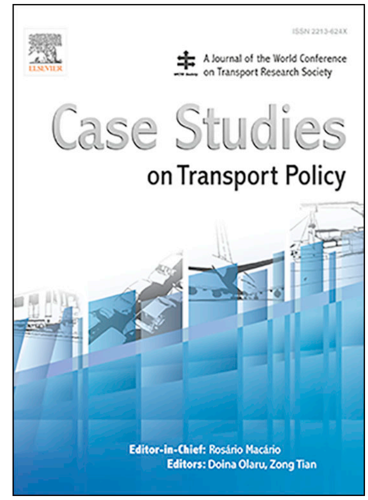
Journal Pre-proofs



Seattle Microhub Delivery Pilot: Evaluating Emission Impacts and Stakeholder Engagement

Seyma Gunes, Travis Fried, Anne Goodchild

PII: S2213-624X(23)00173-6
DOI: https://doi.org/10.1016/j.cstp.2023.101119
Reference: CSTP 101119

To appear in: *Case Studies on Transport Policy*

Received Date: 2 April 2022
Revised Date: 21 August 2023
Accepted Date: 10 November 2023

Please cite this article as: S. Gunes, T. Fried, A. Goodchild, Seattle Microhub Delivery Pilot: Evaluating Emission Impacts and Stakeholder Engagement, *Case Studies on Transport Policy* (2023), doi: https://doi.org/10.1016/j.cstp.2023.101119

Seattle Microhub Delivery Pilot: Evaluating Emission Impacts and Stakeholder Engagement

Seyma Gunes[a], Travis Fried[a], Anne Goodchild[a]

Department of Civil and Environmental Engineering, University of Washington, 3760 E. Stevens Way NE, Seattle, WA 98195; sgunes@uw.edu; tfried3@uw.edu; annegood@uw.edu

Corresponding author: Seyma Gunes

Author Contributions

Seyma Gunes: Conceptualization, Methodology, Software, Data Curation, Formal analysis, Original draft writing, review and editing*; Travis Fried*: Original draft writing, review and editing; *Anne Goodchild:* Conceptualization, Supervision, Project administration, writing – Review and editing

Funding Declaration:

This work was financially supported by the Urban Freight Lab.

Declarations of interest:

None

Seattle Microhub Delivery Pilot: Evaluating Emission Impacts and Stakeholder Engagement

ABSTRACT

Urban freight deliveries using microhubs and e-cargo cycles have been gaining attention in cities suffering from congestion and emissions. E-cargo cycle deliveries and microhubs used as transshipment points in urban cores can replace trucks to make cities more livable. This study describes and empirically evaluates an e-cargo tricycle pilot conducted with multi-sector stakeholders in Seattle to report the potential benefits and pitfalls of such practices. The pilot held stakeholder workshop sessions to collect inputs of interest and expectations from the project. Mobile devices used by drivers on e-cargo tricycle and cargo van routes collected delivery data to use for empirical assessment. Total vehicle miles traveled and tailpipe carbon emissions served as performance metrics when comparing e-cargo tricycle and cargo van deliveries. The results showed the net-benefit of the microhub and e-cargo tricycle routes depend on the upstream operations when replenishing packages.

The participatory approach to pilot design also provided insights into the factors of a successful pilot, with implications for scaling future e-cargo cycle delivery systems in North American cities. Namely, microhubs' ability to host alternative revenue sources and value-added services is a boon for long-term financial competitiveness. However, lack of digital/physical infrastructure and work training/regulations specific to e-cargo cycle delivery operations present a barrier.

Keywords: *microhubs; urban freight; city logistics; last-mile distribution; e-cargo cycles; e-cargo tricycles*

1. Introduction

Urban parcel volumes have soared in the short years following COVID-19 shutdowns. U.S. Postal Service reported package volumes are up 70% since the pandemic, while Canada Post mailed almost 2 million daily packages in April 2020 (Bogage and Dawsey, 2020; Canada Post, 2020). According to the latter agency, these are traditional peak holiday season demands but happening every day. As online retailers and delivery carriers respond to swelling delivery demands, cities have increasingly recognized urban freight as an important action area for broader environmental sustainability, urban livability, and road safety goals (Maxner et al., 2022). Delivery carriers and related 3rd Party Logistic (3PL) providers are simultaneously looking toward more compact and efficient last-mile delivery operations, fleets, and distribution hubs to quell heightening competition for land, curb, and street space (ITF, 2022). At the forefront of tested solutions are electric, pedal-assisted cargo (*e-cargo*) bicycle and tricycle deliveries facilitated by a neighborhood microhub.

Research on e-cargo cycles as a more environmentally and socially responsible alternative to internal combustion engine (ICE) delivery vans and trucks have emerged in the last decade (Oliveira et al., 2017). In a comprehensive literature review, Vasiutina et al. (2021) find general consensus that replacing ICE delivery vehicles with e-cargo bicycle-based deliveries reduces delivery emissions and with important benefits to urban livability. E-cargo bicycles occupy less physical space than vans and trucks and could reduce urban congestion, noise, wear-and-tear on roads, double-parking, and improve road safety (Conway et al., 2017; Melo and Baptista, 2017). E-cargo bicycle-based deliveries are particularly well-suited for last-mile operations in dense commercial or residential environments, given urban parcels' on-average low weights (Perboli and Rosano, 2019) and short travel distances (Wrighton and Reiter, 2016).

Integral to the operational efficiency of e-cargo cycle delivery programs are microhubs. Katsela et al., 2022 define microhubs as a logistical platform in the heart of an urban area where goods are bundled and shipped to nearby markets, optimizing delivery networks (Niels et al., 2018) and enabling a shift to low-emission, last-mile delivery modes (J. Lee et al., 2019; Verlinde et al., 2014). Neighborhood microhubs can host additional value-added services that improve both fiscal sustainability of operations (Panero et al., 2011; van Duin et al., 2016), serve as a storage and charging station for electric delivery vehicles (Ormond et al., 2018), and address auxiliary retail and delivery needs of nearby consumers and businesses (Katsela et al., 2022). When used in conjunction with microhubs, e-cargo bicycles have potential to greatly reduce emissions while introducing operational efficiencies and business services that reduce implementation barriers (Assmann et al., 2020, 2019).

Given their applicability and impact potential, several cities and delivery companies have experimented with pilot e-cargo bicycle delivery programs to measure their effectiveness and work towards broader programmatic scaling. Within urban studies, pilots are an important tool for testing transitional technologies, especially through the framework of "urban living labs" (Bulkeley et al., 2019, 2016). These urban experiments can be an instrumental first step to informing and expanding transformative interventions (von Wirth et al., 2019; Huguenin and Jeannerat, 2017).

Although pilots' effectiveness in bringing about sustainable and scalable change has been called into question (van den Buuse et al., 2021; van Winden and van den Buuse, 2017). Namely, when pilot stakeholders (e.g., city authorities, technology companies) fail to align strategic goals with those of the pilot and omit lessons-learned from long-term planning (McAslan et al., 2021). Regardless, pilots represent a minority of e-cargo bicycle-related studies with limited investigation from academic institutions (Vasiutina et al., 2021). When researchers do investigate e-cargo bicycle/microhub implementation, the majority measure emission impacts and operational cost-effectiveness. Relevant case studies include: Brussels (Verlinde et al., 2014), London (Browne et al., 2011), São Paulo (Ormond et al., 2018), and Barcelona/Valencia (Navarro et al., 2016). However, evaluation of pilot design, stakeholder goals, and lessons learned are absent from most e-cargo cycle pilot studies.

The purpose of this case study is not only to present evidence of the operational and emission effects of introducing a microhub and e-cargo cycle delivery route in a large North American city, which is also underrepresented in global microhub pilot studies. While it is important to measure these effects, as operational efficiency and environmental sustainability are core objectives of most e-cargo cycle delivery systems, this alone does not address the scalability issues presented by many pilots. This study consequently implements a multi-sector, participatory approach to pilot design that aims to capture both the pilot's success factors and barriers. Furthermore, this paper's objectives are two-fold:

1) Empirically evaluate the operational and environmental performance of the pilot.
2) Identify stakeholder success factors and barriers to pilot implementation.

The following section (*Section 2*) details the pilot's participatory design and implementation, methodology for stakeholder engagement, and framework for data collection, processing and estimating emission and operational impact. *Section 3* reports results from the stakeholder engagements and calculations for VMT and tailpipe CO2 emissions per package. The final section (*Section 4*) discusses the findings and conclusions with an emphasis on empirical and stakeholder lessons-learned and their implications for future scaling.

2. Methodology

2.1 Participatory Pilot Design

Between January 2020 and July 2021, Urban Freight Lab (UFL) launched the *Seattle Neighborhood Delivery Hub* (SNDH) pilot. UFL is a structured workgroup that brings together private industry with city transportation officials to design and test solutions around urban freight management and is housed at the University of Washington. SNDH was a static, off-street microhub serving a single e-cargo tricycle in Seattle, Washington's dense, downtown-adjacent Uptown neighborhood (Urban Freight Lab, 2021). UFL's Seattle Neighborhood Delivery Hub project was one of the nation's first zero-emissions, last-mile delivery pilots, serving as a testbed for innovative, sustainable urban logistics strategies on the ground with a living labs approach (Urban Freight Lab, 2021).

UFL launched SNDH after identifying common interest among the workgroup to implement a microhub. During a quarterly group meeting held in July 2019, UFL members voted to conduct a microhub pilot out of a proposed set of research projects. The first year of the project was dedicated to planning and developing the strategy for a business plan. This planning phase consisted of the recruitment of stakeholders to be involved in the pilot, business development and establishing agreements.

The UFL launched the project with a stakeholder engagement workshop session in February, 2020 to understand their motivations and requirements to participate in a microhub pilot (see *Table 1*). Following this workshop, UFL selected a subgroup of members to form a planning committee. UFL selected stakeholders based on their level of desired engagement and activity. All planning committee stakeholders engaged in one of three ways: 1) test an activity at the hub, 2) operate the hub, or 3) contribute resources. Participating stakeholders operated relatively independently within the microhub while sharing the space. *Table 1* lists the participating stakeholders in the planning committee, along with their role and contribution to the pilot test.

Sector	Stakeholder	Role	Contribution/Interest

Real Estate / Parking solutions	REEF Technology	Owned, operated and rented parking lot space for project. Managed the onsite dark kitchen.	1) Test an activity: onsite dark kitchen 2) Operate the microhub
Delivery and logistics infrastructure manufacturer	Brightdrop	Provided electrically assisted storage infrastructure for e-cargo tricycle deliveries and modular, electric pallet/container for cargo towing.	3) Contribute resources: electric pallet/container
E-cargo cycle manufacturer	Coaster Cycles	Manufactured custom-made, e-cargo tricycle to fit pallet/container attachment.	3) Contribute resources: e-cargo tricycle
Logistics startup	AxleHire	Provided route-optimization technology for last mile service, and coordinated e-cargo tricycle deliveries.	1) Test an activity: replaced conventional delivery van 3) Contribute resources: software
Researcher	UFL	Convened and evaluated the project. Operated an onsite common carrier parcel locker.	1) Testing an activity: common carrier parcel locker 3) Contribute resources
Public agency	Seattle Department of Transportation (SDOT)	Facilitated the use of city streets by e-cargo tricycles.	3) Contribute resources

Table 1: Participating Stakeholders

Participating stakeholders utilized the SNDH as a testing ground to gather data and learnings on transforming an open space into a multi-use logistics platform. Seattle Department of

Transportation (SDOT) was involved in the project as a member of the planning committee to support the pilot when there were concerns using e-cargo tricycles for deliveries in the public right of way. A memorandum of understanding (MOU) was signed between the city and the project members, recognizing that the city authorized the use of public streets for testing e-cargo tricycle deliveries. Leveraging the pilot helped SDOT better understand e-cargo bike delivery operations and the ways it may help the city achieve its goal of reducing delivery emissions by 30% by 2030.

After forming the planning committee and holding stakeholder engagement workshop, the search for the project site location started. UFL sent an online questionnaire to stakeholders to document their proposed activity during the pilot and site related requirements. Location related physical requirements included electricity and Wi-Fi connectivity, pedestrian and vehicle access, adequate customer density, and residential/commercial building type mix in the neighborhood. According to the needs of the planning committee, the real estate/parking lot operator company, REEF Technology, created a list of candidate locations that meet the given specifications from its pool of parking lots in Seattle. In October 2020, the UFL committee voted to locate the SNDH at 130 5th Ave. N. in Seattle's Uptown neighborhood. The project timeline is given in *Table 2* below. Operations began in March 2021 and continued through July 2021.

Phase 1 - 2020	January, 2020	Project started.
	February, 2020	Stakeholder engagement workshop took place during an in-person UFL quarterly meeting.
	May, 2020	Planning committee was formed.
	June, 2020	Site selection process started.
	June 4, 2020	Site selection survey sent to participating stakeholders.
	October, 2020	Microhub pilot test site selected as 130 5th Ave.
Phase 2 -	March, 2021	UFL locker started operation on site.

2021		
	April 5, 2021	E-cargo bike deliveries began.
	May 26, 2021	UFL hosted a kickoff event to launch the hub.
	July 23, 2021	Testing operations are completed.
	September, 2021	Evaluation and reporting completed, project closed.

Table 2: Project Timeline

3.2 Stakeholder Engagement

In the case of microhub initiatives, operating a logistics platform inside the city core requires the agreement and collaboration of multiple stakeholders. While diversifying the activities performed at the microhub increases flexibility and profitability, this necessitates the cooperation of many sectors. Maintaining a high level of cooperation between the stakeholders through different stages of the implementation reduces miscommunications and time to launch.

To learn about public and private sector needs and interests from a microhub pilot, UFL designed a structured workshop and focus group for UFL members. The purpose of this workshop was to understand the potential benefits they were expecting from the pilot as well as the physical and operational attributes they deemed necessary for long-term success. There were 12 participants in the workshop including parcel carrier companies, retailers, real estate management companies, and public agencies. The workshop took place in February 2020. The participants were asked two questions as follows:

- Question 1: What is your company's interest in piloting a microhub? How would a microhub align with your company's goals (financial, operational, environmental etc.)? What results do you expect from microhub utilization?
- Question 2: What are the desirable operational and physical characteristics of a microhub for your company?

The workshop was designed in two parts: ideation and voting. The first part started with an open discussion, then all members noted down their answers on post-it notes and posted them on a whiteboard. Later, UW researchers identified common themes to group the answers that share similar or the same ideas. These groups were designated as the options for the workshop participants to vote on. After the same process was repeated for both questions, private sector members cast three votes to choose their three most favored answers to the given two questions.

The findings from the workshop guided the following site selection process and helped narrow down the pool of candidate locations to select from.

3.3 Empirical Analysis of e-Cargo Tricycle Delivery VMT and Emissions

AxleHire, a 3PL and member of the planning committee, completed deliveries to its nearby customers in the study area using an e-cargo tricycle replacing cargo van deliveries that traditionally served these customers. SNDH served as a microhub where a cargo van, deployed from a suburban depot, used the location to transfer packages to the e-cargo tricycle. A shipping container located at SNDH stored and charged the e-cargo tricycle overnight. The e-cargo tricycle (see *Figure 1*), was three meters long and 1.2 meters wide. The storage capacity was approximately 0.65 cubic meters with a payload capacity of 91 kilograms.

Figure 1: The e-cargo tricycle utilized at SNDH (Source: UFL, 2020)

AxleHire hired one e-cargo tricycle delivery driver to complete deliveries. The electrical pedal assistance was in effect only when the pedaling speed was higher than 36 km/h. The packages delivered were meal kits from a food subscription service. Each meal kit had a volume of 0.04 cubic meters and weighed eight kilograms. The e-cargo tricycle performed two to three routes per day, delivering nine packages per route, on average. The driver utilized a mobile app provided by AxleHire, which planned the routes and set the order for customer drop-off locations. The routing algorithm used to calculate the delivery routes is a product of AxleHire that they use for their ongoing delivery operations. There were no customizations made to their model specifically for the e-cargo tricycle deliveries.

3.3.1 Data Collection

Delivery data was collected by AxleHire via a mobile device used by the driver. For each delivery attempted, the delivery dataset recorded the geographical coordinates of the customer location, the timestamp (i.e., when the package was scanned by the driver's mobile device), and the status of the delivery. To compare the performance of e-cargo tricycle deliveries as an alternative to replace ICE vehicles in urban areas another set of delivery data collected from ICE vehicle routes were obtained from AxleHire. The ICE vehicle type used by the carrier company was a cargo van. The performance metrics calculated from these ICE vehicle routes were used as baseline values for the e-cargo tricycle solution to empirically compare the delivery efficiency and environmental impacts. A total of 456 and 589 observations were recorded in the ICE vehicle and e-cargo tricycle delivery datasets, respectively.

Figure 2 maps the customer locations for the e-cargo tricycle and ICE vehicle deliveries. The service area of the e-cargo tricycle deliveries was smaller when compared to the ICE vehicle, however the cargo van serving the microhub completed deliveries in the wider area as normal. Most e-cargo tricycle deliveries took place in proximity of the microhub, in the Central Business District and Uptown neighborhoods of Seattle, west of Interstate 5 (I-5).

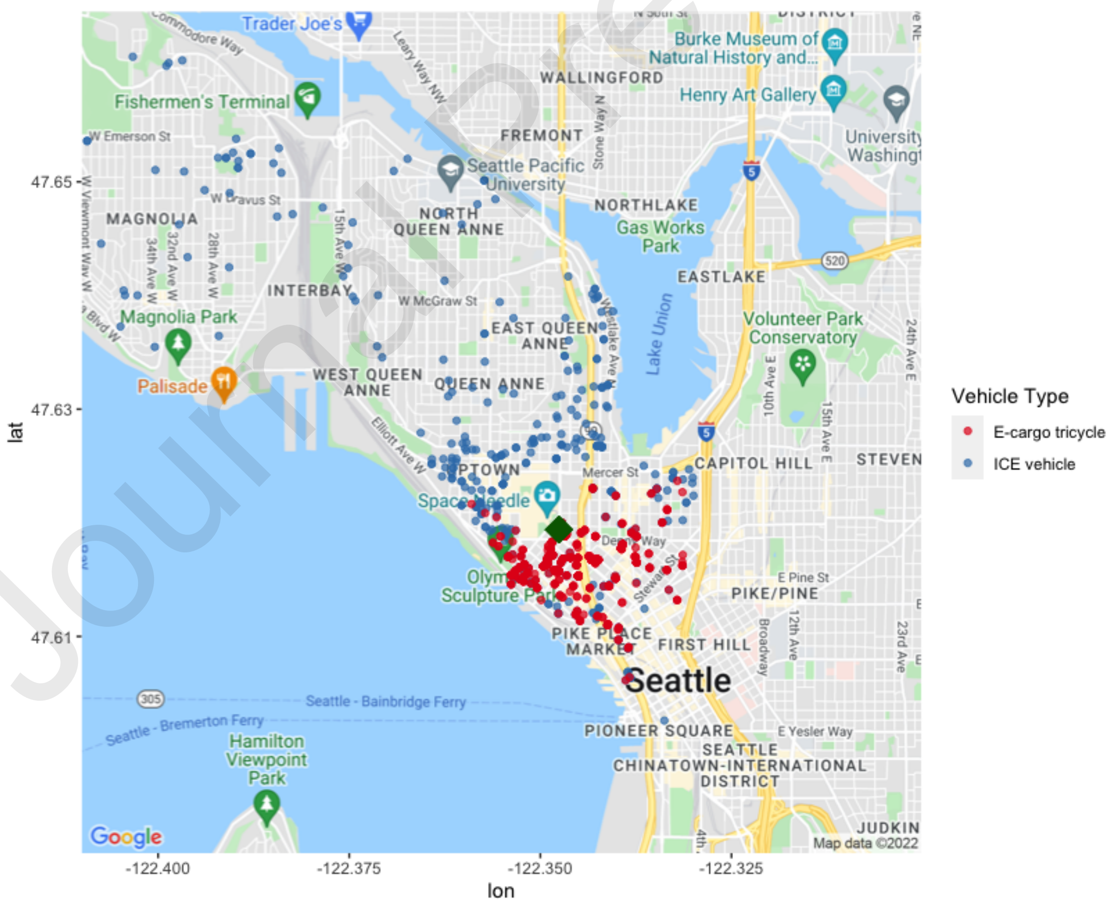


Figure 2: Customer locations for e-cargo tricycle and ICE vehicle routes. Microhub shown as green diamond.

UFL researchers analyzed the delivery data to identify individual delivery routes and to calculate performance metrics for each route. A route dataset was created where each instance was a delivery route using unique route identifiers. *Table 3* gives a sample description for the route data sets used for the analysis. To quantitatively assess the operational performance of delivery routes, two success metrics were used in this study: vehicle miles traveled (VMT) per package and the total tailpipe CO2 emissions per package.

Route solution type	**ICE vehicle (Cargo van)**	**E-cargo tricycle**
Dates	2021-04-14 and 2021-05-03	2021-05-05 and 2021-07-02
Number of days	7	33
Number of routes	17	64
Average route distance (mi)	35.01	3.79
Average number of packages per route	43.70	8.53

Table 3: Route dataset description

3.3.2 VMT per package

For each route, the VMT per package delivered was calculated as the total VMT divided by the number of packages delivered in that route. The total VMT in a route is the sum of all distances between each node that is visited. *Figure 3* describes the two route solutions compared in this study:

1) E-cargo tricycle route solution that consists of the two-way ICE vehicle trip between the suburban depot and the microhub, followed by multiple e-cargo tricycle delivery routes starting and ending at the microhub.

2) ICE vehicle route solution represents the traditional urban freight approach that consists of delivery routes starting and ending at the suburban depot.

Since the e-cargo tricycle solution produced both ICE vehicle and e-cargo tricycle VMT, we use the terms e-cargo tricycle route solution (instead of e-cargo tricycle *route*) and cargo van route solution (instead of cargo van *route*). *Figure 3* presents a conceptual overview of these operational configurations.

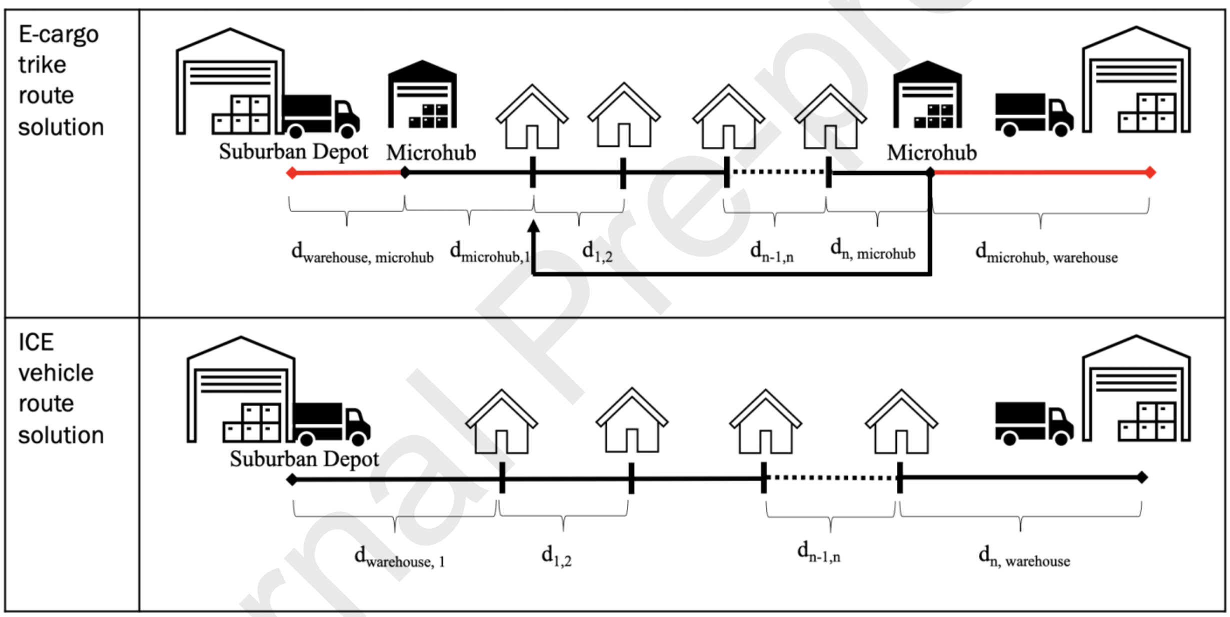


Figure 3: Description of the e-cargo tricycle and ICE vehicle route solutions

Since cargo vans and e-cargo tricycles operated in an e-cargo tricycle route solution, the VMT per package was calculated separately for each vehicle type to differentiate the distances traveled by an ICE vehicle for each e-cargo tricycle route, *r*. The daily trips carrying packages between the suburban depot and the microhub were completed using a cargo van. These daily and two-way package replenishment trips, referred as the *two-way stem* trips, were eight miles long between the suburban depot and the microhub location. This cargo van trip carried 20 packages daily on average to the microhub and was assumed to continue delivering packages to the nearby customers after unloading packages to the e-cargo tricycle and before returning to the suburban depot. This assumption suggested that the cargo van used for the stem trips was shared to carry packages for both the e-cargo cycle and another unknown route, denoted as *X*. However, route *X* covers the same delivery area as the ICE vehicle route solution. In other words, the following equations compare the operational sensitivity of replacing portions of the ICE vehicle route solution with e-cargo tricycle delivery, expressed in VMT per package.

The share of packages delivered in e-cargo cycle routes, 20 packages daily on average, within the total number of packages carried in the stem trip was defined as "stem share" (*SS*) and calculated as shown in *Equation 1*.

Equation 1

$$SS = \frac{P_{e-cargo\ trike}}{P_{stem\ trip}}, where\ P_{stem\ trip} = P_{e-cargo\ trike} + P_X$$

where: $P_{stem\ trip}$ is the total number of packages in the cargo van traveling between the warehouse and the microhub, $P_{e-cargo\ trike}$ is the number of packages carried with the same cargo van and were delivered in e-cargo cycle routes, $P_X$is the number of packages carried with the same cargo van but delivered on an unknown route, *X*. The ICE vehicle VMT per package in the e-cargo cycle route solution was calculated for ranging values of stem share, SS. For example, in a scenario where the stem share is equal to 25% and the cargo van is carrying 80 packages in total, 20 packages are delivered by the e-cargo cycle route and the rest 60 packages are delivered by route *X*.

The ICE vehicle VMT per package in the e-cargo tricycle route solution is calculated as shown in Equation 2.

Equation 2

$$VMT\ per\ package_{r,\ ICE\ vehicle} = \frac{\frac{d_{depot\ ,\ microhub}}{m}}{\sum_{i\ =\ 1}^{n} p_i} * SS$$

where: SS is the stem share, $d_{depot,\ microhub}$ is the distance between the warehouse and the microhub, *m* is total the number of e-cargo tricycle routes completed on the same day, p_i is the number of packages delivered to location i. The notation assumes that each customer location is denoted by $i\ \in \{1, 2, ..n\}$, where n is the total number of customers in route *r*.

The second component of the e-cargo tricycle solution was the distribution of packages from the microhub to customers. Each e-cargo tricycle delivery route started and ended at the microhub location. The e-cargo tricycle miles traveled per package for each route was calculated as shown below in Equation 3.

Equation 3

$$VMT\ per\ package_{r,\, e-cargo\ tricycle} = \frac{d_{microhub,\,1} + \sum_{i=1}^{n-1} d_{i,i+1} + d_{n,\,microhub}}{\sum_{i=1}^{n} p_i}$$

where: $d_{i,j}$ is the distance between locations i and j, and p_i is the number of packages delivered to location i.

In the cargo van route solution, all routes started and ended at the suburban depot. To calculate the VMT per package in a route, the total vehicle miles traveled was divided by the total number of packages delivered, as given in Equation 4.

Equation 4

$$VMT\ per\ package = \frac{d_{warehouse,1} + \sum_{i=1}^{n-1} d_{i,i+1} + d_{n,\,warehouse}}{\sum_{i=1}^{n} p_i}$$

where: m is the number of e-cargo tricycle routes completed on that day, $d_{i,j}$ is the distance between locations i and j, p_i is the number of packages delivered to location i.

The driving distance traveled between each location ($d_{i,\,j}$) was calculated using the geographic coordinates and Google Maps API.

3.3.3 Tailpipe CO_2 emissions per package

For each route solution, the tailpipe CO_2 emissions per package was calculated using a tailpipe CO_2 per mile multiplier and the VMT per package calculated for each delivery vehicle type *k*. In this study the set of delivery vehicles used consisted of $K \in \{e-cargo\ tricycle, cargo\ van\}$.

To calculate the CO_2 emissions per mile multiplier, the tailpipe CO_2 created from burning one gallon of fuel or producing one MWh of electricity (depending on the vehicle type, respectively for cargo vans or e-cargo tricycles) was divided by the fuel economy. The fuel economy is the number of vehicle miles traveled per unit of fuel or electricity used. The calculations and metrics used in this study are given in *Table 4*.

Vehicle Type (k)	Tailpipe emissions CO2 per fuel	Fuel economy	Tailpipe CO2 emissions per mile multiplier (kg/mi)
Cargo van	10.180 kg/gallon (Source: EPA)	9.6 mpg (Source: project stakeholders)	$\frac{10.180\ kg/gal}{9.6\ mi/gal} = 1.06\ kg/mi$
E-cargo tricycle	227 Ibs/MWh (Source: U.S. EIA)	20 mi/kWh (Source: project stakeholders)	$\frac{227\ Ibs/MWh}{20\ mi/kWh} * \frac{1\ kWh}{1000\ MWh} * \frac{0.453592\ kg}{1\ Ibs} = 0.0051\ kg/$

Table 5: Tailpipe CO2 emissions per mile multiplier calculations for cargo van and e-cargo tricycle (2-column)

For each route, the tailpipe CO_2 emissions per package is calculated using Equation 5 below.

Equation 5

$$Tailpipe\ CO_2\ emissions\ per\ package = \frac{\sum_{k \in K} \frac{Tailpipe\ CO2\ emissions\ per\ fuel_k}{Fuel\ economy_k} * VMT_k}{Total\ number\ of\ packages\ delivered}$$

where: k is the delivery vehicle type used and VMT_k is the total miles traveled in that route using vehicle type k.

4. Results

4.1 Stakeholder engagement

UFL found that most companies are interested in **reducing congestion**, **offering customer accessibility,** and **having storage space** as goals for a microhub pilot, with those measures receiving 6, 6, and 5 votes respectively. Members expected the microhub to increase efficiency through decreasing congestion, VMT, number of trips, and stops in urban areas. They also desired the microhub to offer customers a convenient location for goods pick-up/drop-off, and to contain available storage space both for vehicles (e-cargo tricycles) and for backup inventory.

Members determined that the most desirable operational and physical characteristics of a microhub were **security**, **general vehicle access,** and **data connection**, receiving respectively 8, 5, and 5 votes. Stakeholders preferred the microhub to possess adequate lighting, enclosed/fenced area, and surveillance cameras installed to ensure security for people, vehicles, and packages. In terms of physical attributes, stakeholders preferred the microhub be accessible for commercial freight vehicles and trucks with sufficient infrastructure, space, and layout for vehicles to operate and navigate. Stakeholders also expressed the microhub should allow for communication with other intelligent transport systems such as 3PL routing, tracking, and inventory control software by having built-in power and internet connection.

The pilot stakeholders identified the following implementation challenges in the concluding workgroup:

- There is a lack of established workforce for e-cargo cycle delivery drivers. The project team struggled to find a qualified delivery driver that can deliver packages with an e-cargo tricycle. Experienced cyclists have no knowledge of urban deliveries and traditional delivery drivers are not interested in switching to e-cargo cycles.

- Lack of e-cargo bicycle driver training resulted in navigational and building access challenges for the operator.

- The e-cargo bike driver used routing tools that did not provide the most efficient bike-friendly delivery route. A better routing calculation can consider the elevation gain within each route to account for bike-friendliness.

- The pilot e-cargo bike had to be manually locked to a nearby structure using a U-lock, taking valuable time during deliveries.

4.2 VMT per package

The VMT per package metric was calculated and averaged over all instances of e-cargo tricycle and cargo van route solutions (see *Figure 4*). The ICE vehicle carrying packages to and from the microhub completed other delivery routes after dropping off packages at the microhub. Since the number of packages delivered from the cargo van-based delivery routes was unknown in the e-cargo tricycle solution, four levels of stem share (SS) were tested ranging between 25 and 100 percent. Due to limited labor resources the e-cargo tricycle deliveries were operated for four hours per day, completing 2 routes daily. If the cargo van used for the stem trip had no other routes to complete after dropping packages at the microhub, this would translate into a stem share of 50%. This means, the actual stem share in this pilot test was 50% at most. If the e-cargo tricycle operated a full workday of 8 hours and completed 4 delivery routes per day, and there were no other route types, the stem share would decrease to 25%.

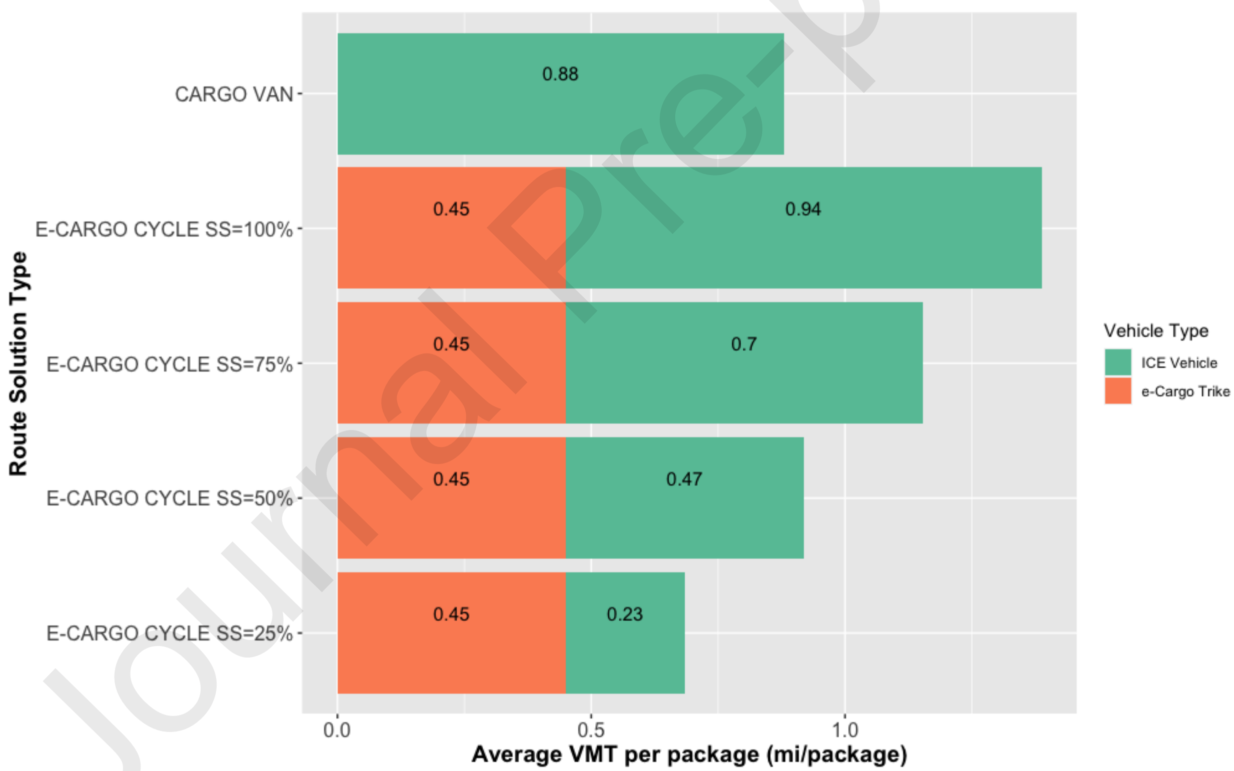


Figure 4: Average VMT per package for ICE vehicle and e-cargo tricycle route solutions (2-column)

The stem share of the e-cargo cycle route solution impacted only the ICE VMT that ranged between 0.23 and 0.94 miles per package for stem 25% and 100% stem shares, respectively. For each package delivered, the e-cargo tricycle route solution required traveling 0.45 e-cargo tricycle miles on average. When the stem trip was used only to carry the packages delivered by the e-cargo tricycle (SS=100%), the ICE vehicle traveled 0.94 miles per package, which is more than double the distance traveled by the e-cargo cycle. The results suggest that the cargo van trip carrying packages between the suburban depot and the microhub can be responsible for 34% to 68% of the total VMT produced from e-cargo tricycle deliveries. This share of ICE vehicle VMT was dependent on the stem share, which was impacted by the total number of packages carried by the cargo van stem trip from the depot.

The traditional ICE vehicle route solution produced 0.88 mi per package delivered. The e-cargo cycle route solution produced less ICE VMT compared to the cargo van route solution when the stem share was less than 75%. When the stem trip was shared between 4 e-cargo cycle routes, i.e. the stem share was 25%, the e-cargo cycle solution replaced 0.65 ICE vehicle miles traveled, indicating a 74% reduction per package. Considering that 17 packages on average were delivered using the e-cargo tricycle solution per day over 33 days, the e-cargo tricycle solution led to an overall reduction of 365 cargo van miles during the pilot.

4.3 Tailpipe CO_2 emissions per package

Figure 5 shows the tailpipe CO_2 emissions per package calculated for the two route solutions: ICE vehicle and e-cargo tricycle.

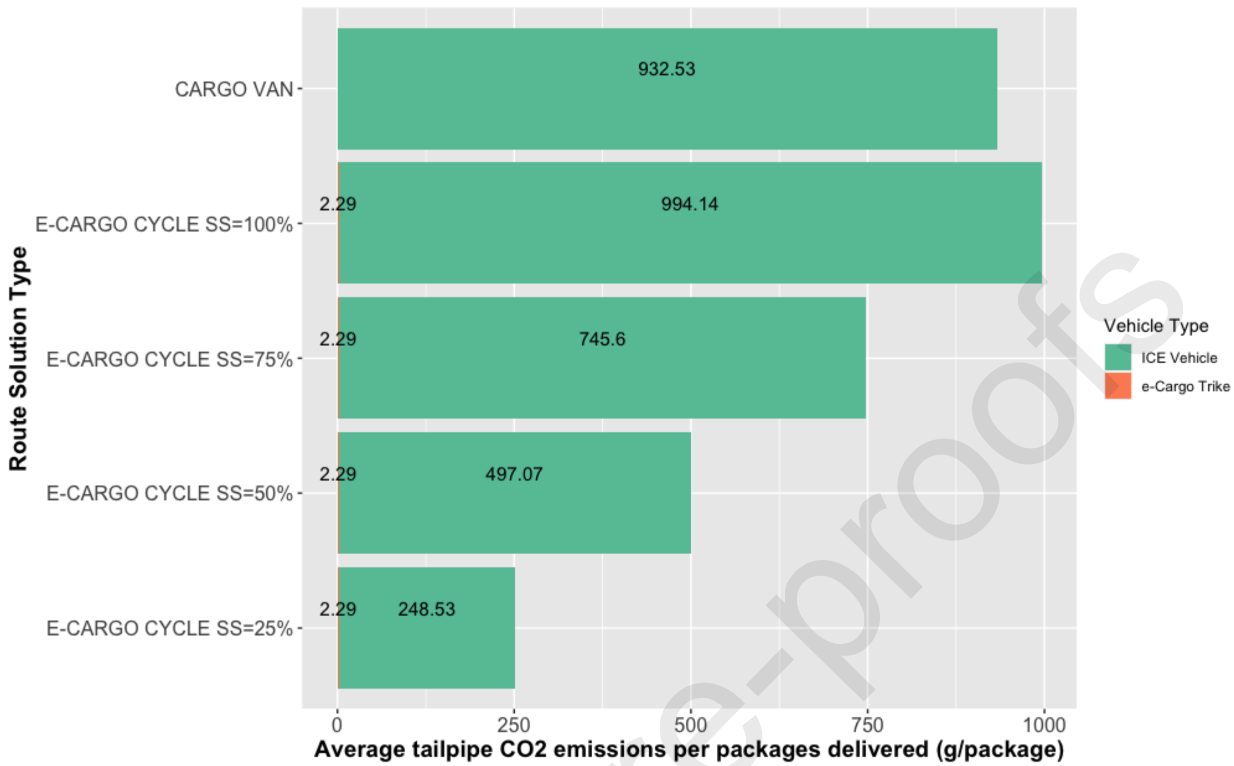


Figure 5: Tailpipe CO_2 per package for ICE vehicle and e-cargo tricycle route solutions (2-column)

For each package delivered, the cargo van produced 933 grams of tailpipe CO_2 emissions. The e-cargo cycle route solution emitted less CO2 only when the stem share was less than 75%. The e-cargo cycle solution saved 682 grams of CO2 per package when compared to the cargo van route, when the stem share was 25%. This demonstrates the potential for even a single hub used for 4 e-cargo cycle routes carrying 10 packages per route to substantially reduce delivery CO_2.

The carbon emissions caused by the electricity consumption were negligibly small when compared to the ICE vehicle; in e-cargo tricycle routes the only notable CO_2 emissions were produced by the daily cargo van trip carrying packages from the suburban depot to the microhub.

5. Discussion and Conclusion

The results presented in this study were obtained from a small-scale pilot that could not reflect the potential gains from scaling impacts. There was only one microhub site and a single e-cargo tricycle operated during the pilot. Operating on such a small scale prevented the e-cargo tricycle from gaining economies of scale. When the number of routes per day increases, the resupply truck or van can carry and replenish more packages at the microhub(s). More daily routes upscale to more microhubs and e-cargo cycles, higher delivery densities, and subsequently greater gains in operational efficiency and environmental sustainability (Beckers et al., 2022).

However, the pilot does present useful lessons for future scaling. The remaining discussion distills knowledge both from the pilot's operational and environmental performance and the stakeholder engagement process.

5.1 Operational and Environmental Performance

When comparing VMT, it is important to distinguish between vehicle types. For the e-cargo cycle route solution, reducing ICE VMT caused by the stem trip is the focus. The cargo van emits more carbon and occupies more space on the street when compared to the e-cargo tricycles. The empirical results showed a 74% reduction in cargo van VMT when packages were delivered by e-cargo tricycles and the stem share was 25%, which resulted in an overall reduction of 365 cargo van miles in the delivery zone. However, when the stem share was 100%, that is the cargo van was only used to carry packages for the e-cargo cycle route, the e-cargo cycle route is not favorable. This indicates that when the e-cargo tricycle solution is not supported with efficient middle-mile operations, the advantages diminish quickly.

Middle-mile cargo van operations require additional consideration as microhubs scale. Research finds commercial modes that resupply microhubs (e.g., diesel or electric trucks and vans) substantially influence overall impacts on traffic and local air pollution (Assmann et al., 2020). Moreover, microhubs act as consolidators not just for goods but also trucks (Rodrigue, 2006), which can have negative localized impacts if project stakeholders fail to consider the resupply mode and surrounding infrastructure. Conventional guidance suggests microhubs be located on the peripheries of dense residential market areas and, in community surveys, street users generally perceive stationary off-street microhubs utilizing small resupply vans as safer and preferred (Assmann et al., 2019). Cities should also consider the infrastructure for last-mile cargo cycle operations and middle-mile resupply trucks by strategizing safe and adequate spaces to accommodate freight movement, loading and unloading activities, and interactions with other road users (e.g., bicycle lanes and curb access that accommodate both bicycles and cargo bicycle operators). Placing additional emphasis on decarbonizing middle-mile vans/trucks, commercial infrastructure in the vicinity of the microhub, and city-wide planning that integrates sustainable passenger and freight mobility can mitigate the negative externalities associated with microhubs such as local concentration of truck traffic, noise, air pollution and collision risk.

While the e-cargo cycle solution reduced cargo van VMT when the stem share was at least 75%, the overall system introduced more VMT than conventional van-only deliveries. These findings are in line with past studies (Browne et al., 2011; K. Lee et al., 2019), which suggest that due to cargo bicycles' limited carrying capacities these systems generate more delivery VMT than the cargo vans they are replacing. Some researchers have questioned the cost competitiveness of e-cargo cycle delivery models when compared to conventional ICE delivery vehicles, despite savings from e-cargo bicycles' lower procurement and maintenance costs (Robichet and Nierat, 2021; Tipagornwong and Figliozzi, 2014). E-cargo cycle delivery competitiveness is sensitive to local operations, infrastructure, real estate costs, and policy environments, with some examples showing break-even with conventional ICE vehicle delivery when drop densities are high, vehicle-based deliveries unattractive (e.g., in traffic-restricted districts), and cost mitigation strategies implemented (Sheth et al., 2019). In the pilot, the e-cargo cycle route solution added only 4.4% in overall VMT compared to the cargo van route solution. This relatively small differential suggests that added operational expenses may be minor and cost mitigation strategies realistic.

Additionally, depending on stem share, the e-cargo tricycle solution reduced tailpipe CO2 emissions per package between 19 and 73% when compared to the cargo van-only routes. Carbon savings multiply in a delivery network with multiple microhubs and dense customer demand because CO2 from re-supply trips would be shared by multiple hubs; trucks would be fully loaded to serve an entire network route instead of serving a single hub. As noted before, the only localized emission-producing part of the hub model comes from the resupply truck. Researchers note vehicle mix, including the resupply truck, greatly influence overall emission impact, although cargo bikes still save GHG emissions regardless of vehicle mix (K. Lee et al., 2019).

5.2 Stakeholder Success Factors and Barriers

UFL took a participatory, urban living labs approach involving several private and public sector partners to implement the SNDH in a high-density, residential neighborhood. This approach to pilot planning allowed UFL to identify several member objectives and conditions for implementation, which were instrumental in determining the location of the microhub and identifying baselines needs for introducing auxiliary business, logistics, and IT services. These auxiliary services included a "dark" kitchen food truck, a storage container for charging and housing the e-cargo tricycle and pallet, a common-carrier parcel locker, and routing app for the e-cargo tricycle operator.

Importantly, companies showed interest in reducing overall urban congestion, in-line with municipal goals, while balancing consumer access and inventory needs. As a result, these auxiliary services introduced important operational efficiencies, improved the multi-functionality of the site, and created additional sources of revenue generation that helped finance operations, leasing, and data collection (Katsela et al., 2022). These considerations allowed SNDH to operate in a logistically important location while also serving complementary delivery and retail needs of the surrounding neighborhood. Important to sustaining these services, members emphasized the importance of security (e.g., video surveillance, lighting, protections against theft and vandalism), data/internet connectivity, and adequate infrastructure provision for commercial vehicles operations. These technical considerations are crucial for the future success and scalability of microhub delivery projects.

Delivering packages with e-cargo tricycles in urban areas is not a wide-spread nor established activity, which poses its own challenges. In fact, the pilot identified two major barriers that impacted both stakeholder's perceptions of programmatic success and upscaling potential: a) bicycle navigability and infrastructure and b) work training, safety, and quality.

Regulations and infrastructure specific to e-cargo cycle delivery is rare in North America. Only New York requires e-cargo bicycles to operate in travel and bicycle lanes and in the direction of traffic flow. However, this pilot found the e-cargo tricycle courier spent 37% of its time operating on the sidewalk; when a bicycle lane was present, the courier only used it half the time (Dalla Chiara et al., 2023). Difficulties accessing the street and curb emerged when the courier delivered on streets counter-flow to traffic, with transit corridors, unprotected and narrower bicycle lanes, and/or to a mid-block address, as intersections had easy-to-access curb ramps.

Therefore, e-cargo cycle's operational advantage to ICE cargo vans—namely, its flexibility on urban transport infrastructure and shorter dwell times—shine on denser streets with better networked, protected bicycle lanes, mid-block sidewalk access, and with digital navigation tools custom-made for bicycling.

The barriers also relate to digital market structure of the on-demand economy and its precarious implications for labor (Vecchio et al., 2022). For instance, Lord et al. (2022) note how gamified delivery quotas and user-based performance ratings on food delivery apps often incentivize faster and more reckless operating behavior as well as car-based couriers over bicycle couriers. The lack of e-cargo cycle-oriented digital and physical infrastructure and proper training meant this pilot's bicycle courier frustratedly perceived they had to work harder and on more stressful infrastructure than they would in their van (even though the pilot compensated them equally for their time). Therefore, operator training for e-cargo cycle couriers can work in conjunction with labor protections that ensure safe and stable working conditions.

5.3 Conclusion

E-cargo cycle delivery is gaining attraction due to its potential to reduce emissions and congestion in urban areas. This pilot's strength was its ability to identify implementation barriers beyond the operational implications of replacing ICE van VMT with e-cargo bicycle VMT. The study revealed insights into system imperfections that are absent in simulation-based studies. Namely, that the lack of training and physical/digital infrastructure supporting e-cargo cycle delivery resulted in the courier utilizing infrastructure in unintended ways and greater frustration in a labor market already rife with tension and worker shortages. The pilot also provided real-world performance data that is rare in literature on e-cargo cycle delivery systems (Oliveira et al., 2017), especially in North America.

Most systems operate in European cities that are conducive to these forms of deliveries given high residential/commercial densities and traffic, infrastructural and regulatory conditions that make truck deliveries unattractive (e.g., in historical, traffic-restricted districts with narrow and dense street networks). While some companies and municipalities have tested e-cargo bicycle and microhub solutions in North American cities like New York City (NYCDOT, 2021), more North American evidence is needed to inform future implementations in a wide array of cities with different vehicle configurations, operations, and microhub business models. SNDH differed from the New York cargo bicycle program in that it was a private system, operated by a single delivery carrier, and utilized an off-street microhub that performed multiple retail and logistics functions. The advantage of this model is that the microhub generated alternate sources of revenue to preform important logistical functions in the urban core, where public space is highly contested and expensive.

This project implemented a participatory living lab approach. The project design allowed researchers to adapt to participating stakeholder goals, conditions, and expertise; capture operational challenges and supporting business models important for scaling future programs; and validate environmental and operational efficiency gains when replacing last-mile ICE vehicle-based deliveries with an electric cargo bicycle in a dense urban area. Future efforts can move to higher microhub and e-cargo bicycle route densities, leveraging economies of scale that bring crucial environmental and social benefits to cities.

This study estimated sensitives of replacing portions of conventional cargo van delivery with an e-cargo cycle in a zonal subset of its usual delivery tour, and the *in-situ* impacts on VMT and GHG emissions per package. Measuring these outputs were based on the stakeholders' stated, desired outcomes of the pilot. However, subsequent research should also measure sensitivities to other socio-environmental externalities—e.g., noise, air pollution, pavement degradation, and road safety. Additionally, this work revealed the impact of middle-mile efficiencies on delivery performance of the e-cargo cycle delivery system. Under-utilizing the stem cargo van makes the entire system less efficient. The pilot's findings suggest that an efficient system incorporates multiple, networked microhubs that host value-added logistical and business services to improve cost-competitiveness. Therefore, future work can explore the impact of alternative microhub locations and test a network of microhubs within a study area.

5. References

Assmann, T., Lang, S., Müller, F., Schenk, M., 2020. Impact Assessment Model for the Implementation of Cargo Bike Transshipment Points in Urban Districts. Sustainability 12. https://doi.org/10.3390/su12104082

Assmann, T., Müller, F., Bobeth, S., Baum, L., 2019. Planning of Cargo Bike Hubs: A Guide for Municipalities and Industry for the Planning of Transshipment Hubs for New Urban Logistics Concepts. Otto von Guericke Universität Magdeburg.

Beckers, J., Cardenas, I., & Sanchez-Diaz, I. (2022). Managing household freight: The impact of online shopping on residential freight trips. Transport Policy, 125, 299–311. https://doi.org/10.1016/j.tranpol.2022.06.009

Bogage, J., Dawsey, J., 2020. Postal Service to review package delivery fees as Trump influence grows. Wash. Post.

Browne, M., Allen, J., Leonardi, J., 2011. Evaluating the use of an urban consolidation centre and electric vehicles in central London. IATSS Res. 35, 1–6. https://doi.org/10.1016/j.iatssr.2011.06.002

Bulkeley, H., Coenen, L., Frantzeskaki, N., Hartmann, C., Kronsell, A., Mai, L., Marvin, S., McCormick, K., van Steenbergen, F., Voytenko Palgan, Y., 2016. Urban living labs: governing urban sustainability transitions. Curr. Opin. Environ. Sustain., System dynamics and sustainability 22, 13–17. https://doi.org/10.1016/j.cosust.2017.02.003

Bulkeley, H., Marvin, S., Palgan, Y.V., McCormick, K., Breitfuss-Loidl, M., Mai, L., von Wirth, T., Frantzeskaki, N., 2019. Urban living laboratories: Conducting the experimental city? Eur. Urban Reg. Stud. 26, 317–335. https://doi.org/10.1177/0969776418787222

Canada Post, 2020. Christmas-level parcel volumes resulting in delays as Canada Post continues to deliver. Int. Post Corp. URL https://www.ipc.be/news-portal/e-commerce/2020/04/24/09/59/christmas-level-parcel-volumes-resulting-in-delays-as-canada-post-continues-to-deliver (accessed 1.10.22).

Conway, A., Cheng, J., Kamga, C., Wan, D., 2017. Cargo cycles for local delivery in New York City: Performance and impacts. https://doi.org/10.1016/J.RTBM.2017.07.001

Crowe, C., 2020. DHL pilots e-cargo bikes in Miami to reduce congestion, pollution [WWW Document]. Supply Chain Dive. URL https://www.supplychaindive.com/news/miami-e-cargo-bike-pilot-dhl-city-congestion-pollution/578137/ (accessed 12.15.21).

Dalla Chiara, G., Donnelly, G., Gunes, S., & Goodchild, A. (2023). How cargo cycle drivers use the urban transport infrastructure. Transportation Research Part A: Policy and Practice, 167, 103562. https://doi.org/10.1016/j.tra.2022.103562

Gruber, J., Narayanan, S., 2019. Travel Time Differences between Cargo Cycles and Cars in Commercial Transport Operations. Transp. Res. Rec. J. Transp. Res. Board 2673, 036119811984308. https://doi.org/10.1177/0361198119843088

Huguenin, A., Jeannerat, H., 2017. Creating change through pilot and demonstration projects: Towards a valuation policy approach. Res. Policy 46, 624–635. https://doi.org/10.1016/j.respol.2017.01.008

International Transport Forum. (2022). The Freight Space Race: Curbing the Impact of Freight Deliveries in Cities. OECD. https://www.itf-oecd.org/freight-space-race

Katsela, K., Güneş, Ş., Fried, T., Goodchild, A., Browne, M., 2022. Defining Urban Freight

Microhubs: A Case Study Analysis. Sustainability 14, 532. https://doi.org/10.3390/su14010532

Lee, J., Kim, C., Wiginton, L., 2019. Delivering Last-Mile Solutions A feasibility analysis of microhubs and cyclelogistics for urban freight delivery in the GTHA. Pembina Institute.

Lee, K., Chae, J., Kim, J., 2019. A Courier Service with Electric Bicycles in an Urban Area: The Case in Seoul. Sustainability 11, 1255. https://doi.org/10.3390/su11051255

Llorca, C., Moeckel, R., 2020. Study of cargo bikes for parcel deliveries under different supply, demand and spatial conditions, in: 2020 Forum on Integrated and Sustainable Transportation Systems (FISTS). Presented at the 2020 Forum on Integrated and Sustainable Transportation Systems (FISTS), IEEE, Delft, South Holland Province, Netherlands, pp. 39–44. https://doi.org/10.1109/FISTS46898.2020.9264864

Lord, C., Bates, O., Friday, A., McLeod, F., Cherrett, T., Martinez-Sykora, A., & Oakey, A. (2022). The sustainability of the gig economy food delivery system (Deliveroo, UberEATS and Just-Eat): Histories and futures of rebound, lock-in and path dependency. International Journal of Sustainable Transportation. https://doi.org/10.1080/15568318.2022.2066583

Maxner, T., Dalla Chiara, G., & Goodchild, A. (2022). Identifying the Challenges to Sustainable Urban Last-Mile Deliveries: Perspectives from Public and Private Stakeholders. Sustainability, 14(8), Article 8. https://doi.org/10.3390/su14084701

McAslan, D., Najar Arevalo, F., King, D.A., Miller, T.R., 2021. Pilot project purgatory? Assessing automated vehicle pilot projects in U.S. cities. Humanit. Soc. Sci. Commun. 8, 1–16. https://doi.org/10.1057/s41599-021-01006-2

Melo, S., Baptista, P., 2017. Evaluating the impacts of using cargo cycles on urban logistics: integrating traffic, environmental and operational boundaries. Eur. Transp. Res. Rev. 9, 30. https://doi.org/10.1007/s12544-017-0246-8

Naumov, V., 2021. Substantiation of Loading Hub Location for Electric Cargo Bikes Servicing City Areas with Restricted Traffic. Energies 14, 839. https://doi.org/10.3390/en14040839

Navarro, C., Roca-Riu, M., Furió, S., Estrada, M., 2016. Designing New Models for Energy Efficiency in Urban Freight Transport for Smart Cities and its Application to the Spanish Case. Transp. Res. Procedia, Tenth International Conference on City Logistics 17-19 June 2015, Tenerife, Spain 12, 314–324. https://doi.org/10.1016/j.trpro.2016.02.068

Niels, T., Hof, M.T., Bogenberger, K., 2018. Design and Operation of an Urban Electric Courier Cargo Bike System, in: 2018 21st International Conference on Intelligent Transportation Systems (ITSC). Presented at the 2018 21st International Conference on Intelligent Transportation Systems (ITSC), pp. 2531–2537. https://doi.org/10.1109/ITSC.2018.8569606

NYCDOT, 2021. Commercial Cargo Bicycle Pilot (Evaluation Repot).

Oliveira, C.M. de, Albergaria De Mello Bandeira, R., Vasconcelos Goes, G., Schmitz Gonçalves, D.N., D'Agosto, M.D.A., 2017. Sustainable Vehicles-Based Alternatives in Last Mile Distribution of Urban Freight Transport: A Systematic Literature Review. Sustainability 9, 1324. https://doi.org/10.3390/su9081324

Ormond, P.A., Telhada, J., Afonso, P., 2018. Evaluating the economic and environmental impact of the urban goods distribution by cargo cycles – a case study in São Paulo City.

Panero, M., Shin, H., Lopez, D., 2011. Urban Distribution Centers: A means to reducing freight vehicle miles traveled.

Perboli, G., Rosano, M., 2019. Parcel delivery in urban areas: Opportunities and threats for the mix of traditional and green business models. Transp. Res. Part C Emerg. Technol. 99, 19–36. https://doi.org/10.1016/j.trc.2019.01.006

Robichet, A., Nierat, P., & Combes, F. (2022). First and Last Miles by Cargo Bikes: Ecological Commitment or Economically Feasible? The Case of a Parcel Service Company in Paris. Transportation Research Record, 2676(9), 269–278. https://doi.org/10.1177/03611981221086632

Rodrigue, J.-P., 2006. Challenging the Derived Transport-Demand Thesis: Geographical Issues in Freight Distribution. Environ. Plan. Econ. Space 38, 1449–1462. https://doi.org/10.1068/a38117

Sheth, M., Butrina, P., Goodchild, A., McCormack, E., 2019. Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. Eur. Transp. Res. Rev. 11, 11. https://doi.org/10.1186/s12544-019-0349-5

Tipagornwong, C., Figliozzi, M., 2014. Analysis of Competitiveness of Freight Tricycle Delivery Services in Urban Areas. Transp. Res. Rec. J. Transp. Res. Board 2410, 76–84. https://doi.org/10.3141/2410-09

Urban Freight Lab, 2021. The Seattle Neighborhood Delivery Hub Pilot Project: An Evaluation of the Operational Impacts of a Neighborhood Delivery Hub Model on Last-Mile Delivery. University of Washington.

Urban Freight Lab, 2018. The Final 50 Feet Urban Goods Delivery System: Common Carrier Locker Pilot Test at the Seattle Municipal Tower. University of Washington.

van den Buuse, D., van Winden, W., Schrama, W., 2021. Balancing Exploration and Exploitation in Sustainable Urban Innovation: An Ambidexterity Perspective toward Smart Cities. J. Urban Technol. 28, 175–197. https://doi.org/10.1080/10630732.2020.1835048

van Duin, J.H.R. van, Dam, T. van, Wiegmans, B., Tavasszy, L.A., 2016. Understanding Financial Viability of Urban Consolidation Centres: Regent Street (London), Bristol/Bath & Nijmegen. Transp. Res. Procedia, The 2nd International Conference "Green Cities - Green Logistics for Greener Cities", 2-3 March 2016, Szczecin, Poland 16, 61–80.

https://doi.org/10.1016/j.trpro.2016.11.008

van Winden, W., van den Buuse, D., 2017. Smart City Pilot Projects: Exploring the Dimensions and Conditions of Scaling Up. J. Urban Technol. 24, 51–72. https://doi.org/10.1080/10630732.2017.1348884

Vasiutina, H., Szarata, A., Rybicki, S., 2021. Evaluating the Environmental Impact of Using Cargo Bikes in Cities: A Comprehensive Review of Existing Approaches. Energies 14, 6462. https://doi.org/10.3390/en14206462

Vecchio, G., Tiznado-Aitken, I., Albornoz, C., & Tironi, M. (2022). Delivery workers and the interplay of digital and mobility (in)justice. *Digital Geography and Society*, *3*, 100036. https://doi.org/10.1016/j.diggeo.2022.100036

Verlinde, S., Macharis, C., Milan, L., Kin, B., 2014. Does a Mobile Depot Make Urban Deliveries Faster, More Sustainable and More Economically Viable: Results of a Pilot Test in Brussels. Transp. Res. Procedia, Sustainable Mobility in Metropolitan Regions. mobil.TUM 2014. International Scientific Conference on Mobility and Transport. Conference Proceedings. 4, 361–373. https://doi.org/10.1016/j.trpro.2014.11.027

von Wirth, T., Fuenfschilling, L., Frantzeskaki, N., Coenen, L., 2019. Impacts of urban living labs on sustainability transitions: mechanisms and strategies for systemic change through experimentation. Eur. Plan. Stud. 27, 229–257. https://doi.org/10.1080/09654313.2018.1504895

Wrighton, S., Reiter, K., 2016. CycleLogistics – Moving Europe Forward! Transp. Res. Procedia, Tenth International Conference on City Logistics 17-19 June 2015, Tenerife, Spain 12, 950–958. https://doi.org/10.1016/j.trpro.2016.02.046

Author Contributions

Seyma Gunes: Conceptualization, Methodology, Software, Data Curation, Formal analysis, Original draft writing, review and editing*; Travis Fried*: Original draft writing, review and editing; *Anne Goodchild:* Conceptualization, Supervision, Project administration, writing – Review and editing

Highlights

- The net-benefit of the microhub and e-cargo tricycle routes depend on the upstream operations when replenishing packages.

- Microhubs' ability to host alternative revenue sources and value-added services is a boon for long-term financial competitiveness.

- Lack of digital/physical infrastructure and work training/regulations specific to e-cargo cycle delivery operations present a barrier.