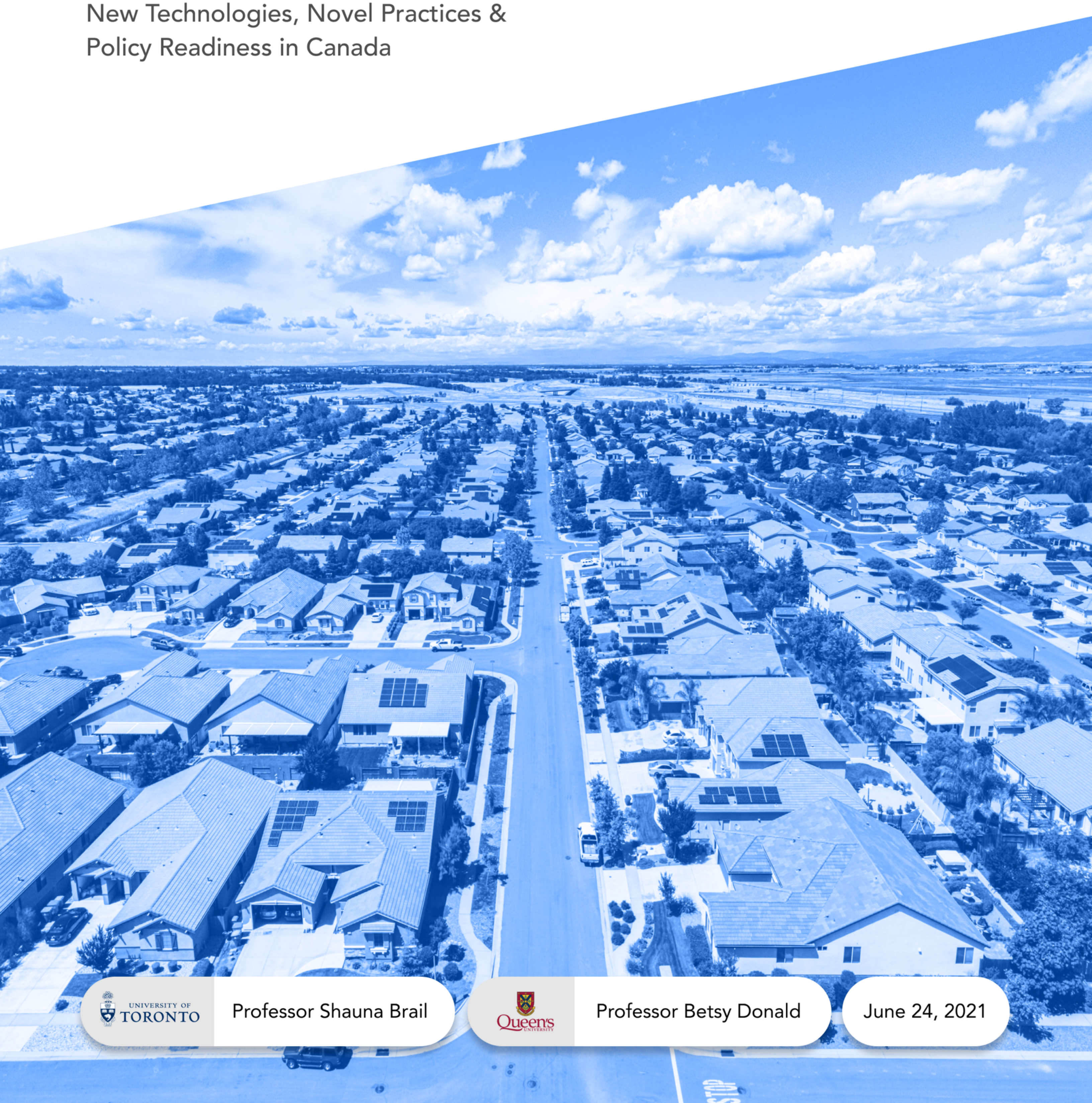
ROBOTIC CARGO TRANSPORT

New Technologies, Novel Practices & Policy Readiness in Canada



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Executive Summary

This report, commissioned by Transport Canada, presents background research about the current state of autonomous cargo delivery and the prospects for future uses. It addresses the technical capacity of autonomous cargo delivery technology, details current uses, and describes the state of the sector based on examples from firms, institutions, governments and jurisdictions around the world. This report also addresses the implications of change in this sector with a focus on policy and regulatory engagement.

The report is structured as follows: Section II provides an overview of the context and trends within which robot and drone delivery activities operate, emphasizing last-mile deliveries. Section III provides an econometric review of robot and drone delivery, based on models developed and applied in a range of scenarios. Section IV presents a jurisdictional scan, highlighting regulatory and policy approaches taken at the municipal, regional and national levels in a selection of global jurisdictions for both robots and drones. Section V concludes with key recommendations for Transport Canada in determining whether and how to test and develop policy for autonomous cargo delivery in the Canadian context.

Key Findings:

- Technological development for autonomous cargo delivery is moving faster than the policy environment
- Benefits of autonomous cargo delivery include the potential for reduced costs, contactless delivery, improved equity, safety and decarbonization
- Challenges associated with autonomous cargo delivery include accessibility, privacy, surveillance and conflicting uses in public space
- Drones are required to operate within the confines of federal regulations while the regulatory environment for robots remains less well-defined
- Meta-analysis of econometric studies demonstrates inconclusive findings and requires more reliable data
- Three Interconnected Challenges
    - Vagueness and underdevelopment in the regulatory environment
    - Ambiguity and uncertainty with respect to social acceptance of these technologies
    - Lack of programming that encourages ongoing testing, firm, product and process development

Recommendations

Recommendation 1: Build Informed Regulatory Capacity

- At the broadest level, Canada needs to develop an innovative decision-making framework that pro-actively embraces decision-making about innovation and disruptive technology, including autonomous cargo delivery.

Recommendation 2: Collaborate to Gauge Social Acceptance

- Deep learning requires deep engagement with many modes of thought and interest groups. Industry players are often well-represented in decision-making processes. For disruptive technologies to be embraced by society, inclusive approaches to decision-making are paramount. To gauge social acceptance, a diverse array of stakeholders need to be included in decisions about regulating emerging technology. This includes key industry players, as well as communities, Indigenous communities and peoples, cities, universities, colleges and researchers.

Recommendation 3: Develop Pilot Programs with Embedded Learning Goals

- Transport Canada could lead in creating dedicated spaces and rules for experimentation which can provide benefits to firms, governments and citizens. Transport Canada should continue to embrace pilot programs that test robots and drones in the public realm.

The report makes clear that technology and business experimentation around autonomous cargo delivery is moving faster than the policy environment. The time is ripe for governments at all levels to prepare and plan proactively, considering both the potential opportunities posed by autonomous cargo delivery, as well as the significant challenges. Embracing approaches that build collaboration and trust is the next step in Canada's path towards innovative and publicly acceptable commercial applications of robotic cargo transport.

Résumé

Le présent rapport a été commandé par Transports Canada et présente les recherches contextuelles sur l'état actuel de la livraison de fret par des robots ou des drones autonomes et les perspectives d'utilisations futures. Le rapport traite de la capacité technique de la technologie de livraison du fret par des robots ou des drones autonomes, décrit en détail les utilisations actuelles et l'état du secteur à partir d'exemples fournis par des entreprises, des gouvernements et d'autres instances à travers le monde. On y aborde également les répercussions du changement dans ce secteur en mettant l'accent sur l'engagement politique et réglementaire.

Le rapport est structuré comme suit : la section II donne un aperçu des tendances et du contexte dans lequel se déroulent les livraisons par robots et par drones en mettant l'accent sur les livraisons sur le dernier kilomètre. La section III examine l'aspect économétrique des livraisons par robots et par drones en se basant sur des modèles élaborés et appliqués à une gamme de scénarios. La section IV examine les approches adoptées par diverses administrations, tant au niveau municipal que régional et national, de divers pays, en matière de réglementation et de politiques relatives aux drones et aux robots. La section V conclut ce rapport par des recommandations importantes à l'intention de Transports Canada pour déterminer s'il faut élaborer une politique relative à la livraison de fret par robots et drones autonomes et comment la tester dans le contexte canadien.

Principales conclusions :

- Les avancées technologiques dans le domaine de la livraison de fret par robots ou drones autonomes progressent plus rapidement que le contexte politique.
- La livraison de fret par robots ou drones autonomes présente plusieurs avantages dont une réduction potentielle des coûts, une livraison sans contact, une amélioration de l'équité, de la sécurité et la décarbonisation.
- Les défis associés à la livraison de fret par robots ou drones autonomes concernent l'accessibilité, la confidentialité, la surveillance et l'utilisation conflictuelle de l'espace public
- Les drones doivent être exploités dans le respect de la réglementation fédérale, alors que le cadre réglementaire entourant les robots demeure nettement plus vague.
- Une méta-analyse des études économétriques a produit des résultats non concluants; des données plus fiables sont nécessaires.
- Trois défis interreliés :
    - Un contexte réglementaire vague et sous-développé
    - L'ambiguïté et l'incertitude quant à l'acceptation de ces technologies par la société
    - Le manque de programmes visant à encourager la poursuite des essais, le développement d'entreprises, de produits et de processus.

Recommandations

Recommandation n° 1 : Développer la capacité de faire des choix éclairés en matière de réglementation

- Le Canada a besoin d'établir un cadre décisionnel novateur qui permet de prendre des décisions de manière proactive concernant l'innovation et les technologies perturbatrices, notamment à l'égard de la livraison de fret par des robots ou des drones autonomes.

Recommandation n° 2 : Travailler en collaboration pour évaluer l'acceptation de ces technologies par la société

- Un apprentissage approfondi nécessite un engagement profond et d'être exposé à de nombreux modes de pensée et à divers groupes d'intérêt. Les acteurs de l'industrie sont souvent bien représentés dans les processus décisionnels. Or, pour que la société adopte ces technologies perturbatrices, il est essentiel de privilégier des approches inclusives en matière de prise de décision. L'évaluation de l'acceptation par la société de ces technologies nécessite la participation d'un large éventail d'intervenants aux décisions relatives à la réglementation visant ces technologies émergentes. Cela inclut les principaux acteurs de l'industrie, les collectivités, les collectivités et les peuples autochtones, les villes, les universités, les collèges et les chercheurs.

Recommandation n° 3 : Élaborer des programmes pilotes avec des objectifs d'apprentissage intégrés

- Transports Canada pourrait être le chef de file dans la création de règles et d'espaces dédiés à l'expérimentation, ce qui peut être avantageux pour les entreprises, les gouvernements et les citoyens. Transports Canada devrait continuer à soutenir les programmes pilotes dans le cadre desquels les robots et les drones sont testés dans l'arène publique.

Selon le rapport, il est clair que l'expérimentation technologique et commerciale de la livraison de fret par robots ou drones autonomes progresse beaucoup plus rapidement que le contexte politique. Le temps est donc venu pour tous les paliers de gouvernement d'être proactifs et de préparer et de planifier en tenant compte des possibilités que présente la livraison de cargo par des robots et des drones autonomes et des défis connexes importants. La prochaine étape dans le cheminement du Canada vers des applications commerciales novatrices et acceptables pour le public du transport robotisé de marchandises est d'adopter des approches qui favorisent la collaboration et établissent un climat de confiance.

SECTION I: Introduction

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Cargo delivery is at a crossroads as Canadian and global businesses are increasingly employing the use of artificial intelligence-driven applications and platforms connected to mobility to improve delivery activities. These activities include the operation of autonomous cargo delivery vehicles, such as aerial and land-based drones which utilize streets, sidewalks, broadband services, and other public infrastructures. The prospects for scaling up autonomous cargo delivery are improving as a result of technological advancement and business case development. Furthermore, COVID-19 has accelerated autonomous cargo delivery activity alongside increasing public demand for contactless delivery.

The regulatory environment in which autonomous cargo delivery operates, however, is uncertain and incomplete. This is the case in Canada, and elsewhere. Amidst this backdrop, some jurisdictions are rewriting regulations to respond to both technological advancement and industry pressure to advance the commercial application of autonomous cargo delivery. Considering this, governments at all levels need to prepare and plan proactively, taking into account both the potential opportunities posed by autonomous cargo delivery, as well as the significant challenges.

Advances: Growth in Parcel Shipments, Autonomous Cargo Delivery

In the past decade, parcel shipments have grown rapidly due to factors ranging from accelerating consumer acceptance of e-commerce as well as the deployment of increasingly sophisticated logistics, shipping and supply chain technologies. According to Pitney Bowes's Parcel Shipping Index, the volume of parcels shipped increased by 19% annually between 2013 and 2019. At a global scale, the number of parcels shipped per person tripled between 2013 and 2019 (Pitney Bowes, 2020). With rising numbers of purchases being made online, it is expected that the total volume of parcels shipped will continue to increase alongside consumer demand for inexpensive and fast delivery.

The technologies underlying consumer cargo delivery – such as the delivery of books, groceries, medicine or pizza - using autonomous means, have improved to the point of implementation in predominantly experimental environments. Over the last few years, significant interest has emerged with respect to leveraging the potential for autonomous delivery vehicles as a means of providing efficient and cost-effective delivery of goods and services. Market analysts suggest there is tremendous growth potential for robot and drone delivery. In 2016, a McKinsey & Company report predicted that autonomous vehicles would be responsible for delivering nearly all business-to-consumer (or X2C) parcels, and would ultimately be responsible for 80% of total parcel deliveries (Joerss et al., 2016). In the five years since that report was published, industry expectations for growth continue. For example, Gartner's research suggests that globally, there were 20,000 drones making retail deliveries as of early 2021, and that these fleets could increase to 1 million drones globally within five years

(Wray, 2021). Fast delivery speeds combined with lower delivery costs generally lead the rationale for this growth. Analysts suggest that by 2024, the global market for delivery by autonomous robot is expected to reach $34B USD in value (Wiggers, 2021), whereas the global drone package delivery market could be worth $7.4B USD by 2027 (Fortune Business Insights, 2020).

Policy Environment: Ready or Not?

The current Canadian policy environment was not designed to respond to the widespread use of autonomous cargo delivery platforms in the public realm. There are challenges in the face of questions about how and whether autonomous cargo delivery should operate in Canada. These include: public apprehension about autonomous delivery technologies and their safety, and consumer reservations over data security, surveillance, privacy and equity. Concerns are directed at both the technologies and firms providing autonomous delivery. Because these devices rely on public space and municipal, provincial and federal infrastructure, governments play a key role in either permitting or rejecting their ability to operate. Furthermore, questions abound with respect to the role of government regulation and policy, and the balancing act required to manage change responsibly. These issues are also bound up in broader debates about the influence that a relatively small number of large technology firms and state actors possess, and the roles that they play in intentionally directing change to their advantage. Failure to proactively develop an acceptable framework for decision-making about innovative and disruptive technology portends lost opportunity for government, industry and society.

Structure of Report

This report, commissioned by Transport Canada, presents background research about the current state of autonomous cargo delivery and the prospects for future uses. It addresses the technical capacity of autonomous cargo delivery technology, details current uses, and describes the state of the sector based on examples from firms, institutions, governments and jurisdictions around the world. This report also addresses the implications of change in this sector with a focus on policy and regulatory engagement.

The remainder of the report is organized as follows: Section II provides an overview of the context and trends within which robot and drone delivery activities operate, emphasizing last-mile deliveries. It includes a brief discussion of the history of technological advancement that preceded the development of autonomous cargo delivery, highlights market and jurisdiction-based examples of robot and drone activities and presents a discussion of opportunities and limitations. Section III provides an econometric review of robot and drone delivery, based on models developed and applied in a range of scenarios. Section IV presents a jurisdictional scan, highlighting regulatory and policy approaches taken at the municipal, regional and national levels in a selection of global jurisdictions for both robots and drones. Section V concludes with key recommendations for Transport Canada in determining whether and how to test and develop policy for autonomous cargo delivery in the Canadian context.

Drones and Robots: Clarification

Whenever possible throughout this document the discussion between drones and robots is separated. While there are similarities in terms of trends, econometrics and thoughtful policy needs and readiness, there are also differences in these areas. In terms of regulations and jurisdictional regulatory responses in particular, unique responses have occurred and are indeed required.

The information and ideas presented in this report are intended to be used by Transport Canada and its stakeholders. Views are the authors' alone and do not necessarily reflect those of Transport Canada or the Government of Canada.

SECTION II:
Context and Trends

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This section provides an overview of the overarching trends for autonomous vehicles designed specifically for cargo delivery purposes. First, we provide an overview of the context in which drone and robotic cargo delivery has developed and is being tested. Second, we highlight the significance of last-mile components and costs of delivery. Here we provide an overview of the firms operating pilot and permanent autonomous cargo delivery services. Lastly, we assess the context of technological, economic and social change in contributing to shifting perspectives, opportunities and challenges regarding autonomous cargo delivery.

Context

The commercial interest in robots and drones has grown dramatically over the last decade. Drones, for example, have seen widespread uptake of consumer uses for recreation, real estate, search and rescue, and photography. Drones are also widely used for collecting sensory data for preventive maintenance of safety inspections in all types of manufacturing and construction projects. As autonomous technologies become more sophisticated, their application to the efficient and effective delivery of cargo becomes more realistic. Logistics companies such as Amazon and UPS, for example, are testing to see if drones in some locations can more effectively and efficiently deliver consumer cargo such as food and medicine. The same can be said for land-based robots to deliver food and groceries. With the pandemic and the demand for contactless delivery accelerating, interest in the role these types of technologies can play in the efficient delivery of food, medicine and other consumer parcels has grown (Biron, 2020).

Industrial Revolution 4.0

Interest in drones and robots for cargo transportation is part of the larger growth of the digital and platform economy, and the search for ways to reduce the cost of transport while allowing for cost-efficient, on-demand logistics services. Autonomous delivery vehicles sit within the fourth industrial revolution category of robotic and automation technologies which has been fueled by an explosion of growth in the capability of computers to harvest data through powerful algorithms embedded in digital platforms. The digital revolution has infiltrated all aspects of everyday life – from how we work, socialize, and access travel and recreational opportunities (Hoffmann & Prause, 2018; Macrorie et al., 2019). Machine to machine communication and the internet of things have become the cornerstone of this 4th industrial revolution, resulting in the ongoing automation of traditional manufacturing and industrial practices.

Many cities and communities around the world have become experimental sites for applying new 4th wave industrial technologies for all aspects of mobility and logistics delivery. The application of drones and robots are no exception. Large drone manufacturers and logistics operations are teaming up with cell phone companies and other digital platforms to experiment with parcel delivery. UPS, for example, has partnered with Verizon and a subsidiary to test delivery in a Florida community using 5G wireless network technology, which can support more devices and improve signal and location data. UPS has also received a patent for a drone that can take off with a payload package from the roof of a truck (Leonard, 2021).

As for land-based robots, there are examples of autonomous devices delivering food and consumer goods in cities around the world. This is the fastest growing type of autonomous delivery vehicle being tested because land-based robots face fewer regulatory barriers. Drones, by contrast, are regulated by stringent air traffic rules and regulations in most countries. Land-based robots, in many jurisdictions, have not been regulated because the technology is emergent and there tends to be less proactive oversight for new ground space uses than for air space. In some jurisdictions such as Pennsylvania, land robots are regulated as 'pedestrians,' whereas drones are regulated as 'mini-airplanes.' For this reason, it is important to recognize that while there may be technological similarities between drones and land-based robots, they operate very differently, and need to be considered as such.

Another distinction between these technologies is functional: are they serving so-called last-mile delivery problems or attempting to resolve logistical issues for remote communities? The last-mile segment is particularly appealing to traditional logistics firms, big tech, and tech startups because of the opportunity to capture and expand profits derived from shipping and deliveries.

Last-Mile Delivery

Interest in autonomous cargo delivery, whether by drone or robot, is growing with respect to last-mile delivery. Reference to the last-mile in logistics speaks to the final step in the delivery process and involves the movement of goods to their final destination. Last-mile logistics are the most expensive part of the delivery process, comprising more than half of total delivery costs (Dolan, 2021; Marks, 2019). Such deliveries are also time-consuming due to cost-pressures that result in bundling geographically adjacent orders into a single delivery vehicle that must navigate through congested urban spaces or to remote rural locations (Dolan, 2021). While last-mile logistics are both expensive and time consuming, customer satisfaction turns on the seamlessness of delivery. Customer expectations with respect to fast and inexpensive delivery have increased alongside the growth of online shopping and the pressure exerted, for instance, on all retailers by Amazon Prime's model for same and next day delivery (Dolan, 2021). Boysen et al. (2020) suggest five factors contributing to shifts in demand for last-mile deliveries: increasing volume, sustainability, costs, time pressure and an aging workforce.

Although autonomous cargo delivery technologies can help address last-mile issues, they may be less helpful over the final metres of delivery, from curb (or backyard) to the front door. This is especially the case where there are stairs, multi-unit buildings, or other barriers.

Despite the logistical challenges associated with the last leg of the last-mile, autonomous cargo delivery offers the prospect of lower cost, more efficient service. Whether or not this vision is realized remains to be seen. We can look to early efforts and trials to develop a better sense of the conditions and markets in which autonomous cargo delivery currently operate.

Autonomous robot and drone delivery technologies share commonalities, for instance with respect to autonomous operations, entrepreneurial history, partnerships, and lobbying. Yet, they are distinct in terms of firm activities, spaces of operation, regulatory oversight and more.

Market players

The technologies that underlie the ability to deliver cargo to consumers via autonomous drone and robot are sufficiently developed to enable testing and operations (with backup human support). However, the business case and models that enable scaling up of autonomous delivery activities are still under development. In part, industry activity is restrained because of regulatory uncertainty which reduces opportunities for firms to scale. Nevertheless, the tables below highlight sector-specific companies, activities and characteristics of robot and drone delivery, drawing on examples that illustrate the current state of the industry.

Robot and drone delivery of consumer goods is being tested in a variety of environments by retailers such as Wal-Mart and Amazon, logistics firms like UPS, and technology startups such as Dianomix and Flytrex.

Robots

Robotic cargo delivery is meant as a last-mile solution for delivery, with robots transporting goods for the final few kilometres of their journey. Delivery pilots are well underway globally. In Calgary, a startup called Dianomix is testing the delivery of consumer goods to homes. Dianomix partners directly with retailers for deliveries and claims that delivery costs are reduced by 50 percent in comparison to traditional delivery. In Moscow, Yandex operates a fleet of robots as a part of a grocery delivery pilot program launched in fall of 2020 (Jennings & Figliozzi, 2020). In the U.K. two municipalities, Milton-Keynes and Northampton, permit robotics firm Starship Technologies to partner with Co-op Supermarket and offer home delivery by robot (Wray, 2020a). The robots operate in defined areas within distances ranging up to a few kilometres at most.

Table 1 presents examples of five robotic cargo delivery firms currently engaged in pilot testing and other operational activities. It represents a sampling of robotic cargo delivery firms and is not exhaustive. Within robotic cargo delivery, there are both large and small firms with global and local footprints. The firms operate using different types of business models. While some, such as Starship or TinyMile, emphasize the development of a fleet to serve retail customers and end users, Amazon by contrast is developing its own in-house technology.

Table 1: Robotic Cargo Delivery Firms

Robot Delivery			
Firm	Founding / Location	Services	Pilots / Uses
Amazon Scout	US-based, Amazon announced in January 2019	Last-mile delivery for Amazon Prime packages Operates on sidewalks	Testing in AT, GA, TN, WA,
Dianomix	Canadian firm based in Calgary, founded in 2019	Last-mile delivery of grocery & consumer goods bought at local retail stores Capacity to deliver to multiple addresses in one trip Retailer subscription model Operates on sidewalks at speeds of 4-5 km/h, potential to operate on bike lanes and paths at 16 km/h	Testing in Discovery Ridge, Calgary
Nuro	U.S.-based, founded in 2016, HQ in Mountain View, CA	Smaller and lighter than a car, designed to transport goods such as prepared food, groceries and drugstore purchases	Tested in Scottsdale, AZ and 2021 pilot in Houston, TX

		Partnered with retailers, customer-fee is $5.95 Operates on streets, max speed is 40 km/h 113 kg max cargo	
Starship	Estonian firm founded in 2014 by two Skype co-founders, based in San Francisco as of 2018, with engineering operations in Tallinn, Estonia	Last-mile delivery (mainly food & grocery items) on college and other campuses, and in cities and suburbs Contracts with retailer / campus / other partners + customer- fee ($1.99) Operates on sidewalks, 6 km/h max speed 10 kg max cargo	Tested in more than 100 cities globally Autonomous with remote control backup
TinyMile	Canadian firm based in Toronto, founded in 2019	Last-mile delivery of restaurant meals Partnerships with restaurants and delivery platforms ($6 fee – split between restaurant and customer) Operates on sidewalks, 6 km/hr max speed 2.7 kg max cargo	Testing in Toronto

The largest and most established of these firms is Starship Technologies, founded in Tallinn, Estonia by two former Skype co-founders in 2014. Starship has a fleet of approximately a thousand robots, has made one million deliveries worldwide, and employs 400 people (Korosec, 2021). It has also attracted just over $100 million USD in venture capital funding over its history (Korosec, 2021). Although it was founded in Tallinn, Estonia, the firm is now headquartered in San Francisco and maintains an engineering office with several hundred employees in Talinn. Starship Technologies operates its robots on more than a dozen university campuses in the U.S., in the British towns of Milton Keynes and Northampton, and in partnerships with food delivery firms such as DoorDash in Redwood City, CA and Postmates in Washington, DC.

Two start-up Canadian robotic cargo firms, Dianomix and Tiny Mile, operate in Calgary and Toronto respectively. Each operates a small fleet. Dianomix, which operates under a set of regulatory approvals at both the provincial and municipal levels (See Section IV for more details), has designed robots that can accommodate deliveries for up to 10 households in one trip. They are testing in a suburban Calgary neighbourhood. The firm partners with local retailers, enabling retailers to offer automated home-delivery services to customers residing nearby. A remote controller can intervene to drive Dianomix robots when necessary. The robots can operate in rain and light snow and can climb curbs. Tiny Mile robots, operating absent regulations, deliver restaurant meals ordered through Uber Eats or directly from a select number of partnered restaurants. Tiny Mile is testing robot delivery to customers within a 2 km radius of select restaurants to downtown Toronto neighbourhoods. The company is based at Ryerson University's Design Fabrication Zone.

Robotic cargo delivery vehicles are best described as semi-autonomous at present. Tiny Mile has human operators driving the vehicles from a remote location. Dianomix describes itself as semi-autonomous. Starship Technologies robots operate predominantly autonomously, but require intermittent interventions from remote operators, for instance when navigating atypical street crossings (Hoffmann & Prause, 2018). In August, 2020, a Starship robot in Milton Keynes drove into a canal and a firm representative had to retrieve it from the water ("Milton Keynes Delivery Robot Takes Plunge into Canal," 2020). Nuro's robot, which will run on streets, does not have a steering wheel or pedals, and is intended to be monitored remotely by an operator. Typically, customers retrieve their packages from robot delivery vehicles by unlocking the robot via a code on a smartphone app and removing their goods.

Drones

Over the last several years, most drone activity has become civilianized, intended for moving cargo or collecting sensory data (ISR) for preventive maintenance or safety inspections. Today there are several firms actively testing drones around the world as a means of cargo delivery. Drones are used to deliver goods in both suburban and rural areas. Because they are airborne, drones appear to be best suited to mid and low-density areas, and to destinations with front or back yards (or other open areas) where the payload can be set down (Lyon-Hill et al., 2020). In fact, some firms, such as Flytrex, specifically emphasize the value of drone delivery in suburban settings. Delivery and courier companies, such as UPS, are experimenting with a system whereby drones are released from the roof of a delivery vehicle, positioned in a central location that is close to the package destination (*UPS Drone Delivery Service | UPS - United States*, n.d.).

Table 2 provides an overview of four drone delivery firms. Given the relatively short distances travelled by cargo delivery drones (typically return trips of around 10 km), the services require access to a nearby store, distribution centre or mobile hub for dispatching drones with goods attached.

Table 2: Drone Delivery Firms

Drone Delivery			
Firm	Founding / Location	Services	Pilots / Uses
Drone Delivery Canada	Canadian firm, launched in 2014	Wide range of drone delivery services: healthcare, remote communities, airports, oil & gas, mining, industrial/commercial and last-mile service for consumer goods Three different drones of varying sizes. Smallest one (suitable for last-mile deliveries): Round trip flights of 60km, speed of 80 km/h, weight limit of 4.5 kg	Deliver supplies during pandemic to Beausoleil First Nation and Georgina Island First Nation
Flytrex	Israeli-based firm, launched in 2013	Drone delivery of consumer goods and food to consumers' backyards Round-trip flights of 11 km, speed of 51 km/hr, weight limit of 3 kg Lowers goods from a tether	Reykjavik, Iceland; Grand Forks, North Dakota; Kfar Netter, Israel (meant for suburban environments)
Wing	Launched in 2012, subsidiary of Alphabet and based in the US in Mountain View	Commercial drone delivery of food, consumer goods, medicine and library books Partnerships with delivery companies and local retailers	Pilots in Canberra, Australia; Helsinki, Finland; Christianburg, Virginia

		Round-trip flights of 9.7km, speed of 97 km/hr, weight limit of 1.5 kg Lowers goods from a tether	
Zipline	US-based firm, HQ in San Francisco, Founded in 2014	On-demand delivery with emphasis on healthcare and medical supplies Round trip flights of 80km, speed of 100km/h, weight limit of 1.7kg Drops goods by parachute	Operates in Ghana, India, Philippines, Rwanda, US, Nigeria

Drone delivery of consumer goods offers the advantage of circumventing local ground-oriented infrastructure, such as streets and sidewalks, and also enables, in principle, autonomous delivery to less developed and lower density areas. In practice, drone delivery to date is more stringently regulated than robotic delivery, especially in the U.S. (Marks, 2019). Because of the way in which airspace is regulated, it is only possible for drones to operate in areas where navigation rules are already in place. More details on regulatory issues are discussed in Section IV of the report.

Flytrex has been testing drone delivery for last-mile goods since 2017, when it first launched a delivery pilot in Reykjavik, Iceland. Continued innovation by the firm includes the improvement that the drones no longer have to land for deliveries, and instead release items from the air using a wire tethered to the drone (French, 2019). Flytrex is part of a U.S.-based drone testing pilot operated by the Federal Aviation Administration (FAA) and emphasizes delivery services in suburban areas.

Wing, a subsidiary of Alphabet, has tested its drones in Canberra, Helsinki and most recently in the U.S. The company was first to receive a certificate to operate by the FAA in April 2019. The firm launched a pilot project in Christiansburg, Virginia, offering approximately 10-minute delivery times for goods from local businesses as well as Fedex packages. The service began a few months prior to the pandemic, and interest accelerated with the introduction of lockdown measures and store closures meant to prevent further transmission of COVID-19 (Biron, 2020).

Zipline, a U.S.-based firm with operations that focus primarily in developing countries such as Rwanda and Ghana, has scaled up as a drone delivery service for on-demand medical supplies, for example, blood and medicine. The firm's drones travel further than most other cargo delivery drones, with a round-trip distance of up to 80 kilometres. Similar to other drones, the payload weight limit is relatively low and multiple drones are used in instances where larger deliveries are needed. Having established itself in the medical supplies field, Zipline has launched into a new partnership with Wal-Mart to test commercial cargo delivery in the U.S. (Lyons, 2020).

Amazon Prime Air, a division of Amazon focused on drone delivery, received approval by the FAA in August, 2020, to deliver packages by drone. Payload parcels can weigh up to 2.3 kg and are intended to be delivered in less than half an hour. Upon announcing this initiative, Amazon said that 75 to 90% of deliveries would be suited to drone delivery (D'Onfro, 2019). Initially, the plans are to deliver packages to low density areas. While Amazon's goal is to scale up the service globally, the company's Prime Air service is still in development (Cerullo, 2020).

Spaces / Sectors

The development and implementation of autonomous cargo delivery initiatives is reliant on access to physical locations in which to operate. Because the technologies are still being developed and tested, and because permission to operate and regulations governing operation of autonomous technology are non-existent to nascent in most places, campus-type environments are often well-suited as preliminary testing grounds. This includes a range of campus-type environments in which spaces are frequently privately owned and managed, including but not limited to universities, hospitals, and corporate campuses. There is precedent for testing emerging mobility technologies, including autonomous vehicles and e-scooters, in privately owned spaces absent regulations governing their use in public spaces (Brail, 2019).

Geographies

While drone and robot cargo deliveries may be desirable in a range of physical environments, they are most suited to areas in which prospective customers are concentrated.

One impetus driving exploration of robotics applications for delivery purposes stems from the convergence of new possibilities associated with technological change, technology firms themselves and interest by municipal governments in improving and streamlining the management of government functions (While et al., 2020). Emphasis on smart city-type initiatives, led by corporations, motivate much of the development and testing of consumer-oriented autonomous cargo delivery technologies (Macrorie et al., 2019).

For robot deliveries, public and well-maintained infrastructure, such as sidewalks, is critical. Furthermore, while some robots can climb a curb, they cannot ascend or descend stairs.[1]

Little has been written about delivery robots in the Canadian context. One exception is Thomasen (2020) who explores the impact of robots in public space and the types of rules and regulations needed to manage public space use by robots. Similar to the recommendations put forward by the National Association of City Transportation Officials, (*Blueprint for Autonomous Urbanism*, 2019), Thomasen (2020) suggests that robots should not necessarily have access to public spaces such as sidewalks. However, this assertion is contested by others who argue that robots could have access to public spaces over humans in certain cases such as emergency uses. Nevertheless, access to public realm, including sidewalks, paths and streets, continues to be one of the biggest barriers to operation outside of testing zones. Harmonize Mobility, a Canadian firm focused on automation and the future of transportation, is developing an ISO standard for "operating automated vehicles and devices at curbs (kerbs) and sidewalks" (Grush, 2020). The standard is expected to include robotic vehicles such as sidewalk delivery robots.

Campus Settings as Testing Zone

University campuses represent an opportunity for autonomous cargo delivery pilots, especially in the U.S. Most typically relying on ground-based delivery robots, campuses often have discrete geographic borders, with internal streets, sidewalks and pedestrian

[1] The majority of robots cannot ascend or descend stairs, although see Boston Dynamics' dog Spot robot as exception. https://www.youtube.com/watch?v=s6_azdBnAlU.

paths all located on private land. In addition, the presence of on-campus entrepreneurship accelerators, an emphasis on research and innovation, and relatively dense concentrations of people working and living on campus, make these locations a natural test-bed for novel technologies.

Starship Technologies, a U.S.-based robotics firm, provides services at 17 university campuses in the U.S. At the University of Wisconsin-Madison, for instance, an autonomous food delivery program was launched by student housing services to serve students, faculty and staff in fall 2019. Thirty Starship Technologies robots operate on the campus, with food ordering taking place through the Starship smartphone app, at a delivery cost of $1.99/order (Barnes, 2019). While the robots operate autonomously, they are monitored by humans who can take control if needed.

On other university campuses, innovation accelerators have also spawned delivery robotics startups. At Nanyang Technical University in Singapore, robots developed by students began free food delivery services on campus in July 2020 (Sholihyn, 2020). The University of California Berkeley also spawned a robotic cargo delivery firm called Kiwi, developed at the University's Skydeck Accelerator, an entrepreneurship initiative that also helped to launch Lime scooters. Kiwi initially launched its service in 2017 and operated in a square mile vicinity of the UC Berkeley campus (Berman, 2019). In 2019, Kiwi announced plans to operate at a dozen other college campuses in the U.S. by partnering with student robotics groups (Coldewey, 2019). Kiwi continues its testing, with recent efforts to scale up delivery services in Los Angeles (Bergman, 2021).

On some self-contained hospital campuses, drones are used in trials to deliver medications and transport blood supplies. An initiative supported by UPS, the parcel delivery service, tested drone use at the WakeMed hospital campus in Raleigh, North

Carolina. The trial included more than 1,000 drone deliveries on the hospital campus (Pressman, 2019). In 2019, the FAA approved commercial drone services, launching primarily on campus-type settings such as universities and hospitals (*UPS Delivery Drones Approved by Government*, 2019).

Food Delivery

For last-mile delivery, prepared meals and grocery are early adopters of autonomous cargo delivery services (Hoffmann & Prause, 2018). Examples of campus-based trials and pilot programs in specific testbed locales abound globally. In March 2016, Domino's Pizza announced the "world's first autonomous pizza delivery vehicle." Robotic delivery of prepared foods including pizza, cafeteria meals and restaurant meals has expanded since the Domino's announcement. In December 2020, Moscow-based tech company Yandex launched robot food delivery in the city's White Square business district. Customers order their meals through a Yandex app and have the choice of selecting robot delivery. Upon arrival, the customer unlocks the robot via the app on their smartphone to retrieve their meal. Similarly in Toronto, Tiny Mile launched a robotic food delivery service in partnership with Foodora (O'Nell, 2020). When Foodora left Canada in 2020, Tiny Mile continued operations via direct partnerships with restaurants as well as with UberEats and RitualOne. Like Starship Technologies and Kiwi, these robots operate on sidewalks and are designed to keep food warm or cold, as needed.

Regulations

Like other emergent technologies, regulations that apply to autonomous cargo delivery are underdeveloped. When regulations do not yet exist, firms with advanced knowledge of the sector and a vested interest in the development of an advantageous regulatory environment are active in advocacy and lobbying. Starship Technologies worked directly with local government decision-makers in Washington, DC, to influence the language used in crafting the city's Personal Delivery Pilot Act of 2016 (O'Kane, 2017). In Kansas, Amazon helped write regulations that were intended to govern robot delivery vehicles across the state. If passed, the bill would have permitted robots weighing up to 150 pounds (pre-cargo) to operate at a maximum speed of 10 km/hour on sidewalks and crosswalks throughout the state. The bill would also have prevented local governments from developing their own regulations governing sidewalk delivery robots. Ultimately, the bill failed to pass, in part due to concerns about the lack of local-level authority and because of apprehension associated with the impact of automation on job loss (Marshall, 2020).

Leaders of start-up firms confirm that pre-regulation is the best time to engage with governments (Marshall, 2020). It is not unusual for private firms to play a part in developing regulations by providing the language for proposed rules to governments. A similar set of interactions occurred in Toronto – and other cities - with the development of regulations governing ride-hailing services.

Considering the largely unregulated environment in which nascent autonomous cargo delivery services can operate, as well as the need to refine and advance the technologies, temporary pilot programs have been instrumental in testing systems, business and pricing models, human interactions, and regulatory frameworks.

See section IV for a more detailed scan of jurisdictional activities.

Opportunities

The rise of autonomous technology as applied to goods delivery presents several potential commercial, technological and social opportunities. These include:

- the cost savings that can make delivery more affordable;
- the use of contactless delivery as a public health measure;
- other safety benefits relative to other modes of delivery;
- the potential for reduced emissions relative to car and truck-based deliveries;
- further opportunities in the digital economy; and
- improving equitable access to delivery services with reduced cost.

Cost savings

The promise of significant cost-savings and the prospects of capturing market share underlies investments and activity in autonomous cargo delivery. By reducing or removing the need for human labour (i.e., couriers, drivers), and by creating greater efficiency in the delivery process with respect to time, distance travelled, and elimination of human error, autonomous cargo delivery represents a potential means of substantially reducing last-mile delivery costs (Joerss et al., 2016). Dianomix estimates that delivery costs for their robotic device are more than 50% lower in comparison to traditional methods. More details on prospective cost savings can be found in Section III of this report.

Pandemic

COVID-19 has accelerated automation, demand for delivery and interest in autonomous cargo delivery (Pani et al., 2020). With public health directives to reduce or minimize physical contact, autonomous delivery either by drone or ground robot presents a means of contactless delivery. From the contactless delivery of medical supplies in field hospitals to the rollout of drone delivery in areas under lockdown, the pandemic has provided an opportunity for more testing. Furthermore, because the pandemic has encouraged greater experimentation, companies and business leaders have a sense that this may have reduced regulatory obstacles to testing (Mims, 2020). Given the relative ease, speed and low cost of delivery for consumers, it is anticipated that demand for delivery services will continue to grow post-pandemic.

Safety

Another factor to consider is the relative safety of autonomous cargo delivery relative to other last mile delivery modes. This is true not only from a health and safety perspective as amplified under COVID-19, but also in terms of last mile robotics which tend to have a much lower risk profile than the alternatives due to low weights and speeds when compared to cars that normally perform these delivery functions.

Decarbonization

Several analysts, autonomous cargo delivery firms and researchers suggest that deliveries made via autonomous cargo vehicles are less energy-intensive as well as less polluting than if those same deliveries were made by truck or car. Furthermore, if distances travelled are reduced due to increased efficiency in delivery planning as a result of automation, this too could lead to a lowering of emissions. While decarbonization is part of the premise of autonomous cargo delivery, it is uncertain whether the promise can be realized (Marks, 2019). In addition, as the anticipated electrification of all delivery vehicles continues, the promised contribution of autonomous delivery vehicles to decarbonization efforts may not materialize.

Digital Economy / Ecommerce / Consumer Demand

Research demonstrates that as online buying increases, so too do customer expectations regarding speed and cost of delivery (Haag & Hu, 2021). Autonomous cargo delivery has the potential to increase delivery speeds and lower costs at the same time, thus supporting retailers in their ability to meet evolving customer expectations. Furthermore, autonomous cargo delivery services can produce time savings for consumers by eliminating travel time constraints.

Equity

Autonomous cargo delivery vehicles have the potential to improve equity. Both with respect to the delivery of health care supplies as well as other perishable and non-perishable goods to remote, underserved areas, and in terms of providing low-cost delivery, autonomous cargo delivery may contribute to equity goals. An example here is in the use of drones to deliver much-needed supplies to geographically remote First Nations in Canada (de Montigny 2017; Moore, 2020). The World Health Organization recently expressed interest in a pilot project involving the University of Calgary and the Stoney Nakoda First Nation as an example of how drones could deliver medical supplies during COVID-19 to remote First Nations in Canada, thus limiting exposure risk that might occur with a manned flight (Graveland, B, 2021). Another example of equity is found in the context of aging societies, where a shortage of available labour can slow delivery speeds and robots can help solve this problem (Wray, 2020b). If drone and/or robot delivery provides improved access to goods at reduced cost for people with mobility challenges or to households without strong automobile or transit access, it could positively impact measures of equity and accessibility.

Limitations and Challenges

In addition to the many benefits of drones and robots, there are significant limitations and challenges discussed in the literature. To ensure we do not conflate drones and robots in this discussion section, we separate out a discussion of each within the division of two main components. The first main component is current practical issues, which fall into both safety concerns and logistical issues, such as limitations on weight, distance and cost. The second main component concerns larger ethical and societal issues which require serious conversation, serving as the backbone to future policy and regulatory issues, discussed in the final section of the report. While some of these broader societal issues may seem extreme to some people, they are important to flag because gaining public acceptance and trust in the delivery of any novel technology cannot be underestimated if we are to move towards policy readiness and wide-spread public acceptance.

Practical limitations: Logistical and safety issues

Drones

At present, there remain serious limitations around the efficiency and effectiveness of drones. Most are limited in the amount of weight they can carry and thus are constrained in the types of goods they can move. They are also limited in the distances they can travel, so questions remain as to the optimal geography for their usage.

Weather, climate and physical location also matter in the deployment of these devices. What works, for example, in a temperate suburban neighbourhood with a close-by field for aerial flight may not work in either a dense urban area or a remote location where subzero temperatures and ice affect materials integrity and battery life.

Another major concern involves safety risks and liability questions. There are risks of drone malfunctions and crashing into objects or falling from the sky. Airspace security is an often-cited issue; hence the robust nature of the drone regulatory landscape.

Robots

In terms of sidewalk robots, there are concerns about collisions involving pedestrians, as well as accidents, such as an explosion in 2018 involving a Kiwi robot that spontaneously combusted while travelling on a Berkeley, California street. This latter example also raises liability questions in terms of who has responsibility. For instance, liability concerns with robots that operate on sidewalks include the potential liability of a collision between a travelling robot and a parked vehicle, or property damage caused by a moving robot. Also of note are navigational complexities like waste bins, construction barriers or strollers that could get pushed over by a robot, creating further complexity and safety risks. Like drones, robots also have limitations in terms of the size and amount of weight they can carry.

Broader Societal Issues

It is beyond the scope of this paper to probe deeply into high-level ethical and societal questions surrounding the adoption of new technologies. Nevertheless, it is worth briefly noting some of the bigger concerns raised because these concerns can make their way into public discourse and influence the successful -- or failed -- adoption of public policy around the practical use and public acceptance of new autonomous cargo technology.

A brief review of the technology in society literature in the North American context found that one of the most oft-discussed issues concerns the perception that these new autonomous technologies are an increased risk to civilian privacy and an instrument of surveillance in society.

Drones

Marks (2019), for example, suggests that drones act as a kind of "mobile surveillance platform" through their use of cameras, sensors, microphones and LIDAR systems (Marks, 2019). This functionality poses a concern from a privacy and surveillance perspective because drones can access information about human activity that many believe had not previously been available to corporations.

Robots

Sidewalk robots act in similar ways, collecting information as they travel using sensing systems, cameras, and microphones, etc. Many people who encounter robots will not be aware that the devices are collecting information about them or their detected conversations (Marks, 2019).

Another concern raised in the literature with respect to robots is the potential exclusion of vulnerable members of society in favour of those who can pay to access, use or support new technologies. Exclusion can happen in several ways. First, data collection and physical intrusiveness can have differential impacts on individuals who are already privacy-vulnerable (Thomasen, 2020:282). Another area of exclusion is in the area of access to public space. Allowing robots access to sidewalks without any standardization or rules could also result in an unpredictable or unsafe environment for pedestrians, especially people with hearing and vision impairment and those in wheelchairs, parents with young children in strollers, and seniors with walkers.

Drones and Robots: similar issues

Labour disruption and change is another area of concern for many individuals. Like many inventions, automation technologies replace work done by humans. Logistics companies and shippers see the use of drones and robots for cargo delivery as a means of reducing last-mile labour costs. Many logistics and shipping firms are multinational, and, in some cases, also unionized, so it would be challenging to shift the workforce to more automated work. All firms in this space will see automation as a means of reducing head counts and overheads, or at least combining or reconfiguring delivery-end jobs (e.g., to remotely managing a fleet of robots). For some advocates it is politically unacceptable to further automate and de-skill the service economy at a time of both high unemployment and substantial growth in the tech sector.

It is true that in a way these above-mentioned issues and the response to them, are part of the larger market and regulatory space for drones more generally– and in that case not directly applicable to the delivery space that is the focus of this paper. Nevertheless, it is important to flag because it is these issues that lead to societal mistrust of the commercial application of drones and robots for cargo delivery.

Public Trust

Test cases of robots and drones in Switzerland have found that building public trust is one of the most important elements of the adoption of autonomous vehicle technologies. If people see autonomous vehicles as intrusive in public space, playing a role in deskilling workers, and their widespread potential for increased surveillance and health and safety risks, their inventions are unlikely to see widespread uptake and acceptance.

SECTION III:
Econometric Analysis

SECTION III: Econometric Analysis

As established previously in this report, consumer demand for rapid delivery is increasing due to urban population growth and the growing market share of ecommerce (Boysen et al., 2020). The last mile is the most expensive and time-consuming portion of any delivery. It is estimated to comprise more than half of total delivery costs (Dolan, 2021) and over one quarter of total logistics expenses (Mccrea, 2016). Therefore, it is seen as the component of the delivery value chain with the potential for greatest productivity growth.

For firms, the chief promise of autonomous cargo delivery - whether by drone or by robot - is cost savings. These can result from reductions in the amount of time spent on last-mile delivery, labour costs, operating costs of vehicles, and costs associated with the transfer of goods to the last-mile delivery system. Given that profit margins for delivery services are low - estimated to be in the 2-5% range (Joerss et al., 2016) - the value of increased productivity is significant. Simoni et al. (2020, 16) conclude, however, that "the extent of achievable travel-time savings is not straightforward and strongly depends on factors such as the speed ratio between truck and robot, the capacity of the robot's storage, and the configuration of customers." Ultimately, the costs of last-mile delivery vary greatly based on a range of conditions and considerations.

In the remainder of this section, we review cost estimates of last-mile cargo transportation and assess the potential for autonomous cargo delivery to reduce carbon emissions. We analyze the conditions deemed necessary to achieve cost-savings and environmental efficiency for autonomous cargo delivery to make sense from an economic perspective. Furthermore, we examine the prospects for autonomous cargo delivery to disrupt last-mile cargo transport in the Canadian context. Within the current and limited context of autonomous cargo delivery, it is not possible to develop an accurate measure of cost savings. We conclude this section with a discussion of factors that play into adequately modelling cost scenarios for autonomous cargo delivery.

Robots or Drones?

In evaluating the costs and potential for savings associated with autonomous cargo delivery, robotic and drone-based methods need to be evaluated independently. On one hand, researchers suggest that drones offer the prospect of greater potential savings because they can travel at much faster speeds than robots (Figliozzi & Jennings, 2020a; Simoni et al., 2020). For instance, Jones-Hill et al (2020) produce a modelling simulation in which drones can travel at 130 kph. Robots, especially those moving along sidewalks, are limited to far slower speeds, e.g., 8-10 kph. However, drones face significantly more stringent regulatory constraints, e.g., restricted airspace - in comparison to robots.

The most common market segments for robot and drone delivery include prepared food, grocery and consumer goods. According to Gartner, the growth of autonomous devices such as vehicles, robots and drones will accelerate, but their use will take place predominantly in controlled environments – e.g., on campuses. "[While] the technologies that enable autonomous things are improving rapidly…social acceptance and regulation will inhibit the broad adoption of autonomous things in public spaces," predicts Gartner's analysis (Burke et al., 2020). For the foreseeable future, Burke et al (2020) conclude that there is more market potential for robots than drones, in large part because of regulatory constraints. More details on the regulation of drones are presented in Section IV of this report.

Delivery Costs

One component in realizing reduced delivery costs for autonomous cargo delivery is a function of the distance between the supply source and the customer. To reduce delivery times, density of customers enables delivery batching (Simoni et al., 2020). It is primarily for this reason that Joerss et al. (2016) conclude the market potential for autonomous cargo delivery resides in last-mile delivery to consumers located in metropolitan areas. Simoni et al. (2020) agree, suggesting that the "ideal deployment scenario consists of a limited area (downtown or neighbourhood size), characterized by a high level of traffic congestion (with average speed below 4m/s or 15 km/h), and with a dense customer configuration (10 or more customers per square kilometer)." For the most part, autonomous delivery in rural areas is uneconomic because costs in lower density areas are high, while consumer willingness to pay the associated premium for faster delivery is low (Joerss et al., 2016).

Conditions to Achieve Lower Delivery Costs

There are several market configurations designed to support autonomous cargo delivery, depending on the geographic proximity of retailers to dense concentrations of consumers. In one scenario, close proximity between the retailer and the consumer enables rapid, efficient delivery. To further illustrate, 78% of the U.S. population lives within seven kilometres of a Walgreens store (Boysen et al., 2020), a density of customers that presents the retailer with the economies of scale required for last-mile autonomous delivery. Another model piloted with both drones and robots is the use of what’s referred to as a ‘mothership,’ which is essentially a mobile hub, such as a truck or van, that dispatches autonomous cargo delivery vehicles (Figliozzi & Jennings, 2020a; *UPS Drone Delivery Service | UPS - United States*, n.d.). A third model, which is a variation on the mobile hub, is the use of a fixed hub that serves as a small warehouse, and from which drones or robots are dispatched. These three models obviously vary depending on the type of good being delivered. For instance, prepared food items that are fresh and meant to arrive hot or cold must be prepared and launched from a nearby, dedicated food service site, such as a restaurant. On the other hand, a mothership or hub model could work for small, non-perishable packaged goods.

External conditions can improve the cost of robot or drone delivery relative to traditional delivery methods. In a study of robot delivery, researchers identified traffic congestion as a factor that contributed to increased efficiency for robots operating on sidewalks (Simoni et al., 2020). However, if sidewalks are congested, this would not lead to expedited delivery times for robots over street-based delivery vehicles. Robot deliveries may also be temporarily more cost-effective than traditional delivery during times when temporary conditions, like emergencies, special events or construction, slow traffic. According to Simoni et al (2020), the cost savings for robot delivery over traditional methods could be as high as 20% in a congested downtown area, rising to 30% in an area with temporary congestion. Figliozzi and Jennings (2020a) suggest that robots can be cost-competitive if they can operate without the need for a mothership-type vehicle, i.e., in a dense urban area.

Most of the autonomous cargo delivery options examined in Section II of this report focused on delivery vehicles designed to serve one household or consumer per trip.

However, Joerss et al (2016) predict that most deliveries will be carried out by autonomous ground vehicles that serve multiple users and are designed with individual lockers from which consumers can remove their goods. They estimate 40% savings and a 15-20% increase in profits, so long as comparative labour costs are relatively high. Conversely, Boysen et al (2020) suggest that the relatively slow speed of robots does not provide time savings relative to traditional delivery vans (Boysen et al., 2020). Several other studies (Joerss et al., 2016; Lyon-Hill et al., 2020) suggest that the ability of a delivery robot to transport multiple packages in one load to nearby consumers improves efficiency and cost savings. For the consumer to receive their delivery, they must be available at the moment of delivery in order to retrieve it promptly from the autonomous device. Robots are unsuitable for deliveries if no one is home (Boysen et al., 2020). Finally, in communities where labour costs are low, the savings from these devices are negligible (Joerss et al., 2016). This means that further examination of gig economy-based delivery activities, which have grown in significance, may be necessary in order to assess the potential cost-savings for deliveries conducted by intermediary firms.

There are other factors that can affect delivery time and cost, and which cannot be solved through automation. These include: congestion on sidewalks and associated issues regarding safety, charging time, speed of the drop-off process, routing errors, and vehicle malfunction.

Cost Estimates

Given the discussion above, it is extraordinarily challenging to accurately estimate the cost savings associated with autonomous cargo delivery. Table 3 below summarizes a range of estimates consulted alongside additional details regarding each study's assumptions. Note that there are several industry and consultant studies that do not provide details on methodology (eg: Joerss et al, 2016; ARK Investment Management, 2021) and therefore are excluded from the table below.

Table 3: Summary of Autonomous Cargo Delivery Studies Estimating Savings

Author / Year	Assumptions	Estimates
Doole et al, 2020	Assumes 70% of urban deliveries can be accomplished by **drone** for last-mile delivery, 1 hour return trip per delivery and operations on 80% of days due to inhospitable meteorological days on remaining 20% of days Requires infrastructure investment to manage air traffic in a city such as Paris, which would be several times greater than current global air traffic Does not consider whether drone delivery is feasible given patterns of urban form	Compares e-bike to **drone** for food delivery Delivery cost per order for **drone**, with 18,458 drones in operation daily: estimates range from conservative – high acceptability, costs ranges from $2.51 - .40 Delivery cost per order for e-bike with 7,383 e-bikes in operation daily: estimates range from conservative – high acceptability. cost ranges from $2.03 – 2.02
Figliozzi and Jennings, 2020	Model **drone and robot** cost per customer based on 9 scenarios with varying area served (from 10-130 km^2), assuming 3 minutes delivery time/customer and 16.1 km distance from delivery depot	**Drone** delivery is most expensive mode (in part because of weight limitations) Sidewalk **robot** deliveries are never the least-cost option; yet cost-competitive for deliveries not requiring a mothership
Lyon Hill et al, 2020	Commissioned by Wing (Alphabet subsidiary), model **drone** delivery over 5 year period in low, mid and high density areas of single family	Christiansburg, VA (low density): Time savings/year go from $2.2M in Yr1 to $23-46M in Yr5

	homes and relative to 3 growth scenarios (low to high use of drones)	Austin, TX (mid density): Time savings go from $4.8M in Yr1 to $323-582M in Yr5 Columbus, OH (higher density): Time savings go from $3.1M in Yr1 to 219-403.8 in Yr5
Simoni et al, 2020	Delivery vehicle + **robots** Each robot delivers to multiple homes 50 customers in 6 km^2 area Travel time as main performance indicator Notably, does not consider time savings relative to bicycle delivery	Ideal: high traffic, dense customers (10+/km^2) results in 20% travel time savings; 30% travel time savings in areas of temporary congestion

In a report commissioned by Alphabet's drone subsidiary, Wing, Lyon-Hill et al. (2020) demonstrate that drone econometrics ought to be assessed based on region-specific considerations, including population density and transportation systems. In their study modelling the economics of drone delivery in three U.S. metropolitan regions – all of them located in areas with a large proportion of single-family homes – Lyon-Hill et al. (2020) forecast significant benefits to homes, businesses and communities over a five-year rollout of services. According to the researchers, benefits associated with drone delivery could include reduced incidence of vehicle accidents, increased access to goods for carless households, time-savings for consumers, and reduced $C0_2$ emissions. Their estimates suggest a reduction in vehicle kilometres travelled by between 9.4 and 14.5% across the three metropolitan regions under study (Lyon-Hill et al., 2020). The researchers assume an S curve that begins with slow rates of adoption which then speed up and begin to stabilize by the 5-year mark. Given that this study was commissioned directly by Wing, policymakers would be well-served to validate the findings with additional research.

Cost estimates vary and have changed over the years as the technology matures. In one European study, delivery costs for robots were estimated to be less than one Euro per trip, or up to 15 times less than current costs (Hoffmann & Prause, 2018). This estimate was based on robots operating in suburban areas with low traffic.

ARK Investment Management (2021) provides cost estimates for a drone delivery service that operates to a maximum of a 14 km return trip. This study suggests the cost of operating an autonomous drone over that distance is $0.25 per trip. Five years earlier, ARK's estimate for a similar trip was $0.90, demonstrating the impact of technological change on pricing. ARK also suggests that drone delivery is less expensive than a consumer driving to a nearby pharmacy to pick up an item (ARK Investment Management, 2021). The investment firm is bullish on the prospects for drones, suggesting that at scale, drone delivery will be faster and less expensive than bike couriers or vehicular ground delivery. They provide an ambitious estimate, suggesting that globally, drones could deliver nearly half of all prepared food within 30 minutes of ordering by 2030 (ARK Investment Management, 2021). It is hypothesized that the ease and low expense of drone delivery could also induce demand, leading to increases in online sales (Keeney, 2020).

With respect to emissions, Figliozzi & Jennings (2020b) find that emissions savings depend on distances travelled from the depot and whether a mothership vehicle is required. Furthermore, they find that road based autonomous vehicles may provide greater emissions savings than sidewalk robots in scenarios where greater distances separate the retailer or depot from the end consumer. With increasing efforts to electrify vehicles in general, emissions savings from autonomous delivery vehicles may not look any different than emissions savings from human operated, but electric, delivery vehicles.

Furthermore, there are costs associated with congestion that autonomous cargo delivery may be able to address (Doole et al., 2020). In their study of sidewalk and road based autonomous delivery robots, Figliozzi and Jennings (2020b) find that while road based autonomous delivery robots increase vehicle kilometres travelled and congestion, sidewalk delivery robots operating under conditions where customer density is high and distance between customers is low can reduce vehicle kilometres travelled. Jennings and Figliozzi (2020) examine reductions in distance travelled on roads when vans operate in conjunction with sidewalk robots, and find on-road travel distance reductions of between 17-31%. Finally, while drones operate separately from road infrastructure, their ability to deliver only one package at a time results in numerous return trips and thus contributes to increases in kilometres travelled (Figliozzi & Jennings, 2020a).

Estimating the Impacts for Canada

There is little data on the cost estimates for last-mile drone or robot delivery in Canada. More work needs to be done on the experimental side of drone and robot delivery in different geographies, with different logistics companies (including public ones), to develop an understanding of the future econometrics of this type of delivery technology.

In general, shipping cargo within Canada is expensive because of the small, dispersed population relative to the country's vast geography and harsh climate zones. Canada's infrastructure and hubs are built in concentrated areas, leaving a large part of the country underserved. Remote and fly-in Indigenous and northern/polar communities are particularly hard to service.

Despite these challenges, there is no question that alternative and new modes of cargo delivery ought to be explored. An examination into the current cost of delivery reveals the challenges ahead and the considerations that should be included in any future cost development models.

Last-Mile Cost Estimates by Cargo Delivery Mode

Last-mile delivery is one of the most expensive aspects of the cargo delivery process. Our brief investigation into last-mile cargo delivery in a real-time rural, suburban and intra-urban setting reveals the high costs of last-mile delivery. Embedded in these costs are logistics infrastructures, fuel, energy and labour.

Rural

Here is an example of how much it costs to ship a standard box 56x46x38, weighing 1 kg and valued at $150.00 within South Frontenac between postal codes K0H 2T0 and K0H 2H0. Although the distance here is greater than typical last-mile estimates (about 24 kilometres over hilly roads), it is a realistic distance between a small rural town with a distribution point and a rural housing area. In this context, the last-mile costs are high given the remote geography. It is here where a drone option may make some cost sense, depending on the cargo and the logistical needs of the client.

Table 4: Lowest Shipping Cost per Mode for Different Cargo Deliveries in Rural Areas

	Lowest shipping cost per mode ($)
Canada Post	35.09 CAD – 3 business days
Taxi	45.00 – same day
Uber	47.11– same day
Local Courier	50-100.00 – same day

Suburban

Here is an example of how much it costs to ship a standard box 56x46x38, weighing 1 kg and valued at $150.00 within the City of Kingston between postal codes K7L 3E4 and K7K 5R2. This is about 2.9 kilometres and the geography is from a downtown distribution point to a suburban village setting on the outskirts of the city. In this suburban geography a mothership in a suburban neighbourhood – a mobile hub such as a van or truck that dispatches autonomous cargo delivery vehicles -- may make effective economic sense if non-perishable cargo items were being delivered to multiple homes on the same day by the same logistics delivery outfit.

Table 5: Lowest Shipping Cost per Mode for Different Cargo Deliveries in Suburban Areas

	Lowest shipping cost per mode
Canada Post	35.09 CAD – 3 business days

Taxi	11.00 – same day
Uber	11.30– same day
Local Courier	15-25.00 – same day

Intra-urban

Here is an example of how much it costs to ship a standard box 56x46x38, weighing 1 kg and valued at $150.00 within the City of Toronto between postal codes M5A 2E4 and M4X 1R7. This is a 2.25 kilometre trip along dense, urban streets in downtown Toronto.

Table 6: Lowest Shipping Cost for Different Cargo Deliveries in Intra-urban Areas

	Lowest shipping cost ($)
Canada Post	29.47 CAD – 3 business days
Taxi	9.30 – same day
Uber	9.77– same day
Local Courier	10-22.00 – same day

Local Courier Companies

Large cities such as Toronto have multiple courier services offering same day delivery. There are many variables that go into pricing, including: the size of the box; whether the courier must go into a building to deliver the package; whether the customer or a designate will be home to receive the package; whether the package is fragile or needs refrigeration; and time of day, traffic and weather conditions. A few courier companies use a social enterprise model, recruiting from `hard to employ' populations. These entities may be eligible for subsidies or grants, thus adding an additional layer of complication to any cost analysis (e.g., Turn Around Courier, Toronto, 2021).

Labour Costs

The cost of labour is one of the most expensive components for cargo delivery services and may be a key motivation for exploring the use of autonomous delivery options. Human skill will still be required for operation and monitoring of autonomous cargo delivery services, but these skills need to be developed within the Canadian context, e.g., via pilot projects in designated neighbourhoods within denser urban zones, lower-density subdivisions, campuses, rural areas and remote communities. Companies or governments who want to develop pilot projects should aim to work with existing labour groups and logistics experts for best results.

Environmental and Social Costs

When one considers the energy and fuel costs associated with any type of technological delivery mode for last mile delivery (as opposed to say bike couriers) the bike delivery option within a dense urban environment will likely be the more sustainable approach. An observation is that if robots and drones are currently constrained by weight, the bike courier may ultimately make more sense to end on those deliveries. E-bikes are another technology that have become increasingly popular. They also have a longer range and low operating cost relative to a vehicle.

Evaluating Econometric Models

There are several factors that play into estimating delivery costs and prospective savings associated with autonomous cargo delivery. Models in the existing literature typically account for some, but not all, of these factors. For instance, most models examine distance between the retailer and end consumer, labour costs, operating costs of delivery vehicles, density of consumers and expected travel times given no intervening challenges. Models generally assume that the end consumer is on site and available to retrieve their item at the moment of delivery, that there are no adverse weather conditions, errors in terms of routing requests or sidewalk blockages in the case of robot deliveries, and that customers are evenly concentrated. Furthermore, models assume consumer demand and trust, and a willingness to accept autonomous cargo delivery. Finally, models assume that the regulatory environment is uniform across space and that it enables operations across large areas.

However, modelling based on perfect or near-perfect conditions does not mimic the reality of communities, society and mobility. Although autonomous cargo delivery may have the potential to produce cost savings and environmental benefits, more details are needed regarding the range of physical, social and regulatory environments in which they operate. Testing and pilot projects present an opportunity to continue this work. However, the processes and costs of scaling up are place-based and far from certain.

SECTION IV: Comparative Regulatory Analysis

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In this section, we present a comparative analysis of existing regulations and regulatory frameworks used to govern cargo robotics. The analysis reviews robots and drones separately, in line with distinct regulatory systems and considerations governing the use of each technology. For the most part, robots are regulated locally – either at the municipal or provincial/state levels of government. Drones, on the other hand, are regulated by national authorities with responsibility for air travel and national security. Examples of robot delivery operating outside of any regulatory authority are not uncommon, while drone delivery operating without specific permissions are scarce.

The case studies below cover six jurisdictions relevant to the Canadian context. Following the jurisdictional scans, we provide a synthesis of overarching regulatory issues with respect to autonomous cargo delivery vehicles.

Jurisdictional Scan: Robots

Below, we review the regulation of cargo delivery robots in three jurisdictions: Toronto, San Francisco and Pennsylvania.

Toronto

The City of Toronto does not currently have any regulations governing the use of robots in public spaces, such as streets and sidewalks. Furthermore, there are, as of Q1 2021, no plans in place to implement a pilot program or develop permanent regulations. In terms of the prospective process of regulating autonomous cargo delivery vehicles in Toronto, or any city in Ontario for that matter, both municipal and provincial governments will have to enact regulations. The provincial government has authority, through the Highway Traffic Act, to define the term 'vehicle' and regulate which types are permitted access to roads and highways. The Province has responsibility for regulating whether a vehicle is permitted to cross the street. The City of Toronto, in turn, governs the use of sidewalks, vehicle licensing, and/or the establishment of testing and piloting opportunities in designated innovation zones. Because the use of such vehicles has not yet been formally examined either by the provincial government and/or at the request of Toronto City Council, legal questions around access to public spaces remain unresolved. Nevertheless, there is a semi-autonomous cargo delivery firm operating in Toronto called Tiny Mile. The firm's devices are driven through a remote-controlled process and are operating, at present, absent specific municipal or provincial regulations.

Jurisdiction	Who holds authority?	Regulatory details	Examples
City of Toronto	Province + Municipality Province of Ontario has authority to determine what constitutes a vehicle Definition of vehicle at provincial level determines whether device is permitted to cross the road and/or operate on a sidewalk Toronto City Council (likely on advice of, and with input from, transportation	No details at present on plans for province to define No permanent or pilot regulations are in place Search of City of Toronto Council minutes from 2018-present shows no mention of the word 'robot'	Tiny Mile: remote-controlled cargo delivery robot operating in downtown area of Toronto, delivering restaurant meals (see Section II for more details) No other known cargo delivery sidewalk robot operations at present

	services, legal services, licensing & regulations, planning, accessibility advisory committee)		

San Francisco

As a global centre for the technology sector and for venture capital, San Francisco plays a key role in the testing of emerging devices, including robotic cargo delivery vehicles. Initially, ride hailing services and e-scooters launched in San Francisco without explicit permission to operate. This produced a chaotic environment characterized by a lack of governance of both firm-based activities and guidelines for public realm use. Challenges included safety, congestion, and data privacy. As a result, in 2017 city council halted the continued rollout of new technologies without advanced permissions in place.

In 2017, San Francisco council passed regulation banning sidewalk delivery robots in an effort to curb unregulated testing of new technologies in the city's public spaces, including on streets and sidewalks. Shortly afterwards, the Board of Supervisors changed the regulations to allow firms to test cargo delivery robots in specified parts of the city that had low pedestrian volumes. At present, firms may apply to test three robots at once; if their requests are accepted, they receive a 180-day operating permit, with the option of two 90-day extensions. Although council passed legislation establishing an Office of Emerging Technology in late 2019, progress appears to be stalled as a result of COVID-19. San Francisco's detailed regulations are available here.

Jurisdiction	Who holds authority?	Regulatory details	Examples
San Francisco	City of San Francisco - Board of Supervisors	San Francisco Board of Supervisors initially banned sidewalk delivery robots outright in SF in 2017, shortly after revised to make exception for certain low-traffic areas of city Concerns focused on pedestrian collisions and surveillance Firms could apply for permits from the city's Public Works office to test up to 3 robots, each robot required to have a person following with 30 foot distance. Permits valid 180 days with 2, 90 day extensions possible. Robots can travel a maximum of 3 mph and must yield to pedestrians In 2018, City established the Emerging Technology Open Working group to help create regulations for robots	Postmates (a food and grocery delivery platform) received the first permit to test sidewalk delivery robots in San Francisco in summer 2019

		and other emerging tech December 2019, Mayor London Breed signed legislation for an Office of Emerging Technology to manage the process of working with private firms wishing to test new technologies in the city's public spaces. It appears that the opening of the office has been postponed due to COVID-19	

Pennsylvania

In 2020, Pennsylvania adopted state-wide regulations governing sidewalk delivery robots, referred to in the legislation as "Personal Delivery Devices." The legislation was first introduced in summer, 2020, and passed in November 2020. It provides the legal framework to consider personal delivery devices as pedestrians and permits their operation on sidewalks and streets. Notably, although the average pedestrian moves at about 5 kph, Pennsylvania's regulations permit robots to travel as fast as 19 kph on sidewalks, and up to 40 kph on streets. The legislation requires operators to have, at minimum, liability coverage of $100,000, and fines for non-compliance can be between $25 and $1000 USD. At present, the legislation does not permit municipalities to develop their own regulations governing autonomous cargo delivery robots. The regulations can be found here.

Jurisdiction	Who holds authority?	Regulatory details	Examples
Pennsylvania	State Government, Senate Bill 1199	Passed by state legislators following first introduction in June 2020 Classifies personal delivery devices as pedestrians, permits sidewalk operation at speeds of up to 12mph, weight of up to 550 pds, and are permitted on shoulders and streets at a speed of 25 mph The legislation does not currently have an avenue for municipal control or input, though large municipalities such as Pittsburgh are attempting to develop intervening policies	Law passed in November 2020, no examples to report

There are numerous other examples of regulations developed to enable and manage robot deliveries. In Calgary, the provincial Ministry of Transportation created a new category for Dianomix to be able to operate. The firm also worked with the City of Calgary to create a permit that enables the firm to operate its sidewalk delivery robots in specific locations and at specific times.

In the city of Washington, D.C., the local government passed the "Personal Delivery Pilot Act of 2016 (O'Kane, 2017). For testing purposes, Washington limited companies to five robots each, dictating that each device must not weigh more than 23 kg (pre-cargo) and could not exceed a 16 kph-speed limit. As well, operators are required to clear broken delivery robots from streets and sidewalks within 24 hours of accidents (Fung, 2016).

In Madison, Wisconsin, Starship began operating on the University of Wisconsin-Madison campus under an informal agreement. In February 2020, the City of Madison passed regulations prohibiting personal delivery devices on city sidewalks, except for the university campus (Gretzinger, 2020).

The State of North Carolina passed legislation in December 2020, that both defines and regulates personal robot delivery devices. The regulations treat the robots as pedestrians but permits their operation on both highways and sidewalks. Local governments have authority to regulate within their jurisdictions, but not until the legislation has been in place through a two-year testing period.

Sidewalk delivery robots are now regulated in 10 states, plus the District of Columbia (Kingson, 2021). At the national level, Estonia adapted their traffic laws in 2018 to allow robots to share sidewalk space with humans (Hoffmann & Prause, 2018).

Some new robotic cargo devices are designed to operate on streets but not sidewalks. In the U.S., these devices (e.g., Nuro) require regulatory approval from the National Highway Traffic Safety Administration. Following three years of review, Nuro became the first firm to receive approval for a vehicle that did not have a steering wheel or mirrors, and does not meet all 75 safety standards required of car manufacturers (Reuters, 2020a).

In nearly every case involving autonomous cargo delivery robots, regulations have been influenced by the firms that build and operate them. While there is insufficient data to assess the current state of unregulated testing, anecdotal evidence – such as the example of robot food delivery in a small part of Toronto - suggests that absent government regulations, the testing of autonomous cargo delivery robots continues in an unregulated manner.

Jurisdictional Scan: Drones

Canada

Federal Government

The regulation of Unmanned Air Vehicles (UAVs)/drones falls under the jurisdiction of the federal government. Transport Canada has primary jurisdiction over matters related to aviation and aeronautics (Ahmed, 2016). The *Aeronautics Act* is the main piece of legislation and drone pilots must follow the rules in the subordinate Canadian Aviation Regulations (CARs), Part IX – Remotely Piloted Aircraft Systems contains most of the rules that apply to drones up to 25 kilograms.

Operators must respect all other laws when flying drones, including relevant sections of the Criminal Code, such as "Offences against Air or Maritime Safety," "Breaking and Entering," and "Mischief." They must also obey provincial Trespass Acts as well as laws related to voyeurism and privacy. Local police may also be involved if other laws are broken.

Transport Canada

Transport Canada issues the regulations, standards and guidelines for drone operation in Canada. Rather than repeat the regulations here, it is best to refer the reader to the latest Transport Canada website which outlines the regulations, standards and guidelines for drone operation which can be found here.

Municipalities

Municipalities can enact bylaws placing additional requirements on drone operators beyond those set out in Part IX of the Canadian Aviation Regulations (CAR). However, the extent to which municipalities have legal authority and jurisdiction to enact bylaws to impact drone operations depends on the specific nature and wording of the bylaw, and whether the bylaw encroaches on the federal government's exclusive authority to regulate aeronautics under the Constitution Act, 1867.3 (McCullough, 2019). For example, a municipal bylaw that would regulate activities such as the use of drones near airports would not be consistent with the CARs (Ahmed, 2016).

Jurisdiction	Who holds authority?	Regulatory details	Examples
Canada	Transport Canada	Main legislation is Aeronautics Act, and its regulations the Canadian Aviation Regulations (CARs). Transport Canada is Department that regulates UAVs Drones must also follow applicable provincial, privacy laws and possibly	All drones operating in Canada must follow Transport Canada regulations and guidelines e.g., Delivery Drones Canada

		local municipal bylaws	

United States

Federal Regulations

Drone operations in the U.S. are regulated by the federal government. The FAA is responsible for the regulations and guidelines for commercial operation of small UAS craft under FAA's Part 107, Small Unmanned Aircraft Rule. To fly commercially, an operator must hold a Remote Pilot Certificate issued by the FAA and register the UAV with the FAA on the FAADroneZone website. The UAV must weigh less than 25 kg, including payload, at takeoff. The UAV must also: fly in Class G airspace; remain within visual line-of-sight; fly at or below 120 m; use anti-collision lighting to operate during twilight or evening; not exceed 160 kph; and yield the right of way to manned aircraft. Drones may not be flown from a moving vehicle, unless in a sparsely populated area. Exceptions exist for pilot and test cases.

State regulations

The U.S. drone regulatory system is highly centralized, but state authorities continue to debate drone regulation, benefits, privacy concerns and potential economic impact. Since 2013, according to the National Conference of State Legislators (2021), at least 44 states have enacted laws regulating drones, and an additional three have passed non-binding resolutions. Common issues addressed in these laws include: the definition of a UAS; uses by law enforcement or other state agencies; and applications for the general public. For the most up-to-date information on the state law landscape, visit the National Conference of State Legislators website (National Conference of State Legislators, 2021).

Municipal and Urban Drone Regulations

The new 2020 FAA rules are generally thought to be more flexible to enable the growth of cargo drones in cities. As Kingson (2021) writes, they "effectively [lay] a welcome mat for future aerial deliveries of takeout food, Amazon packages, prescriptions drugs – you name it." These more flexible rules will require drones flying over cities to use remote identification technology so people on the ground can know what they are doing and who owns them. Kingson describes this provision as "a digital license plate for drones." The City of Los Angeles is preparing its residents for airborne cargo deliveries by developing a policy toolkit that could serve as a national blueprint. In December 2020, the Mayor of Los Angeles, Eric Garcetti, announced the first Urban Air Mobility Partnership, whose members include representatives of the Urban Air Mobility Division of Hyundai Motor Group, the Mayor's Office, the Los Angeles Department of Transportation (LADOT) and a public-private partnership called Urban Movement Labs. Urban Movement Labs advisory partners represent the largest transportation and goods movement agencies in the City of Los Angeles (i.e., Avis Budget Group, Lyft, Mocean labs/Hyundai Motor Group, Waymo, Verizon, Laci) as well as private sector partners innovating on autonomous, shared, connected, and electric transportation. Urban Movement Labs will lead a one-year public relations effort to engage residents about the benefits and future uses of drones in the city. L.A. is also part of a National League of Cities panel of 25 municipalities advising the federal government on integrating drones into local cities and communities. L.A. also contributed to the World Economic Forum report entitled, "Principles of the Urban Sky," to guide cities as to how best to integrate drones into local transportation planning.

Jurisdiction	Who holds authority?	Regulatory details	Examples
United States	Federal/State/Local	FAA, s. 107, State regulations, and local regulations	Commerical drone operators in the City of Los Angeles follow FAA, s 107 rules, but also interact and intersect with California and local laws. LA leading in policy blueprint for commercial UAS

Overarching Regulatory Issues

The above regulatory review highlights the key focus of the jurisdictional geographies between drones and robots. Drones are highly and centrally regulated, as most national governments have jurisdiction over matters related to aviation and aeronautics. Land-based robots, on the other hand, tend to be less regulated and where regulations do exist, are developed more locally.

Our analysis reveals three key considerations in governing autonomous cargo delivery. Governments, at all levels, should:

- Consider the place-based context in which regulations are being developed and design policies and legislation accordingly;
- Understand the risks of not acting in a timely manner;
- Acknowledge that there are a range of flexible approaches which permit the testing of emerging autonomous cargo delivery technologies while safeguarding societal priorities, such as public safety.

Place Matters

Our jurisdictional and literature scan suggests that one of the most important considerations in developing regulations that govern autonomous cargo delivery technologies is the role of place.

While et al., (2020) point out that a government's priorities will influence its regulatory choices. In Japan, for example, the testing and trials of autonomous cargo technologies are driven by the national government's emphasis on innovation, as well as concerns with respect to social challenges, such as the shape of service delivery in an aging society. Conversely, in San Francisco, there is a greater emphasis on locally-based and often small-scale entrepreneurs working locally to determine whether a technology can be scaled up successfully.

Furthermore, not every geography will be suitable for the operation of autonomous cargo delivery vehicles. In some cases, low density areas are best suited, while in other areas, mid to higher density locations will be ideal.

Timeliness Matters

While governments are known for being thoughtful and meticulous but sometimes slow in designing regulations, technology firms move quickly, are often well-resourced and draw on sophisticated networks of government relations expertise. In short, companies have learned to advocate and lobby successfully, in part because their access to information and knowledge can exceed that of regulators.

By entering governance debates early and quickly, firms may have an increased ability to shape legislation. Governments need to be aware of this dynamic and develop strategies for consultation that meet the needs of government, industry and society.

Some entrepreneurs and firm leaders express concern that governments that stifle the use of emerging technologies are effectively reducing opportunities to foster entrepreneurship and innovation, and that this may in turn have a detrimental future impact.

With the rise of platform firms that operate at the centre of digital global networks, Canada is notable in that it has seeded few enduring made-in-Canada successes. Research demonstrates that digitization and the rise of platform firms, is resulting in greater concentration in a smaller number of firms (Brail, 2020a). Furthermore, both emerging mobility firms and automotive parts manufacturers, concentrate research and development activities adjacent to headquarters locations (Brail, 2020b; Research Infosource, 2019). If supporting the development, endurance and economic potential of innovative technologies and firms is a priority, it is important to create welcoming and safe venues for firm development and experimentation. Similar to evaluations of the prospects for connected and autonomous vehicles, regulations play a role in prompting economic development (Council of Canadian Academies, 2021). Conversely, an absence of attention may result in the dispersal of investment in emerging mobility technologies and markets to other places. Uncertainty surrounding the regulatory environment for autonomous cargo delivery represents an impediment to the sector's future (Hoffmann & Prause, 2018).

Flexibility Matters

Pilot programs can be used to develop flexible testing opportunities. In practical terms, pilots provide autonomous cargo delivery vehicles with the permission to operate within specified geographies and under highly managed conditions. Pilot programs are commonplace for the testing of both robots and drones in the public realm as highlighted in Section II, Tables 1 and 2. Creating dedicated spaces and rules for experimentation can provide benefits to firms, governments and residents. The temporary nature of pilots, and the relative ease of changing course should conditions dictate, contributes to their desirability as a means of testing emerging technologies.

SECTION V: Conclusion

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There is no question that autonomous technologies are moving fast while policy and regulatory development are lagging. With the rise of online shopping, accelerated because of the pandemic and the demand for contactless delivery, a growing number of entrepreneurs and governments are looking into the role of robot and drone technologies for efficient and effective cargo delivery. Canada is neither a leader not a laggard with these technologies and is currently undertaking experiments in both robotics and drone delivery in urban, suburban, exurban and remote rural and Indigenous communities across the country.

The benefits believed to accrue from adopting AI-backed applications include lower last-mile costs (especially in terms of labour, energy, and time); health-related pandemic services; decarbonization; consumer demand and equity; and new high-value added jobs. Limitations and challenges include increased concern over safety, and real technological, materials and logistical limitations; surveillance and privacy costs; labour de/reskilling disruption; conflicting uses in public spaces; and potential public mistrust in the technologies and their applications.

As this report demonstrates, pilot projects involving firms like Flytrex, Wing, Zipline, and Drone Delivery Canada are working with federal, state/provincial and local governments in cities, suburbs, exurbs, and remote locations. In the Canadian context, one area in which autonomous cargo delivery via drone has made an impact involves the use of drones to deliver medical supplies to remote First Nations in Canada during COVID-19. These pilot projects are also receiving attention from the World Health Organization as contributing to the improved health and economic well-being of the cargo recipient communities.

While drones must operate within the confines of federal regulations, the regulatory environment for robots remains less well defined. In some cases, especially with respect to autonomous sidewalk robot delivery, firms are either ignoring existing rules or pushing regulators to adopt more flexible regulations to enable further experimentation.

A review of the econometrics literature reveals that beyond modelling, studies are needed to gather reliable data on the costs of last-mile delivery in different settings and geographies, from urban areas to suburban and rural areas. There are several bullish reports on the cost benefits of drones and land-based robots, but the data, so far, is not based on projects that test autonomous cargo delivery in real world environments. There are still many variables at play: changing technologies, labour costs, government regulations, energy sources, specific physical geographies, competing cargo delivery options, and uncertainty regarding social acceptance. In the Canadian context, there is great potential to experiment with both drone and robotic technologies. However, these experiments will require strategic partnerships between infrastructure and logistics companies, new drone and robotic technology companies, federal, provincial and municipal regulators, crown agencies, and university and college researchers in fields such as engineering, robotics, policy, planning and design. Pilot programs could be carried out in deregulated zones, and on university/college campuses or other campus-type spaces, to gain more knowledge.

In terms of the regulatory scan, we found many examples of pilot projects from around the world. One of the key takeaway points in developing regulations that govern autonomous cargo delivery technologies is the role of place-based context. Government responses matter in terms of encouraging or delaying innovation and testing. Timeliness and flexibility also matter in any kind of pilot program. Being flexible can build public trust in the use of these technologies and ease concerns around surveillance, privacy, job loss and other environmental and social costs. To build a societal case for acceptance of autonomous delivery technologies, they must be seen as being useful to society, safe and demonstrated to solve real world logistical challenges.

Recommendations

Governments have a role to play in assessing the use of emerging technologies. Three key interconnected challenges with respect to autonomous cargo delivery remainin the Canadian context:

1. Vagueness and underdevelopment in the regulatory environment;
2. Ambiguity and uncertainty with respect to social acceptance of these technologies; and
3. A lack of coordinated programming that encourages ongoing testing, firm, product and process development.

These challenges lead us to the following recommendations:

Recommendation 1: Build Informed Regulatory Capacity

- At the broadest level, Canada needs to develop an innovative decision-making framework that pro-actively embraces decision-making about innovation and disruptive technology, including autonomous cargo delivery.
- Supporting the development of regulatory certainty at all levels of government through a range of mechanisms may be achieved through a range of initiatives led by Transport Canada, such as:

- Shared briefs highlighting learning from municipal, provincial, federal and international case studies on the regulation of drones and robots;
- Matching funding opportunities to build regulatory capacity and clarity for drone and robot regulation in partnership with other levels of government;
- Creation of an emerging mobility technologies regulatory knowledge centre to serve as a trusted centre of Canadian expertise and to prepare policymakers for technological advances and additional disruptions to mobility.

Recommendation 2: Collaborate to Gauge Social Acceptance

Deep learning requires deep engagement with many modes of thought and interest groups. Industry players are often well-represented in decision-making processes. For disruptive technologies to be embraced by society, inclusive approaches to decision-making are paramount. To gauge social acceptance, a diverse array of stakeholders need to be included in decisions about regulating emerging technology. This includes key industry players, as well as communities, Indigenous communities and peoples, cities, universities, colleges and researchers.

Approaches that build collaboration, and trust, may include:

- The creation of a national advisory council on autonomous cargo delivery inclusive of government, industry, civil society and community representatives.
- Consultations led by Transport Canada that assess challenges in which drones or robots may be appropriate solutions, as well as identify conditions and/or areas for which drones or robots would be unsuitable.
- Identification of unique community-based settings in which testing and pilot programs would be welcome.

Recommendation 3: Develop Pilot Programs with Embedded Learning Goals

Transport Canada could lead in creating dedicated spaces and rules for experimentation which can provide benefits to firms, governments and citizens. Transport Canada should continue to embrace pilot programs that test robots and drones in the public realm.

There are a range of possibilities for the federal government, as follows:

- Identify at the outset, which features of drone and robot delivery are most in need of study. This may include some, or many, of the following: consumer demand, congestion, costs, emissions, delivery time, equity, labour, public health, safety, trust and regulatory impacts. Identify appropriate research partners to support study goals.
- Leverage Innovation, Science and Economic Development Canada's testing stream as a procurement opportunity in which approved start-ups can sell goods and services to the federal government and enable testing in real world situations. To build trust and establish excellence, pilot projects must go beyond partnerships with key industry players, by incorporating engagement with community organizations, Indigenous communities and peoples, cities, universities, colleges and researchers. A range of campus-based environments (health care settings, retirement communities, universities, underutilized shopping centres) represent opportunities for testing.

Drones: Drone deliveries require access to a landing zone in order to be operable, meaning either a front or back yard. Both in principle and in practice (Lyon-Hill et al., 2020), drone deliveries can operate in areas where single family homes dominate. Local access to consumers by means of either a mothership vehicle, a distribution depot, or a central commercial area are all viable options for testing. Canada's population growth is concentrating around the country's largest urban areas, in what Statistics Canada refers to as 'urban spread.' Therefore, it makes sense to:

- Identify municipal, commercial, community and institutional partners with whom to collaborate on drone cargo delivery pilot programs within these metropolitan areas, yet outside the densest municipalities where drone delivery is least feasible.

Sidewalk Robots: Acknowledge that sidewalk robots represent an addition to competing uses for limited sidewalk space and identify opportunities in which collaboration with municipal governments, industry and community organizations supports identified needs, such as support for building innovative capacity, addressing sustainability goals, or contributions to public health.

- Identify residential neighbourhoods in proximity to commercial centres / depots with accessible entranceways and limited sidewalk traffic for testing purposes.
- Consider deploying sidewalk robots in underserved areas as a means of addressing equity and access to groceries, for instance, or to provide delivery services in neighbourhoods with aging populations.

Final Thoughts

As this review has demonstrated, autonomous cargo delivery in many forms and in many geographies has accelerated over the last few years. The technology and business experimentation around autonomous cargo delivery is moving faster than the policy environment in many cases. This is the case in Canada, and elsewhere. The time is ripe for governments at all levels to prepare and plan proactively, taking into account both the potential opportunities posed by autonomous cargo delivery, as well as the significant challenges. Embracing approaches that build collaboration and trust inclusive of government, industry, civil society and community representatives is the next step in Canada’s path towards innovative and publicly acceptable commercial applications of robotic cargo transport that benefit all Canadians.

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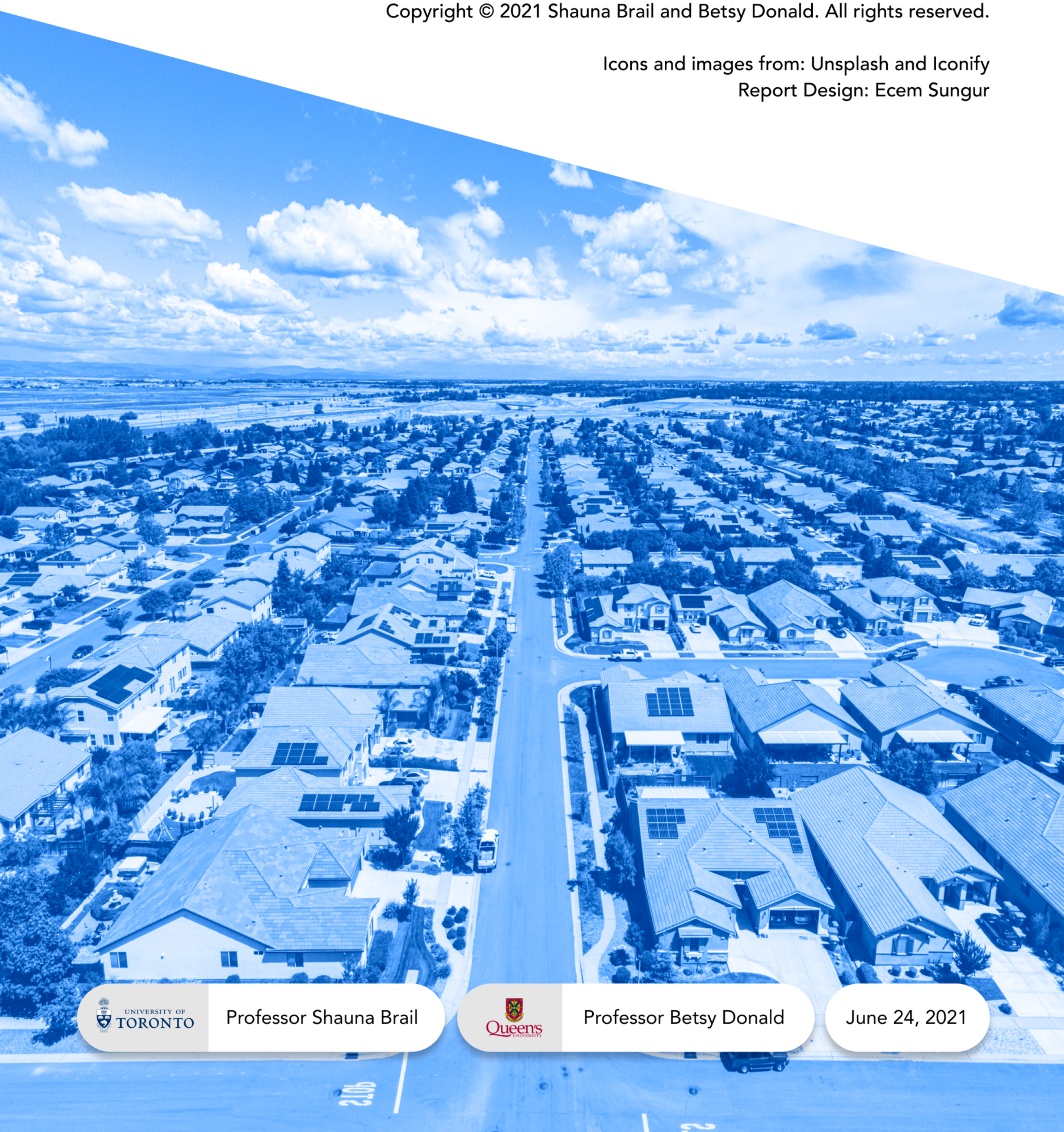

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