Delivering Last-Mile Solutions

A feasibility analysis of microhubs and cyclelogistics in the GTHA

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photo: Carolyn Kim, Pembina Institute

About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions, and convene diverse sets of stakeholders to identify and move toward common solutions.

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Executive summary

Transportation is responsible for approximately one-third of greenhouse gas emissions in Ontario. Freight transportation in particular is a major contributor to emissions — by 2030, it is expected that freight emissions in Canada will exceed passenger emissions. As e-commerce activity and the demand for same-day and home deliveries increases, it is expected that more freight vehicles will be on the road, not only contributing to increased emissions, but also traffic congestion, noise on our streets, and greater competition for the curbside.

In order to keep up with increasing demand for goods movement while mitigating the negative impacts of freight activity in dense urban areas, some businesses are rethinking their delivery operations. This report focuses on two emerging operating models that are being integrated into the goods movement network in North American and European cities to improve the efficiency of deliveries in congested urban areas: delivery microhubs and cyclelogistics. Delivery microhubs (or simply microhubs) are logistics facilities for micro-consolidation, which is the bundling of goods at a location near the final delivery point (e.g. within 1 to 5 km from the final destination). Cyclelogistics is the integration of bicycles, tricycles, or other multi-wheeled cycles for goods movement purposes (also referred to as cargo cycles).

The purpose of this report is to assess whether alternative operating models such as microhubs and cyclelogistics are feasible, and secondly help clarify the conditions under which microhubs and cyclelogistics are successful. Based on delivery practices in other jurisdictions and findings from the Pembina Institute's research and modelling work, microhubs and cyclelogistics have the potential to reduce operational costs for businesses and mitigate freight emissions in the Greater Toronto and Hamilton Area (GTHA).

Under the specific delivery conditions studied in this research, our modelling results suggest that microhubs and the use of electric-assist (e-assist) cargo cycles can be good alternatives to conventional package cars in the following ways:

- **Cost effective:** In certain cases, delivery operations are more cost effective when using e-assist cargo cycles than when using conventional package cars.

- **Operational efficiency:** Although cargo cycles tend to require longer travel times to complete all deliveries, their service time (e.g. time to unload the vehicle and get the package to the customer) is much lower compared to package car operations. This is because cargo cycles are smaller and more nimble, making it quicker for the operator to park and unload deliveries compared to package cars.
- **High productivity:** Cargo cycle operations require more delivery trips compared to package cars due to their smaller payload volume, however, cargo cycle operations do not necessarily require a larger fleet than package car operations.
- **High asset utilization:** Using cargo cycles for deliveries results in higher asset utilization compared to package cars. This is because package cars often carry loads that are below their full capacity.
- **Addresses curbside demands:** Not only are cargo cycles beneficial for improving operational efficiency for businesses, but they also decrease the number of trucks on the road and impeding loading activities in dense urban areas or districts, thereby freeing up curbside space for other road users.
- **Lower freight emissions:** Package cars can produce up to 53 kg CO_2 per day depending on the level of delivery demand. Replacing conventional package cars with cargo cycles or electric vans will eliminate tailpipe emissions, resulting in benefits for both climate and urban air quality.

Although our modelling work indicates that microhubs and e-assist cargo cycles are potentially feasible in the GTHA, examples in other North American and European jurisdictions demonstrate that multi-sectoral collaboration and enabling policies and regulations are necessary to help create an environment where these low-carbon alternative delivery solutions can be piloted and implemented at scale. In order for businesses to test and integrate new logistics models and delivery modes into their operations, they need be certain of the policy and regulatory conditions under which these approaches are financially and operationally viable.

Finding solutions to make urban deliveries more efficient and less carbon intensive requires leadership across public, private and non-governmental sectors. Governments play an important role to help spur innovation and co-design solutions with businesses to address last-mile freight challenges. In doing so, governments can realize public policy objectives, such as alleviating congestion, managing curbside competition, and decreasing transportation emissions. Here are several ways that governments can create an environment in which businesses can introduce more efficient and sustainable freight practices:

- Provide incentives or financial supports for businesses to test and implement low-carbon alternative delivery solutions in dense urban areas, including seed funding:
    - to offset the high real estate cost of establishing microhubs in dense urban areas or districts
    - integrate cargo cycles into their delivery operations.
- Align and clarify legislation, regulations, and policies at all levels of government in order to reduce barriers and restrictions on the use of e-assist cargo cycles.
- Invest in expanding and improving cycling infrastructure, urban design, and educational campaigns to better accommodate the safe use and integration of cargo cycles with other road users.
- Explore policies aimed at increasing the supply of zero-emission commercial delivery vehicles in the Canadian market (e.g., zero emission vehicle mandates).
- Explore policies and incentives to encourage uptake of zero- or low-emission delivery vehicles (e.g., purchase incentives, government procurement policies).
- Develop or modernize land use and transportation plans and strategies (e.g., freight and goods movement strategies, low-emission zones, mobility pricing in dense urban areas) as well as economic development strategies to promote the use of efficient and sustainable urban freight practices.

Businesses can accelerate the adoption of efficient and sustainable urban freight practices by doing the following:

- Establish ambitious goals and commitments to reduce freight emissions by transitioning towards low- or zero-emission freight vehicles.
- Transition towards the use of low- or zero-emission freight vehicles (e.g., cargo cycles, electric vehicles) for last-mile deliveries, taking into account different urban settings.
- Where possible, explore the potential for investing in and sharing microhub spaces with other businesses to consolidate shipments to final destinations.
- For businesses in multi-unit buildings, explore opportunities for pooled ordering to consolidate shipments of specific goods (e.g. one delivery for office supplies for an entire building).

1. Introduction

Rapid urbanization and the growth of e-commerce have put tremendous pressure on businesses to meet increasing demands for goods movement in cities. Canadians will continue to shop online in greater numbers, with sales in Canada to reach $55.78 billion by 2020.[1] To compare, brick-and-mortar sales grew by 2% in 2016, while online retail sales grew by 15%. As growth in e-commerce and increased demand for faster deliveries — particularly home deliveries — disrupt freight activity, some researchers note that it is uncertain whether these trends will result in greater vehicle movement in cities.[2,3] The delivery of goods directly to customers' homes, for example, may reduce the number of shopping trips that people make by car. Nevertheless, there is a strong likelihood that increasing demand for goods movement (both business to business and business to customer) will result in more freight vehicles on the road and consequently increased traffic congestion, noise pollution, air pollution, and greenhouse gas (GHG) emissions. However, such externalities can be mitigated with the willingness and ability of business to modernize their freight practices to become more efficient and sustainable, and with government efforts to develop goods movement strategies and plans that create the conditions whereby innovative delivery solutions can be piloted and scaled.

According to Environment and Climate Change Canada, overall freight emissions in Canada (which include trucks, rail, air and marine) are projected to eclipse passenger emissions by 2030.[4] In Ontario, the volume (tonne-kilometres) of road freight activity grew by 154% between 1990 and 2016.[5] It is not surprising then that in 2016, 35% of

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[1] Canada Post, *Growing E-Commerce in Canada: unlocking the online shopper opportunity (2016),* 10. https://www.canadapost.ca/web/assets/pdf/blogs/canada-post-growing-e-commerce-in-canada-2016_en.pdf

[2] Johan Visser, Toshinori Nemoto and Michael Browne, "Home Delivery and the Impacts on Urban Freight Transport: A Review," *Procedia – Social and Behavioral Sciences* 125 (2014), 26.

[3] Kenneth Boyer, Andrea M. Prud'homme and Wenming Chung, "The Last Mile Challenge: Evaluating the Effects of Customer Density and Delivery Window Patterns," *Journal of Business Logistics* 30, no. 1 (2009), 196.

[4] Environment and Climate Change Canada, *Canada's Second Biennial Report on Climate Change* (2016), Annex 1. https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=02D095CB-1#BR-SecAnnex1

[5] Natural Resources Canada, Comprehensive Energy Use Database, "Table 11: Freight Road Transportation Secondary Energy Use and GHG Emissions by Energy Source."

total GHG emissions in Ontario were attributed to transportation, making it the highest-emitting economic sector in the province.[6] On-road heavy-duty trucks alone are responsible for just over 10% of provincial emissions.[7] These trends have major implications on the quality of life of Ontarians since trucks are a leading source of criteria air contaminants, polluting the air that we breathe.[8]

The freight sector, however, is a core part of Ontario's economy, given that 38% of the province's economy comes from freight-intensive industries, and trade between Ontario and the United States was worth $284 billion in 2011.[9] That is why there is a need for policy actions and practical solutions that decouple the contributions of the goods movement sector to Ontario's economy from freight emissions. One way to do this is to decrease urban freight emissions even in the face of increased freight and goods movement activity.

Urban freight refers to the various activities involved in the delivery of goods — including collection, storage, consolidation, and transport — in cities or other urban contexts.[10] Delivering goods in cities, including the "last mile" of such deliveries, is increasingly difficult due to traffic congestion, curbside competition, and rising land costs to accommodate logistics facilities close to urban centres. Delivery vehicle operators often spend hours stuck in traffic and must compete with other road users, such as cyclists, motorists, and ride-hailing vehicles, for the same road and curbside space. Some municipalities have recognized the extent of these issues and are making efforts to address them through better land use and transportation plans and policies. The City of Toronto, for example, is implementing a *Curbside Management Strategy* that includes actions to manage curbside space in a way that improves mobility and access

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http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=on&rn=11&page=4. Freight activity measured in tonne-kilometres.

[6] Environment and Climate Change Canada, *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada* (2018) Part 3, Table A12-7. https://unfccc.int/documents/65715. The transportation sector category includes domestic aviation, road transportation, railways, marine and off-road transportation.

[7] Ibid. This number does not include on-road movements by commercial light-duty vehicles.

[8] Environment Canada (2017). "Air pollutants – Criteria Air Contaminants." https://www.ec.gc.ca/air/default.asp?lang=En&n=7C43740B-1.

[9] Ontario Ministry of Transportation*, Freight-Supportive Guidelines,* (2016), Chapter 1. http://www.mto.gov.on.ca/english/publications/freight-supportive-guidelines.shtml. Information from Transport Canada.

[10] Damian Stantchev and Tony Whiteing, *Urban Freight Transport and Logistics: An overview of the European research and policy* (European Communities, 2006), 2. https://trimis.ec.europa.eu/sites/default/files/brochure/20060831_105348_30339_Urban_freight.pdf

for people and goods movement activity.[11,12] This curbside management strategy is meant to complement the City of Toronto's forthcoming freight and goods movement strategy.

As a part of the wide range of solutions that are needed to address the challenges associated with increased urban freight activity, consideration should be given to the implementation of microhubs and cyclelogistics. Microhubs are facilities for micro-consolidation, which is the bundling of goods at a location near the final delivery point. Given that 48% of Canadian online shoppers live in dense urban areas,[13] there is a significant opportunity to increase the efficiency of last mile deliveries by reorganizing distribution networks. Microhubs are an example of a delivery operations model that can improve delivery efficiency and reduce urban freight emissions by allowing businesses to consolidate goods closer to their final destination and therefore reduce the number of vehicle kilometres traveled in an urban area. Research has shown that the use of more efficient urban delivery systems that consolidate and coordinate between freight carriers can result in 12–14% savings in operational costs.[14]

Microhubs also grant businesses the flexibility to shift modes in the supply chain so that more nimble and cleaner vehicles, such as electric light-duty vehicles and e-assist cargo cycles, can be used to conduct last-mile deliveries.[15] Cargo cycles are bicycles, tricycles, or other multi-wheeled cycles that are equipped with a cargo unit to store and move goods or people (e.g. children). Conducting goods movement by cycling is referred to as cyclelogistics. Many businesses in Europe — and now also in a few North American markets, including Canada — have integrated microhubs and cyclelogistics into their goods movement practices to increase efficiency, reduce operational costs, and mitigate adverse impacts on cities. In doing so, some businesses have demonstrated significant reductions in last-mile vehicle kilometres traveled and "empty" truck distances, thereby

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[11] City of Toronto, *Curbside Management Strategy: Improving How Curbside Space Is Used* (2017). https://www.toronto.ca/legdocs/mmis/2017/pw/bgrd/backgroundfile-109153.pdf

[12] City of Toronto, *City Council Issue Notes 2018-2022* (2018), 109. https://www.toronto.ca/wp-content/uploads/2018/12/9598-City-Council-Issue-Notes-2018-2022.pdf

[13] Canada Post, *Growing E-Commerce in Canada: unlocking the online shopper opportunity* (2016), 5. https://www.canadapost.ca/web/assets/pdf/blogs/canada-post-growing-e-commerce-in-canada-2016_en.pdf

[14] Mireia Roca-Riu, Miquel Estrada and Elena Fernandez, "An evaluation of urban consolidation centers through continuous analysis with non-equal market share companies," *Transportation Research Procedia 12* (2012), 371.

[15] Carolyn Kim and Nitish Bhatt, *Modernizing urban freight deliveries with microhubs* (Pembina Institute, 2019), 2. https://www.pembina.org/reports/microhubs-factsheet-v4-online.pdf

lowering transportation-related emissions and air pollution.[16] While there is no one-size-fits-all solution to address urban freight challenges — microhubs and cyclelogistics may not be applicable in all contexts — our research demonstrates that given the right context and conditions, these alternative delivery models can be viable and practical. More broadly, our research highlights that there are significant opportunities and untapped potential for Ontario businesses and cities to adopt more efficient logistics models and delivery modes.

In order for businesses to integrate new logistics models and delivery modes into their operations, they need to know the policy and regulatory conditions under which these approaches are financially and operationally viable. The purpose of this report is to assess the feasibility of microhubs and cyclelogistics and identify the conditions under which these mechanisms can be successfully implemented. To inform our research, we model the feasibility of microhubs and cyclelogistics in the Greater Toronto and Hamilton Area of Ontario. More specifically, we model various scenarios under which a microhub delivery system, with deployment of small electric vans or e-assist cargo cycles for last-mile delivery trips, could viably operate, and compare them to a business-as-usual delivery system (deployment of package cars) in select locations within the cities of Toronto and Hamilton.

Our modelling work includes sensitivity analyses to test the feasibility of microhubs and cyclelogistics under various levels of delivery demand and levels of congestion. Based on this modelling exercise, we are able to determine the optimal fleet size, total vehicle kilometres traveled, and total time it takes to conduct a given number of deliveries under different conditions, and to estimate the operational cost and GHG emissions associated with each delivery scenario. While this feasibility study is scoped to illustrative cases in the GTHA, it provides a good first step for policy and planning practitioners in the public and private sectors to understand the conditions under which microhubs and cyclelogistics can be most effective across different Canadian urban contexts.

Finally, this report also draws on experiences from international jurisdictions to identify the range of policies and regulations that have helped incentivize sustainable and efficient urban goods movement solutions such as microhubs and cyclelogistics. The

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[16] Sam Clarke and Jacques Leonardi, *Final Report: Multicarrier consolidation - Central London trial* (Greater London Authority, 2017), 49. https://www.london.gov.uk/sites/default/files/gla-agile1-finalreport-02.05.17.pdf

high cost of delivery operations in cities means that private, government, and non-governmental organizations and actors all play a crucial role to get it right.[17]

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[17] CIVITAS , *Smart choices for cities: Making urban freight logistics more sustainable* (2015), 10. https://civitas.eu/sites/default/files/civ_pol-an5_urban_web.pdf

2. Context: Understanding the last mile

2.1 What is the last mile?

The "last mile" of urban goods movement refers to the delivery of goods from some type of consolidation centre (e.g. a warehouse, distribution centre, or microhub) to its final destination (e.g. a retailer's store or customer's home). Unlike other segments of the supply chain, the last mile is unique because each good being delivered has its own destination. A multitude of delivery destinations make last-mile deliveries time-consuming and complex because many stops are required and delivery operators must devise the most efficient route between delivery locations, considering time and costs. Due to increasing traffic congestion, a lack of loading zones, curbside conflicts and other inefficiencies, businesses spend a large share of their time and costs conducting last-mile deliveries. While the vehicle kilometres traveled of conducting urban deliveries is a small portion of the total distance traveled in the overall supply chain, last-mile distribution represents around 28% of total logistics costs.[18] Addressing inefficiencies in last-mile deliveries is therefore critical for businesses to reduce their costs.

2.2 Disruptions in last-mile deliveries

The shift in consumer preferences toward online shopping, plus increasing expectations for fast and convenient shipping, is disrupting the nature of freight and goods movement. Increased internet access and sophisticated e-commerce platforms and technologies that simplify customer shopping on mobile devices have increased online sales. In addition to online purchases by customers (business-to-consumer or B2C), business-to-business (B2B) e-commerce is an emerging trend between corporate sellers and buyers. According to a study commissioned by Purolator, B2B online selling is a major part of business in Canada, with over half of Canadian B2B sellers reporting that

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[18] Roca-Riu et al., "An evaluation of urban consolidation centers through continuous analysis with non-equal market share companies," 371.

over 25% of their overall sales occur online.[19] These megatrends have collectively put upward pressure on the volume of goods being shipped by trucks and the number of delivery locations being served.[20] Business surveys indicate that an increasing diversity of products are being sold online, including products that have typically required an in-person shopping experience, such as furniture and appliances.[21]

E-commerce has not only increased the volume of online sales, but also increased the demand for expedited and same-day shipping. E-commerce and retailers in North America and globally are in fierce competition to drive down the default standard shipping times, and are now trending towards one-day standard shipping.[22] This is a marked change from customer expectations from only a couple of years ago; in 2016, most customers considered fast shipping to be within two days, and in 2015, the expectation was three or four days.[23] Even as customers' expectations for fast delivery increases, their willingness to pay for it has fallen — 64% of shoppers are unwilling to pay additional fees for two-day shipping.[24] The growth of online retail has also generated an increase in the volume of items being returned by customers from their homes.[25] As such, businesses need to optimize their last-mile distribution networks for both delivery and pick-up operations.

The megatrends and disruptions in e-commerce as well as evolutions in the way customers are buying groceries and day-to-day retail or other discretionary goods has had a tremendous impact on how goods are being moved in cities. As will be discussed later in this report, transportation and goods movement planning strategies are

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[19] Forrester, "Canada Rises to the B2B E-Commerce Challenge: Canadian B2B Sellers Embrace E-Commerce and Prepare For the Future", (2016). https://www.purolator.com/assets/pdf/white-papers/b2b-ecommerce-challenge.pdf

[20] Deloitte, "The future of freight: How new technology and new thinking can transform how goods are moved."

[21] Chaturvedi Nitin, Mirko Martich, Brian Ruwadi, Nursen Ulker, "The future of retail supply chains," McKinsey, https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/retail/articles/future_of_retail_supply_chains.ashx

[22] Shannon Liao, "Amazon says it's working on free one-day Prime shipping," *The Verge*, April 25, 2019. https://www.theverge.com/2019/4/25/18516795/amazon-prime-free-one-day-shipping-update-earnings

[23] Deloitte, "The future of freight: How new technology and new thinking can transform how goods are moved." (2017). https://www2.deloitte.com/insights/us/en/focus/future-of-mobility/future-of-freight-simplifying-last-mile-logistics.html

[24] Ibid.

[25] Ibid.

increasingly important so that cities can adapt to these changing shopping patterns and accommodate growth in goods movement activity in an efficient and sustainable manner.

2.3 Last-mile challenges in urban centres

Based on our interviews with industry experts in urban freight and logistics, last-mile delivery trips are particularly challenging in dense urban areas for a number of reasons. First, delivery vehicles require curbside space to either park or make a temporary stop (e.g. in a loading zone) when making deliveries. In dense urban centres, curbside space — defined as the access point between the road and the sidewalk — is in high demand not only by delivery vehicles, but also other curbside users including ride-hailing vehicles, cyclists, buses, taxis, garbage trucks, emergency services, food trucks, and construction workers.[26] Due to the high demand for limited curbside space, it is not uncommon for delivery vehicles to circle around a delivery zone in attempt to find a designated place to stop to load/unload deliveries. This is costly for businesses because it increases delivery times and fuel costs. It also increases freight related GHG emissions and air pollutants in cities.

A lack of dedicated curbside space for goods movement vehicles has also resulted in inefficient traffic operations as delivery operators often make illegal and ad hoc stops along streets. This impedes the right of way of other road users, particularly cyclists, transit vehicles, and motorists. In 2006, it was estimated that three major courier companies in the City of Toronto were fined a total of $1.5 million in parking tickets.[27] This number has likely increased given the increased demand for curbside space and goods movement activity in Toronto since 2006.

Another major challenge of conducting last-mile deliveries in urban centres is that often customers are not home during delivery times, resulting in a “missed delivery”. Canada Post reports that 35% of Canadian households do not have anyone at home

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[26] City of Toronto, Transportation Services, “Staff report: Curbside Management Strategy: Improving How Curbside Space is Used.” (2017). https://www.toronto.ca/legdocs/mmis/2017/pw/bgrd/backgroundfile-109153.pdf

[27] Murtaza Haider, Lindsay Lalonde, Mateen Mehboubi, Christopher Livett and Derick Spenard, *Challenges facing express delivery service in Canada’s urban centres* (Institute of Housing & Mobility, Ted Rogers School of Management, Ryerson University, 2009), 1-2.

during the day to receive deliveries.[28] Packages may be left outside the customer's home if no one is available to receive them, but this makes them susceptible to theft and could potentially create liability issues for couriers and suppliers. However, industry experts note that multi-unit residential buildings (e.g. apartment towers) are becoming increasingly strict around the types of goods that are allowed to be left in the building when people are not home.[29] If a delivery operator is unable to leave packages unattended at the customer's home (e.g. for contractual obligations with the customer), then businesses must spend additional time and money to return the items to a consolidation depot and re-deliver them the next day. Missed deliveries are also problematic because it is expensive for businesses to hold items and other inventory due to the high cost of space in dense urban areas. It also means customers need to make a trip to the consolidation depot to pick up packages. This also presents challenges from a regional and city-wide goods movement perspective because it means that up to three or four vehicle trips must be made to receive one missed parcel.

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[28] Marc Smith, "Canada Post eCommerce Growth Insights and Impact on Logistics and Delivery," presented at the Toronto Region Board of Trade e-Commerce Movement of Goods Roundtable, Toronto, October 30, 2018, 17.

[29] Janelle Lee, *Modernizing Urban Freight Deliveries Workshop: Workshop Summary Notes* (Pembina Institute, 2019), 12. https://www.pembina.org/reports/modernizing-urban-freight-workshop-summary-notes-final.pdf

3. Addressing last-mile delivery challenges with microhubs

3.1 Defining microhubs

Microhubs are logistics facilities for micro-consolidation, which is the bundling of goods at a location near the final delivery point (e.g. within 1 to 5 km from the final destination).[30,31] In other words, microhubs provide an additional transhipment point in the supply chain that is located in the heart of an urban area.[32] Other terms are also used to refer to different types of micro-consolidation operations and the facilities where micro-consolidation occurs, including micro-consolidation centres, vehicle reception points, goods reception points, and mobile depots. In this report, we use the term "microhubs" to broadly refer to such facilities.

Microhubs are different than urban consolidation centres (UCCs), which are logistics facilities that are typically located just outside a city's border or in a city's suburbs where goods coming from outside of the city can be consolidated before being delivered within the city.[33] In many cases, one UCC is used to serve an entire urban area[34] and therefore a UCC is often relatively large, ranging from approximately 500,000 ft^2 to over 5 million ft^2 depending on the jurisdiction.[35] In contrast, microhubs have smaller

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[30] Milena Janjevic and Alassane Balle Ndiaye, "Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport," *Procedia – Social and Behavioral Sciences* 125 (2014), 285.

[31] Susanne Balm, Amsterdam University of Applied Sciences, personal communication, April 2, 2019.

[32] Janjevic et al., "Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport,", 285.

[33] Bram Kin, Sara Verlinde, Tom van Lier and Cathy Macharis, "Is there life after subsidy for an urban consolidation centre? An investigation of the total costs and benefits of a privately-initiated concept," *Transportation Research Procedia* 12 (2016), 358.

[34] Julian Allen, Michael Browne, Allan Woodburn and Jacques Leonardi, "The Role of Urban Consolidation Centres in Sustainable Freight Transport," *Transport Reviews* 32 (2012), 480.

[35] Michael Gogas and Eftihia Nathanail, "Evaluation of Urban Consolidation Centers: A Methodological Framework," *Procedia Engineering* 178 (2017), 462.

footprints that can range from approximately 1,000 ft^2 to 10,000 ft^2 (see Figure 1).[36,37] Although UCCs are one of the most common consolidation schemes in city logistics, many businesses are experimenting with different consolidation practices, including micro-consolidation, to reimagine the size, function, and location of logistics facilities.[38,39]

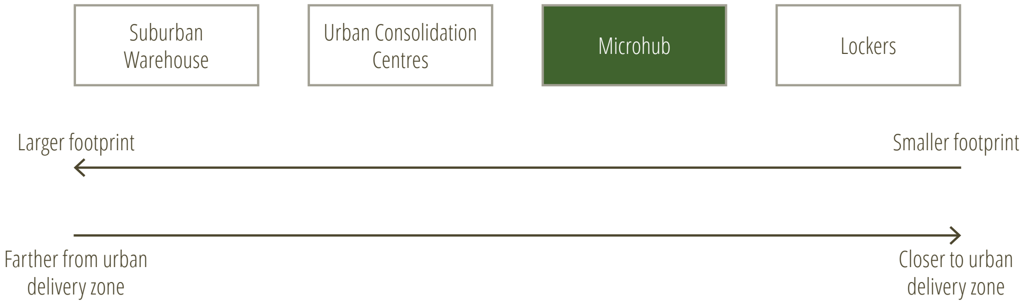

Figure 1. Types of urban logistics spaces

Microhub operations may use a permanent building or a mobile structure, operate on a permanent or temporary basis, and may be operated by one or more businesses in parallel. In general, though, microhub operations have five common characteristics[40]:

- Intend to reduce the number of vehicle trips in an urban area
- Focus on the delivery of smaller and lighter loads
- Allow goods to be transferred to a cleaner mode of transport, such as cycling or walking, for the last mile of delivery
- Are typically operated by privately owned transportation companies
- Facilities are located within an urban area near the final delivery point

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[36] Sam Clarke and Jacques Leonardi, *Agile Gnewt Cargo: parcels deliveries with electric vehicles in Central London (Greater London Authority, 2017), 46.* https://westminsterresearch.westminster.ac.uk/download/53a6644ba063a519a34b7cc11806396479d756214f5f785b2588c71d25dadd1c/2484777/GLA-Agile1-DataReport-3May2017.pdf

[37] Michael Browne, Julian Allen, Toshinori Nemoto, Daniele Patier, and Johan Visser, "Reducing social and environmental impacts of urban freight transport: A review of some major cities," *Procedia – Social and Behavioral Sciences* 39 (2012), 30.

[38] Janjevic et al., "Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport," 285.

[39] *Smart choices for cities: Making urban freight logistics more sustainable*, 42.

[40] Janjevic et al., "Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport," 286.

Many of these characteristics of microhub operations are not new to the urban freight landscape in Canadian cities. Canada Post's depots, for example, are facilities closer to the final delivery point for consolidating and transferring goods into a smaller vehicle for transport. As another example, Rexall and Well.ca have partnered together so that customers can conveniently pick up their online purchases at Rexall locations.[41] Similarly, PenguinPickUp is a business that offers convenient pick-up locations in high density mixed-use and commercial areas for customers to collect their online purchases from a variety of retailers. Section 3.1.1 presents additional examples of different microhub models in Europe and North America.

Although microhubs and parcel lockers are similar in some ways, we differentiate them in this report based on the self-serve characteristic of lockers. Lockers are very small storage units that are located close to the final delivery point in urban or rural areas, and which can be conveniently accessed by customers without the help of a staff person (see Figure 1). This is different than microhubs, where goods are delivered onward to the final destination or where staff is usually available to hand off items to customers for pickup. Lockers are often located inside retail banking locations, grocery stores, transit stations, or condominium lobbies.

3.1.1 Microhub models

Businesses may implement a variety of operational models to integrate microhubs into their logistics and supply chain operations. When choosing an operational model, a key consideration is whether microhubs are to be used solely for one business or designed in a manner that allows a mix of multi-carrier consolidation efforts. Microhub operations are practiced in many European cities, including Berlin, London and Paris. Figures 2 to 4 below illustrate some examples of different microhub models, each with a different micro-consolidation approach. Table 1 provides more details on the different features of each microhub example, including the type of cargo delivered from the microhub, the mode used for last-mile delivery, and different government contributions to support microhub operations.

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[41] Rexall, "Newsroom," November 20, 2018. https://www.rexall.ca/newsroom/view/33/New-Well.ca-Order-Pick-Up-at-Rexall-Launches-Across-Canada-Just-in-Time-for-the-Holiday-Season

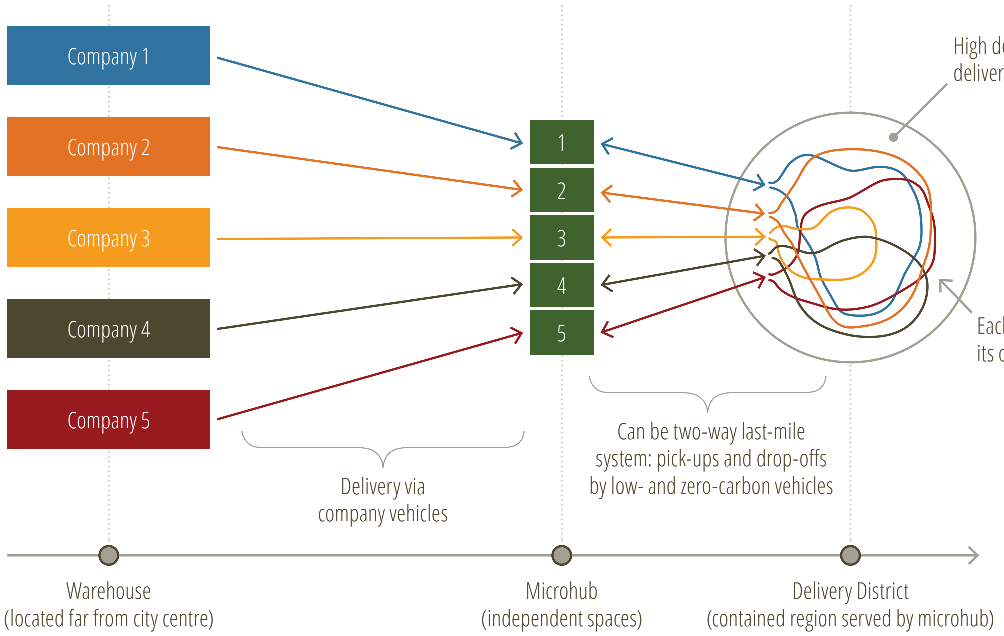

Figure 2. KoMoDo's operations in Berlin use independently operated microhub spaces

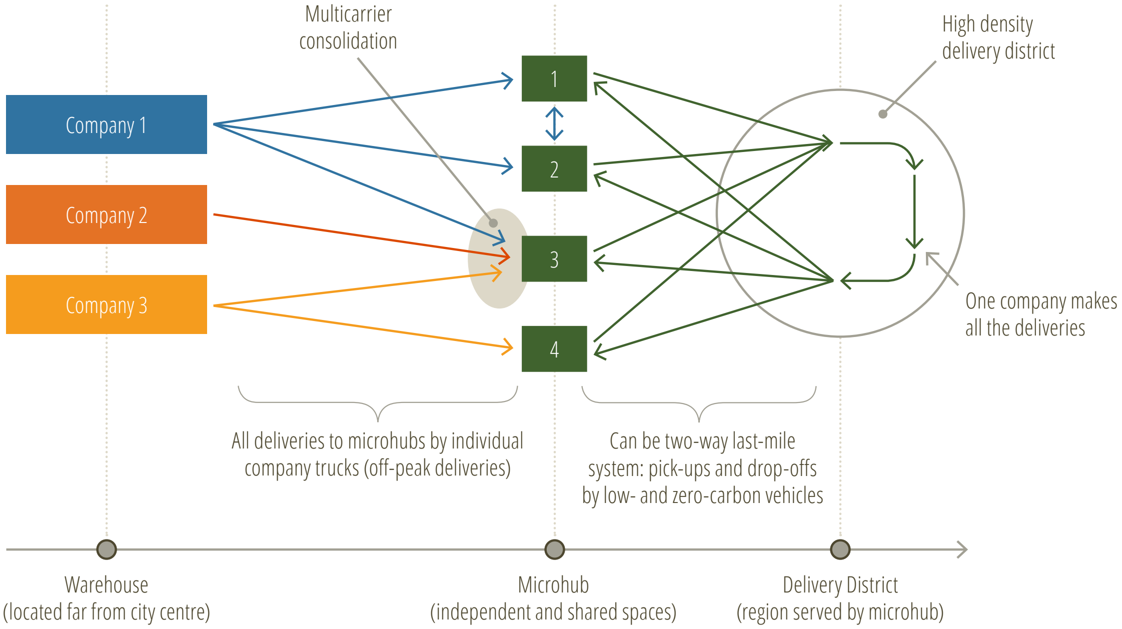

Figure 3. Gnewt Cargo's operations in Central London use a mixed multi-carrier consolidation approach

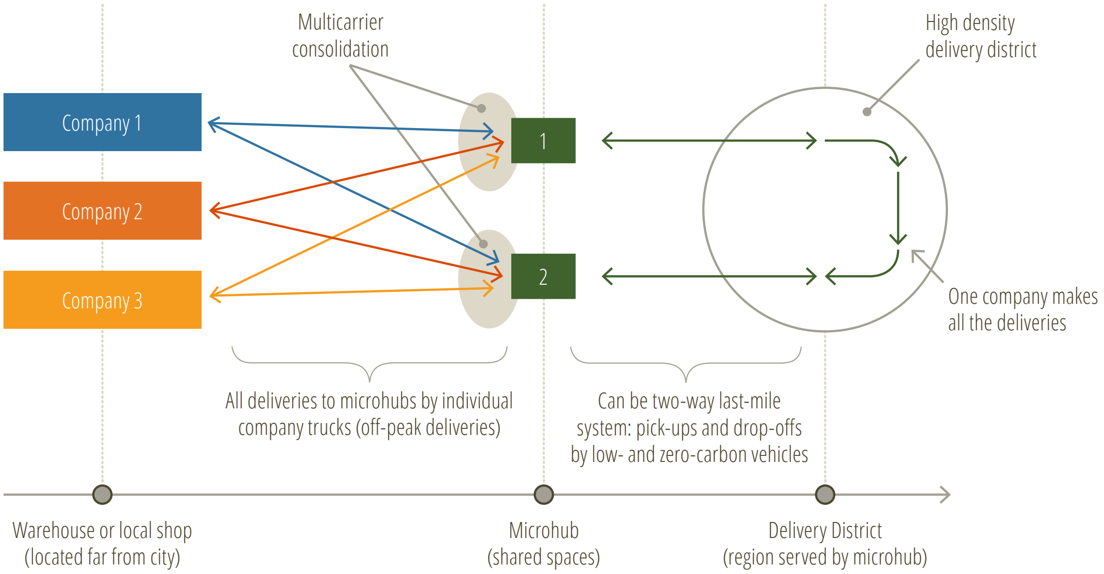

Figure 4. La Petite Reine's operations in Paris use a full multi-carrier consolidation approach

Table 1. Examples of microhub models

	Vehicle Registration within delivery zone	Delivery type*	Type of cargo	Last-mile delivery mode	Time of resupply	Multicarrier consolidation	Specific delivery routes	Delivery zone density	Government contributions
KoMoDo, Berlin	Low-emission zone	B2C	Non-perishable, non-food parcels	E-assist cargo cycles	Unknown	No	Yes	Large areas > 25,000 people/km^2	Free logistics space in city centre
Gnewt Cargo, London Central	Low-emission zone; congestion charge	B2C and B2B	Non-perishable, non-food parcels	Electric vehicles (EVs)	Off-peak	Yes	Yes	Predominantly > 7,000 people/km^2	Operational funding of EUR 288,000
La Petite Reine, Paris	Restricting on-peak large vehicle entry into city centre	B2C and B2B	Mixed; includes perishable food deliveries	Pedal-only cargo cycles and EVs	Off-peak (before morning peak)	Yes	No	Predominantly > 12,500 people/km^2	Discounted underground ULS; analysis and feasibility study
TNT Mobile Depot, Brussels	Low-emission zone	B2C	Non-perishable, non-food parcels	E-assist cargo cycles	Mobile depot arrives at delivery zone at 9:15 am	No	Yes	Predominantly > 9,700 people/km^2	Operational funding of an unknown amount
PenguinPick Up, Canada	N/A	B2C	Mixed; includes perishable food deliveries	Predominantly customer pick up	Unknown	Yes	No (customer pick up)	> 8,000 households in 500m radius	None
UPS Access Points, Canada	N/A	B2C	Non-perishable, non-food parcels	Customer pick up	Unknown	No	No (customer pick up)	Varies	None
Canada Post depots, Canada	N/A	B2C	Non-perishable, non-food parcels	Small delivery trucks and vans	Unknown	No	Yes	Varies	Canada Post is a Crown corporation

*B2C: business to customer; B2B: business to business

3.2 Policy context for the implementation of microhubs

Several policy documents guide freight planning in Ontario, including the Ontario Ministry of Transportation's *Freight-Supportive Guidelines*, Metrolinx's *GTHA Urban Freight Study*, and the Region of Peel's *Goods Movement Strategic Plan*. Although many of the strategies and actions in these documents focus on supporting truck movements (e.g. establishing a strategic truck route network, improving road infrastructure to accommodate the movements of large freight vehicles), some recommendations specifically speak to the need for smaller consolidation facilities or alternative delivery approaches in dense urban areas. While these policies do not explicitly include terms such as 'microhubs' or 'micro-consolidation', they support the essential characteristics of micro-consolidation — namely, reducing the number of vehicle trips and allowing goods to be delivered in smaller vehicles.

Action 11 in Metrolinx's *GTHA Urban Freight Study*, for example, identifies the opportunity and need to establish "localized package drop-off stations" in shopping centres, business parks, or near residential neighbourhoods. Such facilities would allow couriers to consolidate trips and avoid missed deliveries. Similarly, the Region of Peel's *Goods Movement Strategic Plan* identifies a set of actions to consolidate urban freight trips in order to improve delivery efficiency and reduce freight-related traffic. Other policies support the operations of smaller freight vehicles by providing more designated loading zones and/or off-street parking that make it easier for these vehicles to make stops along the curb. Metrolinx's *2041 Regional Transportation Plan* further recognizes the potential for bicycles to be used for goods movement. Table 5 in Appendix A identifies the relevant documents and specific strategies and plans in Ontario that support opportunities for microhubs and alternative ways to move goods along the last mile.

3.2.1 International policy examples

In Europe, some jurisdictions are more prescriptive than Ontario in their approach to improving goods movement efficiency and reducing freight-related emissions by imposing the conditions necessary for businesses to adopt alternative goods movement practices. Low-emission zones (LEZ), for example, are commonly implemented in European cities to restrict the use of certain polluting vehicles in specific parts of a city.[42] In London, trucks are subject to a high fee for operating within LEZs if they do not meet the city's particulate matter emissions standard. An ultra-low emission zone (ULEZ) was also recently implemented in central London where a congestion charge is also in effect. A charge of £12.50 (approximately $21 CAD) is applied to most vehicle types (e.g. cars, van, and motorcycles) under 3.5 tonnes and a £100 charge (approximately $170 CAD) to heavier vehicles (e.g. trucks and buses) over 3.5 tonnes that do not meet European ULEZ emissions standards based on vehicle type and fuel.[43]

Prohibiting or disincentivizing the use of larger polluting vehicles through LEZs, ULEZs, or similar vehicle access restrictions encourages businesses to adopt micro-consolidation approaches that use small, less-polluting vehicles for goods movement. There is growing appetite for similar policies in the Unites States. New York City recently approved congestion pricing in crowded parts of Manhattan, becoming the first city to implement such a policy in North America.[44] Although many details of New York's congestion charge still need to be determined, it is anticipated that trucks will pay a higher charge than cars.

In France, the government has been actively involved in conducting research to understand urban freight activity and supporting the establishment of micro-consolidation spaces.[45] The country's national research program developed a typology of different urban logistics spaces (Espace Logistique Urbain or ELU) based on their location, size, and function. One such ELU is a local logistics point, Espace Logistiques de Proximité or ELP, which is a kind of micro-consolidation facility located within an urban area, ranging in size from 500 to 1,000 m^2. As will be discussed in the following section, municipal governments in France provide businesses with a cheaper rental price than the market value for micro-consolidation spaces to ensure that such facilities are available in dense urban areas.

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[42] Alison Conway, Pierre-Emmanuel Fatisson, Penny Eickemeyer, Jialei Cheng and Diniece Peters, "Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan: Opportunities and challenges," in *Proceedings of the 91st Transportation Research Board Annual Meeting, Washington, DC, USA, 22-25 January 2012,* 9-10.

[43] City of London, "Ultra Low Emission Zone (ULEZ)," 2019. https://www.cityoflondon.gov.uk/business/environmental-health/environmental-protection/air-quality/Pages/ultra-low-emission-zone.aspx

[44] Steven D'Souza, "'A tsunami to get this done': How New York finally accepted congestion pricing," *CBC News*, April 14, 2019. https://www.cbc.ca/news/world/new-york-congestion-tax-explained-1.5097217

[45] Browne et al., "Reducing social and environmental impacts of urban freight transport: A review of some major cities," 29-31.

Yokohama, Japan is another example of a place where governments are supporting urban freight activity in innovative ways.[46] The Yokohama City Government and local police have supported an association of retailers in one of the major shopping districts in the city to establish a cooperative delivery system and shared consolidation centre. The local government also subsidized the low-emission vehicles that serve the consolidation centre.

In Ontario and Canada more broadly, the applicability of microhubs and cyclelogistics depends on the policy and regulatory environment (e.g., policies governing weight requirements for e-assist cargo cycles, subsidized microhub spaces in dense urban areas), as well as the ability for businesses to modify their operations to allow for multi-carrier consolidation where it makes sense.

3.3 Conditions for success

There are three key elements to consider when evaluating the potential success of microhub operations: relevance, suitability, and feasibility.[47] Relevance is defined as the need for micro-consolidation in a given area, which is determined by the current and potential demand for goods delivery. Dense urban areas tend to have higher relevance since there are more businesses and households, increasing the potential demand for deliveries. Research shows that denser areas experience the least vehicle kilometres traveled per delivery since delivery locations are located closer together.[48] If demand for goods movement in an area is too low, there is little reason for companies to establish a microhub since the level of demand will not justify its operational costs.

Suitability is the second condition for success. It refers to the physical attributes of a service area that make it more or less favourable to microhub operations. These attributes include accessibility to and within the service area, availability of loading and unloading infrastructure, and design of the transportation network. Areas that are best suited for micro-consolidation operations are difficult to access by larger delivery vehicles (either due to limited road space, high congestion levels, or vehicle restrictions), have limited space available for delivery vehicles to stop along the curbside, and prioritize infrastructure designed for pedestrians, cyclists, and transit

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[46] Ibid., 25.

[47] Janjevic et al., “Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport,” 294.

[48] Boyer et al., “The Last Mile Challenge: Evaluating the Effects of Customer Density and Delivery Window Patterns,” 195.

users. Together, these characteristics make it difficult to conduct deliveries with a conventional urban freight vehicle, such as a delivery truck or van, and make conditions much more suitable for alternative delivery modes, such as cargo cycles, deploying from microhub locations.

The last condition for success is feasibility, which is the institutional and economic context necessary to support micro-consolidation operations. Feasibility increases when key and supporting stakeholders are involved in the design and operation of a microhub, including business representatives and government actors, to advance shared interests and common goals. The government's participation in establishing a shared consolidation centre in Yokohama is an example.[49] Feasibility also depends on the effective integration and consideration of microhub operations in broader transportation plans and policies. Implementing low-emission zones in dense urban areas, for example, requires businesses to use low- or zero-emission vehicles for deliveries (e.g. cargo cycles). In order to be operationally feasibly, these low- or zero-emission vehicles are typically deployed from microhubs. Thus, low-emission zones encourage the establishment of microhubs in order for businesses to use the permitted vehicle types in these zones.

Government support is particularly important for ensuring the financial viability of microhubs. Although there are many benefits of implementing microhubs, one the major challenges is the high cost of land in dense urban areas where microhubs are located. Incentives or financial supports provided by governments are often necessary to offset the high real estate costs of microhub spaces. Public financing has been used to establish micro-consolidation spaces in France. In the city of Bordeaux, for example, 90% of ELP costs were publicly financed in 2003, 40-45% in 2004, and 10-15% in 2005.[50] Despite the financial cost, supporting urban delivery solutions such as microhubs and cyclelogistics will help governments realize public policy objectives, including improving congestion, alleviating curbside competition, and reducing urban freight emissions and associated air pollutants. In other words, there are additional public benefits from investing in solutions that address the externalities associated with rising urban freight deliveries.

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[49] See section 3.1.2

[50] Janjevic et al., "Development and Application of a Transferability Framework for Micro-consolidation Schemes in Urban Freight Transport," 293.

4. Low-carbon last-mile delivery vehicles

Microhub models utilize different modes of transportation to conduct last-mile deliveries, including small electric vans or cargo cycles, or giving customers the option to pick up their items from a microhub (see Table 1). From a business perspective, the optimal size and composition of a delivery fleet depends on a number of factors such as the volume of goods that need to be delivered, the service area of a microhub, and the number and geographic distribution of delivery locations. These factors determine the operational cost of using different modes for last-mile deliveries. In Section 5 of this report, we model different delivery scenarios to compare the operational cost of using small electric vans and cargo cycles under varying delivery conditions.

Beyond the operational cost of different delivery modes, policies and regulations are also key considerations for businesses when determining which modes to use for last-mile deliveries. As discussed earlier, some cities implement LEZs, ULEZs, or congestion charges to restrict or discourage the use of certain vehicles in specific parts of a city to reduce vehicular emissions and congestion. Such policies encourage businesses to use electric cars, cargo cycles, or other low- and zero-emissions modes for last-mile deliveries.

The supply of low-carbon last-mile delivery vehicles on the market also influences whether businesses are able to use alternative delivery modes. In Canada, there are currently a limited number of commercial zero-emissions vehicles (ZEVs) available for businesses to purchase and integrate into their fleets.[51] Some governments are attempting to change this by implementing ZEV policies. For example, British Columbia recently passed the Zero-Emission Vehicle Act on May 29, 2019, requiring that all new light-duty cars and trucks sold in the province will be clean energy vehicles by 2040. For light-duty vehicles sold in British Columbia, a phased approach will be used: 10% of new light-duty vehicle sales by 2025, 30% by 2030 and 100% by 2040. [52] ZEV mandates

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[51] The Canadian Press, "Sticker shock, limited selection discouraging Canadians from purchasing electric vehicles: survey," *Globe and Mail*, August 20, 2018. https://www.theglobeandmail.com/business/article-supply-lack-of-knowledge-holding-back-electric-vehicle-sales-in/

[52] Government of British Columbia, "New act ensures B.C. remains leader on clean energy vehicles", *BC Gov News,* May 31, 2019. https://news.gov.bc.ca/releases/2019EMPR0018-001077#

require a certain percentage of vehicle sales to be ZEVs, including battery-electric vehicles, plug-in hybrid vehicles, and hydrogen fuel cell vehicles. One of the objectives of a ZEV mandate is to increase the supply of ZEVs on the market by incentivizing customers to purchase them.[53]

The production of both traditional pedal and e-assist cargo cycles is growing across Canada, with an emergence of manufacturers in Halifax, Vancouver, Montreal, Toronto, Guelph, and Quebec City.[54] The local production of cargo bikes in Canada is a way to stimulate the growth of the local manufacturing industry. While this niche market in Canada is growing, businesses may seek to procure and import from international manufacturers to gain access to a wider diversity of cargo cycles for goods movement. One barrier that prevents the uptake and testing of cargo cycles for goods movement in Canada, particularly in Ontario, is the lack of clarity and flexibility in existing cargo cycle regulations. The following section explores this further.

4.1 Regulatory context for cargo cycles

Regulations at all three levels of government in Canada do not define cargo cycles and, by default, they usually fall under the definition of a bicycle if they are propelled solely by muscular power. Many cargo cycles, however, are equipped with some form of e-assist since additional power is needed for a cyclist to carry and move heavier loads with ease. Different jurisdictions use different terms and definitions to refer to cycles equipped with e-assist, such as power-assisted bicycles (PAB) and pedelecs (see Appendix B). Again, since existing regulations do not provide a definition for cargo cycles, cargo cycles with e-assist are usually defined as PABs or pedelecs depending on the terminology used in a given jurisdiction.

Figure 5 differentiates between cycles with different types of e-assist functions. Broadly speaking, there are two categories of cycles that are powered with an electric motor: bicycle-style electric bikes (BSEBs) and scooter-style electric bikes (SSEBs).[55] The latter

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[53] Plug In BC, "What B.C.'s new ZEV mandate means for electric vehicle buyers," December 4, 2018. https://pluginbc.ca/bc-zev-mandate-electric-vehicle-buyers/

[54] Nithya Vijayakumar, *Cyclelogistics: Opportunities for moving goods by bicycle in Toronto* (2017). https://www.pembina.org/reports/cyclogistics-final.pdf

[55] John MacArthur and Nicholas Kobel, *Regulations of E-Bikes in North America: A Policy Review* (National Institute for Transportation and Communities, 2014), 2. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1127&context=trec_reports

are sometimes referred to as a mopeds, with their distinguishing characteristic being that if they are equipped with pedals, the pedals are more ornamental than they are functional.[56] BSEBs have functional pedals that propel the cycle either with or without assistance from the electric motor.[57] A PAB is a form of a BSEB that usually requires muscular power (i.e. pedalling) in order to engage the electric motor. PABs are often referred to as pedelecs in some jurisdictions. Conversely, a power bicycle (PB) is a form of a BSEB that is equipped with a throttle (usually on the handlebar of the cycle) that engages the electric motor without pedalling.[58]

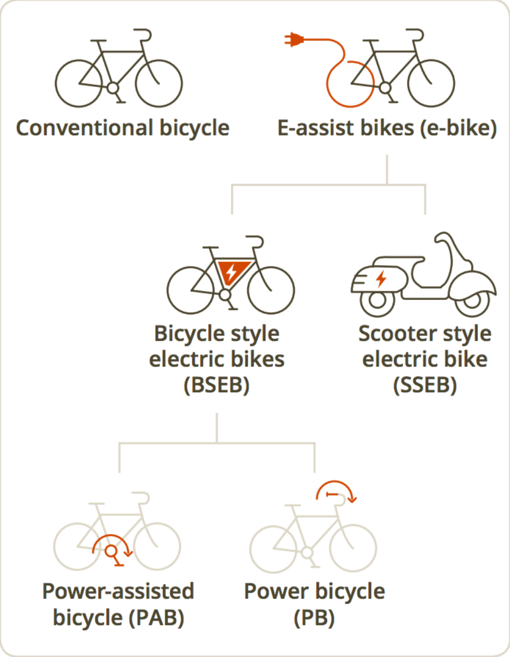

Figure 5. Different types of e-assist cycles

In Canada, existing regulations typically fail to make a clear distinction between PABs and PBs. The federal definition of a PAB in Transport Canada's *Motor Vehicle Safety Regulations*, for example, states that the motor of a PAB may be engaged through the use of muscular power or through the use of an accelerator controller.[59] In other words, the federal definition of a PAB is more aligned with the broader BSEB category in that it includes the propulsion methods of both PABs and PBs. Provinces and municipalities

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[56] Ibid., 7.

[57] Ibid., 3.

[58] Ibid., 4.

[59] Government of Canada, *Motor Vehicle Safety Regulations* C.R.C., c. 1038, Section 2. https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._1038/FullText.html#s-2

generally follow the federal definition of a PAB, which also specifies that a PAB motor must not exceed 500W and that a PAB is incapable of providing further assistance when the bicycle attains a speed of 32 km/h. However, some jurisdictions, such as Ontario and Toronto, have adopted further restrictions on e-assist cycles.

In Ontario, provincial regulation 369/09 under the *Highway Traffic Act* does not permit the use of PABs that are more than 120 kg.[60] This weight restriction is unique compared to other provinces; Alberta, Quebec, and British Columbia, for example, do not impose any weight restrictions on PABs. In the City of Toronto, by-laws 121-2014[61] and 256-2014[62] do not permit PABs that are more than 40 kg to operate on bicycle paths, bicycle lanes, cycle tracks, and multi-use trails.

Such weight restrictions prevent the use of some e-assist cargo cycles that are capable of moving heavier loads more efficiently than pedal-only cargo cycles. Smaller e-assist cargo cycles typically have an unladen weight between 40 kg to 70 kg,[63] which is greater than the permitted weight of a PAB according to City of Toronto by-laws. Larger e-assist cargo cycles tend to exceed the 120 kg weight restriction applied to PABs in Ontario. Although businesses are increasingly interested in incorporating or testing cargo cycles in their delivery operations, such regulations restrict businesses' ability to do so. Furthermore, limiting e-assist functions on cargo cycles may prevent people with mobility challenges or diverse fitness levels from working in cyclelogistics.

In order for cargo cycles to be a scalable solution, businesses also seek regulatory consistency across the jurisdictions that they operate in. As alluded to earlier, regulations for e-assist cycles vary between different provinces and municipalities. This makes it difficult for businesses that are interested in deploying e-assist cargo cycles to comply with different regulations in different places. Ultimately, there is an opportunity to revise existing regulations to provide a clearer typology of cycling technologies, including e-assist cargo cycles, in order to support businesses in integrating and testing cargo cycles for commercial goods movement.

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[60] Government of Ontario, *Highway Traffic Act* Ontario Regulation 369/09. https://www.ontario.ca/laws/regulation/090369/v1

[61] City of Toronto, *By-law No. 121-2014: To amend City of Toronto Municipal Code Chapter 886, Footpaths, Pedestrian Ways, Bicycle Paths, Bicycle Lanes and Cycle Tracks, to amend the definition of bicycle* (February 20, 2014). https://www.toronto.ca/legdocs/bylaws/2014/law0121.pdf

[62] City of Toronto, *By-law No. 256-2014: To amend City of Toronto Municipal Code Chapter 886, Footpaths, Pedestrian Ways, Bicycle Paths, Bicycle Lanes and Cycle Tracks, to permit the use of power-assisted bicycles in bicycle lanes* (March 20, 2014). https://www.toronto.ca/legdocs/bylaws/2014/law0256.pdf

[63] Eric Kamphof, Curbside Cycle, personal communication, February 26, 2019.

4.2 Safety implications of cargo cycles

One of main criteria for the successful implementation of cargo cycles is safety. There are some concerns regarding the safety of cargo cyclists as well as the safety of other road users, including pedestrians and conventional cyclists who also use the road and curbside space. The academic literature acknowledges that there may be safety impacts associated with shifting freight from trucks to cargo cycles; however, researchers also note that existing data is insufficient to measure safety outcomes.[64] Indeed, it is difficult to assess the safety implications of increased cargo cycle activity in the GTHA given that very few are currently being used.

However, research suggests that there is a "safety in numbers" effect for cycling activity more generally (i.e. not specific to the use of cargo cycles).[65] The safety in numbers effect is used to explain the non-linear relationship between the number of cyclists on the road and the number of injuries occurring among cyclists.[66] In other words, when the number of cyclists increases, the number of accidents does not increase proportionally. The European Cyclists' Federation echoes this finding, noting that countries with the lowest levels of cycling activity actually have the poorest safety records for cyclists.[67] One reason is that motorists as well as cyclists are more cautious on the road when there is increased cycling activity.[68] Although there is no data in the GTHA on accidents involving cargo cyclists, presumably similar safety in numbers effects would result if there was increased cargo cycling activity.

Further research can be done to measure whether existing road infrastructure is safe for cargo cycling. This could be done by using a bikeability indicator that measures the quality of cycling infrastructure for utilitarian purposes, such as moving and delivering goods by cargo cycle. A bikeability indicator requires three main inputs: a safety rating for each road and path in the network, a dataset of trip origins and destinations, and a

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[64] Conway et al., "Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan," 11.

[65] Rune Elvik and Torkel Bjørnskau, "Safety-in-numbers: A systematic review and meta-analysis of evidence," *Safety Science* 92 (2017), 274.

[66] A. Fyhri, H.B. Sundfør, T. Bjørnskau, and A. Laureshyn, "Safety in numbers for cyclists—conclusions from a multidisciplinary study of seasonal change in interplay and conflicts," *Accident Analysis and Prevention* 105 (2017), 124.

[67] European Cyclists' Federation, *Safety in Numbers Fact Sheet* (2012). https://ecf.com/sites/ecf.com/files/ECF_FACTSHEET4_V3_cterree_SafetyNumb.pdf

[68] Ibid.

modelling tool that can generate the most realistic cycling routes between origins and destinations.[69] For the purpose of measuring bikeability for cargo cycling, the safety rating for each road or path should consider the needs of cargo cycles. For example, it is usually desirable for cargo cycles to operate on wider bikeways to make it easier for other cyclists to pass. Furthermore, the origins and destinations used to determine bikeability should represent microhub locations and final delivery points (e.g. household or office locations), respectively. Ultimately, a bikeability index could be used to help identify parts of the existing road and cycling network that require infrastructure or design improvements to ensure the safe use of cargo cycles.

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[69] Sebastian Szyszkowicz, *Bikeability as an Indicator of Urban Mobility* (Carleton University, 2018), 42. http://www.sce.carleton.ca/~sz/Bikeability%20as%20an%20Indicator%20of%20Urban%20Mobility.pdf

5. Modelling microhubs and low-emission vehicles scenarios

5.1 Purpose and scope

Research shows that microhub models in European cities paired with the use of cargo cycles or low-emission vehicles have resulted in reduced GHG emissions and lower fuel, insurance, capital, and maintenance costs.[70] Labour and real estate costs tend to be more expensive under a microhub model, but the savings from reduced delivery fleet costs may make microhubs equally or more competitive than a business-as-usual approach.[71] Although these findings are useful, there is limited research on the use of microhubs in a North American context. In order to identify the potential cost savings and emission reductions of implementing microhubs in the GTHA, the Pembina Institute analyzed four scenarios to model different delivery operations in the cities of Toronto and Hamilton:

- Business-as-usual model using conventional package cars
- Microhub model using small electric vans
- Microhub model using large e-assist cargo cycles
- Microhub model using small e-assist cargo cycles

The business-as usual (BAU) scenarios represent the typical delivery operations of existing courier companies in the GTHA that use a UCC. A conventional package car (e.g. a Class 5 city delivery truck or step van) is loaded and dispatched from a UCC located at a suburban location near the city border and drives to its service area within the city to conduct deliveries. For the microhub scenarios, the delivery vehicles (e.g. small electric vans and e-assist cargo cycles) are loaded and dispatched from the microhubs. The purpose of this modelling work is intended to illustrate the potential travel routes and delivery times of cargo cycles assuming the use of the existing road network. The delivery routes were modeled such that cargo cycles use the same road network as cars, similar to how a regular cyclist travels alongside motor vehicles either on a bikeway or in mixed traffic. This assumes that road infrastructure is well maintained and safe to use by cargo cycles, and that cargo cyclists do not have a

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[70] Conway et al., “Urban micro-consolidation and last mile goods delivery by freight-tricycle in Manhattan,” 11.

[71] Ibid.

preference for traveling on specific road types (e.g. major arterial with protected bike lane, minor arterial with a shared lane marking or ‘sharrow’). Future research could test the sensitivity of delivery times and travel distance based on the varying behaviours and preferences of cargo cyclists.

The microhub scenarios also assume that a larger delivery vehicle is needed to supply the microhubs with the items to be delivered; however, the modelling work is scoped to focus on last-mile trips only (i.e. between the microhubs and final destinations). Similarly, the modelling work only focuses on the time and distance travelled within the service area of the BAU scenarios and does not account for the trip between the UCC and the service area.

The BAU and microhub operations were modeled under varying levels of congestion (off-peak, normal congestion, and higher congestion), and different levels of delivery demand (higher and lower demand), for a total of 24 delivery scenarios. The modelling work was divided into two phases:

1. *Determining microhub locations:* In order to model the different delivery scenarios, it was necessary to identify potential locations for microhubs (herein referred to as ‘candidate locations’). Candidate locations for microhubs in Toronto and Hamilton were identified using three criteria:
    - Road classification – ensuring that microhubs do not occur on residential-only streets or highways
    - Household and employment density – locating microhubs in high density areas where the potential demand for deliveries is greater
    - Zoning – ensuring that microhub locations conform to the land use planning polices and by-laws of the City of Toronto and the City of Hamilton
2. *Vehicle routing for different delivery scenarios:* ArcGIS’s vehicle routing problem (VRP) was used to solve 24 delivery scenarios for each of the three microhub locations selected in phase 1.[72] The outputs of the VRP for each scenario are:
    - VKT
    - Operational time (i.e. time required to conduct all deliveries)
    - Number of delivery routes
    - Optimal fleet size

All modelling work was conducted using a combination of ArcGIS and Python. Using the outputs from phase 2 of the modelling, we calculated and compared the associated costs and GHG emissions of each delivery scenario to determine whether microhubs and

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[72] 4 delivery operation models x 2 levels of demand x 3 levels of congestion = 24 scenarios

cyclelogistics are effective last-mile delivery solutions. Because the modelling work is scoped to focus on last-mile delivery trips only, the GHG emissions reported in this research only include tailpipe emissions from these last-mile trips. Readers should refer to Appendix C for a detailed discussion of the modelling methods.

5.2 Results

5.2.1 Microhub locations for delivery scenarios

A map and list of the top 20 candidate locations for microhubs in Toronto and Hamilton are provided in Appendix D. In Toronto, the top 20 candidate locations have densities ranging from 8,698 to 16,398 households and 10,934 to 43,569 employees within a 500 m radius. In Hamilton, densities range from 1,682 to 6,831 households and 1,315 to 14,959 employees within a 500 m radius. Of the top 20 candidate locations in each city, Table 2 lists the three that were selected for modelling the delivery scenarios (also see Figure 6 and Figure 7).

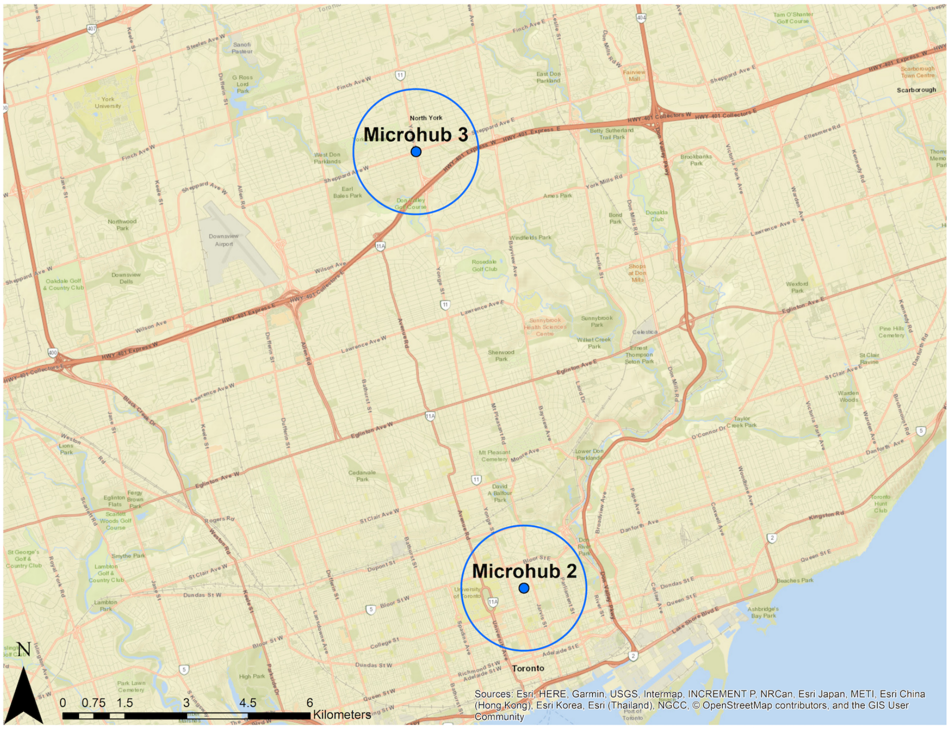
Table 2. Selected candidate locations for delivery scenarios

	Microhub 1	Microhub 2	Microhub 3
City	Hamilton	Toronto	Toronto
Intersection	Main Street W / Bay Street S	Church Street / Wellesley Street	Sheppard Avenue W / Yonge Street
Number of households within 500 m buffer	5,540	16,398	9,131
Number of employees within 500 m buffer	11,884	14,437	19,181
Road classification	Major arterial	Minor arterial	Major arterial
Land Use/Zoning designation	Downtown mixed use	Commercial residential	Commercial residential

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6. Map of Microhub 1 in the City of Hamilton

Circle around each microhub indicates a 1.5 km radius service area



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 7. Map of Microhubs 2 and 3 in the City of Toronto

Circle around each microhub indicates a 1.5 km radius service area

5.2.2 Vehicle routing outputs

Each microhub location produced similar patterns in their vehicle routing outputs, including the total vehicle kilometres traveled, total operational time, number of delivery routes, and optimal fleet size. This suggests that the criteria used to determine candidate microhub locations were able to identify places with similar characteristics such that the routing outputs for the delivery scenarios do not vary significantly between the selected locations. The following sections will identify and discuss key findings from the modelling work. Tables that present all vehicle routing outputs for each delivery scenario are provided in Appendix E.

Total vehicle kilometres traveled

Scenarios with lower delivery demand require fewer vehicle kilometres traveled compared to scenarios with higher delivery demand, regardless of the level of congestion or vehicle type. This makes sense given that additional travel is required to deliver more packages to a larger number of destinations under high demand conditions. Table 3 compares the average, minimum, and maximum vehicle kilometres traveled under lower and higher levels of delivery demand when all congestion levels are considered (e.g. off-peak, normal congestion, and higher congestion). For the minimum and maximum vehicle kilometres traveled, the letters in Table 3 indicate the vehicles used in the scenarios that result in the lowest and highest distance travelled, respectively.

Table 3. Vehicle kilometres travelled (VKT) under different levels of delivery demand

		Microhub 1	Microhub 2	Microhub 3
Lower delivery demand	Average VKT	33 km	32 km	42 km
	Minimum VKT	29 km LB/DV	28 km LB	38 km LB/DV
	Maximum VKT	39 km SB	37 km SB	47 km SB
Higher delivery demand	Average VKT	77 km	81 km	93 km
	Minimum VKT	61 km LB/DV	67 km DV	77 km DV
	Maximum VKT	109 km SB	110 km SB	124 km SB

SB = small e-assist cargo cycle; LB = large e-assist cargo cycle; DV = small electric delivery van

Under lower delivery demand conditions, the difference in vehicle kilometres traveled for scenarios with the maximum and minimum distance travelled is approximately 10 km for each microhub location. Under higher demand conditions, the difference ranges from 43 km to 48 km, depending on the microhub location. This suggests that under higher demand conditions, the vehicle kilometres traveled required to complete all deliveries is more variable than when demand is lower.

Delivery scenarios that use small cargo cycles consistently generate the greatest vehicle kilometres traveled out of all other delivery scenarios, regardless of the level of delivery demand, congestion, or microhub location. Scenarios that require the least vehicle kilometres traveled are those that use large cargo cycles or small electric vans. One of the primary reasons that small cargo cycles generate the greatest vehicle kilometres traveled is that a single small cargo cycle has a lower cargo capacity and must therefore run more routes to complete the same number of deliveries. Since a delivery operator must return to the microhub to reload their vehicle before dispatching on a new route, scenarios that use small cargo cycles generate more vehicle kilometres traveled from these return trips. Conversely, delivery scenarios that use large cargo cycles, small electric vans, or package cars only use one vehicle per route and therefore do not generate additional vehicle kilometres traveled from return trips to reload a vehicle.

The differences in vehicle kilometres traveled between scenarios with varying levels of congestion are marginal, primarily because congestion affects travel time more than distance travelled. The next section will discuss the results regarding total operational time.

Total operational time

The total operational time (OT) is the sum of both travel time (time spent driving or cycling) and service time (time required for an operator to hand off a package to the customer, including time spent unloading the delivery). Figures 8 to 11 show the breakdown of travel and service times for different delivery scenarios under normal and higher levels of congestion. The operational times for off-peak scenarios (i.e., free-flow traffic) are not illustrated since they are not substantially different from the operational times under normal congestion levels. This is not surprising for delivery operations that use cargo cycles, given that the same travel speed was assumed for both off-peak and normal congestion scenarios (see Appendix C). For delivery operations that use small electric vans and package cars, travel times are marginally longer under normal congestion than off-peak conditions. This suggests that the road capacity at each microhub location is able to keep traffic flowing even during peak hours (i.e., normal congestion).

Similar to vehicle kilometres traveled, the total operational time is greater for scenarios with higher demand than lower demand since additional time is needed make more deliveries (see Figures 8 to 11). Scenarios that use large cargo cycles (LB) consistently have the shortest operational times while scenarios that use package cars take the longest to complete all deliveries.

Overall, service time is substantially greater than travel time across all scenarios. This is reflective of the challenges of making deliveries in cities, such as finding curbside space for unloading, and accessing buildings where customers are located. For delivery operations that use package cars and small electric vans, service time comprises a larger portion of the total operational time compared to cargo cycle operations. This illustrates the fact that larger vehicles, especially package cars, are more cumbersome to park and unload, so much so that the service time of each package car scenario is greater than the total operational time required for all other delivery scenarios.

It should be noted that the total service times are highly dependent on the model inputs (i.e., service time required per delivery); however, the results do reflect the time-savings advantage of using smaller, more nimble modes such as cargo cycles. For example, even though small cargo cycles result in the largest VKT (as discussed earlier), they also result in some of the lowest operational times.

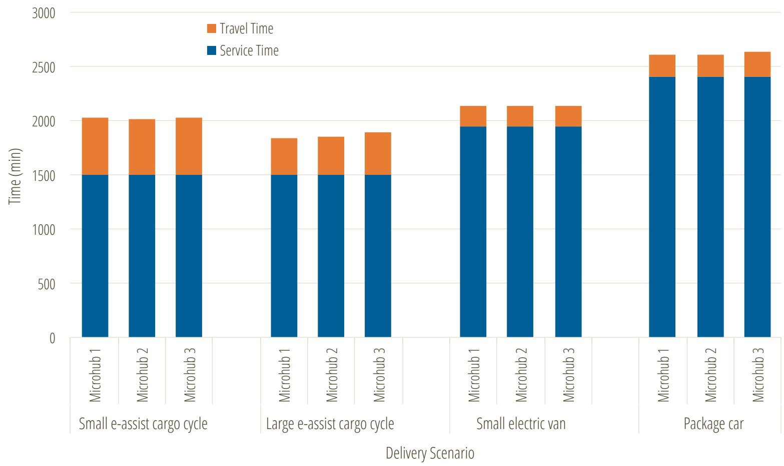


Figure 8. Total operational time under normal congestion, high demand conditions

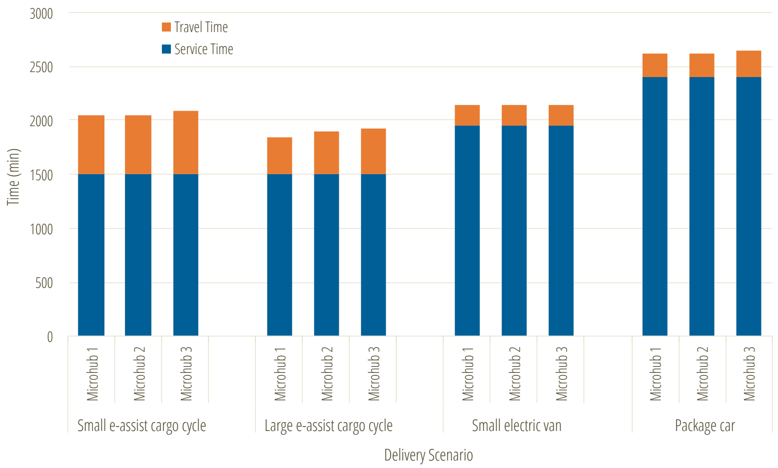


Figure 9. Total operational time under high congestion, high demand conditions

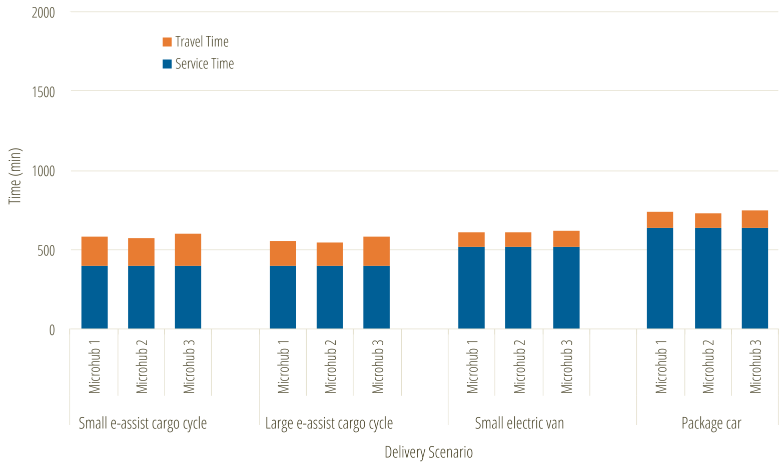


Figure 10. Total operational time under normal congestion, low demand condition

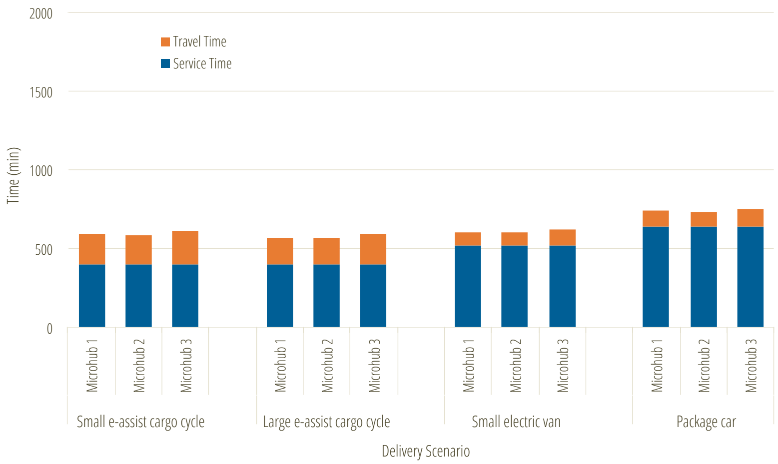


Figure 11. Total operational time under high congestion, low demand conditions

Number of delivery routes and optimal fleet size

Scenarios that use small cargo cycles require the greatest number of routes to complete all deliveries given that small cargo cycles have the smallest payload volume among the delivery modes modeled in this research. Despite this, small cargo cycle operations do not require a larger fleet than package car operations — since, as shown in Table 4, small cargo cycles with their quick operational time can complete more than one route per day. Thus, although each vehicle type has a very different payload volume, the optimal fleet size for each mode is the same under different levels of demand (with the exception of using small electric delivery vans under high demand conditions). For example, six small cargo cycles are needed to complete all the deliveries under high demand conditions, which is the same optimal fleet size for package cars under the same conditions.

Because there is no difference in optimal fleet size, it makes sense for businesses to use the delivery mode with the cheapest capital cost over its lifetime — in this case, small e-assist cargo cycles. The same optimal fleet size also suggests that the labour requirements for the different delivery operations are similar, assuming that only one operator is required per vehicle, whether a car, electric van, or cargo cycle.

The modelling outputs also suggest that under the delivery conditions studied in this research, using package cars for deliveries results in poor asset utilization. For the purposes of this study, it is assumed that package cars are capable of carrying loads of up to 23,400 L,[73] which is almost double the total delivery volume assumed under higher demand conditions (12,600 L[74]). Although one package car has the capacity to carry all the deliveries, the modelling results suggest that it is more efficient for the deliveries to be made by multiple (partly-loaded) package cars, hence an optimal fleet size greater than one. It should be noted that businesses often own a fleet of different sized package cars and can therefore deploy the most appropriately sized vehicle according to the delivery demand in a given service area. As such, the asset utilization of package cars may be higher in practice than indicated by the modelling results.

In cases where cargo cycles do have better asset utilization than other delivery modes, businesses delivering small- to medium-sized packages (i.e. as opposed to large,

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[73] Theodoros Athanassopoulos, Kerstin Dobers, and Uwe Clausen, "Reducing the Environmental Impact of Urban Parcel Distribution," in *Logistics and Supply Chain Innovation: Bridging the Gap between Theory and Practice* (Springer International Publishing, 2016), 163.

[74] Assumes the typical levels of demand in downtown Toronto

awkward-shaped items such as furniture) in dense urban areas are likely best suited for cargo cycle operations. Courier companies, for example, are well positioned to deliver small- and medium-sized parcels by cargo cycle. That said, examples in Europe suggest that cargo cycle deliveries are feasible for a wide range of industries delivering a variety of goods including linen and dry cleaning[75], catering[76], electronics and appliances[77], and others.[78]

Table 4. Number of routes and optimal fleet size for different delivery scenarios under normal congestion levels

		Number of routes*	Optimal fleet size*	Routes per vehicle*
Lower delivery demand	Small e-assist cargo cycle	8	2	4
	Large e-assist cargo cycle	2	2	1
	Small electric van	2	2	1
	Package car	2	2	1
Higher delivery demand	Small e-assist cargo cycle	28	6	4 to 5
	Large e-assist cargo cycle	6	6	1
	Small electric van	5	5	1
	Package car	6	6	1

* Results are the same for each microhub location

5.2.3 Scenario costs and emissions

Figure 12 and Figure 13show the breakdown of the average costs for delivery scenarios under conditions with high and low demand, respectively. The graphs are similar in that

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[75] OXWASH, https://www.oxwash.com/

[76] Marleenkookt, https://www.marleenkookt.nl/

[77] Cool Blue, https://www.coolblue.nl/

[78] Pedal Me, https://pedalme.co.uk/

small and large cargo cycles result in the lowest daily total cost and package cars the highest daily total cost. For each delivery scenario, labour is the largest business expenditure, followed by capital, maintenance, and fuel costs. Package car operations in particular have the most expensive labour cost not only because package car operators receive a higher wage than operators of other vehicles modeled (see Table 9 in Appendix C), but also because the total operational time of package car deliveries is the highest of the delivery modes (see Figures 8 to 11). The results therefore suggest that business should invest in cargo cycles for their delivery operations since the daily cost is significantly lower than business-as-usual practices that use package cars.

Employing cargo cycles and electric vans for deliveries also has environmental benefits since these vehicles have zero tailpipe emissions. Delivery scenarios that use package cars, however, produce an average of 24 kg CO_2 per day under low demand conditions and 53 kg CO_2 per day under high demand conditions. Replacing conventional package cars with cargo cycles or electric vans will mitigate these tailpipe emissions.

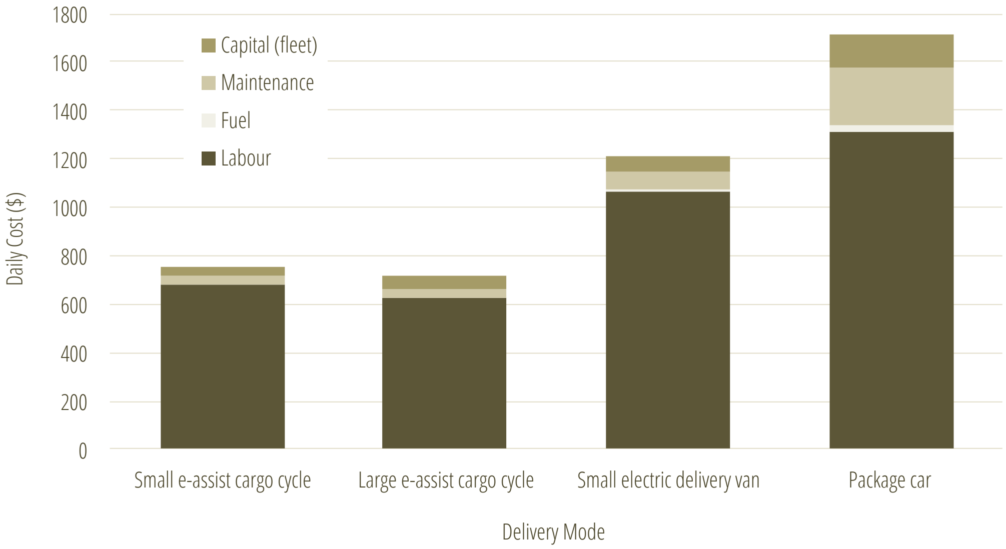

Figure 12. Average scenario costs under high demand conditions

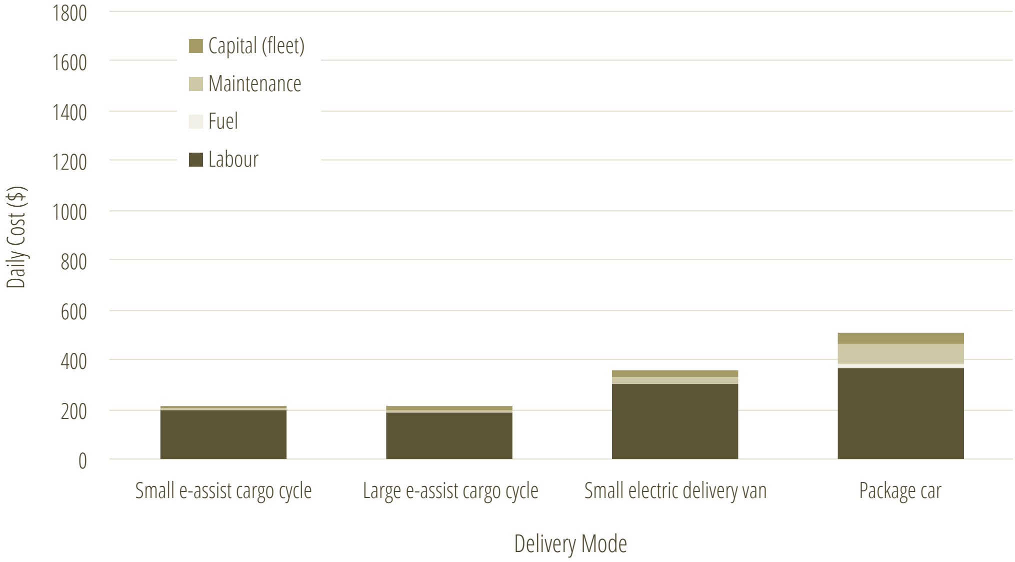

Figure 13. Average scenario costs under low demand conditions

6. Future research

This report serves as a foundation and first step for understanding how microhubs and cyclelogistics may be implemented. Cities and businesses could benefit from additional transportation planning research and analyses to further understand the complexities of operating these delivery systems in practice. Implementing pilot projects is an excellent way to gather data and evaluate the on-the-ground performance and feasibility of such models. As a next step, we recommend that future research and pilot projects work to better understand the following:

- **Magnitude of impact:** model existing and forecasted truck traffic volumes under various scenarios (e.g. with and without microhubs and cyclelogistics) to understand how different delivery operations will reduce freight traffic
- **Multi-carrier consolidation:** explore opportunities for businesses to share resources (e.g. shared microhub space) to increase the efficiency of urban delivery operations
- **Government support:** design financial programs and policies to help businesses implement solutions that improve the efficiency of goods movement in order to reduce freight-related congestion, emissions, and curbside competition
- **Operations:** determine the parameters in which microhubs and cyclelogistics work for businesses (e.g. scale of operations, location of logistics facilities, required infrastructure, minimum delivery density, impacts of variable weather conditions, risks and liabilities)
- **Scalability:** align and harmonize the policies and regulatory frameworks that allow businesses to test, deploy, and scale up cyclelogistics across Canadian jurisdictions
- **Infrastructure:** determine how roads and cycling infrastructure are best designed and enhanced to allow for the safe integration of cargo cycles with other road users

7. Conclusions and recommendations

The purpose of this report is to assess the feasibility of two delivery operating systems — microhubs and cyclelogistics — and to help identify the conditions under which these solutions can be successfully implemented to improve urban freight efficiencies and reduce emissions. Based on delivery practices in other jurisdictions and findings from our modelling and scenario analyses, the use of microhubs paired with cargo cycles and electric vans in dense urban areas havethe potential to reduce operational costs for businesses and mitigate urban freight emissions in the GTHA. The delivery scenarios modeled in this research demonstrate that microhubs and the use of cargo cycles are operationally feasible and can be good alternatives to the use package cars under the right conditions and in the following ways:

- **Cost effective:** In certain cases, delivery operations are more cost effective when using e-assist cargo cycles than when using conventional package cars.
- **Operational efficiency:** Although cargo cycles tend to require longer travel times to complete all deliveries, their service time (e.g. time to unload the vehicle and get the package to the customer) is much lower compared to package car operations. This is because cargo cycles are smaller and more nimble, making it quicker for the operator to park and unload deliveries compared to package cars.
- **High productivity:** Cargo cycle operations may require more delivery trips (and therefore greater VKT) compared to package cars due to their smaller payload volume, however, cargo cycle operations do not necessarily require a larger fleet than package car operations.
- **High asset utilization:** Using cargo cycles for deliveries results in higher asset utilization compared to package cars. This is because package cars often carry loads that are below their full capacity.
- **Addresses curbside demands:** Not only are cargo cycles beneficial for improving operational efficiency for businesses, but they also decrease the number of trucks on the road and impeding loading activities in dense urban areas or districts, thereby freeing up curbside space for other road users.

- **Lower freight emissions:** Based on the delivery scenarios modeled in this research, package cars can produce up to 53 kg CO_2 per day depending on the level of delivery demand. Replacing conventional package cars with cargo cycles or electric vans will eliminate tailpipe emissions, resulting in benefits for both climate and urban air quality.

Although our modelling work indicates that microhubs and e- assist cargo cycles are potentially feasible in the GTHA, multi-sectoral collaboration and enabling policies and regulations as well as infrastructure investments are needed to create an environment where these low-carbon alternative delivery solutions can be piloted and implemented at scale. In order for businesses to test and integrate new logistics models and delivery modes into their operations, they need be certain of the policy and regulatory conditions under which these approaches are financially and operationally viable.

Finding solutions to make urban deliveries more efficient and less carbon intensive requires leadership across public, private and non-governmental groups and sectors. Governments play an important role to help spur innovation and co-design solutions to address last-mile freight challenges. In doing so, governments can realize public policy objectives, such as alleviating congestion, managing curbside competition, and decreasing transportation emissions. Here are several ways that governments can create an environment in which businesses can introduce more efficient and sustainable urban freight practices.

- Provide incentives or financial supports for businesses to test and implement low-carbon alternative delivery solutions in dense urban areas, including seed funding:
    - to offset the high real estate cost of establishing microhubs in dense urban areas or districts
    - integrate cargo cycles into their delivery operations.
- Align and clarify legislation, regulations and policies at all levels of government in order to reduce barriers and restrictions on the use of e-assist cargo cycles
- Invest in expanding and improving existing cycling infrastructure, urban design, and educational campaigns to better accommodate the safe use and integration of cargo cycles with other road users.
- Explore policies aimed at increasing the supply of zero-emission commercial delivery vehicles in the Canadian market (e.g., zero emission vehicle mandates).
- Explore policies and incentives to encourage uptake of zero- or low-emission delivery vehicles (e.g., purchase incentives, government procurement policies).

- Develop or modernize land use and transportation plans and strategies (e.g., freight and goods movement strategies, low-emission zones, mobility pricing in dense urban areas) as well as economic development strategies to promote the use of efficient and sustainable urban freight practices.

Businesses can accelerate the adoption of efficient and sustainable freight practices by doing the following:

- Establish ambitious goals and commitments to reduce freight emissions by transitioning towards low- or zero-emission freight vehicles
- Transition towards the use of cargo cycles and other low- or zero-emission freight vehicles (e.g., cargo cycles, electric vehicles) for last-mile deliveries in different urban settings.
- Where possible, explore the potential for investing in and sharing microhub spaces with other businesses to consolidate shipments to final destinations.
- For businesses in multi-unit business buildings, explore opportunities for pooled ordering to consolidate shipment for specific goods (e.g., one delivery for office supplies for an entire building)

Ultimately, as e-commerce activity and the demand for goods movement grows, we need to implement solutions that will mitigate the potential for increased freight emissions. Without improving existing delivery practices in urban centres, we will also face increased traffic congestion, noise on our streets, and greater competition for the curbside. Based on our modelling and feasibility analysis, microhubs and cyclelogistics are effective ways to reduce the impact of goods movement in Canadian cities while also helping businesses save time and money in their delivery operations. While this feasibility study is scoped to illustrative cases in the GTHA, it provides a good first step for policy and planning practitioners in the public and private sectors to understand the conditions and considerations in which microhubs and cyclelogistics can be most effective across different Ontario urban contexts.

Appendix A. Freight-planning documents in Ontario

Table 5. Freight-planning documents in Ontario

Authority	Year	Relevant Policies	Potential Strategies Identified
Freight-Supportive Guidelines[79]			
Ontario Ministry of Transportation	2016-present	Guideline 2.2.6 Protect smaller scale freight movement, such as mail delivery, courier services, and daily restaurant and retail deliveries to ensure an effective and efficient use of resources	• Establish standards for small freight, which consider the size and number of freight vehicles that need to serve a core urban area • Provide shared loading facilities for multiple users
		Guideline 2.4.3 In high density areas, deliveries and freight movements are particularly challenging. Consider implementing strategies to minimize conflicts between freight and other users	• Provide a variety of spaces for freight vehicles to park or load/unload, including rear laneways, off-street parking, and designated on-street parking lanes or bays
		Guideline 3.7.1 Improve truck movements to allow for the efficient and safe flow of goods into and out of the area	• Consider the use of small delivery vehicles and shared consolidations facilities in high density arrows with narrow roadways
		Recommended Action 5.1.2.1 pertaining to official plans	• Municipalities should encourage initiatives through their official plans that improve the efficiency of goods movement, such as consolidation centres and alternative delivery practices

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[79] Ontario Ministry of Transportation, *Freight-Supportive Guidelines* (2016), 34, 54, 78, 128. http://www.mto.gov.on.ca/english/publications/pdfs/freight-supportive-guidelines-english.pdf

Draft Northern Ontario Multimodal Transportation Strategy[80]			
Ontario Ministry of Transportation and Ministry of Development and Mines	2018-2041	Direction 4.4: Facilitate the adoption of new and emerging innovative methods of goods movement, where appropriate, such as airships and hoverbarges	• Innovative methods of goods movement could include new logistics practices such as consolidated warehousing
GTHA Urban Freight Strategy[81]			
Metrolinx	2010-2035	Action 11: Support the development of innovative freight hubs	• Improve freight efficiency by developing a variety of different freight hub facilities, including localized package drop-off stations that allow couriers to consolidate trips and avoid missed deliveries
		Action 17: Implement reserved curbside delivery options	• Designate reserved parking or loading areas for delivery vehicles in congested urban areas where space for deliveries is limited
2041 Regional Transportation Plan[82]			
Metrolinx	2017-2041	Priority Action 3.10: Define and support a regional goods movement system	• Support the development of and increase awareness on innovative freight practices, including the use of freight hubs, delivery models that reduce the number of door-to-door deliveries, and other innovations such as bicycle use for goods movement • Consider using transit stations and parcel pick-up locations for customers

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[80] Ontario Ministry of Transportation and Ministry of Northern Development and Mines, *Draft 2041 Northern Ontario Multimodal Transportation Strategy* (2017), 77.

[81] Metrolinx, *GTHA Urban Freight Study* (2011), 16-17. http://www.metrolinx.com/en/regionalplanning/goodsmovement/GTHA_Urban_Freight_Strategy.pdf

[82] Metrolinx, *2041 Regional Transportation Plan* (2018), 88. http://www.metrolinx.com/en/regionalplanning/rtp/Metrolinx%20-%202041%20Regional%20Transportation%20Plan%20%E2%80%93%20Final.pdf

Goods Movement Strategic Plan[83]			
Region of Peel, Transportation Division	2017-2021	Action Item 1: Goods movement and logistics planning coordination	• Identify strategic locations for goods movement in coordination with Peel Region's Strategic Goods Movement Network
		Action Item 4: Adapt to advancements in the e-commerce shift	• Study the impact of e-commerce on goods distribution in order to discover new ways that urban freight trips can be consolidated to improve delivery efficiency and reduce traffic • Assess how increasing demand for home deliveries will impact residential areas, including the availability of on-street parking and the safety challenges posed by different delivery practices • Understand how emerging innovations and technologies will impact freight and logistics activities
		Action Item 8: Pursue alternative fuels and fuel efficiency alternatives	• Leverage partnerships with industry to develop and use technologies that reduce GHG emissions from freight transportation

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[83] Region of Peel, *Peel Region Goods Movement Strategic Plan 2017-2021* (2017), 30, 36, 44. https://www.peelregion.ca/pw/transportation/goodsmovement/pdf/goods-movement-strategic-plan-2017-2021.pdf

Appendix B. E-bike and cargo cycle regulations

B.1 Federal legislation and regulations

Transport Canada's *Motor Vehicle Safety Regulations*,[84] under the *Motor Vehicle Safety Act*, define a power-assisted bicycle (bicyclette assistée) (PAB) as a vehicle that:

(a) has steering handlebars and is equipped with pedals,
(b) is designed to travel on not more than three wheels in contact with the ground,
(c) is capable of being propelled by muscular power,
(d) has one or more electric motors that have, singly or in combination, the following characteristics:
  (i) it has a total continuous power output rating, measured at the shaft of each motor, of 500 W or less,
  (ii) if it is engaged by the use of muscular power, power assistance immediately ceases when the muscular power ceases,
  (iii) if it is engaged by the use of an accelerator controller, power assistance immediately ceases when the brakes are applied, and
  (iv) it is incapable of providing further assistance when the bicycle attains a speed of 32 km/h on level ground,
(e) bears a label that is permanently affixed by the manufacturer and appears in a conspicuous location stating, in both official languages, that the vehicle is a power-assisted bicycle as defined in this subsection, and
(f) has one of the following safety features,
  (i) an enabling mechanism to turn the electric motor on and off that is separate from the accelerator controller and fitted in such a manner that it is operable by the driver, or
  (ii) a mechanism that prevents the motor from being engaged before the bicycle attains a speed of 3 km/h

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[84] Canada, *Motor Vehicle Safety Regulations,* Section 2.

B.2 Provincial legislation and regulations

The Ontario Ministry of Transportation's (MTO) *Highway Traffic Act*[85] defines a PAB as a bicycle that:

(a) is a power-assisted bicycle as defined in subsection 2 (1) of the Motor Vehicle Safety Regulations made under the Motor Vehicle Safety Act (Canada),
(b) bears a label affixed by the manufacturer in compliance with the definition referred to in clause (a),
(c) is fitted at all times with pedals that are operable to propel the bicycle, and
(d) is capable at all times of being propelled on level ground solely by using muscular power to operate the pedals

The Ontario Regulation 369/09 under the *Highway Traffic Act*[86] further specifies that:

- The unladen weight of a PAB must not be more than 120 kg
- The wheels of a PAB must not be less than 35 mm wide
- The diameter of the wheels of a PAB must not be less than 350 mm
- The battery and motor of a PAB must be securely fastened to the bicycle to prevent them from moving while the bicycle is in motion
- The motor of a PAB must disengage if pedaling ceases, the accelerator is released or the brakes are applied

The Ontario *Highway Traffic Act*[87] defines a "motor assisted bicycle" ("cyclomoteur") as a bicycle:

(a) that is fitted with pedals that are operable at all times to propel the bicycle,
(b) that weighs not more than fifty-five kilograms,
(c) that has no hand or foot operated clutch or gearbox driven by the motor and transferring power to the driven wheel,
(d) that has an attached motor driven by electricity or having a piston displacement of not more than fifty cubic centimetres, and
(e) that does not have sufficient power to enable the bicycle to attain a speed greater than 50 kilometres per hour on level ground within a distance of 2 kilometres from a standing start

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[85] Ontario, *Highway Traffic Act*, Section 1.

[86] Government of Ontario, *Highway Traffic Act Ontario Regulation 369/09*. https://www.ontario.ca/laws/regulation/090369/v1

[87] Ontario, *Highway Traffic Act*, Section 1.

B.3 City of Toronto by-laws

City of Toronto by-law no. 121-2014[88] defines a bicycle as follows:

> BICYCLE - includes a bicycle, tricycle, unicycle, and a power-assisted bicycle which weighs less than 40 kilograms and requires pedalling for propulsion ("pedelec"), or other similar vehicle, but does not include any vehicle or bicycle capable of being propelled or driven solely by any power other than muscular power.

City of Toronto Municipal Code Chapter 886, Footpaths, Pedestrian Ways, Bicycle Paths, Bicycle Lanes and Cycle Tracks[89] permits PABs (as specified under the definition of a 'bicycle' under by-law no. 121-2014) anywhere that a conventional bicycle is allowed to operate, including bicycle paths, bicycle lanes, and cycle tracks. Municipal Code Chapter 608 permits PABs in parks while being pedalled but not when the electric motor is engaged.[90]

Cycles that have e-assist but are not PABs/pedelecs under the municipal definition of a bicycle are considered to be e-scooters, which fall under the provincial definition of a motor assisted bicycle under the *Highway Traffic Act*. E-scooters are permitted on painted bike lanes, but not physically separated bikeways (e.g. cycle tracks) or multi-use trails.[91,92]

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[88] Toronto, *By-law No. 121-2014.*

[89] City of Toronto, *Toronto Municipal Code Chapter 866, Footpaths, Pedestrian Ways, Bicycle Paths, Bicycle Lanes and Cycle Tracks* (2017). https://www.toronto.ca/legdocs/municode/1184_886.pdf

[90] City of Toronto, *Electric Bikes – Proposed Policies and By-laws* (2013), 12. https://www.toronto.ca/legdocs/mmis/2014/pw/bgrd/backgroundfile-65205.pdf

[91] City of Toronto, "Cycling & the Law." https://www.toronto.ca/services-payments/streets-parking-transportation/cycling-in-toronto/cycling-and-the-law/

[92] Toronto, *Electric Bikes – Proposed Policies and By-laws*, 1.

Appendix C. Modelling methods

Modelling work used in this report is presented in detail in the report *Microhub Locations and Delivery Scenarios in Toronto and Hamilton, Ontario*, prepared by Darren M. Scott.[93]

C.1 Determining microhub locations

In order to model the different delivery scenarios, it was first necessary to identify potential locations for microhubs (hereby referred to as 'candidate locations'). Candidate locations for microhubs in Toronto and Hamilton were identified using three criteria:

1. Road classification
2. Household and employment density
3. Zoning

It should be noted that many of the industry experts interviewed for this research identified the availability of loading zones as a top criterion for determining microhub locations. However, this was excluded from the analysis because spatial data for loading zones in Hamilton and Toronto are not publicly available.

C.1.1 Road classification

The road classification data for each city were used to identify non-local and non-expressway roads only (hereby referred to as 'arterials') to ensure that candidate locations do not occur on residential-only streets or highways. The centerline data for each Toronto and Hamilton's road network were obtained from each city's open data portal and filtered to select only arterial roads. For modelling purposes, candidate locations were generated such that they occur at the intersection and midpoint of an arterial. This provides an approximate location for where a microhub could occur (i.e. as opposed to generating candidate locations at all possible x, y coordinates).

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[93] Darren M. Scott, *Microhub Locations and Delivery Scenarios in Toronto and Hamilton, Ontario: Data and Methods,* prepared for the Pembina Institute (2019).

C.1.2 Household and employment density

Through our engagement with industry experts, household and employment density was identified as one of the top criteria for determining microhub locations.[94] As noted in Section 0, high-density areas have greater potential for delivery demand so therefore microhubs should be strategically placed in these areas. In this research, buffers with a radius of 500 m were created around candidate microhub locations to determine the household and employment density within those buffers. A 500 m buffer was used based on the same threshold that one business in Toronto uses to identify their microhub locations.

The following data were obtained from Statistics Canada to determine household and employment density: 2016 census dissemination areas (DAs), number of private households in DAs, and number of people working in DAs. Rather than assuming that private households and number of workers were distributed uniformly throughout a DA, these variables were first allocated, respectively, to residential areas and employment areas within each DA for each city. For Toronto, these areas were selected from the zoning data set taken from the City's open data portal. For Hamilton, they were selected from a parcel data set developed by McMaster University's TransLAB (Transportation Research Lab), which is directed by Darren Scott. The buffers around candidate locations were intersected with the residential and employment areas producing cross-tabulations of households and workers from DAs residing and working within buffers based on the proportion of a DA's total residential and employment areas found within a buffer. The cross-tabulation was then aggregated to the candidate location level to produce the household and employment density within the 500 m buffer around each candidate location.

C.1.3 Zoning

Zoning was included in the analysis to ensure that candidate locations conform to land use by-laws from Toronto and Hamilton. Using the zoning data from Toronto's open data portal, the candidate locations for Toronto were reduced by selecting only those locations falling within the following zoning categories:

- Residential apartment commercial (RAC)
- Commercial local (CL)
- Commercial residential (CR)
- Commercial residential employment (CRE)

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[94] Lee, *Modernizing Urban Freight Deliveries Workshop: Workshop Summary Notes*, 10.

- Employment industrial (E)

These zones permit ‘retail service’, which is defined as premises in which photocopying, printing, postal, or courier services are sold or provided.[95] The number of candidate microhub locations in Toronto, after removing those that did not meet the zoning constraint, was 828.

Zoning was not available as a spatial data set for Hamilton through its open data portal, and therefore, the candidate locations could not be filtered based on land use constraints. As such, the number of candidate locations in Hamilton (2227) was much larger. Of this number, 129 candidates had neither households or workers within their 500 m buffers. These locations were removed prior to scoring them according to their households and employment density (see below).

C.1.4 Selecting candidate locations for delivery scenarios

Each candidate location was given a weighted score based on the number of households and number of workers within a 500 m buffer. This was done to identify the most relevant locations for a microhub. The weight assigned to each criterion was calculated as follows:

$$w_i = \frac{n - r_i + 1}{\sum_{i=1}^{I}(n - r_i + 1)}$$

where w_i is the normalized weight of criterion i, ranging from 0 to 1, n is the number of criteria under consideration, and r_i is the rank position of criterion i. It was assumed that number of households was more important to microhub location than number of workers, and therefore, it was ranked 1 while number of workers was ranked 2. Consequently, the weights assigned to each criterion according to the above equation were 0.67 and 0.33, respectively.

Weighted scores (s_{ij}) for each criterion i for each candidate location j were calculated as follows:

$$s_{ij} = w_i \left(\frac{x_{ij} - \min x_i}{\max x_i - \min x_i} \right)$$

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[95] City of Toronto, *By-law 569-2013: Zoning By-law for the City of Toronto* (2019). https://www.toronto.ca/wp-content/uploads/2018/07/97ec-City-Planning-Zoning-Zoning-By-law-Part-1.pdf

where x_{ij} is the value of criterion i for candidate location j, min x_i is the minimum value x for criterion i, and max x_i is the maximum value x for criterion i. The two weighted scores were then summed to arrive at a final score for each candidate location. The scoring mechanism ensures that final scores range between 0 and 1.

Following the scoring of candidate locations, the 20 locations with the highest scores were selected for each city to compare their locations, zoning designation, road class, and household and employment density (see Appendix C for a map and list of top 20 candidate locations in each city). For Hamilton's top 20 candidates, the zoning designation was determined based on a visual comparison of each candidate's location with respect to the interactive zoning website found on Hamilton's open data portal.

For the purpose of modelling different delivery scenarios, two microhub locations in Toronto and one in Hamilton were selected from the top 20 locations. For Toronto, the top and bottom ranked locations (i.e., 1 and 20) were selected for modelling delivery scenarios. For Hamilton, the top location was selected.

C.2 Vehicle routing for different delivery scenarios

The second phase of the modelling work used ArcGIS's vehicle routing problem (VRP) to solve 24 delivery scenarios for each of the three microhub locations selected in phase 1. The outputs of the VRP are the total VKT, total operational time, number of delivery routes, and optimal fleet size required to complete all deliveries.

The 24 delivery scenarios include the following delivery operation models under different levels of congestion and delivery demand:

- Business-as-usual model using conventional package cars
- Microhub model using small electric vans
- Microhub model using large e-assist cargo cycles
- Microhub model using small e-assist cargo cycles

Network-based service areas were created around each of the three selected microhubs. The radial distance used for these service areas was 1.5 km to represent the approximate service area of a typical courier's package car route. The service areas serve two purposes: 1) to identify potential customers (i.e. delivery locations) and 2) to site an entry/exit point into/out of the service area for the package cars operating in the BAU scenarios. The entry/exit points were located on the edge of the service areas near expressways, which would serve as the most likely conduits for package cars entering the service areas.

In order to solve the VRP for each delivery scenario, the following parameters were applied:

- All deliveries must be made within an eight-hour time window (480 minutes) from 8:00 a.m. to 4:00 p.m.
- All delivery vehicles need to return to the location from which they were dispatched within that time window.[96]
- The volume of packages loaded onto a vehicle cannot exceed the capacity of the vehicle.
- The curb approach for each delivery vehicle is set to the right side of the vehicle.
- Global turn penalties of 10 seconds for a right turn, 15 seconds for a left turn, 10 seconds for straight, and 15 seconds for reverse were applied.

In addition to these parameters, Table 6 below lists the assumptions used for each delivery vehicle.

Table 6. Delivery vehicle assumptions

	Package car (PC)	Small electric delivery van (DV)	Large e-assist cargo cycle (LB)	Small e-assist cargo cycle (SB)
Payload volume	23,400 L[97]	4,200 L[98]	2,200 L[99]	500 L[100]
Service time[101]	8 min/package	6.5 min/package	5 min/package	5 min/package

The service times per package are intended to account for the time it takes for an operator to handoff a package to the customer (e.g. unloading time, getting the

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[96] For the microhub scenarios, this is the microhub location. For the business-as-usual scenarios, this is the entry/exit point at the edge of the service area.

[97] Theodoros Athanassopoulos, Kerstin Dobers, and Uwe Clausen, "Reducing the Environmental Impact of Urban Parcel Distribution," in *Logistics and Supply Chain Innovation: Bridging the Gap between Theory and Practice* (Springer International Publishing, 2016), 163.

[98] Nissan, "Nissan e-NV200." https://www-europe.nissan-cdn.net/content/dam/Nissan/gb/brochures/Vehicles/Nissan_e-NV200_van_UK.pdf

[99] UPS Canada, "Canada Cargo Bike Fact Sheet," 2017.

[100] Eric Kamphof, presentation at the Pembina Institute's Modernizing Urban Deliveries Workshop, Toronto, January 29, 2019, 11.

[101] Sam Clarke and Jacques Leonardi, *Agile Gnewt Cargo: parcels deliveries with electric vehicles in Central London*, (Greater London Authority, 2017), 35. https://westminsterresearch.westminster.ac.uk/download/53a6644ba063a519a34b7cc11806396479d756214f5f785b2588c71d25dadd1c/2484777/GLA-Agile1-DataReport-3May2017.pdf

customer to sign for the package). In other words, it does not account for the time to drive or, in the case of cargo cycles, ride between delivery locations. A service time of 8 minutes per package and 5 minutes per package for the package car and cargo cycle scenarios, respectively, is based on the unloading times reported from Gnewt Cargo's operations in Central London. The service time for the small electric van scenarios was assumed to be in-between that of the package cars and cargo cycles at 6.5 minutes per package.

C.2.1 Delivery volumes and locations

As shown in Table 7, each delivery operation was modeled under two different delivery volumes to represent higher and lower levels of demand. For modelling purposes, it was assumed that each delivery location received one package and that each package being delivered has the same volume based on the typical volume of a medium-sized package for a courier operating in Canada package. We recognize that this is a limitation of the modelling work given that package sizes can vary greatly and that larger items are increasingly being purchased online.[102]

Table 7. Delivery volume assumptions

Level of demand	Volume per package[103]	Total number of packages delivered[104]	Total volume of deliveries
Lower	42 L	80	3,360 L
Higher	42 L	300	12,600 L

Delivery locations were generated from the point address data sets obtained from open data portals from the City of Hamilton and the City of Toronto. From these data sets, only the addresses on residential and employment lands within the service areas around the microhubs were selected. The Hamilton data set contains all distinct municipal addresses in the city, meaning that each unit in a building or development has a point feature associated with it. From a modelling perspective, using the point features for all distinct addresses accounts for the fact that one building may receive multiple deliveries, each going to a different unit within that building. The delivery locations in

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[102] Nitin et al. , "The future of retail supply chains."

[103] Assumes the typical volume of a medium-sized package for a courier operating in Canada.

[104] Assumes the typical levels of demand in downtown Toronto (higher demand) and the GTHA (lower demand).

Hamilton were therefore chosen by randomly selecting 300 and 80 of the possible delivery addresses for the higher and lower demand scenarios, respectively.

The same random selection process was applied to determine the delivery locations in Toronto. Unlike Hamilton, however, the Toronto data set does not provide information for all distinct municipal addresses. Rather, the addresses in the data set correspond to buildings. To reconcile this, several of the land-use types in Toronto's data set were assumed to contain multiple units in a building: high density residential, other office building, commercial locations, and neighbourhood shopping center. Due to a lack of data on the average number of deliveries made within a multi-unit building, a random number between 1 and 4 was generated and assigned to each building to represent the number of deliveries being made to that multi-unit building. These numbers were then tallied and a corresponding number of addresses were randomly removed so that only 300 and 80 delivery locations were selected for the higher and lower demand scenarios, respectively (i.e. as opposed to 300 and 80 buildings).

C.2.2 Congestion

In addition to varying the levels of demand, each delivery operation was also modeled under three different levels of congestion: free flow traffic (i.e. off-peak), normal congestion, and higher congestion. Different congestion levels affect the speed at which a delivery vehicle can travel and therefore impacts the time needed to complete all deliveries.

The travel times under free flow traffic conditions for the package car and small electric van scenarios were determined in GIS using a road network also developed by McMaster University's TransLAB. The travel times for the same vehicles under normal congestion conditions were determined by running a user equilibrium traffic assignment in TransCAD, another GIS software package developed for solving transportation problems. These travel times pertain to one hour of the morning peak period (8:00 a.m. to 8:59 a.m.). The input to the traffic assignment was an origin-destination flow matrix of trips taken at this time in the region by automobile drivers in 2016. A limitation of the input data is that similar data were not available for 'trucks,' which may lead to under-reporting of traffic congestion, especially on expressways. However, an important feature of these congested travel times is that they are bi-directional — that is, they can differ by direction of travel along a link. Travel times for package cars and small electric vans pertaining to higher congestion were added to the network by increasing the congested travel times on each link by 10%. This means that higher congestion for vehicles is modeled as bi-directional travel times. Increasing congested travel times by 10% was intended to test the sensitivity of the VRP's outputs to changes in travel time.

Travel times for the small and large e-assist cargo cycles were determined using the same road network as above. Because the cargo cycles modeled in this research are assumed to have e-assist, the model does not account for potentially slower cycling speeds due to cyclist fatigue; it is assumed that the e-assist function allows cargo cyclists to sustain a consistent speed throughout the day. Under free-flow traffic and normal congestion conditions, it was assumed that large cargo cycles travel at a speed of 17 km/h and small cargo cycles at 20 km/h.[105,106] The resulting travel times derived for each link based on these speeds were increased by 10% to account for higher congestion.

C.2.3 Determining optimal fleet size

Using all the model parameters discussed above, the VRP in ArcGIS generates the number of routes required to complete all deliveries. There are cases where the optimal number of delivery vehicles (i.e. fleet size) is less than the number of required routes. In other words, fewer vehicles are needed to serve the same number of routes.

The optimal fleet size for each scenario was determined by examining the minimum, maximum, and mean delivery route times for each scenario. Further, it was assumed that a 30 minute loading time was required to reload a vehicle after it completes its first route. This means that in order for a scenario to offer the possibility of reducing the number of vehicles required, the minimum route time must be less than or equal to 210 minutes.[107] Only the scenarios using small cargo cycles for Hamilton and Toronto fit this criterion.

In determining the optimal fleet size for the small cargo cycle scenarios, the mean route time was used. For each additional route after the first one of the day, 30 minutes was added to mean route time to account for reloading. Such routes were added to the first route until the total route time was within 15 minutes of the 480-minute time window

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[105] Clarke et al., *Agile Gnewt Cargo: parcels deliveries with electric vehicles in Central London*, 23.

[106] Eric Kamphof, presentation at the Pembina Institute's Modernizing Urban Deliveries Workshop, Toronto, January 29, 2019, 11.

[107] This was calculated by taking 240 minutes, which is half of the time window available for deliveries, minus 30 minutes for loading new orders.

available for deliveries.[108] This number of routes were then divided into the original number of routes and rounded up, thus determining the optimal fleet size.

C.2.4 Calculating scenario costs and GHG emissions

Using the outputs of the VRP (total VKT, total operational time, number of routes, and optimal fleet size) for each delivery scenario based on the model parameters discussed above, the costs and GHG emissions associated with each scenario were calculated using the equations in Table 8. The inputs for the cost and emissions calculations are presented in Table 9.

Table 8. Calculations for costs and emissions

Cost type/emissions	Calculation
Daily labour costs [$]	$WC \times OT$ Where WC = wage of vehicle operator [$/hr] OT = total operational time [hr]
Daily fuel costs [$]	$GC \times FC \times VKT$ Where GC = cost of fuel [$/L or $/kWh] FC = fuel consumption [L/km or kWh/km] VKT = total vehicle kilometres traveled [km]
Daily fleet maintenance costs [$]	$MC \times VN$ Where MC = daily maintenance cost [$/vehicle] VN = optimal fleet size [# vehicles]
Capital cost of fleet [$]	$VC \times VN$ Where VC = cost per vehicle [$/vehicle] VN = optimal fleet size [# vehicles]
Daily emissions [kg CO_2]	$EF \times VKT$ Where EF = emissions factor [kg CO_2/km] VKT = total vehicle kilometres traveled [km]

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[108] A 15-minute time buffer was used to account for the fact that some routes may take longer than the mean route time.

Table 9. Inputs into cost and emission calculations for each delivery mode

	Package car (PC)	Small electric delivery van (DV)	Large e-assist cargo cycle (LB)	Small e-assist cargo cycle (SB)
Vehicle operator wage (WC)[109]	\$30/hr	\$20/hr	\$20/hr	\$20/hr
Fuel cost (GC)[110]	\$1.228/L (diesel)	\$0.1066/kWh	\$0.1066/kWh	\$0.1066/kWh
Fuel consumption (FC)	0.245 L/km[111]	0.16 kWh/km[112]	0.025 kWh/km[113]	0.005 kWh/km[114]
Maintenance cost of vehicle (MC)[115]	\$40/day	\$15/day	\$7/day	\$7/day
Vehicle cost (VC)	\$70,000 [116] / 3102.5 days [117] = \$22.56/day	\$35,000 / 2920 days = \$11.99/day [118]	\$12,000 [119]/ 1460 days [120] = \$8.22/day	\$7,400 [121] / 1460 days [122] = \$5.07/day

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[109] PC wage: UPS Canada and Canadian Council of Teamsters, *Collective Agreement 2015-2020*, 79. https://www.sdc.gov.on.ca/sites/mol/drs/ca/Transport/492-27603-20%20(507-0268).pdf ; wages for DV, LB and SB operators: personal communications from Alex BG, Send It Courier, May 1, 2019; Darryl Brown, The Drop, April 30, 2019; Devan McClelland, Shift Delivery, April 30, 2019.

[110] PC fuel cost: Based on diesel prices for Southern Ontario. Government of Ontario, "Motor fuel prices," April 29, 2019. https://www.ontario.ca/page/motor-fuel-prices ; fuel (electricity) costs for DV, LB and SB: Based on average prices for large-power customers. Hydro Quebec, *Comparison of Electricity Prices in Major North American Cities* (2018), 7. http://www.hydroquebec.com/data/documents-donnees/pdf/comparison-electricity-prices.pdf

[111] Andrew Burke and Hengbing Zhao, *Fuel Economy Analysis of Medium/Heavy-duty Trucks: 2015-2050* (Institute of Transportation Studies, UC Davis, 2017), 6.

[112] Based on the average mid-driving range of a fully charged battery (40 kWh/250 km). Nissan, "Nissan e-NV200." https://www-europe.nissan-cdn.net/content/dam/Nissan/gb/brochures/Vehicles/Nissan_e-NV200_van_UK.pdf

[113] 1.92 kWh for 76 km. UPS Canada, "Canada Cargo Bike Fact Sheet," 2017.

[114] 0.418 kWh for 80 km. Larry vs. Harry, "STePS eBULLITT technical info." http://www.larryvsharry.com/steps-ebullitt-technical-info/

[115] Maintenance costs for each vehicle type are estimated based on operations of different delivery businesses.

[116] Based on prices for a new Class 5 diesel stepvan. Commercial Truck Trader, May 1, 2019. https://www.commercialtrucktrader.com/Class-5-Medium-Duty-Stepvans-For-Sale/search-results?type=class5&category=Stepvan%7C2013294

Emissions factor	0.652 kg CO_2/km [123]	0 kg CO_2/km	0 kg CO_2/km	0 kg CO_2/km

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[117] Based on the approximate useful life span of a light dump truck, which has a similar weight of a Class 5 package car and also make frequent stops. USF, “Vehicle Average Replacement Schedule,” February 24, 2018. https://www.usf.edu/administrative-services/documents/asbc-resources-field-equipment-replacement.pdf

[118] Life span based on Nissan’s 8 year warranty for the vehicle battery. Nissan, “Nissan e-NV200.” https://www-europe.nissan-cdn.net/content/dam/Nissan/gb/brochures/Vehicles/Nissan_e-NV200_van_UK.pdf

[119] Velove, “The Armadillo.” https://www.velove.se/pricing

[120] Eric Kamphof, Curbside Cycle, personal communication, May 5, 2019.

[121] Curbside Cycle, “Larry vs. Harry E-Bullitt - Steps E6000 – Bike only.” https://curbsidecycle.com/products/bullitt-shimano-steps-e6000-bike-only/

[122] Eric Kamphof, Curbside Cycle, personal communication, May 5, 2019.

[123] Andrew Burke and Hengbing Zhao, *Fuel Economy Analysis of Medium/Heavy-duty Trucks: 2015-2050* (Institute of Transportation Studies, 2017), 13.

Appendix D. Modelling outputs

Table 10. Top 20 candidate locations for microhubs in Hamilton

Street Name	Candidate location ID	Number of households within 500 m buffer	Number of employees within 500 m buffer	Household score	Employment score	Weighted score	Zoning designation
Bay Street South	360 (Microhub 1)	5540	11884	0.54	0.26	0.81	Downtown mixed use (D3)
Bay Street South	365	6831	4029	0.67	0.09	0.76	High density multiple dwellings (E-3)
Bay Street South	359	4622	13185	0.45	0.29	0.74	Downtown mixed use (D3)
Main Street West	2693	5497	8699	0.54	0.19	0.73	Downtown central business district (D1)
James Street South	1961	4882	10148	0.48	0.22	0.70	Central business district (I)
Main Street West	2678	3986	13431	0.39	0.30	0.69	Downtown central business district (D1)
King Street West	2471	4261	11074	0.42	0.24	0.66	Downtown prime retail streets (D2)
Bay Street North	346	3506	14124	0.34	0.31	0.66	Downtown prime retail streets (D2)

John Street South	2009	4399	9503	0.43	0.21	0.64	Mixed use medium density (C5)
Main Street West	2689	5517	4185	0.54	0.09	0.63	Downtown central business district (D1)
Queen Street South	3299	5037	5056	0.49	0.11	0.61	Downtown prime retail streets (D2)
Queen Street South	3305	5529	1315	0.54	0.03	0.57	Multiple dwellings (DE-3/S-828a)
Bay Street North	347	2554	13920	0.25	0.31	0.56	Downtown central business district (D1)
King Street West	2467	4312	5891	0.42	0.13	0.55	Downtown prime retail streets (D2)
King Street West	2462	2033	14959	0.20	0.33	0.53	Downtown central business district (D1)
James Street South	1957	3879	5969	0.38	0.13	0.51	Mixed use medium density pedestrian focus (C5a)
James Street South	1956	2152	13586	0.21	0.30	0.51	Downtown prime retail streets (D2)
St. Joseph's Drive	3821	3651	6088	0.36	0.13	0.49	Major institutional (I3)
Main Street East	2630	2043	12977	0.20	0.29	0.49	Downtown central business district (D1)
James Street South	1955	1682	14107	0.16	0.31	0.48	Downtown prime retail streets (D2)

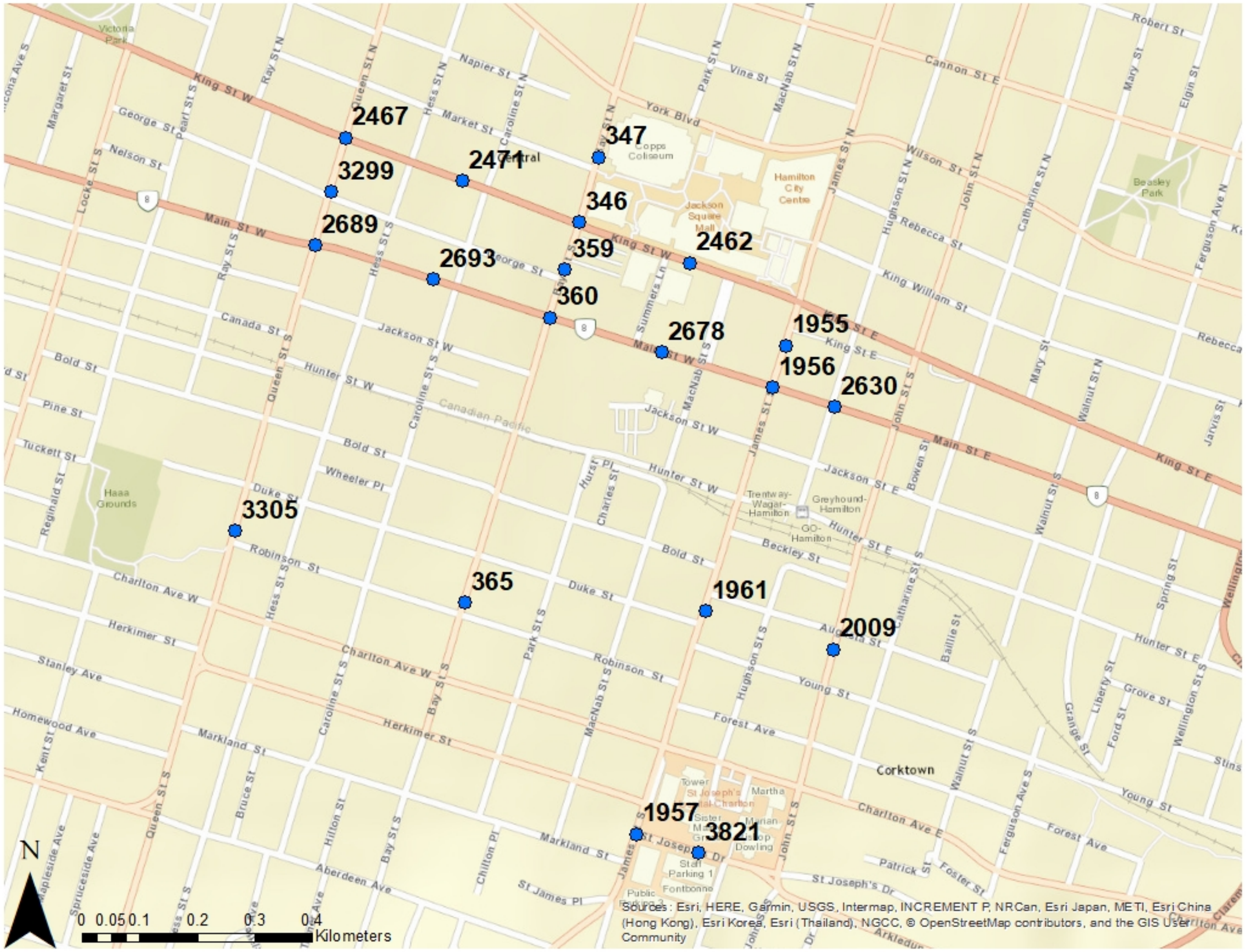

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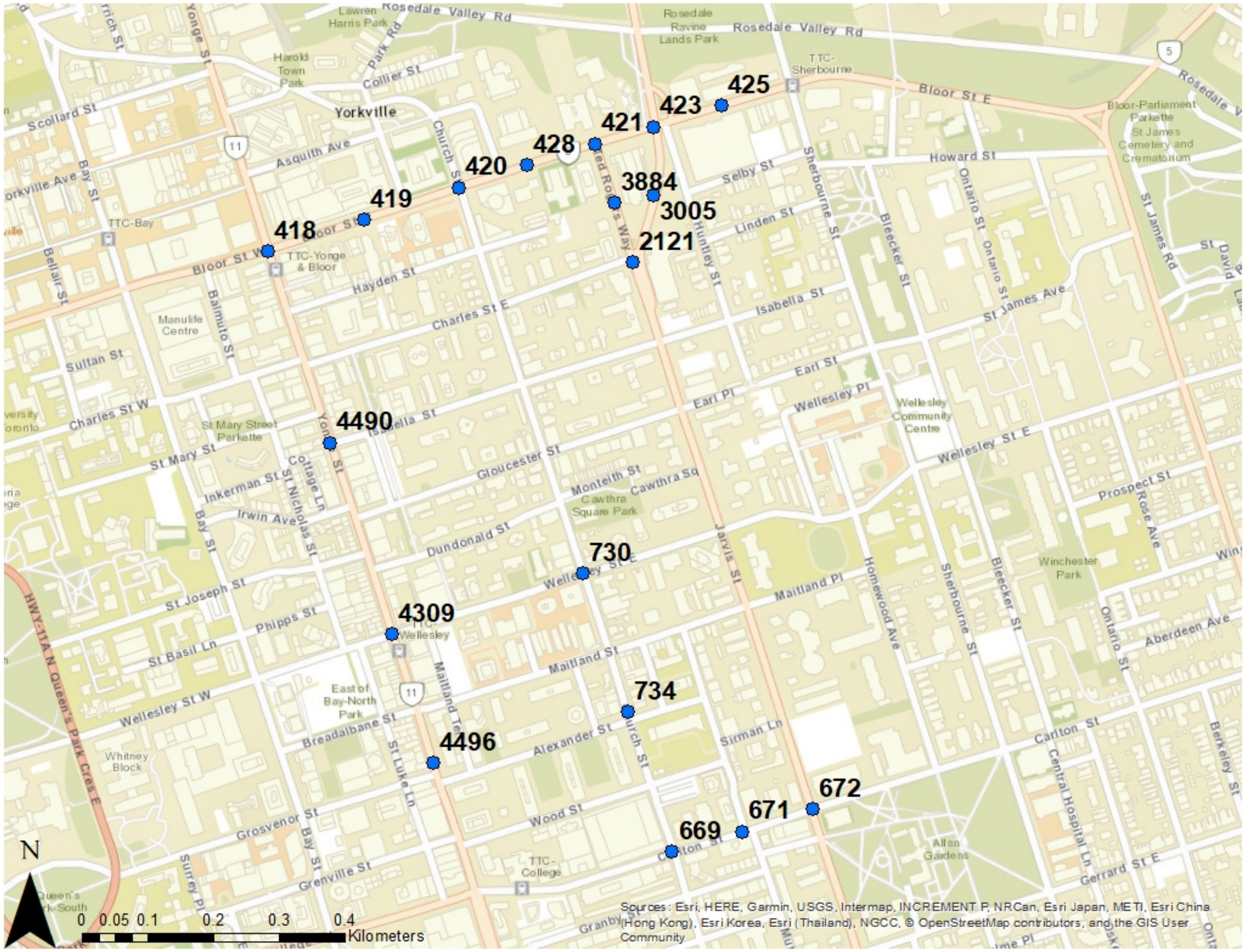
Figure 14. Map of the top 20 candidate locations in Hamilton.

Numbers correspond to candidate location ID.

Table 11. Top 20 candidate locations for microhubs in Toronto

Street Name	Candidate location ID	Number of households within 500 m buffer	Number of employees within 500 m buffer	Household score	Employment score	Weighted score	Zoning designation
Church St	730 (Microhub 2)	16398	14437	0.67	0.03	0.70	Commercial residential (CR)
Jarvis St	2121	12859	27661	0.53	0.05	0.58	CR
Mount Pleasant Rd	3005	11708	25626	0.48	0.05	0.53	CR
Ted Rogers Way	3884	11397	27932	0.47	0.05	0.52	CR
Church St	734	11880	15839	0.49	0.03	0.51	CR
Wellesley St E	4309	10369	26371	0.42	0.05	0.47	CR
Carlton St	672	11003	10934	0.45	0.02	0.47	CR
Bloor St E	421	9782	28133	0.40	0.05	0.45	CR
Eglinton Ave E	1376	10203	18128	0.42	0.03	0.45	CR
Yonge St	4490	9477	33877	0.39	0.06	0.45	CR
Bloor St E	419	9016	43569	0.37	0.08	0.45	CR
Carlton St	671	10002	15921	0.41	0.03	0.44	CR
Bloor St E	428	9172	32121	0.37	0.06	0.43	CR
Bloor St E	423	9451	24768	0.39	0.05	0.43	CR
Bloor St E	418	8698	40609	0.36	0.08	0.43	CR

Bloor St E	420	8700	37397	0.36	0.07	0.42	CR
Yonge St	4496	8811	34392	0.36	0.06	0.42	CR
Carlton St	669	9075	21629	0.37	0.04	0.41	CR
Bloor St E	425	9050	20988	0.37	0.04	0.41	CR
Sheppard Ave E	3601 (Microhub 3)	9131	19181	0.37	0.04	0.41	CR



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 15. Map of 18 of the top 20 candidate locations in Toronto.

Numbers correspond to candidate location ID.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 16. Map of the remaining 2 of the top 20 candidate locations in Toronto.

Numbers correspond to candidate location ID.

Appendix E. Vehicle routing outputs

Table 12. Scenario names and corresponding abbreviations.

Name	Abbreviation
Business as usual (package car) - high cargo volume, off peak	PCOP_H
Business as usual (package car) - high cargo volume, normal congestion	PCNC_H
Business as usual (package car) - high cargo volume, high congestion	PCHC_H
Business as usual (package car) - low cargo volume, off peak	PCOP_L
Business as usual (package car) - low cargo volume, normal congestion	PCNC_L
Business as usual (package car) - low cargo volume, high congestion	PCHC_L
Microhub (delivery van) - high cargo volume, off peak	DVOP_H
Microhub (delivery van) - high cargo volume, normal congestion	DVNC_H
Microhub (delivery van) - high cargo volume, high congestion	DVHC_H
Microhub (delivery van) - low cargo volume, off peak	DVOP_L
Microhub (delivery van) - low cargo volume, normal congestion	DVNC_L
Microhub (delivery van) - low cargo volume, high congestion	DVHC_L
Microhub (large cargo bike) - high cargo volume, off peak	LBOP_H
Microhub (large cargo bike) - high cargo volume, normal congestion	LBNC_H
Microhub (large cargo bike) - high cargo volume, high congestion	LBHC_H
Microhub (large cargo bike) - low cargo volume, off peak	LBOP_L
Microhub (large cargo bike) - low cargo volume, normal congestion	LBNC_L
Microhub (large cargo bike) - low cargo volume, high congestion	LBHC_L
Microhub (small cargo bike) - high cargo volume, off peak	SBOP_H
Microhub (small cargo bike) - high cargo volume, normal congestion	SBNC_H
Microhub (small cargo bike) - high cargo volume, high congestion	SBHC_H
Microhub (small cargo bike) - low cargo volume, off peak	SBOP_L
Microhub (small cargo bike) - low cargo volume, normal congestion	SBNV_H
Microhub (small cargo bike) - low cargo volume, high congestion	SBHC_L

Table 13. Scenario outputs for selected microhub in Hamilton (location ID 360)

Scenario	Number of Routes	Optimal Fleet Size	Time (min)		Total Operational Time (min)	VKT (km)	Route Time (min)		
			Service	Travel			Mean	Minimum	Maximum
H1LBNC_L	2	2	400	156	556	29	278	252	305
H1LBOP_L	2	2	400	156	556	29	278	252	305
H1LBHC_L	2	2	400	165	565	29	282	264	300
H1SBNC_L	8	2	400	186	586	39	73	63	81
H1SBOP_L	8	2	400	186	586	39	73	63	81
H1SBHC_L	8	2	400	193	593	38	74	47	91
H1DVOP_L	2	2	520	85	605	29	303	277	328
H1DVNC_L	2	2	520	85	605	29	303	277	328
H1DVHC_L	2	2	520	88	608	29	304	271	338
H1PCNC_L	2	2	640	95	735	33	368	335	401
H1PCOP_L	2	2	640	96	736	33	368	335	401
H1PCHC_L	2	2	640	102	742	34	371	340	401
H1LBNC_H	6	6	1500	335	1835	63	306	253	344
H1LBOP_H	6	6	1500	335	1835	63	306	253	344

H1LBHC_H	6	6	1500	346	1846	61	308	283	344
H1SBNC_H	28	6	1500	521	2021	109	72	62	86
H1SBOP_H	28	6	1500	521	2021	109	72	62	86
H1SBHC_H	28	6	1500	553	2053	109	73	53	87
H1DVOP_H	5	5	1950	178	2128	61	426	264	478
H1DVNC_H	5	5	1950	179	2129	62	426	305	478
H1DVHC_H	5	5	1950	190	2140	63	428	269	479
H1PCOP_H	6	6	2400	206	2606	71	434	291	476
H1PCNC_H	6	6	2400	210	2610	73	435	323	478
H1PCHC_H	6	6	2400	218	2618	73	436	397	475

Table 14. Scenario outputs for selected microhub in Toronto (location ID 730)

Scenario	Number of Routes	Optimal Fleet Size	Time (min)		Total Operational Time (min)	VKT (km)	Route Time (min)		
			Service	Travel			Mean	Minimum	Maximum
H2DVHC_H	6	6	1950	195	2145	68	358	247	454
H2DVHC_L	2	2	520	89	609	30	304	302	307
H2DVNC_H	5	5	1950	186	2136	67	427	354	479
H2DVNC_L	2	2	520	87	607	31	303	283	324
H2DVOP_H	5	5	1950	185	2135	67	427	353	480
H2DVOP_L	2	2	520	87	607	31	303	283	324
H2LBHC_H	6	6	1500	391	1891	71	315	293	335
H2LBHC_L	2	2	400	164	564	29	282	253	311
H2LBNC_H	6	6	1500	358	1858	68	310	294	328
H2LBNC_L	2	2	400	144	544	28	272	253	292
H2LBOP_H	6	6	1500	358	1858	68	310	294	328
H2LBOP_L	2	2	400	144	544	28	272	253	292
H2PCHC_H	6	6	2400	217	2617	78	436	375	478
H2PCHC_L	2	2	640	95	735	33	368	296	439

H2PCNC_H	6	6	2400	209	2609	77	435	356	476
H2PCNC_L	2	2	640	92	732	33	366	295	437
H2PCOP_H	6	6	2400	212	2612	80	435	364	476
H2PCOP_L	2	2	640	91	731	33	366	295	437
H2SBHC_H	28	6	1500	546	2046	110	73	56	84
H2SBHC_L	8	2	400	185	585	37	73	48	82
H2SBNC_H	28	6	1500	508	2008	109	72	62	79
H2SBNC_L	8	2	400	173	573	37	72	48	80
H2SBOP_H	28	6	1500	508	2008	109	72	62	79
H2SBOP_L	8	2	400	173	573	37	72	48	80

Table 15. Scenario outputs for selected microhub in Toronto (location ID 3601)

Scenario	Number of Routes	Optimal Fleet Size	Time (min)		Total Operational Time (min)	VKT (km)	Route Time (min)		
			Service	Travel			Mean	Minimum	Maximum
H3DVHC_H	5	5	1950	196	2146	77	429	372	475
H3DVHC_L	2	2	520	101	621	38	310	268	353
H3DVNC_H	5	5	1950	186	2136	77	427	384	465
H3DVNC_L	2	2	520	95	615	38	307	264	351
H3DVOP_H	5	5	1950	187	2137	78	427	370	472
H3DVOP_L	2	2	520	96	616	38	308	265	351
H3LBHC_H	6	6	1500	420	1920	81	320	302	334
H3LBHC_L	2	2	400	198	598	38	299	260	338
H3LBNC_H	6	6	1500	389	1889	80	315	256	331
H3LBNC_L	2	2	400	183	583	38	291	269	314
H3LBOP_H	6	6	1500	389	1889	80	315	256	331
H3LBOP_L	2	2	400	183	583	38	291	269	314
H3PCHC_H	6	6	2400	246	2646	96	441	379	474
H3PCHC_L	2	2	640	114	754	45	377	323	431

H3PCNC_H	6	6	2400	233	2633	94	439	352	480
H3PCNC_L	2	2	640	109	749	45	374	321	428
H3PVOP_H	6	6	2400	230	2630	94	438	325	478
H3PCOP_L	2	2	640	108	748	45	374	320	428
H3SBHC_H	28	6	1500	581	2081	124	74	58	100
H3SBHC_L	8	2	400	217	617	47	77	56	91
H3SBNC_H	28	6	1500	525	2025	120	72	54	94
H3SBNC_L	8	2	400	201	601	47	75	63	84
H3SBOP_H	28	6	1500	525	2025	120	72	54	94
H3SBOP_L	8	2	400	201	601	47	75	63	84