goods delivered by vehicle type.

Key Takeaway 4: Restaurant food delivery represented the highest share of goods delivered.

In congruence with the dominance of invisible freight in on-street parking events shown in Figure 10 as well as the dominance of personal vehicles in freight vehicle typology shown in Figure 11, Figure 14 details that restaurant food delivery events represented the greatest share of deliveries across the municipalities included in the data collection, most of those deliveries occurring by passenger vehicles.

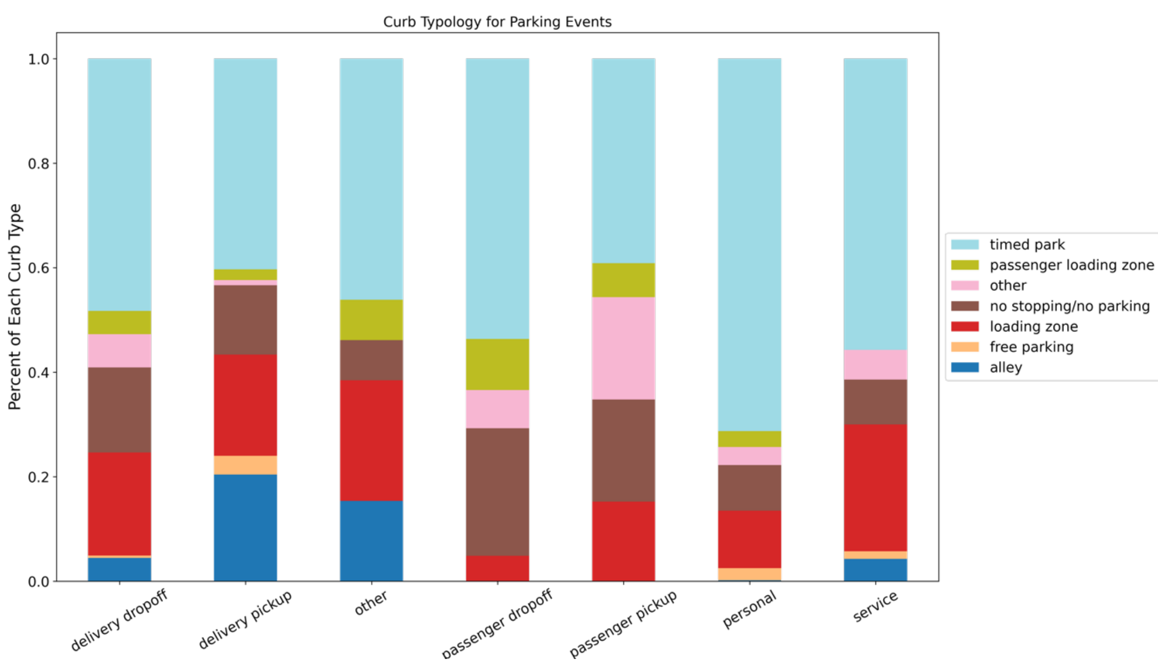

Figure 15 Percentage of curb typology by parking task.

Key Takeaway 5: All on-street parking activities included events in no stopping/no parking.

While not all sites had the same curb layouts, we can see preferences for curb types for each parking task (Figure 15). Metered parking represented the greatest percentage of curb choice for most tasks, excluding unspecified drop-off or pick-up delivery (loading zone parking).

Parking events from every task occurred in no stopping/no parking zones and loading zones. Some of these task-curb combinations represent illegal parking activity, which is detailed further in Figure 16.

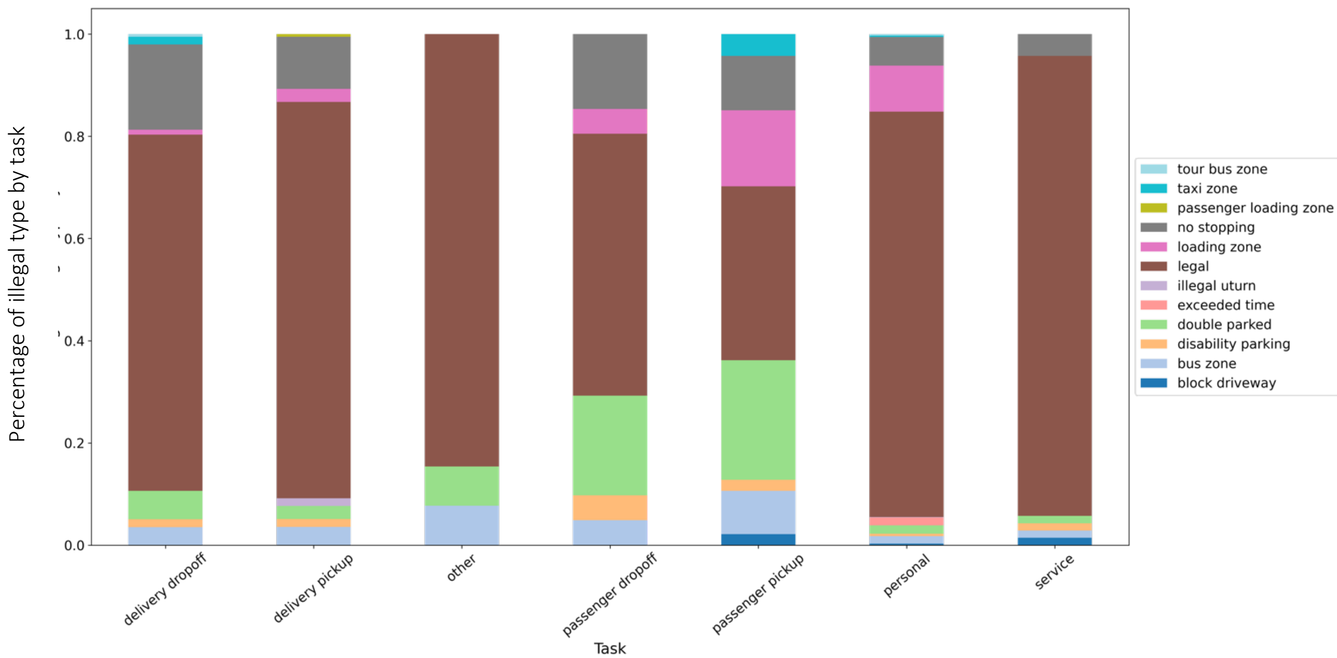

Figure 16 Percentage of illegal activity by task.

Key Takeaway 6: All on-street parking activities included illegal parking, with passenger pick-up and drop-off having the highest proportion of illegal parking.

While most of the parking observed was legal parking (76% of all parking events), the most common illegal parking activities across all tasks were illegal parking in no-stopping zones (7.7%), parking in a loading zone (6.7%), and double parking in the street (3.4%). Although, we note that we did not include payment at metered parking because it was difficult to determine if the driver paid the meter by phone from inside the car or destination. If we were able to accurately assess this, the proportion of legal parking might be lower than reported. By task, service tasks and personal parking activity were predominantly legal, but any illegal activity was mostly in no-stopping and loading zones, respectively. Passenger pick-up and passenger drop-off had the highest rates of illegal activity for all parking events at 66% and 49%, respectively. The highest proportion of passenger pick-up and drop-off illegal activity was double parking (23% and 19.5%, respectively), while the highest proportion for delivery drop-off and pick-up was in no-stopping zones (16.7% and 10%, respectively). We observed that 26% of invisible freight delivery occurred in illegal parking zones, while traditional freight parking activity was 32% illegal for cargo vans, 23% for vans, and 18.7% for box trucks. Service vehicles only parked illegally 5% of the time.

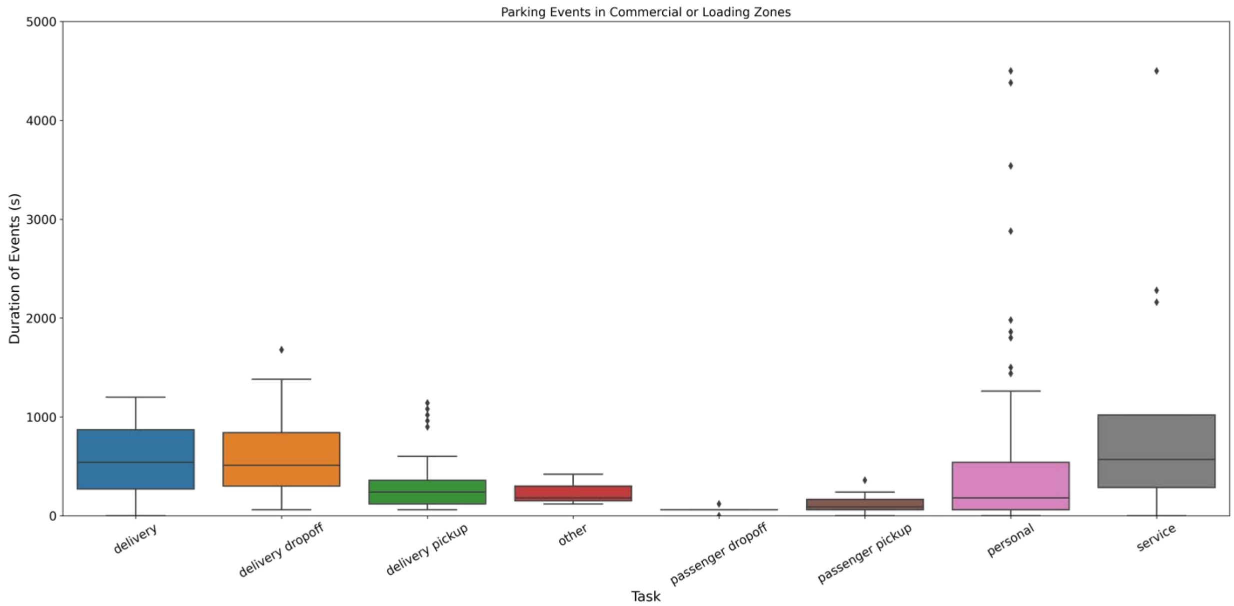

Figure 17 Duration of parking events specifically in commercial or loading zones by task.

Key Takeaway 7: Parking in on-street loading zones was primarily less than 25 minutes for all activities.

For vehicles parked in commercial or loading zones, the duration of that parking event can be seen in Figure 17 denoted by the task. When private vehicles parked for personal use were illegally parked in loading zones, 50% of the events were between 2.7 minutes and 21 minutes long. For delivery drop-off, 50% of events were between 8 minutes and 23 minutes, while 50% of delivery pick-ups were between 3.8 minutes and 9.7 minutes.

To capture the service providers involved in the urban and invisible freight activity in Metro Vancouver, when possible, company names were recorded. The frequency of these companies was aggregated across all nine sites and represented in Figure 18 as a word cloud.

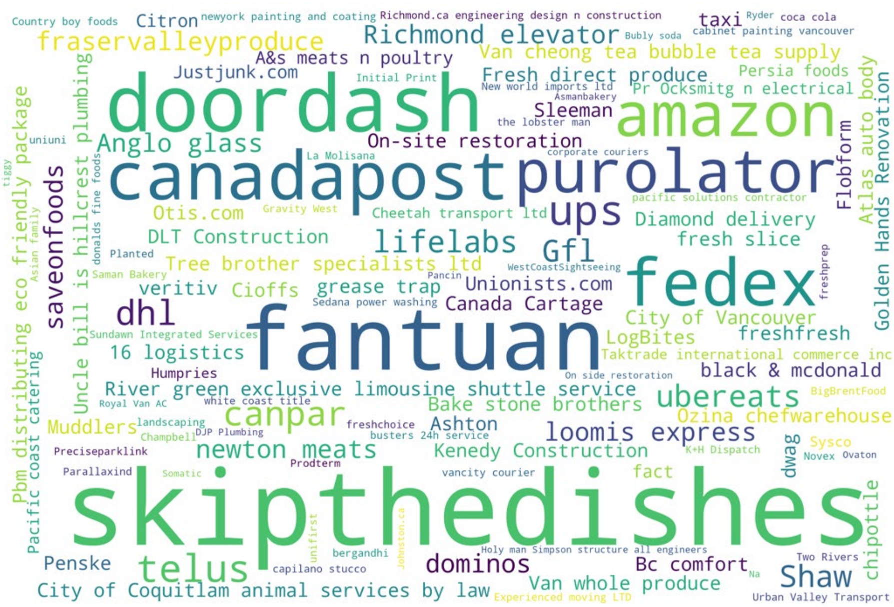

Figure 18 Aggregation of company names collected from all nine sites represented as a word cloud.

Key Takeaway 8: Food delivery companies were overrepresented in freight companies observed.

Across all sites, food delivery services like Skip the Dishes, Fantuan, and Doordash overshadow freight activity from other companies (Figure 18) . This is consistent with abovementioned findings on the rate of invisible freight, and the prevalence of food delivery with passenger vehicles. Package and mail delivery services like Canada Post, FedEx, and Purolator fill a second-tier frequency of companies recorded.

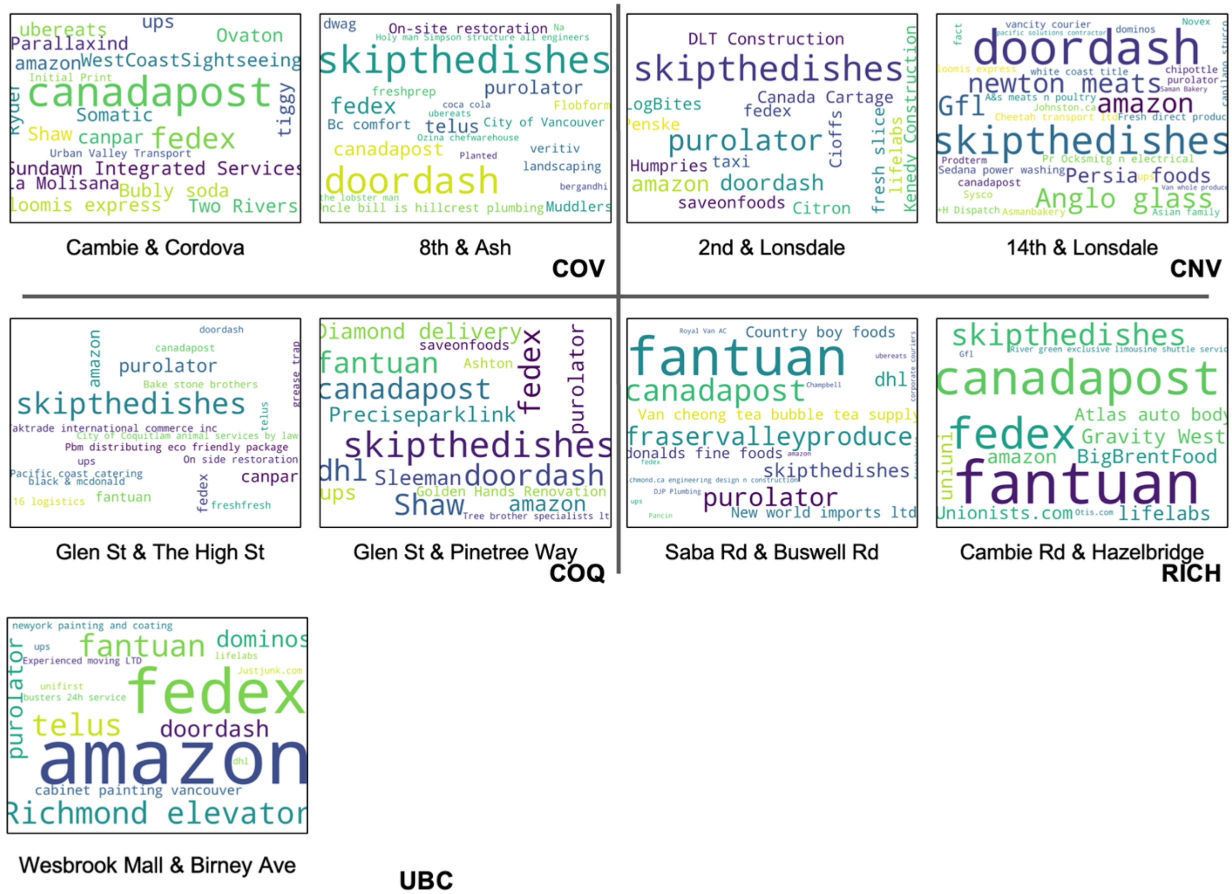

Figure 19 Company word clouds by the site.

The company recordings can be visualized per site to make any connections to the underlying urban landscape as seen in Figure 19. While food delivery continues to be overrepresented in most sites, a few including Cambie St & Cordova St in Vancouver and Wesbrook Mall & Birney Ave at UBC, saw higher percentages of general courier companies. This is likely due to the surrounding businesses of the collection areas, including office businesses.

Statistical Analysis

Data Cleaning

515 freight activity observations were collected with 49 not leaving the parking spot prior to the end of the 2-hour data collection period (i.e., censored observations). The following steps were taken to clean and infer missing values:

- If freight typology was missing and the picture of the vehicle was available, the typology was inferred (N=3).
- For 37 observations the availability of the loading zone was not recorded. If there was no loading zone in the curb inventory of the site, the missing availability was assigned as *no*

(N=17). For the remaining missing availability, the value was replaced with *available* if the majority of observations in the same site and same time period had a loading zone available to them.

- If the visibility of the commercial label (i.e., company name) was not recorded but the company name was recorded, the missing value was populated based on the company name (N=21). For instance, if the company name was recorded as Amazon, the commercial label was assigned as visible. For the rest of the missing visibility, invisible freight is assumed (N=14).
- If the task was not recorded but the delivery good had a value, a task of delivery was assigned (N=6). For the rest of the missing tasks (N=11), *other* was assigned. For observations where drop-off/pick-up was not distinguished (N=17), a value was assigned based on the majority of delivery activities that had been taking place at the same location. Two observations with the task of passenger drop-off were discarded.
- Missing good types were grouped under unknown and added to *other* category (N=42). Furthermore, flowers (N=2), alcohol (N=1), furniture (N=1), and grocery (N=20) were included in *other* category due to a relatively low number of observations.
- Unfortunately, many observations (~40%) had the number of goods missing which might be due to delivery packages that food delivery operators use and it renders observation of the number of goods infeasible. Therefore, this variable was excluded from the model hoping the effect is being captured by other variables (such as the number of workers).

Parking Duration Analysis

A model was developed using all site and data collection variables. In the final model (see Table 9) only significant variables at p-value<0.05 are maintained. Interestingly, none of the site variables appear to significantly influence parking duration. Recall that sites were selected from census tracts with high composite measure values which in turn is positively related to site variables. Therefore, we expect the data collection sites to be marginally different from each other in terms of site variables. This finding was further confirmed by the mixed effect model results. We investigated the random intercepts for sites, cities, and sites nested in cities. The standard deviation across random intercepts was found to be 0.12 minutes across 18 sites when random intercepts were assigned to sites, 0.14 minutes across 5 cities when random intercepts were assigned to cities, and 0.01 minutes across sites nested in cities, and 0.14 minutes across their respective cities when random intercepts were assigned to sites nested within their cities. Universally, low standard deviations indicate that sites (and cities) were not significantly different from each other in terms of parking duration which collaborate the insignificant contribution of site variables to the model. For all three models, ANOVA test showed that the simple model (containing only fixed effects) was not significantly different than the three models with random intercepts in terms of goodness of fit. Therefore, we selected the most parsimonious model (fixed effect model), shown in Table 9.

Table 9 Parking Duration Model

Variable	Hazard Ratio	Standard Error	p-value
Curb type (Reference level= alley/lot)			
Curb type=loading zone	2.03	0.17	<0.01
Curb type=no curb	3.36	0.19	<0.01
Curb type=other	2.10	0.27	0.01
Curb type=paid parking	2.09	0.17	<0.01
Curb type=passenger zone	1.70	0.31	0.09
Curb type=time parking	1.68	0.18	0.01
Good type (Reference level= food)			
Good type=other	0.30	0.15	<0.01
Good type= package/parcel/mail	0.34	0.12	<0.01
Good type=service	0.22	0.16	<0.01
Log likelihood= -2425.67 number of observations=513 number of events (leaving parking)=464			

The results show that all curb types compared to parking lots/alleys have shorter parking duration, however, the time duration between passenger zones and parking lots/alleys were not significantly different perhaps due to a low number of freight vehicles parked in passenger zones (only 3% of total freight vehicles). The probability of a freight vehicle leaving a no parking curb space (i.e., illegal spaces) at any given time was 3.36 times higher than freight vehicles parked in alleys/lots, keeping every other variable constant. The model suggests the parking duration was the shortest in illegal spaces which is consistent with the literature (*19*, *25*). The closest parking duration to parking lots/alleys belonged to time constraint parking spaces (the probability of a freight vehicle departing from a timed parking space was 68% higher than parking lots/alleys). The endogeneity of parking choice in explaining parking behavior should be further tested.

Key Takeaway 9: Food deliveries took less time than package and mail deliveries.

Consistent with the descriptive statistics, food deliveries occupied the curb for a shorter time. This finding implies the probability of a service vehicle departing a curb space was 78% lower than food delivery vehicles. Delivery of package/parcel/mail tended to took a more time than food deliveries but significantly less time than service vehicles with a probability of a freight vehicle delivering package/parcel/mail leaving the curb being 66% less than food delivery vehicles, everything else constant.

Emission Impacts of Invisible Freight

76% of the entire collected data were from private and freight passenger vehicles (from this share, 22% were passenger vehicles undertaking freight activity and the rest were private passenger vehicles being used for non-commercial personal purposes). For 4% of these vehicles, detailed information including make, model, and model-year was extracted from the license plate lookup website, however, for others, the API request returned empty. For observations with complete data, average CO_2/km was estimated. From the remaining passenger vehicles, 80% of the observations include make and model but lack the model-year. For these vehicles (N=1005), we estimated the weighted average CO_2/km. Weights for different years were obtained by the distribution of passenger vehicle age observed in 2021 passenger vehicle population data across data collection sites (see Figure 20). 55% of recorded make and models were not found in the fuel consumption dataset possibly due to the data entry errors or inconsistencies between our dataset and the fuel consumption dataset. Regardless, the distribution is large enough ($N_{freight}$=188 and $N_{personal}$=578) to enable the systematic comparison.

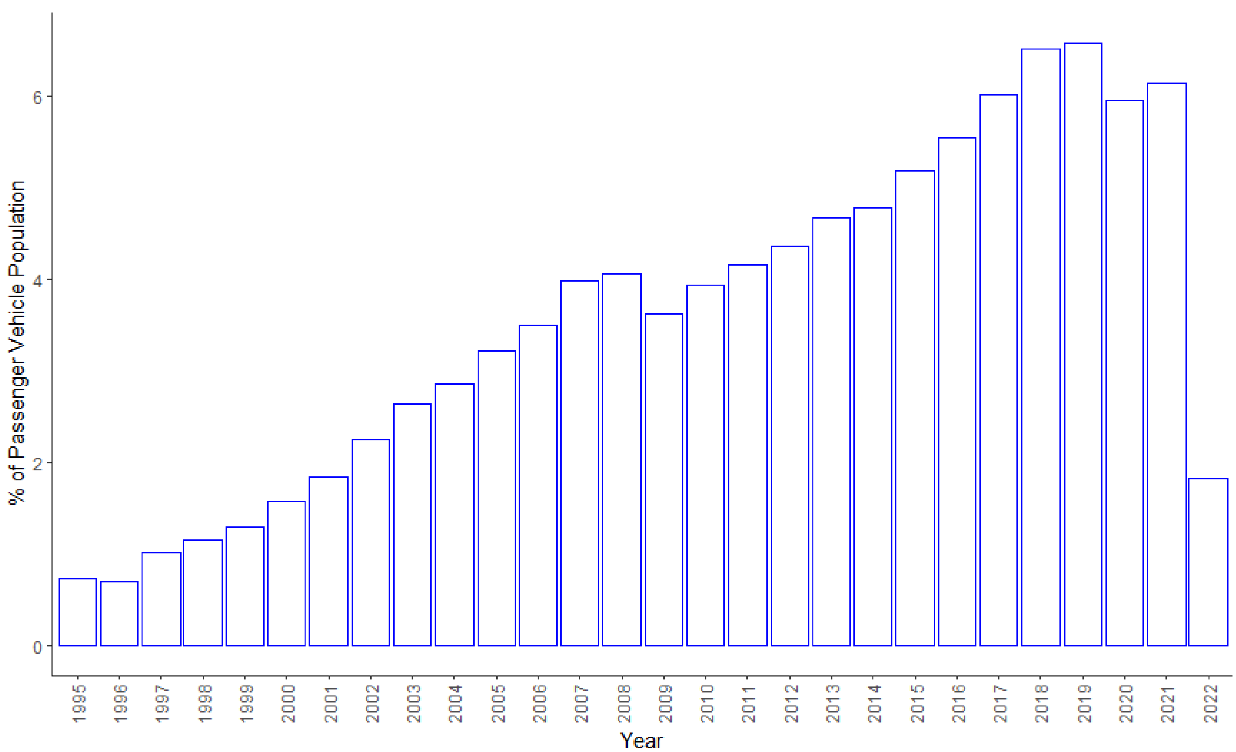

Figure 20 2021 vehicle population distribution for vehicles in Metro Vancouver.

Figure 21 demonstrates the distribution of emission factors for freight passenger vehicles compared to personal passenger vehicles. The average emission factor for freight passenger vehicles is 197.5 g CO_2/km whereas the corresponding value for personal vehicles is 222.97 g CO_2/km. Running a t-test indicates a significant difference between the two at a 95% confidence interval suggesting that the sample freight vehicles were indeed more efficient than the sample personal vehicles. In both samples (freight and personal passenger vehicles), zero emission vehicles (CO_2/km=0) constituted 4% of freight and personal passenger vehicles with higher shares concentrated in City of North Vancouver and City of Vancouver. This share (4% of the total sample being zero emission vehicles) is consistent with 3% electric vehicles present in 2021 passenger vehicle population data across data collection sites. Freight zero emission vehicles were used solely for delivery. However, results should be interpreted with caution. We have no evidence that the traveling behavior of freight passenger vehicle drivers is more efficient than personal passenger vehicles. A substantial portion of freight passenger vehicles were invisible freight vehicles (48%) making deliveries of only a few goods at a time. Therefore, If the total distances traveled by freight passenger vehicles are higher than personal passenger vehicles, freight passenger vehicles generate more aggregate emissions. Anecdotally, there were invisible freight drivers that appeared on the same site multiple times to pick up/drop off deliveries. This observation suggests greater driving distances compared to typical personal car travel.

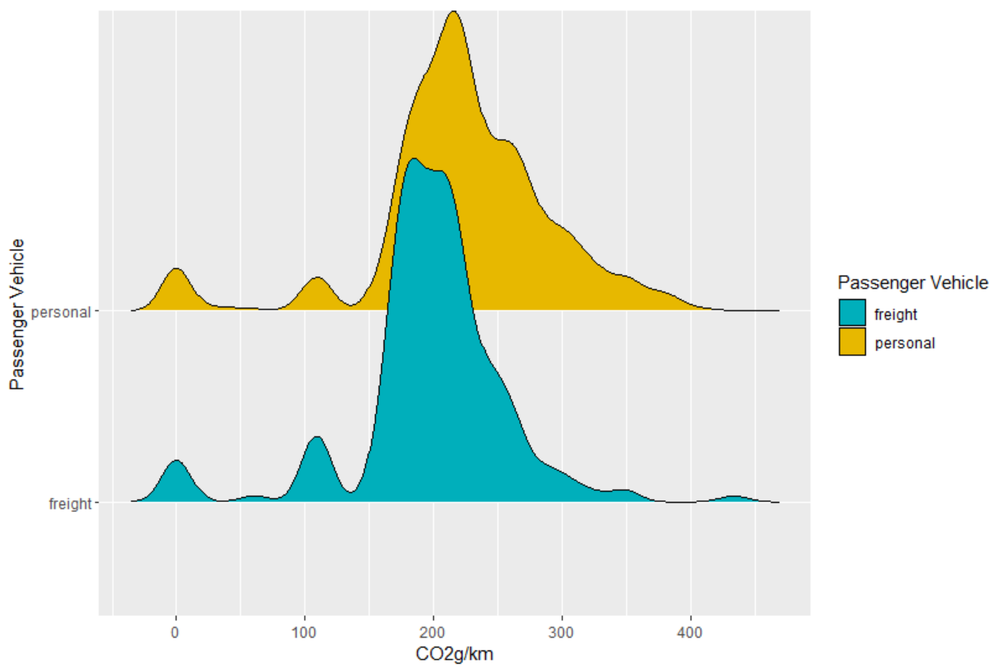

Figure 21 Environmental efficiency of freight passenger vehicles vs personal passenger vehicles

Key Takeaway 10: At the sites observed, passenger vehicles used in invisible freight tend to be slightly more efficient vehicles.

While collecting data, the license plate pictures were collected which can be input into a license plate recognition algorithm and thus reducing the entry errors and increasing the sample size behind the above distributions. To enhance accuracy and resolve any bias in the resultant distributions above (with regards to only identifying specific make and models), the inferred license plates can be further matched against official ICBC license plate data (unavailable for this study).

It is worth noting only about 2% of freight activity was operated out of micromobility devices with zero tail emissions (mostly e-scooter) which is comparable to general travel trends in the region (1.6% of total trips reported in the 2017 travel diary were made by bike(*91*)). As illustrated in Figure 14, micromobility devices were observed to make food and grocery deliveries.

Findings & Recommendations

Based on the results above, we find that invisible freight had the highest share of on-street freight parking activity, primarily food delivery drop-off and pick-up from passenger vehicles in Metro Vancouver. This freight activity was higher during the weekdays as opposed to the weekends, and slightly higher from 4pm-6pm over 11am-1pm, likely due to the increase in food delivery demand. Delivery drop-off parking durations were 53% longer than delivery pick-up durations (t-test with p-value of <0.01). Anecdotally, this may have been due to the readiness of food delivery pick-up at restaurants countered with the waiting time of delivering food to the recipient in larger residential buildings, or the obviousness of restaurant signage in comparison with residential building address signage. Delivery drop-off drivers may also have had multiple drop-off locations requiring them to park in one location and walk between destinations.

We did not capture high rates of conflict among freight and other road users (only one conflict was recorded with a pedestrian involving a freight vehicle parked illegally in a bus zone). While most parking activities were occurring legally, 29% of freight vehicle were illegally parked (most frequently observed to be passenger vehicles). Note that we were unable to confidently collect information about compliance with paid parking as some of the drivers likely made payments by the phone. Therefore, transaction data can help address this issue (not available for this study). Almost all delivery, ridehailing, and taxi events were short duration parking events (15 minutes or less) and occurred in metered parking spots, including 1-hour and 2-hour parking locations. Future research can also employ transaction data to understand the extent of lost parking revenue due to unpaid parking by freight drivers who occupied the parking for very short durations. If the unpaid parking by freight services comprises a large share of lost revenue, GPS based auto payment could alleviate the cost by easing the burden of paying for freight drivers with a busy schedule. According to the model, the probability of a freight vehicle leaving a no parking curb space (i.e., illegal spaces) at any given time was 3.36 times higher than freight vehicles parked in alleys/lots, keeping every other variable constant. The model also suggests the parking duration was the shortest in illegal spaces which is consistent with the literature (*19*, *25*). This may represent a mismatch in curb demand and current curb typology. Future research can expand the data collection to cover more hours and have a reflective temporal trend of freight activity by curb typology. Further these data can be utilized to create hotspot maps of illegal parking. Such maps can guide cities to design a curb typology that accommodates the curb demand by all users. Additionally, certain stakeholders are more prominent in freight activity than others. In particular, Skip The Dishes, Fantuan, and Doordash are prominent in food delivery, while Canada Post, FedEx, and Purolator were common in package and parcel delivery. Interestingly, the distribution of prominent food deliveries is different across sites. This finding suggests that freight generation is a function of site characteristics (such as land use).

The average emission factor for freight passenger vehicles in CO_2/km was lower than the value for personal vehicles, indicating that freight passenger vehicles (mostly present in invisible freight) were more efficient than the sample personal vehicles. The share of zero emission vehicles and active modes in freight activity mirror similar shares in the overall travel trends (with 4% of freight passenger vehicles being zero emission and 2% of total freight being made by active modes). Although due to good size and weight, active modes are not always feasible to be used, but our observation suggests the food delivery can benefit from the shift to active modes (given the travel distance is viable to be made by active modes). For larger size cargos, zero emission vehicles present a good substitute to vehicles with internal combustion engine. However, this can only be claimed for the vehicles used themselves as we are unable to model the full driving patterns of personal and delivery drivers.

This study was not without limitations. First, while we were able to complete 36 two-hour collection periods across nine sites, the time constraints of the project start and end times as well as the inclusion of weekend collections limited the number of collected sites. With more collectors available or more weekend days within the project time limits, more site collections across the region would be possible. Second, given the more singular position of the collector, collection of off-street freight activity was limited or, in most cases, excluded. While this paints an accurate picture of on-street freight activity, it may bias towards invisible freight in understanding the entirety of freight activity in a region. Additionally, we were able to capture only a longitudinal idea of each time as opposed to a longitudinal study of each driver. In terms of the statistical approach, the composite measure can be enhanced by using a more granular scale than census tracts. The availability of relevant urban freight data was a barrier to developing a more comprehensive measure. Particularly, there is a need for georeferenced curb typology to be utilized in understanding urban freight behavior. We should note that we did not record if a freight driver generated multiple observations, this (if large) might influence the assumption of independent and identically distributed random variables behind modeling parking behavior. Data entry errors might be present in the collected data, however, the cleaning procedure reduces such errors. Coupled with the randomness of such errors and that the general inferences were made from large sample size data, the results can be interpreted with confidence. The highest missing data were for the number of goods, this can be captured by a surrogate in future data collections such as if the driver uses a trolly. Finally, out of scope for this project was any interaction with the freight stakeholders themselves. This also limited the understanding of the driver routing around the city as well as the emissions created from delivery travel as opposed to parking.

Based on these findings and the stated limitations, we recommend a curb typology that reflects the businesses and residents of the area. We see that invisible freight vehicles represent shorter parking durations and increasingly at off-peak delivery times which may not reflect the standard curb designations of traditional freight. We also see heavy usage of loading zones by both invisible and traditional freight. This may suggest that these areas are important in the street landscape. Additionally, we recommend a follow-up study with the ability to follow individual invisible freight delivery paths through the city. This may offer insight into the patterns and behaviors of people who are increasingly undertaking freight delivery in urban contexts. Finally, we recommend the inclusion of real-time curb availability data into the common routing applications. Such data might decrease the cruising in search for parking and facilitate the management of curb.

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Appendices

Appendix A Freight Transport Solutions

Clusters and Solutions
1. New distribution and logistics models
City lockers [1]
Off-hours deliveries [1]
Home deliveries system
Businesses recognition scheme
E-commerce system for small shops
Reverse logistics integration into supply chain
Public transport indirect promotion for shopping
2. Capacity sharing
Multi-users lanes [1]
Public transport for freight
3. Infrastructure development and vehicle characteristics
Urban consolidation centres [1]
Electric vehicles diffusion in businesses (zero-emission transport) [1]
Cargo bikes for B2B and B2C
Enforcement and ITS adoption for control and traffic management
Urban planning measures
4. Access control
Low emission zones [1]
Trans-shipment facilities
Access by load factor
5. Regulations on enabling activities
Loading/unloading areas and parking [1]
Multimodality for urban freight
Freight travel plans
6. Enforcement, routing optimization, and training
ITS for freight monitoring and planning/routing [1]
Harmonization and simplification of city logistics rules
7. Emerging solutions
Crowdsourcing [1]
Autonomous vehicles
Drone deliveries [1]
3D-printing

Various solutions for urban freight transportation, from (92)

Appendix B Data Collection Methods for Parking Studies

Type of Method to Detect Parking Occupancy	Opportunities	Considerations
In-ground sensors	Can detect vehicles fairly accurately Data available in real time	Not movable; must be installed in the ground. Spaces require demarcation. Pilots on undemarcated have been unsuccessful. Requires installation and maintenance costs. Sensors may not detect vehicles accurately in poor weather conditions (standing water, snow cover). Detection algorithms need to be adjusted to account for "urban noise" such as underground utilities, subways, buses on curb lanes, etc. Coordination with capital and maintenance projects and snow removal operations.
Portable CCTV	Movable Spaces don't need to be demarcated Measures space between cars and vehicle lengths May also detect pedestrians with improved algorithms	Without additional expense and assets, data are not available in real time since data are stored locally. Shorter battery life than sensors (requiring more frequent maintenance). Privacy concerns. May be prone to vandalism. Requires automation using algorithms that can detect cars; otherwise, requires staff time to review video. Moving cameras can be difficult. Requires time and labor for installation and maintenance.
Time-lapse cameras	Long battery life Relatively small size Portable	Data are not available in real time. Requires automation using algorithms that can detect cars; otherwise, requires staff time to review video. Moving cameras can be difficult; may require permits, municipal approvals.
Cameras with GPS	Commercially available product	Data are not available in real time. Requires staff time to review set up driving routes and review video. Urban canyon effect can hinder GPS data.
Manual counts	No need to invest in technology	Accuracy is hard to verify. Generally, requires more labor costs than any other methods. Data are not available in real time. Requires significant labor.
Payment data	Data available in real time Can have users pay by space or pay by license plate numbers	Requires labor for data management. Payment data not always good proxies for occupancy. Does not account for turn-over, length of stay, exempt parkers, or illegal parkers.
Dome-mounted sensors	Data available in real time Can use assets already in place Can be networked using same system as networked meters	Not movable; must be installed within existing single-space meters. Requires installation and maintenance costs. May require changes to infrastructure (yoke redesign). Might impact meter battery life.
Fixed camera	Spaces don't need to be demarcated Automated Potential to also provide vehicle counts, vehicle speeds, vehicle classification, bicycle, and pedestrian counts Measures space between cars and vehicle lengths	Not movable. Privacy concerns. Requires installation and maintenance costs. Requires labor for installation and maintenance. Requires labor for data management. Requires accurate computer vision algorithms.
License plate recognition technology	Can detect vehicle plate numbers and be used for enforcement purposes Automated process	Data are not available in real time. Requires labor costs as people need to drive vehicles around an area to detect license plates. Requires staff to either drive vehicles or needs to be mounted on fleet vehicles. Must purchase LPR devices and install them on enforcement vehicles. Urban canyon effect can hinder GPS data, GPS accuracy. Cameras are not able to differentiate vehicles that are parked versus in transit. The cameras do not distinguish between legal parkers at a parking meter and illegal parkers in a loading zone. Routes need to be constructed to address this.
Crowdsourcing applications	Rates by block segments per block for all streets in pilot zone Sometimes broken down into zones and subzones based on location (i.e., Ballpark District Zones/Subzones)	Users must agree to share their location information in order to get complete data. Data may be incomplete. Engage with various app developers to either develop a crowdsourcing application or use their data to integrate with other data the agency obtains. May require contracts and some staffing for data integration.

Parking data collection methods from (Dey et al., 2017)

Appendix C Freight Initiative Example Output from Web Service[7]

Peak-Hour Clearways	
Description: Peak-hour clearways are roadway corridors defined by clearway signs at each end, where parking and standing of vehicles is prohibited during peak hours	
Targeted mode: All traffic	**Geographic scope:** Corridor
Type of initiative: Parking/loading areas management: on-street parking and loading	**Primary objective:** Reduce congestion
Expected costs and level of effort to implement: Peak-hour clearway restrictions require careful consideration of freight movements and land use in the target area. Implementation and enforcement by local authorities is required. Changing policy and adding appropriate signage will bring minor costs; enforcement of parking during peak hours will be additional costs. This type of initiative could be implemented in a short period of time.	
Advantages: • Reduce congestion • Environmental sustainability • Enhance safety • Improve mobility during peak hours	**Disadvantages:** • May face private-sector opposition • Moderate probability for unintended consequences • Reduce residential parking • Reduce access to businesses during peak hours • May create confusion among drivers
Examples: • Perth, Australia (Government of Western Australia 2013) • Red Route Network, London, England (SUGAR 2011) • New Zealand (New Zealand Transport Agency 2007)  Source: (Government of Western Australia 2013) Transport Agency 2007) Western Australia 2013	 Source: (New Zealand Transport Agency 2007
Related alternatives: 1. Freight Parking and Loading Zones; 2. Timesharing of Parking Spaces; 3. Staggered Work Hours Program	
References: (Ogden 1992, SUGAR 2011)	

Example web service output, nature of the problem is set to Congestion and geographic scope is set to Corridor in the web service.

[7] https://cite.rpi.edu/iselector/

Appendix D Preferential Parking for Freight Vehicles

STRATEGY

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●●○ Effectiveness
●●○ Cost
●●○ Time

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Preferential Parking

At a Glance

DESCRIPTION

Preferential access to on street parking for freight vehicles that meet required conditions.

TRANSPORTATION MODE

- Multimodal
- Roadway

PROBLEM ADDRESSED

- Social Problems
- Economic Problems
- Land Use Problems
- Logistics Operational Issues

OTHER STRATEGIES IN SAME STRATEGY GROUP

- Preferential Zoning
- Taxation and Fees

Implementation Notes

Understand city logistics to identify specific commodities and types of operations best suited to the parking infrastructure available for use. For example, perishable products going into high density areas are well suited to this strategy. Stakeholder participation is required.

Opportunities & Constraints

FACILITATORS

- Optimize last mile efficiency
- Enhance environmental sustainability
- Reinforce access regulations

BARRIERS

- Limited parking for other road users
- Increased enforcement by local authorities
- Increased costs for freight vehicle operations

RECOMMENDATIONS FOR IMPLEMENTATION

- Identify the commodities and types of operations that will most benefit
- Define areas of the city where the positive impact is greatest
- Examine existing or proposed infrastructure to understand the costs of change
- Engage stakeholders including the public to promote the benefits

Examples

Preferential parking permits to freight vehicles that meet the strictest environmental standards; preferential parking to commercial vehicles carrying specific goods (e.g., medicines).

Selected References

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Preferential parking for freight vehicles, from (Eisele et al., 2018)

Appendix E Metro Vancouver Freight Company Details

Details of freight companies operating in Metro Vancouver including general package delivery by courier or delivery service, restaurant, grocery, and alcohol delivery. Because it was infeasible to gather every possible courier and delivery stakeholder, preference was given to stakeholders in the five municipalities included in the study collection as well as a sampling from each of the above delivery categories. In this, only 25-30 (or less if not available) of each delivery service is included.

Company Name	Mode	Service Area	Delivery Type	Deliverer Type	Fleet Size	Hours of Op
City Core Messenger Services	Hybrid Car, Electric Car, Vans	Lower Mainland	General Courier	Employee	Over 20	8-5 M-F
Flash Courier Services	Vehicle, Van	Lower Mainland	General Courier	Employee		7:30-5 M-F
Flash Courier Services	Bike	Downtown Vancouver	General Courier	Employee		7:30-5 M-F
Novex Delivery Solutions	Hybrid Car, Ultra Low Emission Car, Freight Truck	Lower Mainland	General Courier	Employee	Over 100	7:30-5:30 M-F
Novex Delivery Solutions	Bike	Downtown Vancouver	General Courier	Employee		7:30-5:30 M-F
PDX Courier	Car, Truck	Lower Mainland	General Courier	Employee	Over 40	8-5 M-F
PDX Courier	Bike	Downtown Vancouver	General Courier	Employee	Over 40	8-5 M-F
Phantom Couriers	Car	Lower Mainland	General Courier	Employee		7:30-5:30 M-F, 10-2 Sa-Su
Phantom Couriers	Bike	Downtown Vancouver	General Courier	Employee		7:30-5:30 M-F, 10-2 Sa-Su
Vancouver Rush Courier		Lower Mainland	General Courier	Employee		8-6 M-F
Rocket Ship Couriers Ltd. of Vancouver		Lower Mainland	General Courier	Employee		{'8AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], '11AM-5PM': ['Sa'], '11AM-5PM': ['Su']}
Shipexa Courier		Lower Mainland	General Courier	Employee		{'11AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Veracity Courier Service		Lower Mainland	General Courier	Employee		{'8am-5pm': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Nanook Delivery		Lower Mainland	General Courier	Employee		{'7:30AM-5:30PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Tent Mix Courier		Lower Mainland	General Courier	Employee		{'7AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
EEKO COURIERS INC.		Lower Mainland	General Courier	Employee		{'8AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
FlagShip Courier & Shipping Solutions		Lower Mainland	General Courier	Employee		{'8am-5pm': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Mayfair Services		Lower Mainland	General Courier	Employee		{'9:30AM-7PM': ['Fr'], 'Closed': ['Sa', 'Su'], '9AM-5:30PM': ['Mo', 'Tu', 'We'], '10AM-3:30PM': ['Th
Legal Alternative Courier		Lower Mainland	General Courier	Employee		
Ready Set Go Delivery & Courier Service		Lower Mainland	General Courier	Employee		{'7AM-7PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
FedEx Ship Centre		Lower Mainland	General Courier	Employee		{'9:30AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
ParcelPal		Lower Mainland	General Courier	Employee		{'7AM-5PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Lightspeed Courier & Logistics		Lower Mainland	General Courier	Employee		{'8:30AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Wyagit Delivery Inc.		Lower Mainland	General Courier	Employee		{'9AM-5PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Chapman's Express INC		Lower Mainland	General Courier	Employee		{'9AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
DHL Express		Everywhere	General Courier	Employee		{'10AM-6PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Vancouver Business Plus		Lower Mainland	General Courier	Employee		{'10AM-6:30PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], '11AM-7PM': ['Sa'], 'Closed': ['Su']}
The UPS Store		Everywhere	General Courier	Employee		{'8:30AM-6:30PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], '10AM-5PM': ['Sa'], 'Closed': ['Su']}
Planning Lynn Services		Lower Mainland	General Courier	Employee		{'10AM-6PM': ['Fr', 'Sa', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Su']}
DHL	Car	Everywhere	General Courier	Employee		9-7 M-F
UPS	Car	Everywhere	General Courier	Employee		9-7 M-F
Ace Courier		Lower Mainland	General Courier	Employee		
Diamond Delivery		Lower Mainland	General Courier	Employee		
DashFoss Courier		Lower Mainland	General Courier	Employee		
SHIFT delivery	bike	Vancouver	General Courier	Employee	~20	
Instacart	Car	Everywhere	Grocery	Gig-Based		8a-10p M-Su
Kiki's Delivery	Vehicle	Vancouver, UBC	Grocery	Employee		VC 1-4 M,T,Th,F; UBC 1-4 W
SaveOnFoods	Van	Lower Mainland; Reasonable distance from SaveOnFoods	Grocery	Employee		7-10 M-Su
SPUD.ca	Van	Lower Mainland	Grocery	Employee		{'8AM-8PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], '10AM-7PM': ['Sa', 'Su']}
Walmart	Vehicle	Lower Mainland	Grocery	Employee		7-10 M-Su
Galloway's Wholesome Foods-VE		Vancouver	Grocery	Employee		{'7am-12am': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Nam Nam Delivery		Vancouver	Grocery	Employee		{'12-8PM': ['Fr', 'Th'], 'Closed': ['Sa', 'Su', 'Mo', 'Tu', 'We']}
Tiggy Grocery Delivery		Vancouver	Grocery	Employee		{'9am-11pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Vancouver	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Jar		Vancouver	Grocery	Employee		{'8AM-7PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Save-On-Foods	Van	Vancouver	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Buy-Low Foods		Vancouver	Grocery	Employee		{'8AM-9PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Food to Home		Vancouver	Grocery	Employee		
Grocket Online Grocery Store		Vancouver	Grocery	Employee		{'9AM-5PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Real Canadian Superstore		Vancouver	Grocery	Employee		{'7AM-11PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Foodsline (formerly Coastline Market)		Vancouver	Grocery	Employee		{'9am-5pm': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Tiggy Grocery Delivery		Vancouver	Grocery	Employee		{'8AM-11PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Foodies		Vancouver	Grocery	Employee		{'9am-9pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Vancouver	Grocery	Employee		{'7am-10pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Donald's Market		Vancouver	Grocery	Employee		{'8AM-9PM': ['Fr', 'Sa', 'Mo', 'Tu', 'We', 'Th'], '9:30AM-8PM': ['Su']}
MapleStaple - Zero Waste Grocery Delivery		Vancouver	Grocery	Employee		{'9AM-5PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
McGill's Store		Vancouver	Grocery	Employee		
Best Foods Grocery		Vancouver	Grocery	Employee		{'9AM-9PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Fresh Prep Foods Inc.		Vancouver	Grocery	Employee		{'8AM-5PM': ['Fr', 'Th'], '9AM-5PM': ['Sa', 'Su'], '8AM-9PM': ['Mo', 'Tu', 'We']}

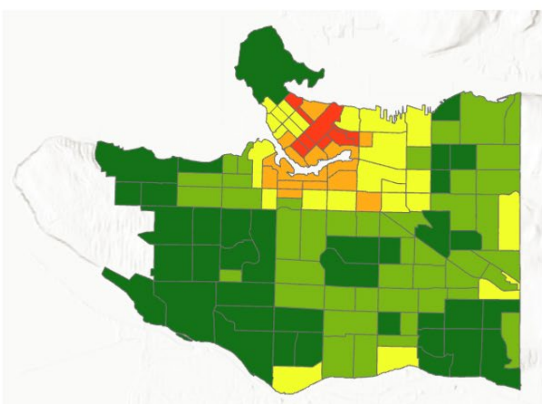
Sungiven Foods (West Broadway Store)		Vancouver	Grocery	Employee		{'8am-9p.m.': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Shang's Market		Vancouver	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Kiki's Grocery Delivery	Vehicle	Vancouver, UBC	Grocery	Employee		{'8AM-8PM': ['Fr', 'Th'], 'Closed': ['Sa', 'Su'], '9AM-8PM': ['Mo', 'Tu', 'We']}
Buzzr Delivery		Vancouver	Grocery	Employee		{'2-10PM': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
G3 Grocery Store by Fail		Vancouver	Grocery	Employee		{'9am-5pm': ['Fr', 'Mo', 'Tu', 'We', 'Th'], 'Closed': ['Sa', 'Su']}
Famous Foods		Vancouver	Grocery	Employee		{'8AM-8PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
FreshOnFood		Richmond	Grocery	Employee		{'8AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Real Canadian Superstore		Richmond	Grocery	Employee		{'7AM-11PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Safeway Seafair		Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
PriceSmart Foods		Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
FreshCo No. 2 Rd. & Blundell		Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Success Supermarket		Richmond	Grocery	Employee		{'9:30AM-7PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Super Grocer & Pharmacy		Richmond	Grocery	Employee		{'9am-9pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Banana Pepper		Richmond	Grocery	Employee		{'9am-9pm': ['Fr', 'Sa', 'Mo', 'Tu', 'We', 'Th'], '9am-7pm': ['Su']}
FoodyWorld		Richmond	Grocery	Employee		{'8AM-12AM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Sungiven Foods (Richmond Bridgeport Store)		Richmond	Grocery	Employee		{'8AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
T&T Supermarket		Richmond	Grocery	Employee		{'8AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Popeye		Richmond	Grocery	Employee		{'10am-9pm': ['Fr', 'Mo', 'Tu', 'We', 'Th'], '11am-9pm': ['Sa', 'Su']}
FreshCo No. 3 Rd. & Williams		Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Richmond	Grocery	Employee		{'7am-10pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Supermarket 2000		Richmond	Grocery	Employee		{'8AM-8PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Richmond	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Global Orchards		Richmond	Grocery	Employee		{'Open 24 hours': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Fresh Goods		Richmond	Grocery	Employee		{'10am-9pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
T&T Supermarket		Richmond	Grocery	Employee		{'10AM-9PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Coquitlam	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Dennis' No Frills		Coquitlam	Grocery	Employee		{'9am-9pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Real Canadian Superstore		Coquitlam	Grocery	Employee		{'7AM-11PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Coquitlam	Grocery	Employee		{'7am-10pm': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Save-On-Foods	Van	Coquitlam	Grocery	Employee		{'7AM-10PM': ['Fr', 'Sa', 'Su', 'Mo', 'Tu', 'We', 'Th']}
Tippy	Car, Scooter	Everywhere	Grocery	Gig-Based		
InstaBuggy		Vancouver, North Vancouver, Richmond, Burnaby	Grocery and Alcohol	Gig-Based		9a-10p M-F, 9-7 Sa-Su
Canada Post		Everywhere	Mail Delivery	Employee		9-5 M-F
TaskRabbit	none, vehicle (car or truck)	Vancouver	office/home delivery	Gig-based		
Amazon Delivery	Van	Lower Mainland	Package Delivery	Employee		
DoorDash	Car	Everywhere	Restaurants	Gig-Based		24/7
DoorDash	Scooter, Bike	Downtown Vancouver	Restaurants	Gig-Based		24/7
FaceDive Foods	Car	Richmond	Restaurants	Gig-Based	Over 3500	Business Hours
FanTuan	Bike, Car, Motorcycle, Scooter	Metro Vancouver	Restaurants	Gig-Based		Business Hours
GrubHub		Everywhere	Restaurants	Gig-Based		24/7
SkipTheDishes	Car	Lower Mainland	Restaurants	Gig-Based		24/7
SkipTheDishes	Bike	Downtown Vancouver	Restaurants	Gig-Based		24/7
UberEats	Bike, Car, Scooter	Everywhere	Restaurants	Gig-Based		24/7

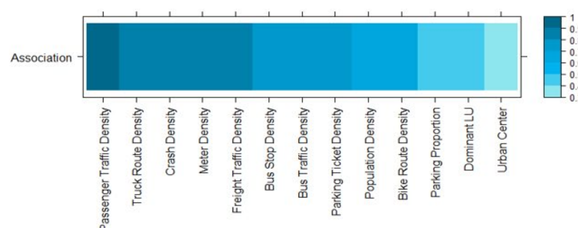
Appendix F Composite Measure Distribution Across Cities

Following table details the input variables to the composite measure for each city. The input variables are constructed based on the availability of data for each city. The unit of analysis for all cities are census tract.

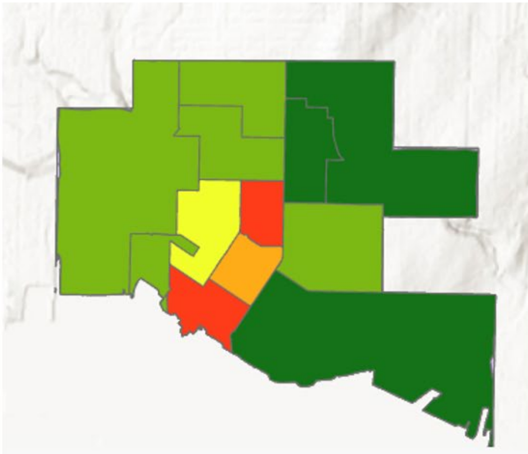
City	Input Variables
Vancouver	Parking ticket density, collision density, meter density, urban center, dominant land use, truck route density, parking proportion, population density, passenger volume density, freight volume density, frequent transit development area (FTDA), bike route density, bus volume density, bus stop density
North Vancouver, Richmond, Coquitlam	collision density, urban center, dominant land use, truck route density, parking proportion, population density, passenger volume density, freight volume density, frequent transit development area (FTDA), bike route density, bus volume density, bus stop density

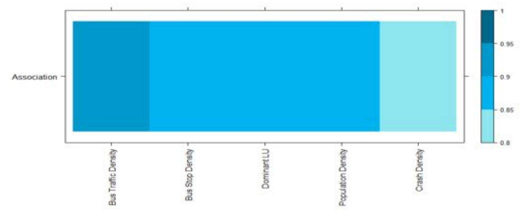
The distribution of composite measure values across each city is presented along association of each constituent variable to the composite measure (only variables with significant association at 95% are maintained in the composite measure). Note the direction of associations are consistent across the cities but the magnitude of associations is different.



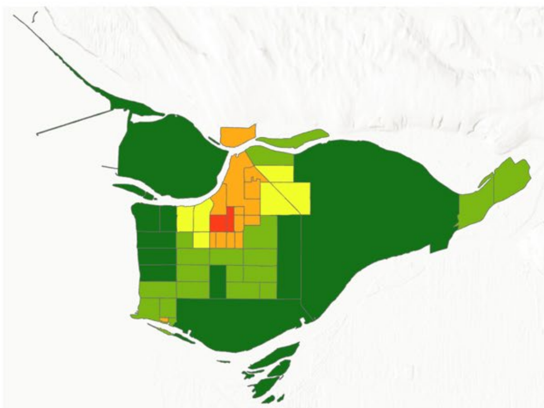


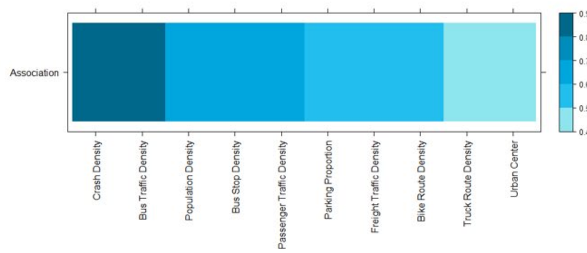
City of Vancouver, composite measure distribution and association with underlying variables (FTDA did not appear to be significantly associated with the composite measure at 95%)



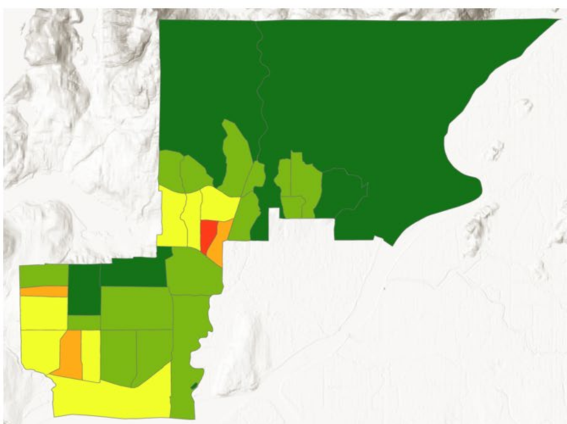


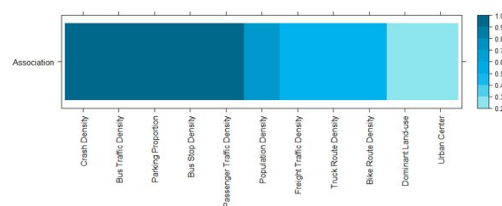
City of North Vancouver, composite measure distribution and association with underlying variables (passenger volumes, freight volumes, bike route density, truck route density, parking proportion, urban center, and FTDA did not appear to be significantly associated with the composite measure at 95%)





City of Richmond, composite measure distribution and association with underlying variables (dominant land use and FTDA did not appear to be significantly associated with the composite measure at 95%)





City of Coquitlam, composite measure distribution and association with underlying variables (FTDA did not appear to be significantly associated with the composite measure at 95%)

Appendix G Curb Inventory of Collected Sites

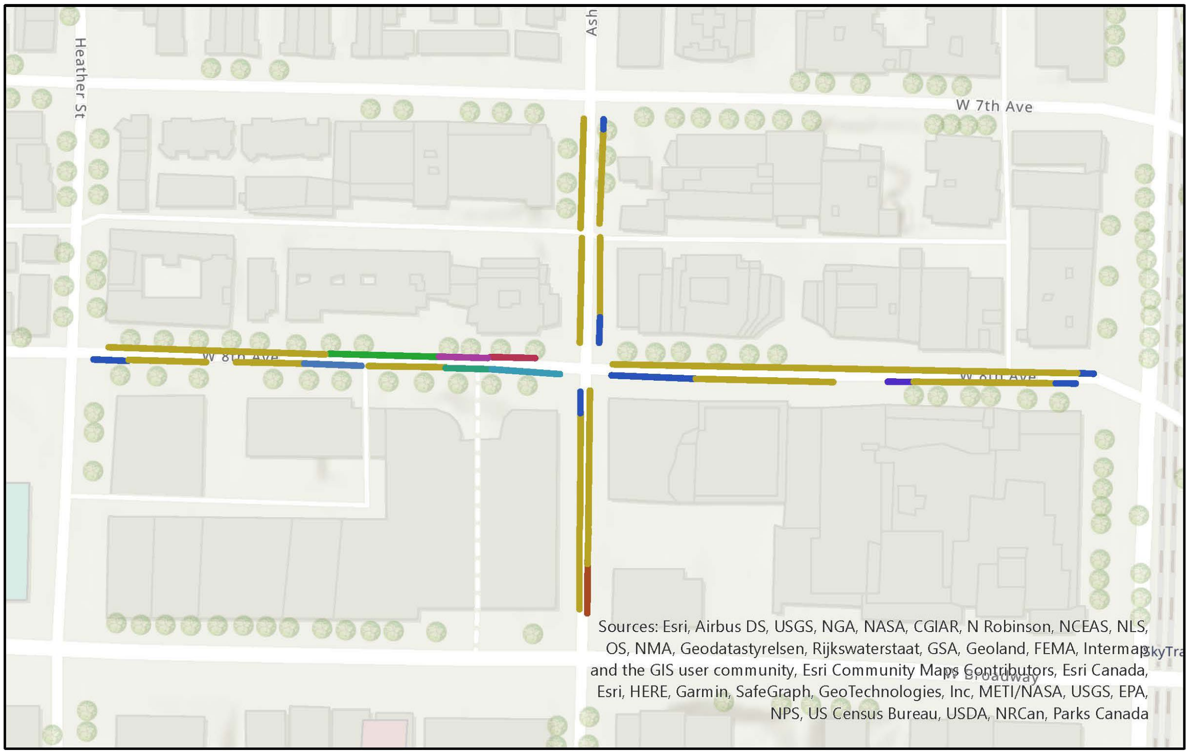
City of Vancouver- Site: Cambie and W Cordova

Legend

Curb Regulation

- 2 hr Parking 9am-6pm, No Stop 3pm-6pm
- 2 hr parking 9am-10pm
- Commercial Loading Zone 7am-6pm Mon-Sat
- Commercial Parking
- Commercial Parking 930am-9pm, Taxi Zome 6pm-930am
- No Stop
- No Stop except Bus
- No Stop except Disable
- No Stop except Tour Bus
- Passenger Loading Zone

City of Vancouver- Site: Ash and West 8th

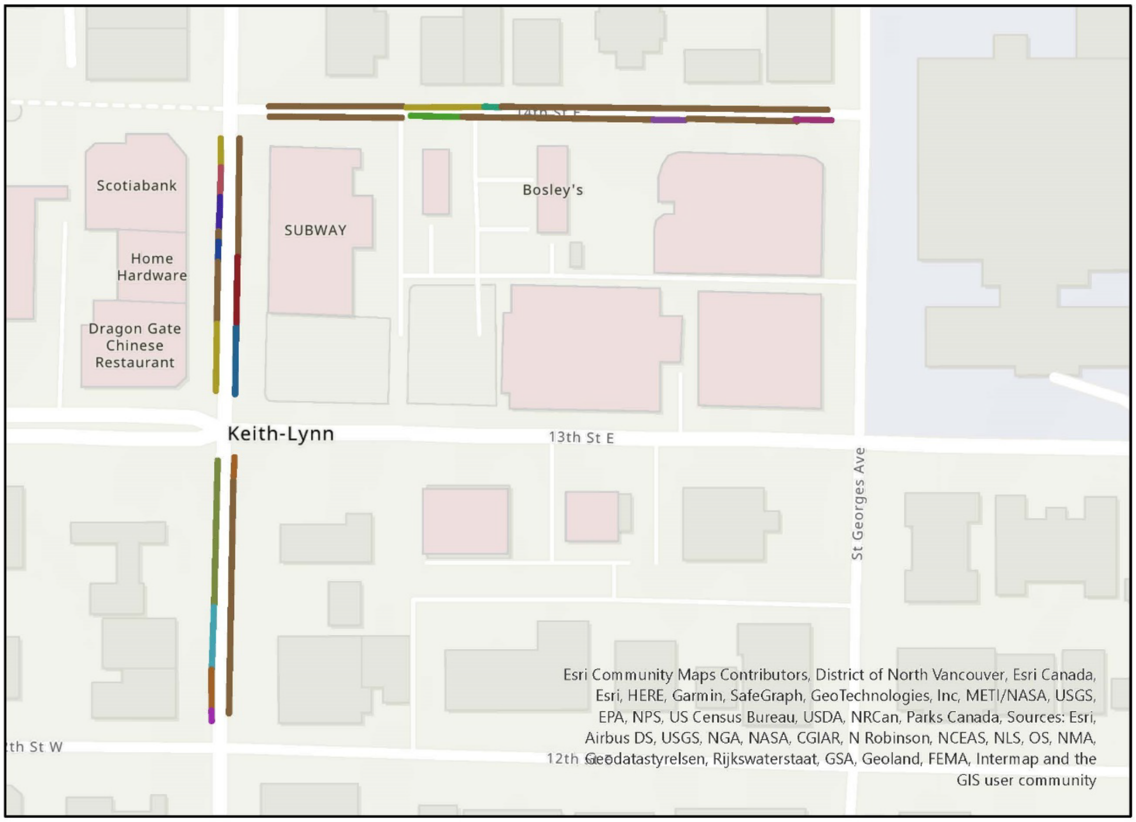


Legend

Curb Regulation

- 2 hr parking 9am-6pm Mon-Fri except with permit
- 2 hr parking 8am-6pm Mon-Fri except with permit
- Loading Zone
- Loading Zone 7am-6pm Mon-Sat
- Metered Parking
- No Stop
- No Stop except Bike Share
- No Stop except Disable
- No Stop except Motorcycle
- Passenger Zone 7am-6pm Mon-Fri

City of North Vancouver- Site: Lonsdale and E 14th

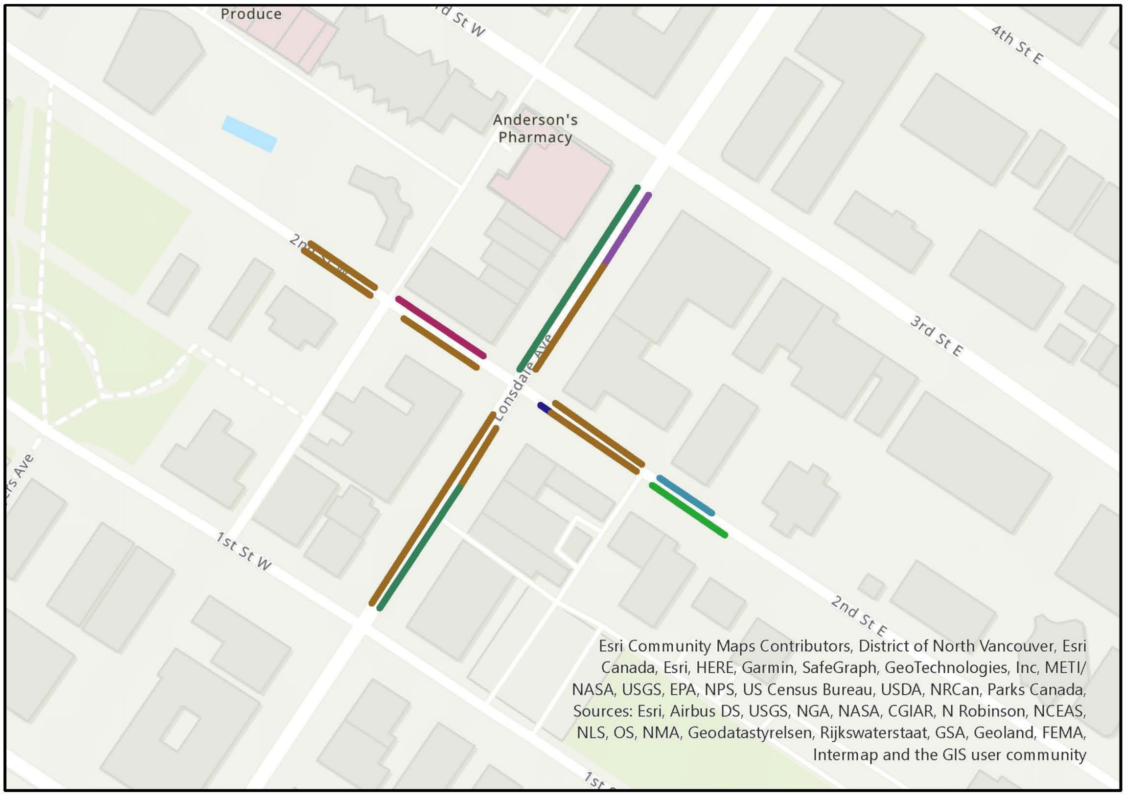


Legend

Curb Regulation

- 15 min parking
- 3 min passenger loading zone
- Loading Zone 7am-11am; 1hr parking 11am-6pm
- No Stop
- No Stop except Bus
- Police only
- 1 hr parking 9am-6pm
- 15 min loading zone 7am-9am and 4am-6pm; 15 min parking 9am-4pm
- 90 min parking 9am-6pm (temporary No Parking June14-June30 am-3pm Mon-Fri)
- Curbside Pick-up Priority 10 min max
- Fire Zone
- Loading Zone
- No Parking except Disable
- No Stop except Bus
- No Stop except Car2go/ Evo

City of North Vancouver- Site: Lonsdale and E 2nd

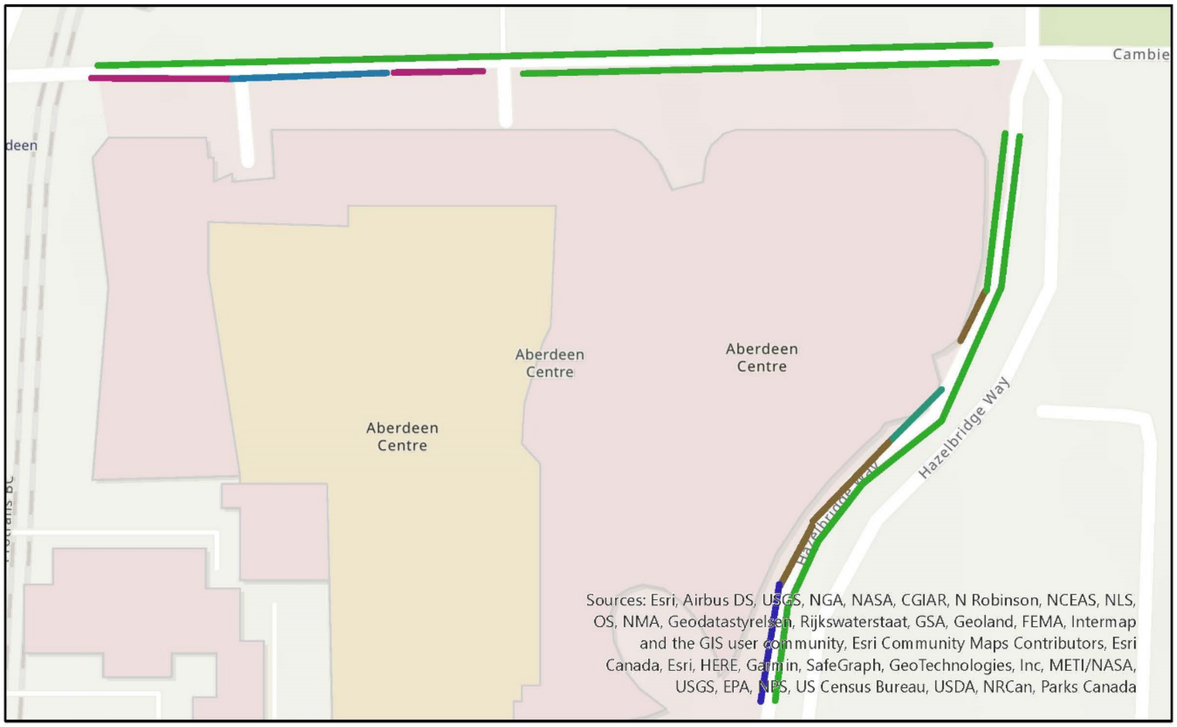


Legend

Curb Regulation

- 1 hr parking 9am-6pm
- 10 min Loading Zone
- 15 min parking 9am-6pm
- 2 hr parking 9am-6pm
- 30 min parking 9am-6pm
- No Stop
- No Stop except Bus

City of Richmond- Site: Cambie and Hazelbridge

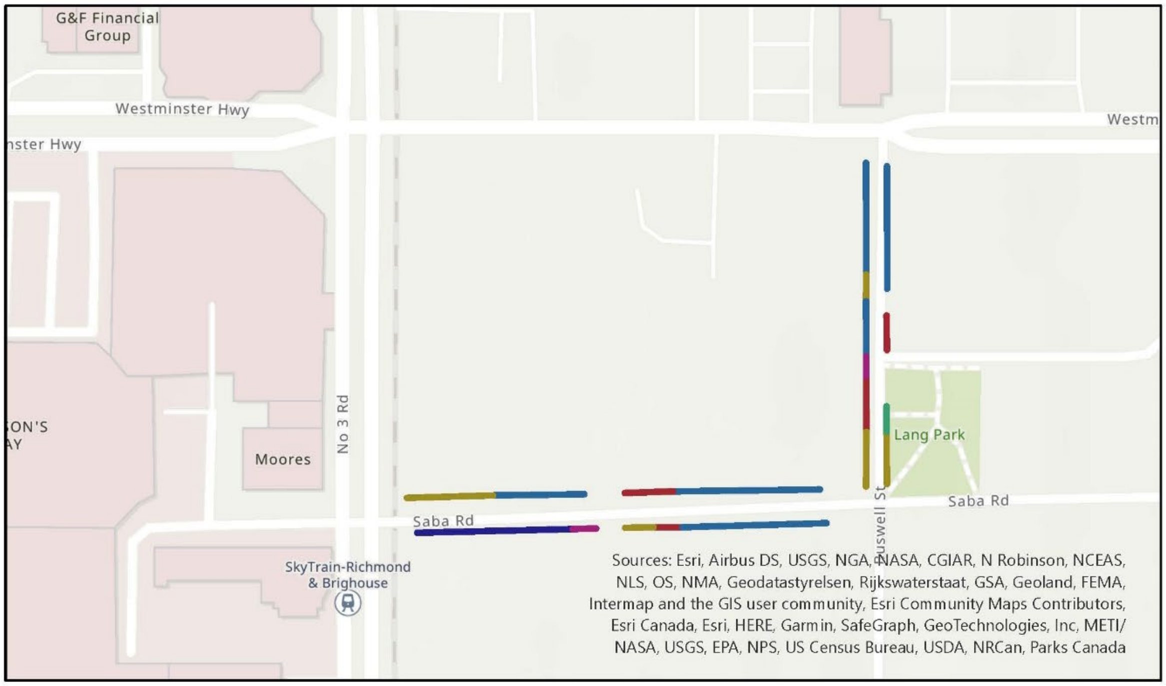


Legend

Curb Regulation

- 2 hr parking 8am-9pm
- Loading Zone
- Loading Zone 8am-8pm
- No Stop
- No Stop except Bus
- No Stop except Taxi 3 min

City of Richmond- Site: Saba and Buswell



Legend

Curb Regulation

- Authorized Parking Only
- Bus Zone
- Loading Zone
- Meter Parking 8am-9pm
- No Stopping
- Taxi 3 min

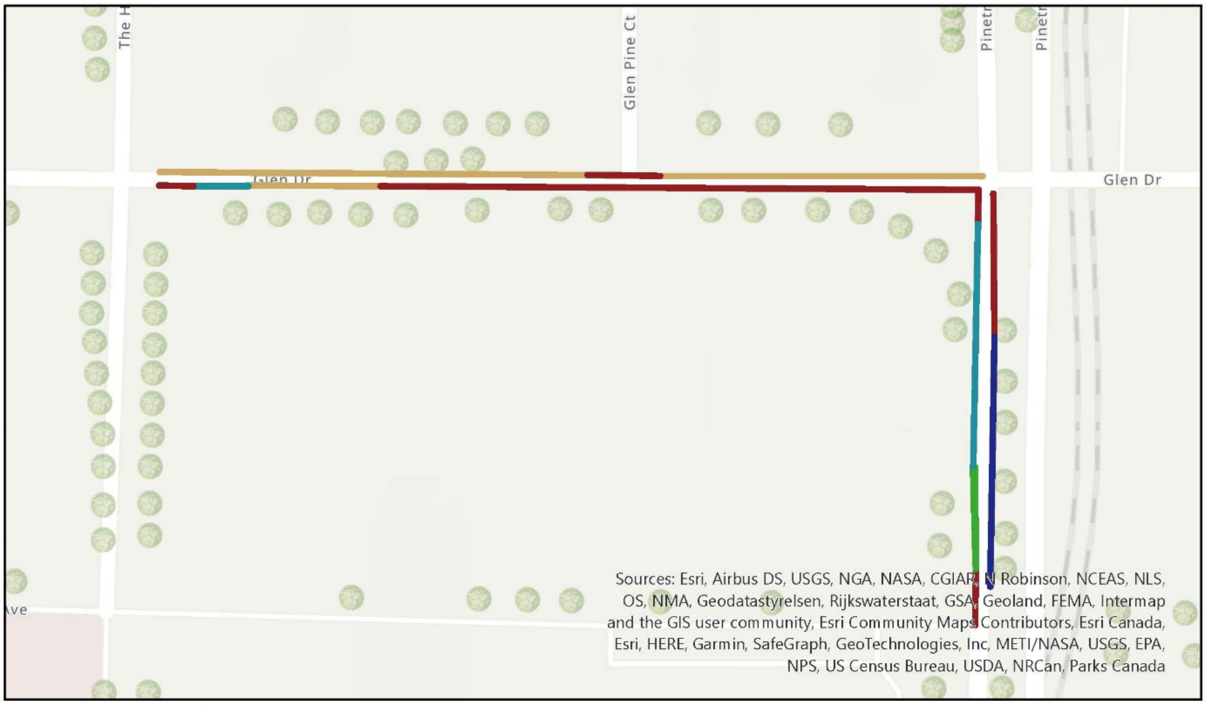
City of Coquitlam- Site: Glen and High

Legend

Curb Regulation

- 2hr parking 8am-6pm Mon-Sat
- Commercial Loading Zone
- No Parking
- No Parking except Disable
- No Stop
- No Stop except Bus
- Pay parking 2 hrs max 8am-6pm Mon-Sat

City of Coquitlam- Site: Glen and Pinetree



Legend

Curb Regulation

- 2 hr max 9am-3pm Mon-Sat; No Parking 3pm-6pm Mon-Sat
- Loading Zone 9am-6pm Mon-Sat; No Parking 7am-9am Mon-Fri
- No Stop
- No Stop except Bus
- Pay parking 2 hrs max 8am-6pm Mon-Sat

UBC- Site: Birney and Wesbrook Mall

Legend

Curb Regulation

- 1 hr parking 7am-10pm
- 2 hr parking 7am-10pm
- Carsharing Only
- Modo Only
- No Parking
- No Parking except Disable
- No parking 8am-5pm Mon-Fri except maintainance & authorized vehicles