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How cargo cycle drivers use the urban transport infrastructure

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ABSTRACT

Electric cargo cycles are often considered a viable alternative mode for delivering goods in an urban area. However, cities in the U.S. are struggling to regulate cargo cycles, with most authorities applying the same rules used for motorized vehicles or traditional bikes. One reason is the lack of understanding of the relationship between existing regulations and transport infrastructure and cargo cycle parking and driving behaviors.

In this study, we analyzed a cargo cycle pilot test in Seattle and collected detailed data on the types of infrastructure used for driving and parking. GPS data were augmented by installing a video camera on the cargo cycle and recording the types of infrastructure used (distinguishing between the travel lane, bicycle lane, and sidewalk), the time spent on each type, and the activity performed.

The analysis created a first-of-its-kind, detailed profile of the parking and driving behaviors of a cargo cycle driver. We observed a strong preference for parking (80 percent of the time) and driving (37 percent of the time) on the sidewalk. We also observed that cargo cycle parking was generally short (about 4 min), and the driver parked very close to the delivery address (30 m on average) and made only one delivery. Using a random utility model, we identified the infrastructure design parameters that would incentivize drivers to not use the sidewalk and to drive more on travel and bicycle lanes.

The results from this study can be used to better plan for a future in which cargo cycles are used to make deliveries in urban areas.

1. Introduction

Historically, the movement of goods in urban areas has predominantly been achieved by large internal combustion engine (ICE) vehicles—trucks and vans, which have picked up goods at depots outside the urban core and delivered them to businesses and households in the city.

However, in recent years ICE vehicles have struggled to maintain their efficiency in traveling the “last mile.” The rise of e-commerce has increased the demand for smaller-volume deliveries to residential addresses, but accessing these areas with larger vehicles is more complicated, especially because of road and parking congestion (OECD, 2003; Marcucci et al., 2015). Because of a lack of available parking, drivers have adopted several parking behaviors that further exacerbate the cost of the last mile. Large carrier companies are known to pay millions of dollars every year on parking tickets (Kawamura et al., 2014; Wenneman et al., 2015). Dalla

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Chiara and Goodchild (2020) estimated that a parcel delivery van in downtown Seattle spent on average 1.1 h per day searching for parking. Larger vehicles have been shown to queue to access busy commercial vehicle parking, as well as to re-route to the next delivery address in the absence of available parking (Dalla Chiara et al., 2021; Dalla Chiara and Cheah, 2017).

Moreover, many local and national governments are increasingly advocating to reduce cities' carbon footprint, to which urban transportation is a major contributor. One the one hand, cities are incentivizing private vehicle owners to use alternative energy-efficient vehicles, while on the other hand, they are reducing road and parking spaces for ICE vehicles and increase spaces for active transportation such as bike lanes, sidewalks, and pedestrian roads (Chen et al., 2016, 2017).

Because of the increased complexity of traveling the last mile and the pressure to reduce vehicle emissions in urban areas, carriers and cities are considering alternative modes to ICE vehicles to deliver goods. One of such alternatives is the cargo cycle (thereafter referred to as "cargo bike").

1.1. The cargo bike as a new urban delivery mode

Cargo bikes lie at the intersection between micro- and electric mobility. They are two- to four-wheeled vehicles with cargo-carrying capacity, often supported by an electric motor that assists the driver when pedaling.

Cargo bikes have several operational advantages over ICE vehicles. They are more agile in navigating urban road traffic, and they can use alternative road infrastructure such as bike lanes and sidewalks to drive and park. They can park closer to their delivery destinations, reducing walking distances and parking dwell times. Last but not least, fully electric cargo bikes do not produce tailpipe emissions, unlike ICE vehicles, and they consume less energy than electric vans (Verlinghieri et al., 2021).

However, cargo bikes also present several limitations. Because they depend on electric motors, their driving range is more limited than ICE vehicles. Also, their cargo-carrying capacity is much smaller. Consequently, they need to be stored closer to customers, and ICE vehicles are often still needed to carry goods from depots located outside city centers to cargo bike staging locations. Public authorities are also concerned that the widespread use of wide-body cargo bikes in urban areas (where transport infrastructure is often not bike-friendly) might increase congestion on bike lanes and sidewalks, potentially creating safety issues for pedestrians and other bikers.

One key factor influencing the success of cargo bikes as an alternative mode for urban deliveries is how cities regulate their use, and therefore how cargo bikes are allowed to navigate the urban transport infrastructure.

1.2. How are cargo bikes regulated in the U.S.?

While several U.S. cities have identified the use of cargo bikes as part of sustainable urban logistics practices, most of them are not directly regulating cargo bikes. From a regulatory perspective, cargo bikes are often considered like any other electric bike (PeopleForBikes.org, 2021). As of 2021, 35 states had updated their codes to adopt a three-class system that differentiates electric bikes according to whether they are equipped with motors that can propel the vehicles only when riders are pedaling (classes 1 and 3) or any time (class 2) and according to speed, with a maximum limit of 20 mph (classes 1 and 2) and 28 mph (class 3) (PeopleForBikes.org, 2021). The three-class system helps cities better target rules and restrictions to specific types of bikes, but it does not involve cargo bikes.

Only New York City has set specific regulations for cargo bikes, which limit their ability to drive on only travel and bike lanes, require them to ride in the direction of car traffic, and include several licensing and safety regulations (New York City Department of Transportation).

The lack of regulations for cargo bikes is also due to a lack of understanding of cargo bike operation, their use of the urban infrastructure, and their impacts on other road users and pedestrians. That is why several cities are rolling out pilot studies to gather more data and gain a better understanding of how cargo bikes can safely operate in the urban environment (Hu and Haag, 2019; Baruchman, 2018).

The current study included results from one such pilot project, analyzing data from a cargo bike that operated in Seattle, Washington.

1.3. Research objectives

There is a need to understand how cargo bike drivers use the urban infrastructure to better plan for the introduction of these new vehicles at a larger scale, and to better understand the impacts of existing infrastructure and regulation on cargo bike driving and parking behaviors. This motivated the current study to address the following research question:

How does a cargo bike use the urban transport infrastructure?

We fine-tuned the question by considering that a cargo bike has two main "states": parking—stopping and walking to a delivery destination—and driving—moving through the transport infrastructure from one delivery location to the next or from/to a depot. We therefore empirically analyzed both the parking and driving behaviors of cargo bikes and addressed the following questions.

- Where does a cargo bike park?
- For how long does a cargo bike park and what factors influence its dwell time?
- Where does a cargo bike drive?

- How do cargo bike travel times compare to those of ICE vehicles?
- Which factors influence the choice of driving infrastructure?

To address these questions, detailed data were collected from a cargo bike pilot test that took place in Seattle, Washington, between May and July 2021. We augmented the Global Positioning System (GPS) data collected by installing a video camera on the cargo bike and processing the video recordings to precisely observe the types of urban transport infrastructure used for parking and driving and the time spent on each type of infrastructure. The urban transport infrastructure was classified into travel lane, curb lane, bike lane and sidewalk. The time spent on each type, and the main characteristics of the different types (e.g. bike lane width and whether the bike lane used were protected or not, sidewalk width, number of travel lanes, street grade, etc.) were recorded. We then matched the GPS traces with the processed video data to gather information about both the chosen route and the characteristics of the existing infrastructure available on the route. Using this data, we analyzed the driver's parking and driving behaviors. Descriptive statistics on the amount of time spent driving on each type of infrastructure were reported. The cargo bike trip times were also benchmarked with the expected travel times estimated using the Google Maps Distance Matrix API to understand how fast cargo bikes with respect to motorized vehicles in urban areas are, as well as their cruising for parking behaviors. Furthermore, the parking behaviors were analyzed, including the distribution of observed parking dwell times, the number of deliveries performed per parking stop, and the driver's walking distance. Finally, the choice of driving infrastructure (between travel lane, bike lane and sidewalk) for each traversed road segment was modeled using a random utility model, and the main characteristics of the infrastructure that makes the cargo bike driver less likely to ride on the sidewalk are described.

Results from this analysis will help planners better understand the impacts of larger scale implementation of cargo bikes on road and sidewalk congestion and, therefore, how to regulate and facilitate the adoption of such vehicles by private carriers.

We refer the reader to Section 6.3 for a discussion of the potential policy implications of these empirical findings. The rest of the paper is organized as follows. After a review of the relevant literature, the methodology used is outlined, including descriptions of the cargo bike pilot test, the classification of the urban transport infrastructure, and the behavioral framework of the cargo bike driver. Afterward, the data sources and the data processing method are described, followed by the analysis results. Finally, we discuss the results obtained and their policy implications.

2. Relevant literature

Several efforts have studied the economic, environmental, and operational efficiency of cargo bikes for urban delivery distribution (Simoni et al., 2018; Choubassi et al., 2016; Marujo et al., 2018; Dalla Chiara and Goodchild, 2020; Melo and Baptista, 2017; Arnold et al., 2018; Perboli and Rosano, 2016, 2019). These studies have often used simulation methods to test different cargo bike scenarios, and their results have been based on hypotheses regarding how cargo bikes navigate the urban transport infrastructure. For instance, Dalla Chiara et al. (2020) assumed that cargo bikes can make the same number of deliveries per stop with a 40 percent shorter parking dwell time than trucks. Choubassi et al. (2016) assumed that the bikes are always able to access bike lanes and are therefore not affected by road congestion. Simoni et al. (2018) assumed as well that cargo bikes' average speed is not affected by traffic congestion. Figliozzi et al. (2017, 2020) assumed that cargo bikes can deliver faster than trucks and vans because they don't spend time searching for parking. Perboli and Rosano (2016, 2019) performed a simulation analysis and found that the operational advantages of using cargo bikes are heavily based on the increased level of service, in particular, they assumed that cargo bike drivers' service times are shorter than those of delivery van drivers and that cargo bikes are as fast as delivery vans and faster under peak hour congestion.

Few studies have focused on validating these assumptions, focusing instead on a more micro-scale analysis of cargo bikes by collecting and analyzing GPS data from real-world cargo bike implementations. Gruber and Narayanan (2019) compared real cargo bike trip times with their respective cars' trip times estimated from Google Maps and analyzed how different spatial attributes explained travel time differences. They found that half of the cargo bike trips were at most 1 to 2 min slower than a car, and 90 percent were at most 20 min slower. They also found that higher congestion levels on roads and the ability of cargo bikes to take "shortcuts" in comparison to car routes favored their speed competitiveness. Similarly, Gruber et al. (2014) observed that cargo bikes are on average 1.4 km per hour slower than cars. Conway et al. (2017) analyzed speed data from two cargo bike pilot studies in New York and found that cargo bikes were generally slower on smaller streets than on larger arterials and that their speeds on streets were higher than truck speeds. The authors also compared cargo bike speeds on streets and arterials with and without bike lanes and found mixed results, with cargo bikes being faster on arterials with bike lanes but not on streets with bike lanes.

Even fewer studies have analyzed cargo bike parking behaviors. Conway et al. (2017) observed mean dwell times for delivery stops between 9.5 and 14.9 min and found that parking regulations didn't explain the observed variations in dwell times. The authors explained that the reason was that cargo bikes were usually parked on the sidewalk, but no data were provided to substantiate that observation. Figliozzi et al. (2017, 2020), using data from a cargo bike carrier based in Portland, Oregon, observed an average dwell time per customer of 10 min.

While previous studies have attempted to find the relationship between cargo bike driving and parking behaviors with urban infrastructure typologies and regulations, the data used have not been detailed enough to discern the exact use of infrastructure type. This is because GPS data, the most common data source used in these studies, have an error range of around 7 to 13 m (22 to 43 feet). That allows, at best, an understanding of which road segment on which the cargo bike was located but not the type of infrastructure the cargo bike was using (e.g., a sidewalk or a bike lane) nor the type of activity performed (Merry and Bettinger, 2019).

In the current study, we augmented GPS data with video recordings to precisely detect the type of infrastructure the cargo bike was using as well as the activity performed. This allowed us to obtain a level of precision never achieved before in the analysis of cargo bike behaviors. The availability of such data allowed us to better understand the relationship between existing infrastructures and regulations and cargo bike behaviors.

3. Methodology

3.1. The Seattle cargo bike pilot

The current study was based on detailed data collected from the cargo bike shown in Fig. 1. The bike was part of a Seattle "neighborhood delivery hub" pilot, a central shared urban space dedicated to the pick-up and delivery of goods (Schubert, 2021.).

The bike used was 3 m long and 1.2 m wide. It was electrically assisted only when the driver was pedaling up to 32 km per hour (20 miles per hour). Its expected mileage range was 19 to 39 km. It had a storage capacity of approximately 0.65 cubic meters and a payload capacity of 91 kg.

The cargo bike operated between May to July 2021 and consisted of a single driver delivering meal kits. Each meal kit measured approximately 0.04 cubic meters and weighed 8 kg. The cargo bike was stored overnight in a container at the delivery hub location, thereafter referred to as the "depot". A truck carried the meal kits from a depot to the container at the hub location in the morning, then the driver loaded the parcels into the bike and rode it to deliver the meal kits to the final customers.

The driver delivered on average nine meal kits per route and rode two to three routes per day, each route starting and ending at the hub. The routes were planned by the carrier, and route information was provided to the driver via a mobile app.

The cargo bike was regulated as an e-bike, which in Seattle is allowed to ride on vehicle travel lanes, sidewalks, and bike lanes. At the time of the study, there were no specific regulations regarding cargo bike parking restrictions. While Seattle is provided with racks for bike parking, mostly located on sidewalks, the cargo bike didn't need to be locked to a rack.

3.2. Study area

The cargo bike operated in the downtown core of Seattle, Washington, within the neighborhoods of Belltown, South Lake Union, Lower Queen Anne, Central Business District, and Pike-Market (see Fig. 2), covering an area of 5.6 km^2 (2.2 miles^2). The depot was in an off-street parking area located at the corner of John St. and 5th Avenue North, approximately in the middle of the area where the cargo bike operated. Table 1 reports the main characteristics of the study area. Predominantly, the study area is designed as mixed land use, hosting both commercial and residential buildings. A total of 121.8 km (75.7 miles) of curb is allocated mostly to no parking and paid parking, with about 4.4 percent of curb allocated to commercial vehicles parking. It also contains a total of 8.5 km of non-continuous bike lanes that are characterized by some form of separation from car traffic. The mean sidewalk width is 1.8 m (City of Seattle Department of Transportation, 2021).

3.3. Urban infrastructure classification

The urban transport infrastructure comprises different streets and roads spaces. We categorized the urban transport infrastructure into four main types (see Fig. 3)—travel lane, curb lane, bike lane, and sidewalk—and for each type, describe several attributes.

The travel lane is a dedicated space for the transit of motorized vehicles. Whenever a road comprises multiple travel lanes, these can be either one or two traffic directions. Travel lanes are also characterized by different road grades, measured in percent of slope.

Fig. 1. The cargo bike used in the Seattle pilot test.

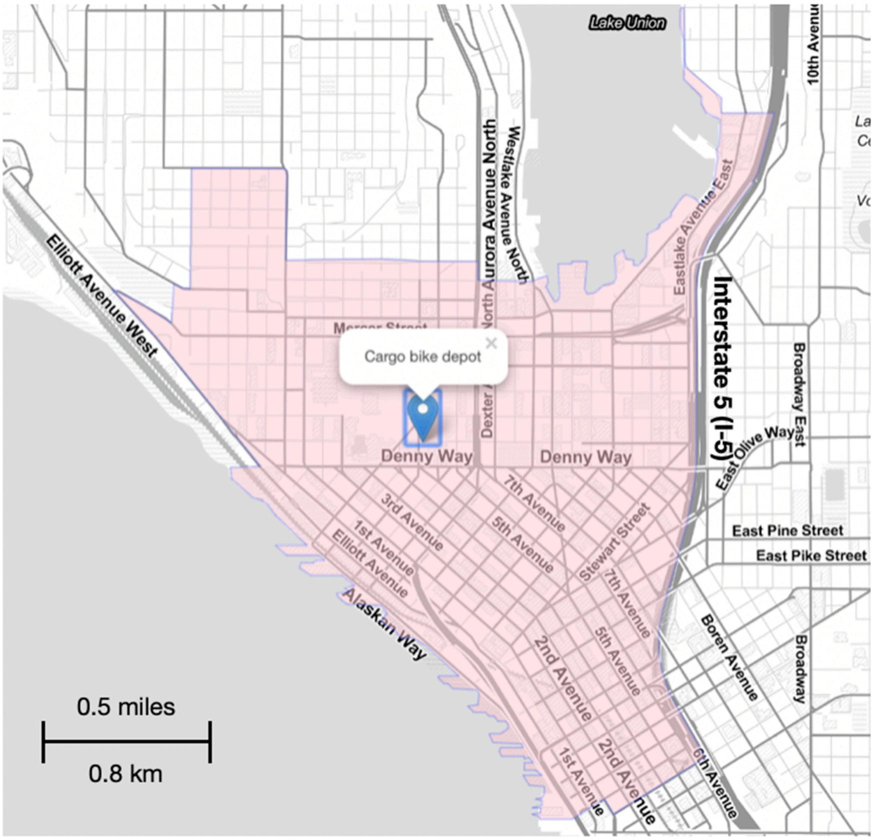


Fig. 2. Study area and the location of the depot.

Table 1
Study area characteristics.

Variable	Stat.	Value
Land use	Total area	5.6 km^2
	Mixed	97.4 %
	Commercial	0.7 %
	Residential	1.9 %
Curb allocation [a]	Total length	121.8 km
	CVLZ	4.4 %
	PLZ	2.5 %
	PP	24.7 %
	NP	63.3 %
	Bus	5.1 %
Protected bike lanes	Tot. length	8.5 km
Sidewalk width	Min.	0 m
	Median	1.8 m
	Mean	1.8 m
	Max	15.9 m

[a] CVLZ = Commercial Vehicle Load Zone; PLZ = Passenger Load Zone; PP = Paid Parking; NP = No Parking.

The curb lane is the portion of the road that separates pedestrians from moving vehicles, and it allows vehicles to stop and load/unload people and goods. Different portions of the curb lane are dedicated for different vehicles and purposes: paid parking (PP) is for the storage of any vehicles upon payment of a parking fee; commercial vehicle load zones (CVLZ) are used by commercial vehicles making deliveries or performing services; passenger load zones (PLZ) are for passenger pick-ups and drop-offs; bus zones (Bus) are for bus stops; no parking zones (NP) are curb spaces that do not allow any vehicle to stop.

The bike lane is a travel lane that allows bicyclists to ride separately from vehicle and pedestrian flows. A road might include none, one,

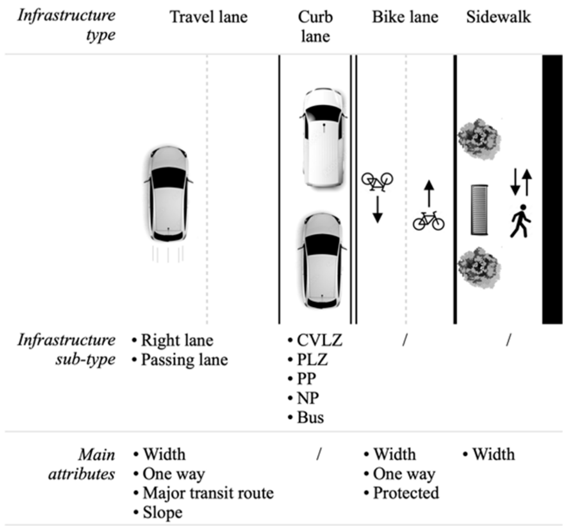


Fig. 3. Classification of the urban transport infrastructure.

or more bike lanes, and these can be physically separated from vehicle traffic, the latter are referred to as protected bike lanes.

Finally, a sidewalk is that portion of road space dedicated to pedestrian flow. Different sidewalks are characterized by different widths.

3.4. Behavioral framework

The driver was provided at the start of the day with one or more tours, consisting of a list of delivery addresses and a recommended path between each pair of addresses. The driver was not able to change the order of deliveries, and we assumed that the driver followed the recommended path. At the beginning of each tour, the driver loaded the meal kits into the cargo bike and then started driving to the first destination. In conducting a delivery tour, the driver decided where to park and for how long, how many deliveries to make per stop, how far to walk, and on which type of infrastructure to drive. By using a video camera, we recorded the parking and driving infrastructure used by the cargo bike driver while performing deliveries in Seattle. We then introduced a random utility model (RUM) of choice of driving infrastructure for the cargo bike (Train, 2003). The driver was provided with a delivery address and a path to reach it. We split the path into a sequence of independent road segments, each starting and ending with an intersection. We assumed that each segment was characterized by a uniform infrastructure, i.e., the characteristics of the segment (e.g., the number of lanes, width of the sidewalk, etc.), did not change within the segment. At the beginning of each segment, the driver chose between driving on the travel lane (*TL*), bike lane (*BL*), or on the sidewalk (*SW*). We assumed that the set of infrastructure types from which the driver could choose (C_i) depended on the specific segment *i*:

$$C_i \subseteq \{TL, BL, SW\}.$$

The driver entering segment *i* at time *t* chose driving infrastructure $j \in C_i$, given several alternative-specific attributes, such as the width of the travel lane, bike lane, and sidewalk, whether the road segment traffic flow was one- or two-directional, the road grade, whether the road was designated as a major transit route by the local transport authority, whether the bike lane traffic flow was one- or two-directional, whether the bike lane was protected or not, and whether a parking event occurred at segment *i* at time *t* or not. We denoted x_{ijt} as the vector of attributes. The cargo bike driver perceived utilities $\{U_{ij}\}_{j \in C_i}$ and chose the alternative with the highest utility. Utilities were modeled as follows:

$$U_{ij} = \beta' x_{ijt} + \varepsilon_{ij}$$

where β' was a vector of unknown parameters and ε_{ij} were random error terms. We computed the multinomial logit (MNL) choice probabilities P_{ij} as follows:

$$P_{ij} = \frac{e^{\beta' x_{ijt}}}{\sum_{j \in C_i} e^{\beta' x_{ijt}}}$$

To obtain estimates $\widehat{\beta}$ of unknown parameters, we collected data from the Seattle cargo bike pilot test.

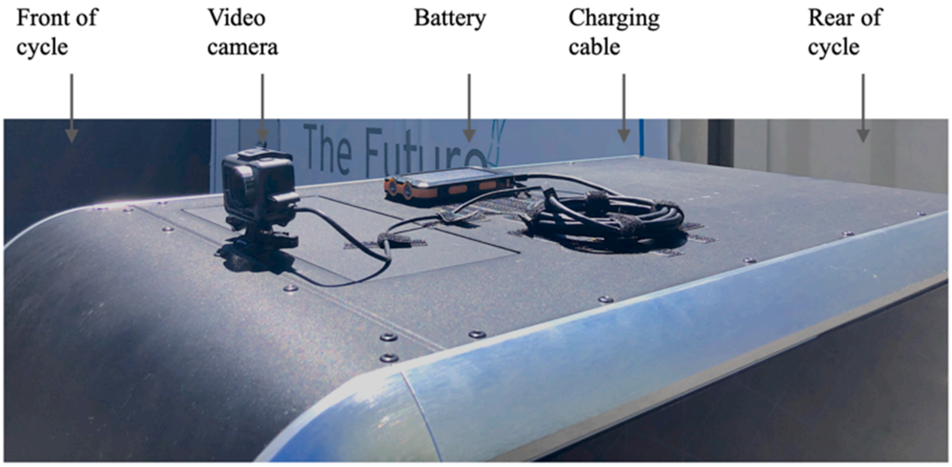


Fig. 4. Video camera set-up.

4. Data

4.1. Data sources

Four data sources were used: (1) video data, (2) GPS data, (3) delivery data, and (4) infrastructure data. The next four subsections provide details for each data source.

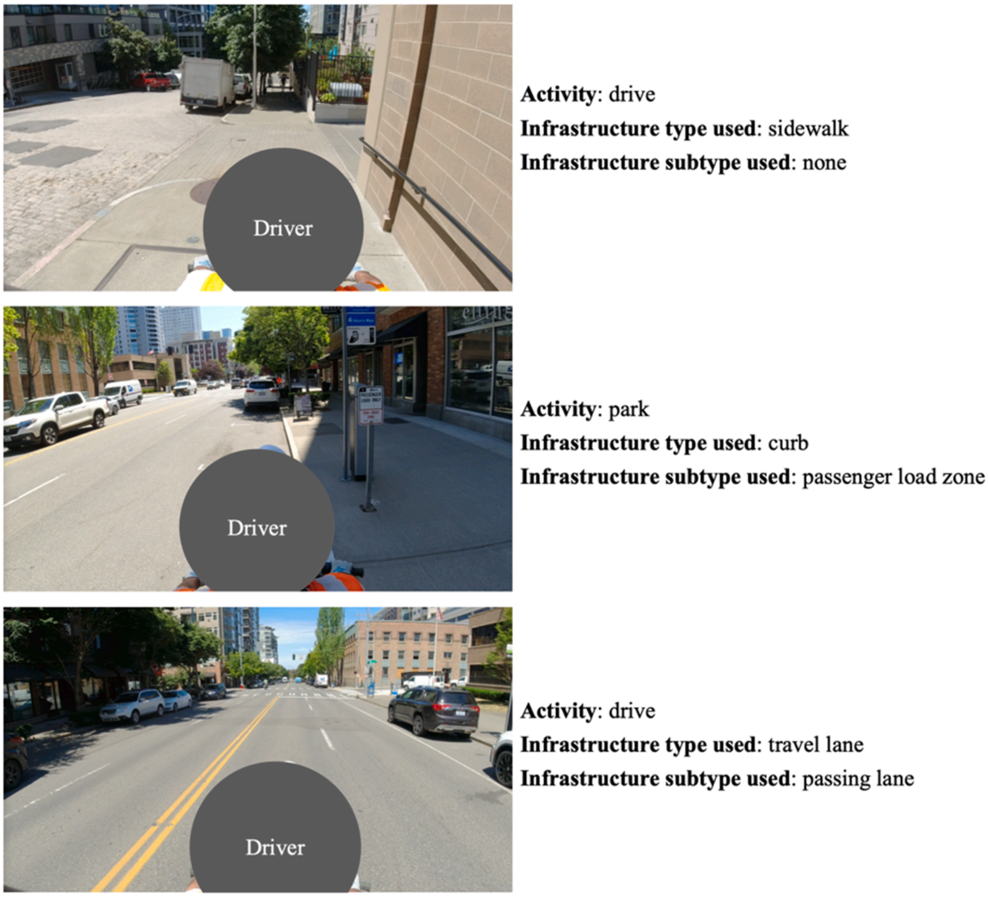


Fig. 5. Snapshots from the video recordings.

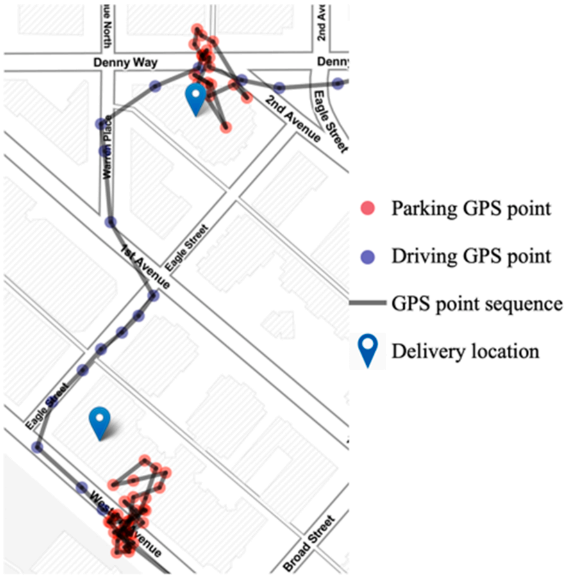


Fig. 6. Map showing sample of GPS traces with colors identifying the type of activity performed (blue = driving, red = parking) and markers showing the delivery locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.1.1. Video data

To observe where the bike drove and parked, a video camera was installed on the top of the cargo box, recording the front view of the driver. Fig. 4 shows the video camera set-up.

The camera was manually activated at the start of each working day, and it was deactivated at the end of each day. The camera was

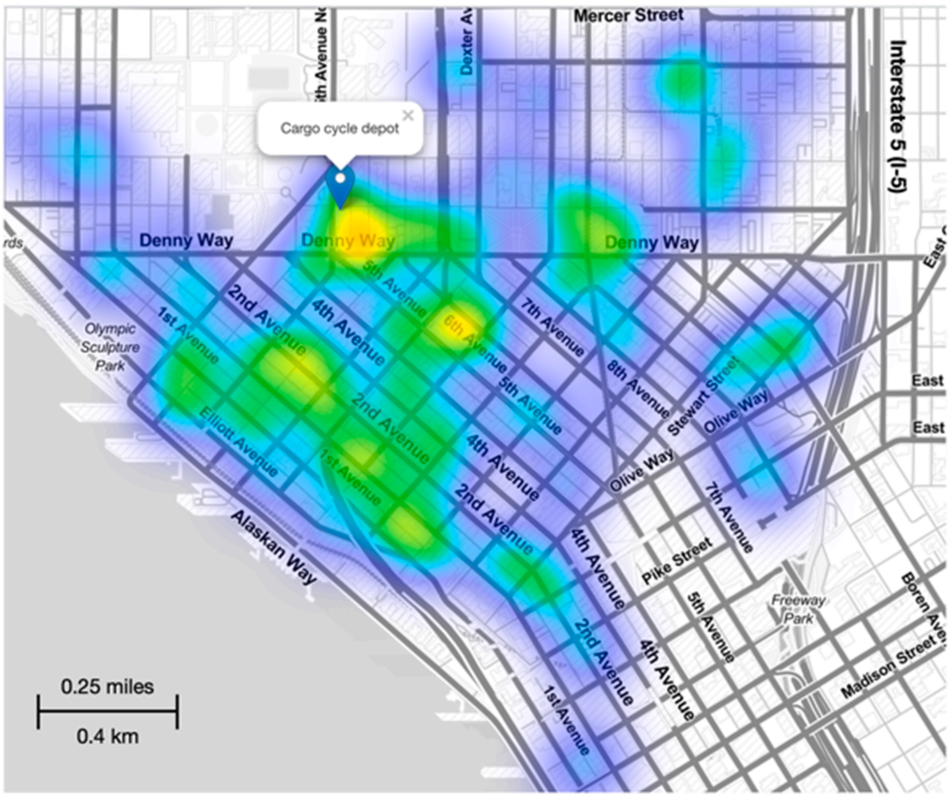
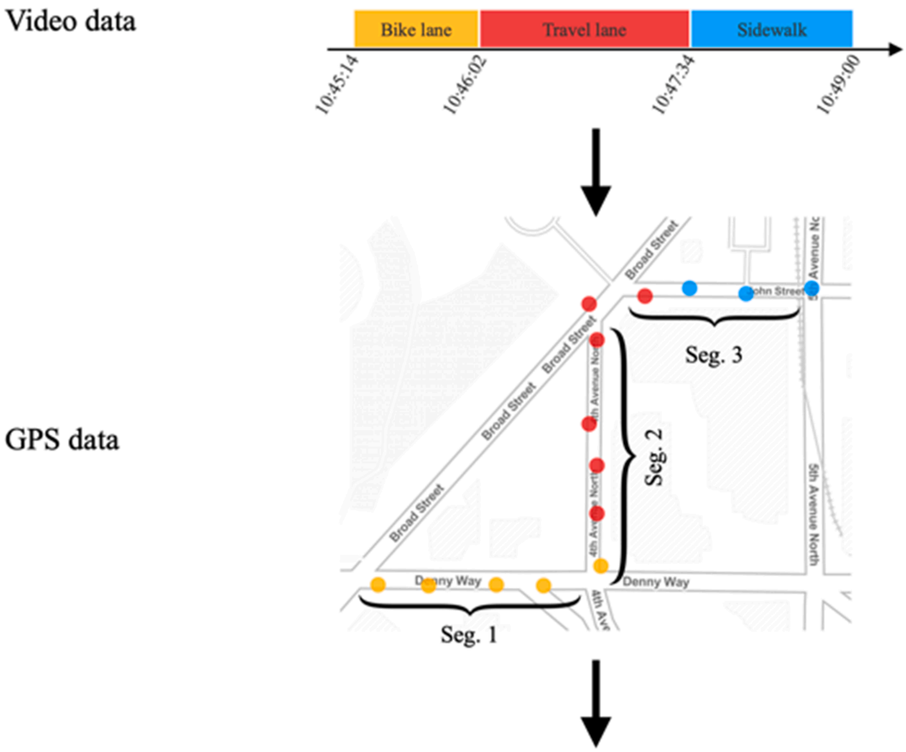


Fig. 7. Heatmap of the deliveries made by the cargo bike and the location of the depot.



Segment	Main infrastructure used	Street width	Sidewalk width	…
Seg. 1	Bike lane	74 ft.	6 ft.	…
Seg. 2	Travel lane	52 ft.	5 ft.	…
Seg. 3	Sidewalk	56 ft.	12 ft.	…

Fig. 8. Overview of data processing.

reset, and the battery was recharged every evening. Fig. 5 shows three snapshots from the videos obtained, each showing a different use of the infrastructure and activity. Due to privacy concerns as well as limited capacity of the camera's memory card, the quality of the video recordings was kept low, such that individuals and license plates of vehicles were not recognizable and to not incur into loss of video recordings. Moreover, the driver agreed and was supportive of the data collection.

4.1.2. GPS data

GPS data were collected by using the driver's mobile device, with an average recording frequency of one GPS point every 20 s. For each point, the date, timestamp, and longitude/latitude coordinates were recorded. GPS traces were collected when the driver was both driving and walking. Fig. 6 shows a sample of GPS traces. By merging the GPS data with data obtained from the video recordings, it was possible to identify the activity performed during each GPS trace and time. (The data processing algorithm is described in the next section.).

4.1.3. Delivery data

For each delivery made we recorded the longitude/latitude coordinates of the delivery location and the time. Delivery data were obtained from the driver's mobile device. Fig. 6 shows the locations of a sample of deliveries next to the GPS traces of the driver. Fig. 7 shows a heatmap of the deliveries and the location of the cargo bike depot. Most of the deliveries occurred in the central business district and Belltown neighborhoods of Seattle, west of Interstate 5 (I-5).

4.1.4. Infrastructure data

Data describing the characteristics of the road segments traversed by the cargo bike were obtained by querying geographic information system (GIS) layers obtained from the City of Seattle Open Data Portal (City of Seattle Department of Transportation, 2021). The following spatial layers were used.

- The street layer contained characteristics of the road segments, including street width, whether the road was one- or two-directional, number of lanes and the road grade, measured in percent slope.
- The sidewalk layer contained characteristics of the sidewalks of the road segments, including sidewalk width.
- The bike lane layer contained the characteristics of existing bike facilities, including the presence of a bike lane, its width, whether it was one or two ways, and whether it was protected.
- The public transit layer included the presence of bus stops, the presence of bus lanes, and whether the road segments driven by the cargo bike were major transit routes.

4.2. Data processing

The data analyses reported in the rest of the paper used either a single data source or a combination of the data sources described above.

Fig. 8 shows an overview of the data processing. The video recordings were processed manually by segmenting the driver's time into different time segments, each identifying a given activity performed and the infrastructure used. For instance, on the top of Fig. 8, the cargo bike drove through a bike lane, travel lane, and then to a sidewalk, thus identifying three distinct driving time segments.

Then, each GPS trace was matched uniquely with a video time segment, as shown in the middle of Fig. 8. Finally, by querying different GIS layers, we identified the road segments traversed by the cargo bike and their respective characteristics (as shown at the bottom of Fig. 8). For each road segment, the main type of infrastructure used was obtained by identifying the infrastructure type associated with the largest number of GPS traces in that segment. Moreover, we assumed that the infrastructure characterizing a given segment was uniform within the segment. This was a reasonable assumption, given that the road segments in the Seattle urban core are relatively short—on average 80 m (263 feet)—and therefore, their infrastructure does not generally change significantly within a segment.

4.3. Data sample description

Table 2 describes the final data obtained. A total of 28 h of cargo bike activity were video recorded across 14 days, between May and July 2021. The total video time was divided into 1,185 time segments, each characterized by a type of infrastructure used and activity

Table 2
Data sample description.

Data source	Summary statistic	Value
Video data	No. of observations	1,185 video segments
	No. days recorded	14 days
	Total recording time	28 h
Delivery data	No. of observations	224 deliveries
Infrastructure data	No. of observations	706 road segments
	No. of travel lanes (lanes per direction)	
	Min	1.00 lane
	Median	2.00 lanes
	Mean	1.84 lane
	Max	4.00 lanes
	Std. deviation	0.83 lanes
	Sidewalk width (meters)	
	Min	1.04 m
	Median	1.96 m
	Mean	2.21 m
	Max	9.14 m
	Std. deviation	0.69 m
	Bike lane width (meters)	
	Min	1.17 m
	Median	3.00 m
	Mean	2.60 m
	Max	3.05 m
	Std. deviation	0.61 m
	Road grade (% point)	
	Min	0.00 %
	Median	1.00 %
	Mean	2.12 %
	Max	14.00 %
	Std. deviation	2.19 %
	% of segments: major transit routes	44.00 %
	% of segments: one-way road	47.00 %
	% of segments: bike lane available	14.00 %
	% of segments: protected bike lane	11.47 %
	% of segments: two-way bike lane	9.00 %

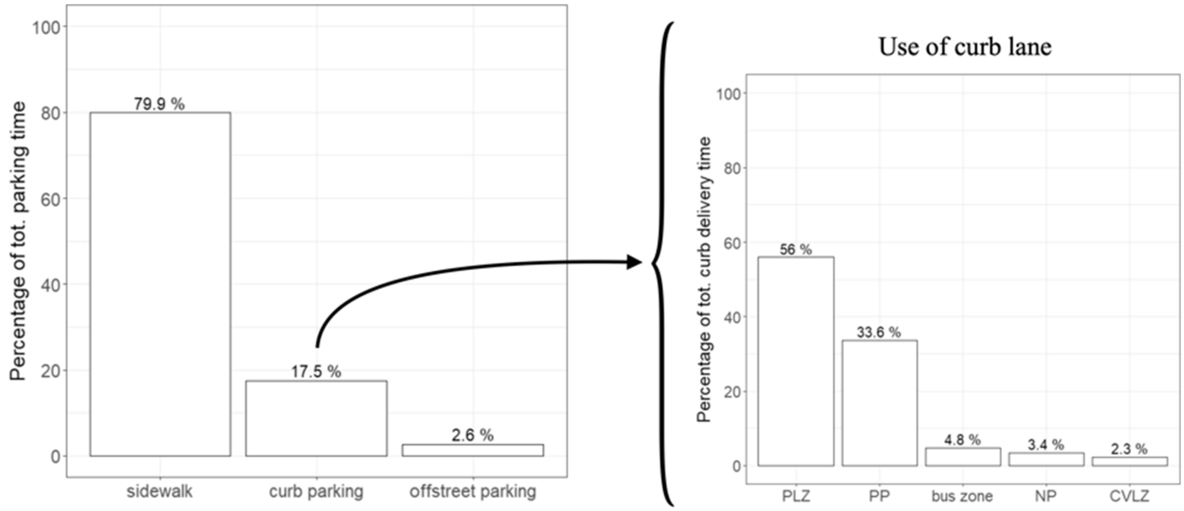


Fig. 9. Left: percentage of time spent parking by type of infrastructure. Right: percentage of time spent parking by type of curb zone used.

type. A total of 224 deliveries were recorded, with an average of 16 deliveries made per day, or eight deliveries made per hour. The video and delivery data sources were merged with 4,590 GPS traces, which were then mapped to 706 road segments traversed by the cargo bike at a given time *t*. The main characteristics of the road segments contained in the final data set are reported in Table 2.

5. Results

5.1. Where did the cargo bike Park?

To make a delivery, a driver first chose a parking location and then walked to the customer's address. We merged data from the video recordings with the delivery data (times and locations of deliveries) and obtained 143 parking events with at least one delivery made per event. We then aggregated the total time spent parked by the type of infrastructure where the vehicle was parked.

The left plot in Fig. 9 shows the percentage of time spent parking on a sidewalk, in the curb lane, or off-street. While most time was spent parked on the sidewalk – almost four times the other types of infrastructure combined—the driver still spent a considerable amount of time (~20 percent) parked at the curb.

The right plot in Fig. 9 breaks down the time spent parked at a curb lane into different types of curb zones. We observed that the largest share of curb parking time was spent on PLZs and PPs (more than 80 percent of the total parking time). There was only one instance each in which the cargo bike parked in a bus zone, NP, or CVLZ.

A similar analysis was performed using parking events as measurement unit instead of parking time. The resulting distribution of the percentage of parking events by type of infrastructure did not change much compared to Fig. 9, and therefore it was not reported here.

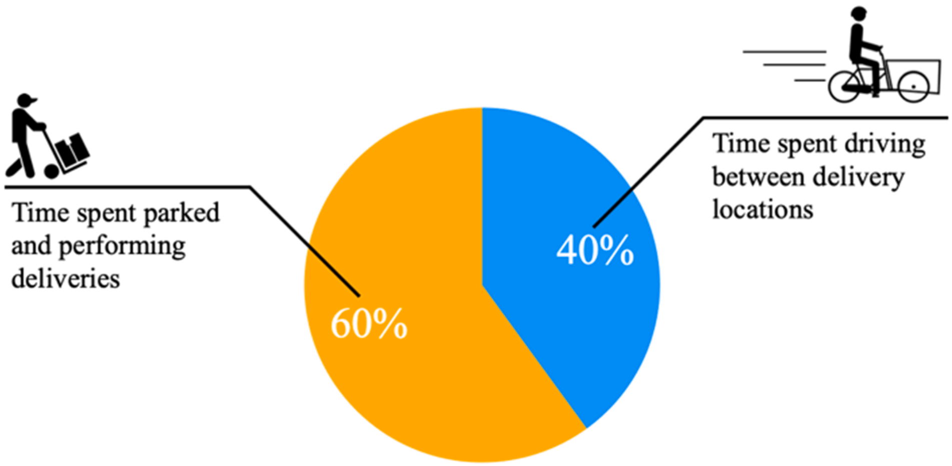


Fig. 10. Percentage of total route time the cargo bike driver spent parked and making deliveries vs driving between delivery destinations.

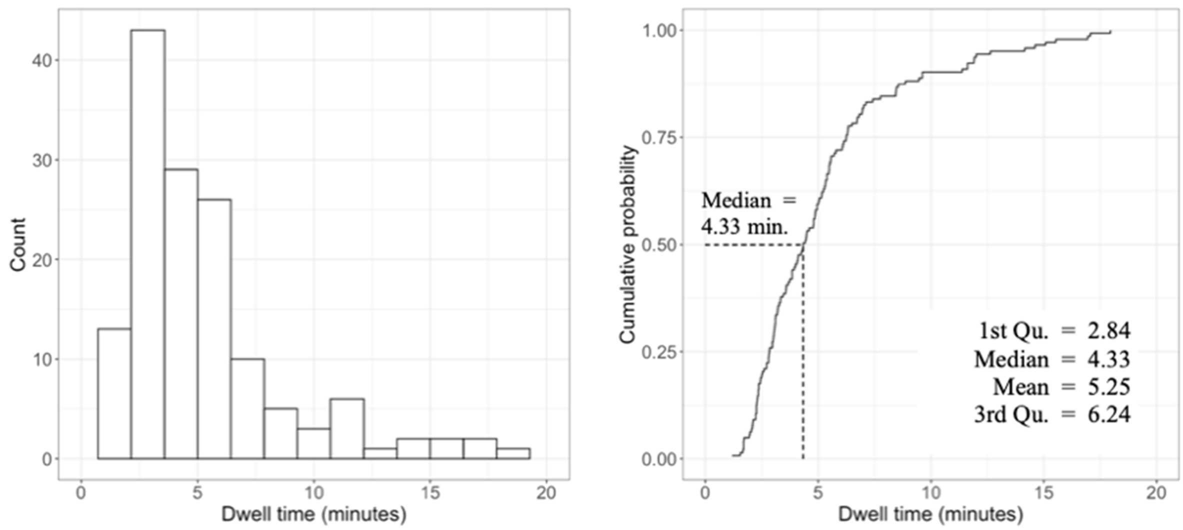


Fig. 11. Left: empirical distribution of the cargo bike parking dwell time (in minutes). Right: cumulative distribution of the same dwell times and summary statistics.

5.2. How long was the cargo bike parked for and what factors influenced its dwell Time?

For every cargo bike route, we broke down the driver's time into time spent parking and driving. At least one delivery was made during all the parking time segments considered; the time spent for reloading the e-cargo bike with packages or breaks was excluded in this calculation. We found that the cargo bike driver spent approximately 60 percent of the time parking and walking to a delivery destination, and 40 percent driving in between delivery locations and to/from the depot (see Fig. 10).

We then analyzed individual parking dwell times, i.e., the time spent in a parking location while making a delivery. Fig. 11 shows the empirical and cumulative probability distribution of parking dwell times. We observed a right-skewed distribution with a mode of 1.7 min and a median dwell time of 4.3 min, with most dwell times ranging between 2.8 min and 6.2 min. The empirical distribution was found to best fit the lognormal distribution with a log mean of 1.48 and log standard deviation of 0.578.

On average, the dwell time was longer for delivery stops where the cargo bike was parked on a sidewalk than at the curb, as seen in Fig. 12. The cargo bike spent, on average, 5.55 and 4.11 min parked per stop on a sidewalk and at the curbside, respectively. The dwell times for parking at the sidewalk had a higher variability and more outliers than those for curb parking.

Fig. 13 shows the percentage of stops by the number of deliveries made per stop, i.e., the number of delivery addresses to which the driver walked from a single parking location. The driver made only one delivery in 72.7 percent of the stops. Only 3.5 percent of the stops involved at least three deliveries.

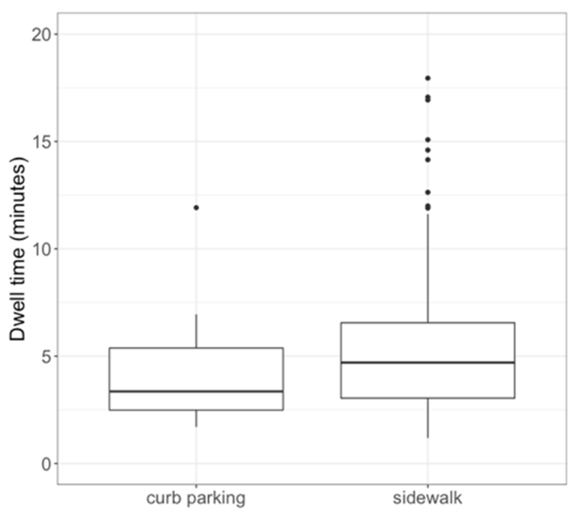


Fig. 12. Boxplot of empirical distributions of parking dwell time by infrastructure used. The horizontal lines of the boxes indicate respectively, from the top, the 3rd quartile, median, and first quartile.

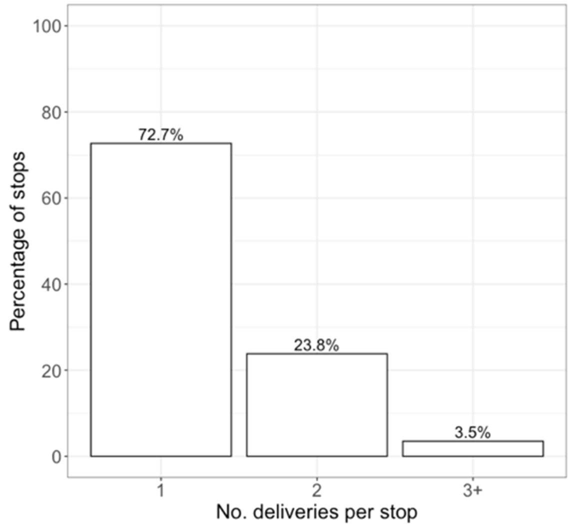


Fig. 13. Percentage of stops by the number of deliveries made per stop.

The mean Euclidean distance between a delivery location and the respective parking stop location was 32 m, with most distances measuring between 20 and 40 m, as seen in Fig. 14.

We performed a regression analysis of the logarithm of dwell time on the stop-to-delivery location distance, the number of deliveries per stop, and whether the cargo bike was parked at the sidewalk. Only the coefficient for the number of deliveries per stop was statistically significant, showing that adding a delivery per stop increased the dwell time by 37 percent.

Overall, we concluded that the cargo bike made short stops, often parking right in front of the targeted building, and rarely made more than one delivery per stop.

5.3. Where did the cargo bike drive and what factors influenced the choice of driving Infrastructure?

Using data from the video recordings, we established the total time spent driving for each type of infrastructure. Fig. 15 shows the percentage of time spent driving on a travel lane, sidewalk, bike lane, and others (alleys and off-street areas). While 55 percent of the time was spent on a travel lane, a considerable share of time was spent driving on a sidewalk (37 percent). From the video recordings we noted two main reasons for the driver to choose the sidewalk:

- Whenever the driver had to make a delivery to a building located in the middle of the block;
- Whenever the driver was riding against the traffic flow.

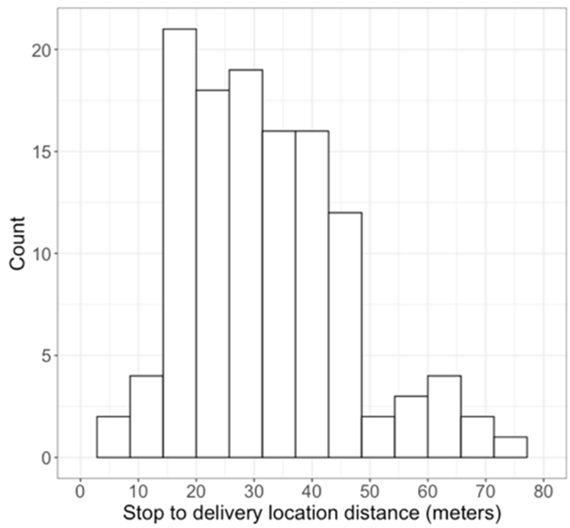


Fig. 14. Empirical distribution of the Euclidean distance between the parking stop location and the respective delivery destination (in meters).

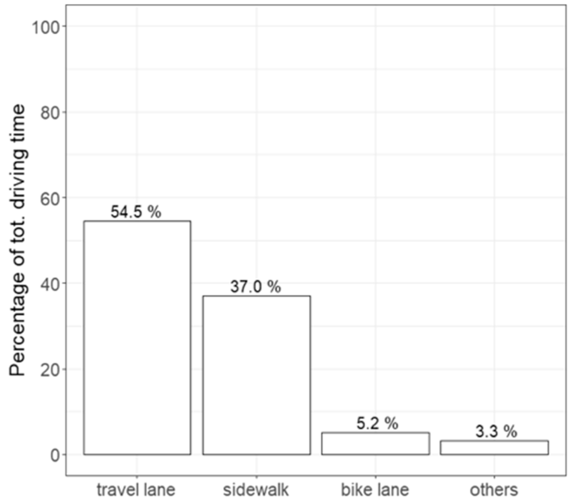


Fig. 15. Percentage of time spent driving by infrastructure type.

Only 5.2 percent of the driving time was spent on bike lanes. Considering only the road segments that had a bike lane available, the driver chose to drive in the bike lane approximately 49 percent of the time.

By merging the video data with the infrastructure data, a total of 706 observations were obtained, each consisting of a road segment traversed by the driver at a certain moment in time. For each segment, the driver's choice of riding the cargo bike on the travel lane, sidewalk, or bike lane was recorded, together with several characteristics describing the design and availability of each type of infrastructure, as well as characteristics of the driver's activity, e.g., if the driver was riding against the traffic flow, if any parking occurred, etc. A multinomial logit (MNL) model was fit with the collected data using PythonBiogeme, open-source software for maximum likelihood estimation (Bierlaire, 2016). Table 3 reports the estimated model coefficients, their robust standard errors, t-tests, and p-value ranges. The meaning of each explanatory variable used and the interpretations of the estimated coefficients are reported below (see Table 3).

Table 3
Estimation results for the multinomial logit (MNL) model.

Explanatory variable	Estimated coefficient	Robust st. error	Robust *t*-test
Travel lane (TL) utility:			
1) Dummy: previous segment TL	0.85	0.44	1.91·
2) Street grade (percentage) × Dummy: downhill	−0.28	0.09	−3.12***
3) Street grade (percentage)	0.07	0.08	0.82
4) Number of lanes	0.12	0.19	0.62
5) Dummy: major transit route	−0.65	0.29	−2.23*
6) Dummy: one-way segment	−0.07	0.29	−0.24
7) Dummy: parked at the curb	1.80	0.707	2.55**
Bike lane (BL) utility:			
8) BL-specific constant	3.29	1.72	1.91·
9) Dummy: previous segment BL	1.17	0.59	1.98*
10) Dummy: the bike lane is protected	1.95	1.18	1.65·
11) Dummy: two-way bike lane	−1.39	1.11	−1.25
12) Bike lane width (meters)	−1.83	0.94	−1.96*
Sidewalk (SW) utility:			
13) SW-specific constant	−1.79	0.66	−2.73**
14) Dummy: previous segment SW	1.59	0.48	3.33***
15) Sidewalk width (meters)	−0.09	0.16	−0.60
16) Dummy: parked on the sidewalk	3.65	0.35	10.50***
17) Dummy: ride counterflow	2.42	0.32	7.60***
Summary statistics			
Sample size	706		
Initial log-likelihood	−528.81		
Final log-likelihood	−273.01		
Rho-square value	0.48		
Adjusted rho-square value	0.45		

Note: *** $p-value \leq 0.001$; ** $p-value \in (0.001, 0.01]$; * $p-value \in (0.01, 0.05]$; $\cdot p-value \in (0.05, 0.15]$.

- *Alternative-specific constants (coefficients 8 and 13)*. The estimated alternative-specific constants for the bike lane and sidewalk showed a relative preference for the cargo bike driver to ride on the bike lane, followed by the travel lane and the sidewalk.
- *Connected infrastructure (coefficients 1, 9, and 14)*. These coefficients multiplied dummy variables that were equal to 1.0 whenever in the previous traversed segment the driver chose the travel lane, bike lane, or sidewalk, respectively. All three estimates were positive and significant, showing that the driver had a general tendency to remain on a certain type of infrastructure. This was especially true for the bike lane, which showed the largest estimated coefficient among the three. This result showed the importance of providing a connected network of bike lanes.
- *Street grade (coefficients 2 and 3)*. Both coefficients captured together the effect of street grade, measured in percent of the slope, on the preference for riding on a travel lane vs bike lane and sidewalk. The higher the percentage point was, the steeper the road. Coefficient 2 multiplied with the road grade and with a dummy variable that took value 1.0 whenever the bike was going downhill, while coefficient 3 multiplied only with the road grade variable. Coefficient 2 was negative, larger than coefficient 3, and significant, indicating that the steeper the road, whenever the driver was riding downhill, the more likely the driver was to ride on a sidewalk. Instead, whenever the driver was riding uphill or flat (hence coefficient 2 was multiplied by zero), the effect of road grade was close to zero, hence it did not affect driver preferences (coefficient 3 was small and not statistically significant). Given that the bike was rear-loaded, this result could be interpreted such that the driver felt less confident in driving downhill than uphill, and therefore he/she preferred the sidewalk to keep a lower speed.
- *Travel lanes characteristics (coefficients 4, 5, and 6)*. Coefficients 4 to 6 multiplied with three different characteristics of the road, namely the number of travel lanes, whether the road was considered a major public transit road, and whether the road was one-way. Only coefficient 5 was statistically significant, showing a preference for riding on the sidewalk or bike lane whenever a road segment was a major transit route. This showed that the driver was less willing to ride on a travel lane in the potential presence of bus traffic. Coefficients 4 and 6 were not statistically significant.
- *Parking choice (coefficients 7 and 16)*. These coefficients multiplied dummy variables that were equal to 1.0 whenever the driver traversing a given segment stopped the cargo bike and parked it at the curb or the sidewalk, respectively. Both coefficients were positive, large, and significant, showing a strong preference for riding on a travel lane and on a sidewalk whenever the driver wanted to park the vehicle at the curb and on the sidewalk, respectively. We assumed here that the choice of parking is exogenous to the choice of driving infrastructure. These results can be explained by the fact that curb parking can be easily accessed from a travel lane, whereas sidewalk parking can often be accessed only by riding on the sidewalk from the beginning of the road segment, where the driver could use the ramps to access the sidewalk. This showed that parking choice influenced the type of infrastructure used to ride the vehicle.
- *Bike lanes characteristics (coefficient 10, 11, and 12)*. These coefficients multiplied three different variables describing the characteristics of the bike lane: coefficient 10 multiplied a dummy variable equal to 1.0 whenever the bike lane was protected, i.e., a physical separation exist between the bike and travel lanes; coefficient 11 multiplied with a dummy variable that was equal to 1.0 whenever the bike lane was two-way; coefficient 12 multiplied with a variable describing the width of the bike lane in meters. Coefficient 10 was positive, large, and significant, showing a preference for using the bike lane whenever it was protected. Coefficient 11 was negative and large, showing a preference for one-way bike lanes; however, the estimate was not statistically significant, and more data should be collected to validate this result. Coefficient 12 was negative, large, and significant, and while it seemed to indicate a preference for narrower bike lanes, the effect of this coefficient was seen after we controlled for two-way bike lanes and protected bike lanes, which are also wider than unprotected bike lanes and one-way bike lanes. To better unravel the effect of bike lane width on the choice of riding on a bike lane, more data with a larger variability of bike lane width should be collected.
- *Sidewalk characteristics (coefficient 15)*. This coefficient is multiplied by the variable describing the width of the sidewalk in meters. A negative coefficient might indicate a preference for smaller sidewalks, which might be intuitive if larger sidewalks were associated with more pedestrian traffic or more street furniture and plants. However, the coefficient was not statistically significant, and therefore this result could not be validated. Additional variables not captured in the data collection might explain the driver's behavior of riding on the sidewalk, including the presence of street furniture (plants, lamp posts, street benches, etc.) and pedestrian flow.
- *Driving behaviors (coefficient 17)*. This coefficient is multiplied by a dummy variable equal to 1.0 whenever the driver rode against the designated travel lane traffic flow. The positive, large, and significant estimate showed a strong preference for riding on the sidewalk whenever the driver was riding counter to the traffic flow.

5.4. How did the cargo bike travel times compare to those of ICE Vehicles?

To understand how the cargo bike travel times—the time the cargo bike took to drive between a pair of destinations—compared with ICE vehicle travel times, we first computed the real cargo bike travel times from GPS data and then benchmarked them with the respective estimated trip times from ICE vehicles. The latter were obtained by querying the Google Maps Distance Matrix API (Platform and "Distance Matrix API", 2021) for the driving time for the same origins, destinations, departure times, and days of the week. While the estimates obtained did not necessarily reflect the exact traffic conditions to which the cargo bike was exposed, they represented a good estimate of the average driving times of motorized vehicles under normal traffic conditions, controlling for time of the day and day of the week. A total of 139 cargo bike trips were used in the following analysis, with an average trip being 0.3 miles (~0.5 km) long and lasting for 2.2 min.

The left plot of Fig. 16 shows the histogram of the trip time deviations, computed by subtracting the estimated driving time of a

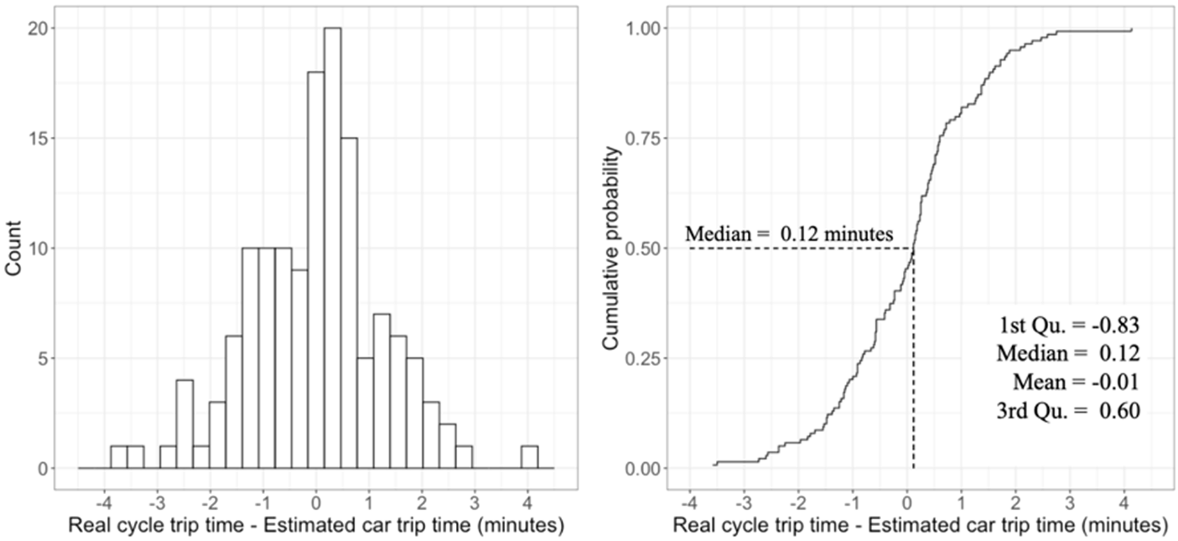


Fig. 16. Left: empirical distribution of the difference between the real cargo bike trip times and the estimated car trip time obtained from Google Maps distance matrix API. Right: cumulative distribution of the same trip time deviations and summary statistics.

motorized vehicle from the real trip time of the cargo bike. We observed a relatively symmetric distribution centered at zero. From the cumulative empirical distribution (right plot of Fig. 16) we observed a median trip time deviation of 0.12 min. Therefore, approximately half of the times the cargo bike was faster than a motorized vehicle, while half of the times the cargo bike was slower, with most of the deviations being within -1 and $+1$ min. We conclude that the cargo bike was able to match, on average, the trip time of an ICE vehicle in the observed urban area. Note that the travel time estimates for an ICE vehicle did not include time spent cruising for parking (see Dalla Chiara and Goodchild (Dalla Chiara and Goodchild, 2020) for a discussion on cruising for parking for commercial vehicles), and therefore, we conclude that on average the cargo bike spent no time cruising for parking.

6. Discussion

6.1. Cargo bike vs Delivery van

Previous research has identified and quantified parking and driving behaviors for ICE commercial vehicles. In particular, a few studies (Dalla Chiara and Goodchild, 2020; Dalla Chiara et al., 2021; Dalla Chiara et al., 2021) have quantified ICE vehicle behaviors by using data from Seattle, which were comparable to the data collected in this study. Therefore, to better understand the results obtained in the current study, we identify comparable descriptive statistics on driving and parking behaviors for delivery drivers for ICE vehicles in Seattle and report them side by side in Table 4.

Overall, a cargo bike driver spends a larger portion of his/her time driving than a parcel van driver (40 percent compared to 20 percent for a van). Parking dwell times for cargo bikes are shorter than those of parcel vans. This can be explained by the fact that cargo bikes make mostly-one delivery per parking stop (73 percent of the times the cargo bike parked, only one customer was served), whereas a van driver mostly makes more than one delivery per stop. Moreover, the van driver is willing to park farther away from the delivery destination whereas the cargo bike driver seems to park closer. The cargo bike driver might be able to do so by riding the vehicle on a larger variety of urban transport infrastructure and not only on travel lanes, with a large portion of driving time spent riding on sidewalks (37 percent of total driving time). From the analysis discussed above, we also noted that cargo bike drivers also drive counterflow. This allows the bike to make shorter trips and therefore make more stops per tour. This implies a reduced “fear” of re-parking the vehicle. When we benchmarked the travel times between pairs of destinations with the respective estimated travel times for a motorized vehicle, the median deviation obtained for the cargo bike was almost zero (0.12 min), whereas delivery vans show a median deviation of 2.3 min. The larger deviation for vans can be explained by the fact that commercial vans spend a considerable amount of time searching for parking (cruising for parking time was not reflected in the estimated travel times obtained from Google Maps). This validates the hypothesis that cargo bikes spend less time searching for parking than commercial vans, and therefore they can park closer to their destination, make more stops per tour, and make each stop shorter and focused on delivering only to one single destination.

Table 4
Comparison of variables describing the parking and driving behaviors of cargo bike and parcel van drivers, from data collected in the Seattle downtown.

Variable	Value	
	Cargo bike	Parcel van
Percentage of time spent:		
Driving	40 %	20 %
Parking	60 %	80 %
Median parking dwell time	4.3 min	17.6 min
Percentage of parking stops with		
1 delivery made	73 %	33 %
2 + deliveries made	27 %	67 %
Mean parking to delivery location distance	32 m	53.3 m
Percentage of time spent driving on		
Travel lane	55 %	98 %
Bike lane	5.2 %	0 %
Sidewalk	37 %	0 %
Others	3.3 %	2 %
Mean trip time	2.2 min	6.2 min
Mean trip distance	0.3 mile (0.5 km)	0.5 mile (0.8 km)
Median deviation from estimated ICE vehicle travel time	0.12 min	2.3 min

6.2. *Policy implications*

Some of the operational advantages of cargo bikes seem to be tied to their ability to use alternative infrastructure other than travel lanes for driving and curb lanes for parking, such as riding on sidewalks and riding counterflow. This allows the bike driver (as shown in this study) to park closer to delivery destination, reduce walking distances, and serve just one or a few customers per stop and thus to make more stops in a tour and to shorten parking dwell times. Moreover, we also showed that cargo bikes do not cruise for parking and can park at the curb or on the sidewalk according to need and current curb availability.

However, some of these parking and driving behaviors, especially related to driving and parking on sidewalks, could potentially lead to safety concerns and other externalities for pedestrians, bikers, and other road users. This has led cities like New York to prohibit sidewalk usage by cargo bikes. However, prohibiting sidewalk usage, without offering a suitable alternative infrastructure for cargo bike driving and parking, might have the consequence of reducing cargo bike operational advantages over vans and trucks, and might shift the problems elsewhere, for instance by clogging the bike infrastructure or creating more curb parking congestion.

This study suggested that there is a win–win strategy that can reconcile the need for operational efficiency and safety concerns: building a better infrastructure that can support cargo bikes' driving and parking behaviors. That is, instead of prohibiting the use of sidewalks by cargo bike drivers, city planners should implement the right measures to incentivize the use of bike lanes and create a cargo bike-friendly environment that can allow private companies to efficiently use cargo bikes while reducing the probability of conflicts with other road users. But what are these measures?

One obvious measure is to create more bike lanes. The current study showed that of the total time the driver spent riding the cargo bike in between delivery stops, bike lanes were used only 5 percent of the total driving time. This was in part because there simply weren't enough bike lanes. However, it is also true that, even if there had been a bike lane, the driver not always chose not to use it. The study showed that the presence of protected bike lanes (which are often wider than unprotected ones) led to a higher likelihood for the driver to choose to ride on the bike lane over the sidewalk or travel lanes. While it might not be feasible to place bike lanes in every road segment, the study showed a tendency for the driver to avoid travel lanes on major transit routes. Therefore, one possible measure could be to create protected bike lanes on roads that carry a lot of public transit traffic. The study also highlighted the importance of connected networks of bike lanes: the cargo bike driver was more likely to ride on a bike lane if he/she was already in a bike lane in the previous road segments.

Another issue was accessing the sidewalk from the travel lane and curb. There was a strong correlation between the choice of a parking location and driving infrastructure. Whenever the driver parked on the sidewalk, he/she had to ride the bike on the sidewalk as well. In contrast, whenever the driver chose to park at the curb, he/she chose also to ride the bike in the travel lane or bike lane. This happened because the sidewalk was most often accessible via ramps, which were often located at intersections. And if the delivery destination was located mid-block, that incentivized the driver to ride on the sidewalk for the whole block. This could be resolved by making sure that mid-block access to the sidewalk exists, or by creating bike lanes that are at the same level of the sidewalk and not on the travel lanes.

When it comes to parking, the study showed that cargo bike's dwell times were extremely short (the median dwell time was 4.3 min). However, the cargo bike was parked more often than an average van or truck. Moreover, the cargo bike driver did not always park on the sidewalk, but a considerable amount of the time (20 percent) the cargo bike was parked at the curb. Therefore, dedicated curb space or sidewalk space for cargo bikes, which could be possibly shared with other micro-mobility vehicles, and with the right access to bike lanes or the travel lane, could incentivize cargo bike drivers to avoid blocking the sidewalk while also riding in travel lanes or bike lanes to access these dedicated spaces. Moreover, policies to reduce use of curb for long-term parking (for instance (Evangelinos et al., 2018) would free more parking space on the curb to be used for freight and service vehicles such as cargo bikes.

Cargo bikes not only need space to park but also space to be stored overnight. In the observed cargo bike pilot project, the vehicle was stored overnight in a "micro-hub," a shared space for storage, pick-up, and delivery of goods, located in a central urban area near the delivery customers. On the other hand, the meal kits that the cargo bike distributed were carried from a depot located outside the city to the micro-hub location in consolidated trips off-hour by a truck. There is therefore a need for such space to incentivize companies to use cargo bikes.

Finally, different routing algorithms from those used for trucks and vans are needed. These algorithms might consider (i) the availability of bike lanes to promote their use, as well as (ii) avoidance of major transit routes, (iii) avoidance of driving downhill on roads that do not have bike lanes, and (iv) consideration for the width of sidewalks on roads where the cargo bike driver is more likely to use them (e.g., sidewalks located close to delivery destinations), and (v) location of ramps to access the sidewalk.

A future in which cargo bikes coexist with vans, trucks, and other road users, in a safe manner, is possible, but it will require more—and the right—infrastructure.

7. Conclusion: How cargo bike drivers use the urban transport infrastructure

With an increasing number of cities and companies aiming to reduce their carbon footprint, cargo bikes are seen as a viable alternative to trucks and vans for transporting goods in dense urban areas. The current study followed a cargo bike pilot that took place in Seattle, Washington, from May to July 2021. GPS data from the bike were augmented by installing a video camera on the top of the cargo bike and recording the type of transport infrastructure used and the time spent on each type. Data analysis was performed to address the main research question: how does a cargo bike driver use the urban transport infrastructure? We organized the analysis by first describing the observed driver's parking behavior and then the driving behavior. The main results are summarized in Fig. 17.

Concerning the parking behavior, we observed that most parking time (80 percent) was spent on the sidewalk. However, unlike what previous studies had assumed, a considerable amount of parking (18 percent) still took place at the curb. Moreover, the most used curb spaces were passenger load zone (PLZ) and paid parking (PP), which are both generally considered authorized curb parking spaces. The average parking dwell time was 4.33 min, with most parking events lasting 3 to 6 min. Most stops were short and characterized by only one delivery, and the driver parked approximately 30 m away from a delivery address.

Concerning driving behavior, we first benchmarked the cargo bike travel times between each pair of delivery destinations with travel time estimates for ICE vehicles. We found that on average the cargo bike was as fast as an ICE vehicle in navigating the urban space. Moreover, this also showed that the cargo bike spent virtually no time cruising and searching for parking, which is often not true for commercial vans and trucks.

As to the choice of driving infrastructure, we observed that a considerable amount of time was spent driving on the sidewalk (37 percent of total driving time). The preferred driving infrastructure consisted of travel lanes (55 percent), while only 5 percent of the time was spent on bike lanes. This might reflect a preference for other transport infrastructure and a general lack of bike lanes available on the cargo bike routes. We then modeled the driver's choice between driving on the travel lane, bike lane, and sidewalk, given the availability of infrastructure and its characteristics. The driver showed a preference to ride on bike lanes whenever the bike lane was

Detailed data from a cargo bike used to perform parcel deliveries in Seattle downtown were obtained to analyze the driver's parking and driving behaviors. The following main results were obtained.

1) On average, the cargo bike driver spent 60% of his/her time parking and 40% driving.

2) The cargo bike driver predominantly rode on the travel lane (55%) followed by the sidewalk (37%) and the bike lane (5%)

3) The cargo bike driver made more frequent and shorter delivery stops than a parcel delivery van.
   - Median parking dwell time: 4.3 minutes
   - 73% of stops served one delivery location, the remaining serving 2 or more locations

4) The cargo bike driver predominantly parked on the sidewalk (80%) followed by curb lane parking (18%), parking on average 30 meters (98 feet) away from a delivery destination

5) The cargo bike driver was more likely to ride on bike lanes whenever they were protected. The driver was less likely to use travel lanes whenever she/he was riding downhill and on major transit routes. The driver was also more likely to ride on the sidewalk whenever she/he had to perform a delivery mid-blockface.

Fig. 17. Summary of empirical findings.

protected. Moreover, if a road was considered a major transit route, the driver also preferred to ride on a bike lane or sidewalk. An increased preference to ride on the sidewalk was shown whenever the route took the driver downhill, whenever the driver was riding against the car traffic flow, and whenever the driver needed to park on the sidewalk. Conversely, whenever the driver intended to park at the curb, he/she was more likely to drive in the travel lane.

These results are empirical in nature and are tied to the context of the cargo bike pilot test that was observed. In particular, the major limitation of the study is that data were collected from a single driver. In a future extension of the study, data should be collected from different cargo bike drivers to capture heterogenous effects and include drivers-specific variables in the analysis. The limited scope of the study is partially explained by the limited availability of cargo bike pilots in the U.S. at the time of the study, as well as the fact that the data collection developed for this study was resource intensive. The results obtained should also be interpreted considering the context of the study area: the Seattle downtown. In general, the lesson learned from this pilot can more generally describe the behavior of a cargo bike parcel delivery driver operating in a dense North American city, but they are less generalizable to other contexts.

The study proposed an innovative methodology and research direction, being the first in using video cameras to analyze cargo bike driving and parking behaviors, reaching a level of detail never obtained from previous studies. Replicating such study in different urban context, with different drivers, would further enrich the variability of data obtained and provide more generalizable policy implications.

Moreover, we highlight that the scope of the current study is to understand how a cargo bike driver used the existing urban infrastructure in the context observed. The current study did not explicitly collect data on safety of the cargo bike, such as interactions between the cargo bike and other sidewalk or road users, accidents, or other data sources that could relate to safety concerns. The current methodology could be modified to include in the analysis the effect of infrastructure usage (hence the probability of interaction with other users) in the cargo bike's driving and parking behaviors. A different methodology should be used to directly assess the safety of cargo bikes.

CRediT authorship contribution statement

Giacomo Dalla Chiara: Conceptualization, Methodology, Software, Formal analysis, Data curation, Visualization, Supervision, Project administration. **Griffin Donnelly:** Software, Investigation, Data curation, Visualization. **Seyma Gunes:** Software, Investigation, Visualization. **Anne Goodchild:** Conceptualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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