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The New Mobility Era: Leveraging Digital Technologies for More Equitable, Efficient and Effective Public Transportation

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IN BRIEF

Digital technologies have the potential to enhance urban mobility to achieve a variety of societal and environmental benefits: They can improve access to public transit for those who are underserved. They can help transit users optimize routes and combine various modes of transportation through integrated apps and contactless payment. And they can improve the effectiveness, efficiency and sustainability of public transportation systems that are increasingly electrified. However, to reach their full potential, digital technologies must be a part of a broader government-led transformation, which includes greater joint planning of land use and transportation, and improving shared-mobility services such as ride-hailing, car-sharing and bike-sharing. Governments at all levels have an important role to play in shaping this transformation in ways that improve the equity, efficiency and effectiveness of public transportation.

EN BREF

Les technologies numériques ont le potentiel d'améliorer la mobilité urbaine et d'apporter toute une série d'avantages sociétaux et environnementaux. Elles peuvent améliorer l'accès aux transports en commun pour les personnes mal desservies ; aider les usagers à optimiser leurs itinéraires et à combiner différents modes de transport grâce à des applications intégrées et au paiement sans contact ; et améliorer l'efficacité, l'efficience et la durabilité des systèmes de transport en commun qui sont de plus en plus électrifiés. Cependant, pour atteindre leur plein potentiel, les technologies numériques doivent faire partie d'une transformation plus large menée par les gouvernements, qui comprend une plus grande planification conjointe de l'utilisation du territoire et des transports, et l'amélioration des services de mobilité partagée tels que les applications de voitures de transport avec chauffeur, l'autopartage et les vélos en libre-service. Les gouvernements à tous les niveaux ont un rôle important à jouer dans l'élaboration de cette transformation de manière à améliorer l'équité, l'efficacité et l'efficience des transports publics.

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KEY FINDINGS

Transportation is increasingly intertwined with societal and environmental outcomes. The ability to move from one point to another in a way that is safe, convenient and affordable is critical to daily life. Traffic congestion and urban sprawl are increasingly making it difficult to do so. Transportation is also a major source of air pollution and greenhouse-gas emissions, and finding ways to move people and goods with fewer emissions is growing in importance.

Digital technologies offer the potential to enable a transformation of urban mobility in Canada. They can improve access to public transportation for areas and populations that are currently underserved, enabling on-demand microtransit (e.g., vans or minibuses with flexible routing) and affordable first- and last-mile connecting rides to transit hubs. They can help users optimize routes and combine various modes of transport through integrated apps and contactless payment. And they can improve the effectiveness, efficiency and sustainability of public transportation systems by adopting sensors and centralized train control, driver-assistance technology or automation, traffic-management systems that prioritize buses, electric vehicle battery and charging management and more.

Digital technologies need to be part of a broader government-led transformation. However, on their own, they could fail to deliver their full potential.

The first building block of transformation is greater joint planning of land use and transportation. They are too often in separate departments of governments, leading to inefficiencies and exacerbating challenges in achieving equity and affordability. Convenient and affordable mobility requires putting affordable housing where public transit is and transit where affordable housing is. This is essential for low-income households, which are more likely to rely on public transportation.

The second building block of transformation is a concerted focus on improving the shared mobility ecosystem, where rail and fixed-route bus services combine with shared mobility services such as ride-hailing, car-sharing, on-demand microtransit, bike-sharing and scooter-haring. Facilitating greater choice in mobility also requires safe pathways for walking, biking and other forms of micromobility.

There are several barriers to successfully transforming public transit systems into digitally enabled and electrified mobility services that are safe, convenient and affordable for users. Cost is one of the most significant impediments. There are capital costs associated with infrastructure, railway electric locomotives/power cars, e-buses and charging, as well as operating costs associated with the logistics of charging and greater integration of different modes. For on-demand transit with electric minibuses, driver wages represent the highest proportion of costs. Additional upfront investment in digital technologies can help reduce ongoing operating costs through automation and system optimization.

Equity benefits from transformation are also not guaranteed. Governments and transit authorities need to consider the needs of vulnerable users at every stage of

decision-making. Options such as discounted transit passes for low-income people, alternatives to apps and automatic payment systems for those with limited digital access and banking, public Wi-Fi at transit stations, safety measures at transit stops, convenient paratransit options for those with disabilities and on-demand transit for those living in low-population-density areas can help improve equity outcomes. Several U.S. cities, such as Chicago, use equitable development scorecards to evaluate projects through the lens of vulnerable residents and neighbourhoods.

All levels of government have a role to play in achieving more equitable, efficient and effective public transportation systems.

There are two main areas that should be addressed:

1. **Change the approach to funding and managing public transit to incorporate digital technologies and greater consideration of equity and long-term efficiency.**
    a. **Municipal:** Review transit decisions through an equity lens. Municipal governments need to do more to systematically consider the impacts of transit decisions on vulnerable people and ensure the equitable distribution of benefits from transit investments. The impact of digital technology implementation on equity will depend on local decision-making. For example, cities moving to digital transit payment can continue to provide convenient payment options for those who do not have data-enabled phones or bank accounts.
    b. **Provincial/Territorial:** Encourage and enable integrated mobility. Provincial and territorial governments are generally not doing enough to use their funding and regulatory powers to drive integrated mobility across different modes of transportation (e.g., allowing bikes on transit or connecting scooter-sharing options with online route planning). Funding, regulatory frameworks and deployment of digital technologies can help connect different transportation systems, improve user outcomes and reduce operating costs.
    c. **Federal:** Infrastructure funding should support operating costs and digital technologies. Federal infrastructure funding only supports capital costs, which disadvantages on-demand transit options where driver wages represent the most significant cost barrier. Digital technologies should also be an eligible cost because they can help optimize dispatch and routes, enable integration with other transportation modes and improve the user experience through contactless payment, dynamic reservation and real-time tracking of vehicles.
    d. **All levels of government:** Break down silos in decision-making. Organizations responsible for transportation, housing, infrastructure and land-use planning should have mechanisms in place to better align planning and projects to achieve societal outcomes.

2. **Target barriers to the deployment of technologies that can achieve more sustainable, equitable, efficient and effective public transportation.**
    a. **Safety concerns:** Shared micromobility options such as rental scooters, bicycles or e-bikes present various safety concerns. Strong regulation is needed on the age of use, helmets, speed limits and obstruction of sidewalks while also

ensuring safer infrastructure. While most of this would be done at the municipal level, best practices could be shared by provincial/territorial governments. Digital technologies can help educate users and promote compliance.

b. **Electrification of public transit:** Transit authorities and municipalities often lack the information they need to plan and make informed decisions with respect to digital technologies that can enable electrification of bus systems and commuter rail. In addition to existing funding programs, enhanced federal and provincial research and development could support electrification in smaller municipalities that lack capacity. Programs aimed at supporting Canadian clean-technology companies can also target economic opportunities in digitally advanced battery electric buses (full-size and mini) along with charging infrastructure and associated software.
c. **Protection of digital information**: As local governments and transit authorities adopt digital technologies, they will need support from federal and provincial governments to implement programs that protect data from misuse.
d. **Insufficient broadband service:** Municipalities may need to consider enhanced affordable high-speed internet options to support digital transportation assets such as transit controllers, traffic lights and digitally enabled public transit.

Canada's transportation systems are already transforming in response to technological change and efforts to reduce greenhouse-gas emissions. Governments at all levels have an important role to play in shaping this transformation in ways that improve the equity, efficiency and effectiveness of public transportation.

FAITS SAILLANTS

Les transports sont de plus en plus étroitement liés aux bilans sociétaux et environnementaux. Pouvoir se déplacer quotidiennement d'un point à un autre de manière sécuritaire, pratique et abordable est essentiel. Les embouteillages et l'étalement urbain rendent ce besoin de plus en plus difficile à combler. Les transports sont également une source majeure de pollution atmosphérique et d'émissions de gaz à effet de serre, et il est de plus en plus important de trouver des moyens de déplacer les personnes et les marchandises en produisant moins d'émissions.

Les technologies numériques offrent la possibilité de transformer la mobilité urbaine au Canada. Elles peuvent améliorer l'accès aux transports publics pour les zones et les populations qui sont actuellement mal desservies, en permettant un microtransit (comme les fourgonnettes et les minibus avec des itinéraires flexibles) sur demande et des trajets de correspondance abordables sur le premier et le dernier kilomètre jusqu'aux centres de transport en commun. Elles peuvent aider les utilisateurs à optimiser leurs itinéraires et à combiner différents modes de transport grâce à des applications intégrées et au paiement sans contact. Elles peuvent également améliorer l'efficacité, l'efficience et la durabilité des systèmes de transport public en fournissant des capteurs et un contrôle centralisé des trains, des technologies d'aide à la conduite ou d'automatisation, des systèmes de gestion du trafic qui donnent la priorité aux bus, des outils de gestion des batteries et de recharge des véhicules électriques et bien d'autres choses encore.

Les technologies numériques doivent s'inscrire dans le cadre d'une transformation plus large menée par les gouvernements. Toutefois, isolées, elles pourraient ne pas donner la pleine mesure de leur avantages.

La première pierre d'assise de la transformation est une meilleure planification conjointe de l'utilisation du territoire et des transports. Elle relève trop souvent de ministères distincts, ce qui est source d'inefficacité et exacerbe les problèmes d'équité et d'abordabilité. Pour que la mobilité soit pratique et abordable, il faut placer les logements abordables là où se trouvent les transports en commun et vice versa. Cette planification est essentielle pour les ménages à faibles revenus, qui sont plus susceptibles de dépendre des transports en commun.

La deuxième pierre d'assise de la transformation est un effort concerté pour améliorer l'écosystème de la mobilité partagée, où les services ferroviaires et de bus à itinéraire fixe se combinent avec des services de mobilité partagée tels que les applications de voitures de transport avec chauffeur, l'autopartage, le microtransit à la demande, et les vélos et les trottinettes en libre-service. Faciliter un plus grand choix en matière de mobilité nécessite également des voies sûres pour la marche, le vélo et d'autres formes de micromobilité.

Il existe plusieurs obstacles à la transformation réussie des réseaux de transport public en services de mobilité numérisés et électrifiés sécuritaires, pratiques et abordables pour les usagers. Le coût est l'un des obstacles les plus importants. Il y a des coûts d'investissement associés à l'infrastructure, aux trains et aux bus électriques et à leur recharge. Il existe aussi des coûts d'exploitation associés à la logistique de la recharge et à une plus grande intégration des différents modes de transport. Pour les

transports en commun à la demande avec des minibus électriques, les salaires des chauffeurs représentent la plus grande part des coûts. Des investissements initiaux supplémentaires dans les technologies numériques peuvent contribuer à réduire les coûts d'exploitation grâce à l'automatisation et à l'optimisation des systèmes.

Les avantages de la transformation en termes d'équité ne sont pas non plus garantis. Les gouvernements et les autorités de transport doivent prendre en compte les besoins des usagers vulnérables à chaque étape de la prise de décision. Plusieurs options existent pour améliorer l'équité : des passes de transport à prix réduit pour les personnes à faible revenu, des options de rechange aux applications et aux systèmes de paiement automatique pour les personnes ayant un accès limité aux ordinateurs et aux services bancaires, le Wi-Fi public dans les stations de transport, des mesures de sécurité aux arrêts, des options de transport adapté pratiques pour les personnes handicapées et le transport à la demande pour les personnes vivant dans des zones à faible densité de population. Plusieurs villes américaines, comme Chicago, utilisent des grilles d'évaluation du développement équitable pour évaluer les projets sous l'angle des résidents et des quartiers vulnérables.

Tous les niveaux de gouvernement ont un rôle à jouer dans la mise en place de systèmes de transport public plus équitables, plus efficaces et plus efficients.

Deux domaines principaux doivent être abordés :

1. **Changer l'approche du financement et de la gestion des transports publics pour intégrer les technologies numériques et prendre davantage en compte l'équité et l'efficacité à long terme.**
    a. **Municipalités :** Examiner les décisions relatives aux transports en commun sous l'angle de l'équité. Les gouvernements municipaux doivent faire davantage pour prendre systématiquement en compte les impacts des décisions en matière de transport en commun sur les personnes vulnérables et assurer une distribution équitable des bénéfices des investissements dans le domaine du transport en commun. L'impact de la mise en œuvre de la technologie numérique sur l'équité dépendra de la prise de décision locale. Par exemple, les villes qui adoptent le paiement numérique des transports en commun peuvent continuer à offrir des options de paiement pratiques aux personnes qui n'ont pas de téléphone avec des données mobiles ou de compte bancaire.
    b. **Provinces/territoires** : Encourager et permettre la mobilité intégrée. Les gouvernements provinciaux et territoriaux n'en font généralement pas assez pour utiliser leurs pouvoirs de financement et de réglementation afin de favoriser la mobilité intégrée entre les différents modes de transport (par exemple, en autorisant les vélos dans les transports en commun ou en reliant les options de partage de trottinettes électriques à la planification d'itinéraires en ligne). Le financement, les cadres réglementaires et le déploiement des technologies numériques peuvent contribuer à relier les différents systèmes de transport, à améliorer l'expérience pour les usagers et à réduire les coûts d'exploitation.
    c. **Gouvernement fédéral** : Le financement des infrastructures devrait soutenir les coûts d'exploitation et les technologies numériques. Le financement fédéral des infrastructures ne prend en charge que les coûts d'investissement, ce qui désavantage les options de transport en commun à la demande pour

lesquelles les salaires des chauffeurs représentent l'obstacle le plus important en termes de coûts. Les technologies numériques devraient également faire partie des coûts admissibles car elles peuvent aider à optimiser la répartition et les itinéraires, permettre l'intégration avec d'autres modes de transport et améliorer l'expérience de l'utilisateur grâce au paiement sans contact, à la réservation dynamique et au suivi en temps réel des véhicules.

d. **Tous les niveaux de gouvernement** : Éliminer les cloisonnements dans la prise de décision. Les organisations responsables des transports, du logement, des infrastructures et de l'aménagement du territoire devraient disposer de mécanismes permettant de mieux aligner la planification et les projets afin d'améliorer les résultats pour l'ensemble de la société.

2. **Cibler les obstacles au déploiement de technologies permettant de rendre les transports publics plus durables, plus équitables, plus efficaces et plus efficients.**
   a. **Problèmes de sécurité** : Les options de micromobilité partagée (comme les trottinettes et vélos électriques et les vélos en libre-service) posent divers problèmes de sécurité. Une réglementation stricte est nécessaire en ce qui concerne l'âge d'utilisation, les casques, les limites de vitesse et l'obstruction des trottoirs, tout en garantissant une infrastructure plus sûre. Bien que la plupart de ces mesures soient prises au niveau municipal, les meilleures pratiques pourraient être partagées par les gouvernements provinciaux/territoriaux. Les technologies numériques peuvent contribuer à éduquer les utilisateurs et à promouvoir le respect des règles.
   b. **Électrification des transports publics** : Les autorités de transport et les municipalités manquent souvent des informations dont elles ont besoin pour planifier et prendre des décisions éclairées en ce qui concerne les technologies numériques qui peuvent permettre l'électrification des systèmes d'autobus et des trains de banlieue. En plus des programmes de financement existants, l'amélioration de la recherche et du développement au niveau fédéral et provincial pourrait soutenir l'électrification dans les petites municipalités qui manquent de capacité. Les programmes visant à soutenir les entreprises canadiennes de technologies propres peuvent également cibler les occasions économiques dans les bus électriques à batterie numériquement avancée (pleine taille et mini) ainsi que l'infrastructure de recharge et les logiciels associés.
   c. **Protection de l'information numérique** : Au fur et à mesure que les collectivités locales et les autorités de transport adoptent les technologies numériques, elles auront besoin du soutien des gouvernements fédéral et provinciaux pour mettre en œuvre des programmes qui protègent les données contre les utilisations abusives.
   d. **Insuffisance des services à large bande** : Les municipalités peuvent avoir besoin d'envisager des options d'Internet haute vitesse plus abordables pour soutenir les actifs de transport numérique tels que les contrôleurs de transport, les feux de circulation et les transports publics numériques.

Les systèmes de transport du Canada sont déjà en train de se transformer en réponse aux changements technologiques et aux efforts de réduction des émissions de gaz à effet de serre. Les gouvernements à tous les niveaux ont un rôle important à jouer pour façonner cette transformation de manière à améliorer l'équité, l'efficience et l'efficacité des transports publics.

INTRODUCTION

Public transit needs to become more sustainable and travel times improved if it is to compete with single-occupancy vehicular travel and encourage users to shift modes. While this is a widely acknowledged goal, there are several challenges to achieving it. This paper presents a nuanced reading of the shift toward shared, automated and technology-supported transportation with the goal of better understanding the potential of digital technologies to better serve all users. The research emphasizes the needs and patterns of vulnerable users (persons with mobility challenges, visible minorities, low-income groups, seniors, women, youth, immigrants and refugees) and describes opportunities to leverage technology to improve the equity (access, affordability), efficiency (frequency, lower operating costs) and effectiveness (safety, emissions reduction) of transportation initiatives. By addressing conventional public transit, microtransit (on-demand minibus or van service) and micromobility (bikes, e-bikes and e-scooters for rent), the paper aims to ensure an equitable transformation of the entire urban mobility landscape.

In this paper, we define equity as going beyond equality, where all users are treated the same or offered the same alternatives (for other definitions of equity in transportation, see Bruzzone et al., 2023; Khan & Shaheen, 2022). Achieving equity for all public transit users requires acknowledging the demographic groups that have traditionally faced barriers or been systematically underserved, and then making choices to serve them better. Unfortunately, most often when transportation technologies, routes and planning decisions are made, the impacts on all users are not considered. Many municipal transit agencies have had lower ridership since the pandemic, and so have had to raise fares and decrease service, to the detriment of those who may no longer be able to afford transit but may also not have alternative options.

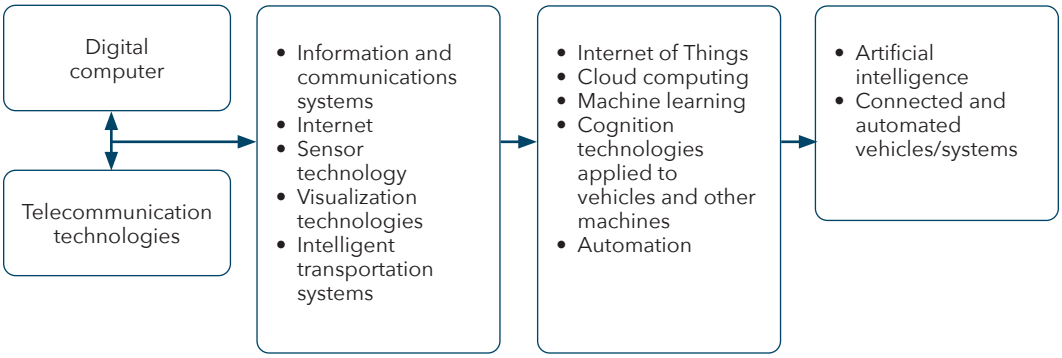
The groups of vulnerable users mentioned above tend to use public transit more often, have lower incomes and have travel patterns that differ from those of the median-income commuter travelling during peak hours. For example, the 2021 Census shows that 9.7 per cent of people with incomes between $20,000 and $29,999 used public transit as their primary mode of commuting to work, compared to just 4.6 per cent of people with incomes between $70,000 and $79,999. Women use public transit for commuting at a higher rate than men (16.6 per cent compared to 11.1 per cent), and seniors are the fastest growing population in Canada. Furthermore, studies of transportation equity have found that transit users have lower levels of access to a vehicle and fewer have a driver's licence (Golub et al., 2022), suggesting that most transit users are not choosing to forgo driving. For the captive rider, it is therefore essential to have access to public transit to access jobs and essential services (Prayitno & Moos, 2022).

Although technology alone will not make public transit equitable, efficient and effective, electrification and digital tools will serve as the main drivers of change along with other advanced methods. The former entails replacing petroleum-fuel-based engines with electric traction to obtain zero emissions. But the decarbonization of transportation can also begin at the source of electrical power, for instance by obtaining hydrogen produced from zero-emission electricity to fuel transportation by hydrogen fuel-cell technology.

In the case of digital tools, computer and telecommunication technologies have already enhanced urban transportation systems, namely by adding functionalities through information and communication technology (ICT) (Castellanos et al., 2022). In recent years, the phenomenal progress in these technologies and their applications have resulted in many notable products that are now commonly referred to as digital technologies (figure 1). As these technologies advanced, their specific applications were determined through new methodologies such as artificial neural nets (ANN), advanced analytics and AI-based predictive algorithms (see box 1).

Digital tools have an important role to play in improving equity in public transit. A report prepared for the World Government Summit of 2020 notes that it is already possible to analyze and evaluate the benefits of digital technologies for various societal groups and, in case of adverse impact, to implement measures that will mitigate a "digital divide" between those who have excellent internet access and those who do not (Center for Digital Government, 2023a; KPMG, 2021). Digital equity means ensuring all individuals and communities have the technological capacity required to access essential services and fully participate in democracy, society, the economy and lifelong learning (Center for Digital Government, 2023b). Connecting communities improves mobility and digital equity supports transportation equity (Center for Digital Government, 2023a).

Figure 1. Progression in digital technologies



Box 1. Definitions of new methodologies

- **Artificial Neural Network (ANN):** Similar to neurons in the human brain, ANNs can be used for purposes like prediction, comparison and evaluation, based on training with actual data. Common applications in public transit are travel-demand forecasting and machine learning for automation tasks.
- **Advanced analytics:** Mathematical and statistical methods are adapted as computational tools for performing specific tasks that generate information for decision-making. Examples in shared mobility systems are predicting the clustering at certain stations of shared vehicles and e-bikes, which then require relocation to other stations.
- **Artificial Intelligence (AI)-based predictive algorithms:** Machine learning and Bayesian artificial intelligence are applied to algorithms that can make predictions without human intervention. For example, algorithms can predict maintenance of railway and other transportation infrastructure, reducing cost and improving reliability of service.

All levels of governments in Canada are already developing and implementing policies and programs on upgrading digital readiness and digital equity, and the provision of secure and modern digital services is outlined in Canada's digital ambition 2023 update (Government of Canada, 2023a). Provincial, municipal and territorial governments have also initiated policies and programs to move toward a digital future. According to the 2023 digital readiness index compiled by Cisco Canada (2023), Canada ranks well among the countries studied but still has digital inequities. The index includes components such as basic needs, investment, ease of doing business, human capital, startup environment, technology adoption and infrastructure.

While the federal government may provide funding to develop new technologies, implementation will be undertaken at the municipal and regional level, and most cities struggle with both the capital and operational costs of their transportation systems. Furthermore, governments will need to support users who may face inequities and barriers in new systems, such as access to credit cards or banks, distance-based fares and routes that exclude low-income areas. To this end, this paper proposes actions that governments at all levels can take to accelerate the adoption of electrification and digital technologies in public transit, with the aim of improving mobility and generating positive outcomes for all users.

BUILDING BLOCKS OF A SUCCESSFUL URBAN MOBILITY TRANSFORMATION

Land use and transportation planning are often siloed in separate departments, even separate organizations, which leads to inefficiencies and makes integrating equity priorities challenging. In recent decades, neotraditional urban design and Smart Growth have emphasized the need to co-ordinate land use planning with transportation planning to maximize choices for residents (increased density, mixed-use development, walking and cycling infrastructure). More recently, land use and planning approaches have shifted to align with trends toward denser urban areas, transit corridors and decreased car ownership among some key demographics. To understand the potential for land use-transportation integration (LUTI) and opportunities for new transportation technologies, it is useful to have a brief overview of governance and policy frameworks.

Joint planning of land use and transportation

Governance and policy framework

Each province and territory has its own planning act that specifies the type of municipal plan(s) required, how often they are reviewed and how the public must be consulted in their development. In some provinces, such as Ontario, municipal plans must be approved by the provincial government. Provincial responsibilities also include schools, highways and hospitals, while federal responsibilities include airports and military institutions. Indigenous communities also have land and treaty rights. Therefore, municipalities do not have control over all the built form within their jurisdictions. Other provincial acts, such as *Municipal Government Acts,* may lay out the responsibilities and

powers of municipalities, including the ability to tax residents and the types of levies or charges allowed. Some municipalities have charters (Vancouver, Edmonton), but the powers granted therein can be removed at any time by their provincial governments. Local and regional transportation authorities are also granted responsibilities by provincial or territorial governments and are dependent on the provincial and federal governments for major infrastructure (new light rail lines) and capital (new vehicles).

Because they rely on fare-box revenue for the majority of their operational costs, public transit agencies often make decisions based on revenue generation, at the expense of low-income users. It is rare for Canadian municipalities to take an equity approach to planning for transportation. Chicago offers an example: it uses an Equity Transit Oriented Development (eTOD) Scorecard to evaluate potential transportation projects based on their impacts on vulnerable neighbourhoods, helping decision-makers mitigate these impacts or choose alternative solutions. Another example is Germany, where states and the federal government started offering a flat fare ticket (regardless of distance travelled) for local and regional transit in May 2023, to help make public transit permanently more attractive than driving. In Canada, some municipalities have introduced services to make transit more equitable, such as transit passes for low-income users, improved safety measures for women, or rural transit services to help people access health care and services beyond their community (e.g., Halifax Regional Municipality, City of Edmonton). And yet, when the Toronto Transit Commission's Transit City plan was first proposed in 2007, it aimed to ensure most city residents would live within two kilometres of high-order transit, but was not promoted as an equity approach (Kramer & Mettke, 2016).

Land use-transportation integration

Land use, housing and transportation usually involve multiple levels of government. Land use is primarily controlled through municipal zoning bylaws and official plans, which allow municipalities to determine what types of uses (commercial, industrial, residential) can be located in which parts of the city. Zoning bylaws specify the use and the built form allowed (maximum heights, setbacks from the road and adjacent properties). Municipal and regional transportation authorities have plans and strategies that include an analysis of current travel patterns and trends, how the current system is working (over/underuse of certain routes, frequency of key routes) and proposals for its expansion or improvement. LUTI offers a more co-ordinated planning model and many opportunities to create neighbourhoods with better transit service. For instance, parts of the Cambie Corridor in Vancouver were rezoned to include different types of new housing (including affordable multi-unit rentals) along the light rail transit (LRT) line, as well as an improved cycling network. To achieve this, careful co-ordination to integrate the city's land use zoning bylaw with TransLink's LRT line and existing bus rapid transit (BRT) lines began in 2018 and is ongoing.

While LUTI offers opportunities, it also has its challenges. First, a key consideration is avoiding the displacement of low-income populations from areas with good transit service, including BRT and LRT corridors. Governments must ensure that existing affordable housing is preserved and incentivize new affordable housing, as this will also maintain or increase transit ridership (Ren Thomas Urban Consulting & Research, 2022). LUTI is

also challenging in low-density areas (suburbs, small towns, rural areas) because most municipalities use density (number of dwellings, residents or jobs per acre) to determine the viability of fixed-route transit services. Microtransit is well suited to low-density areas and, while some cities have partnered with municipalities on initiatives, private companies are expected to remain focused on dense urban areas (Heineke et al., 2023).

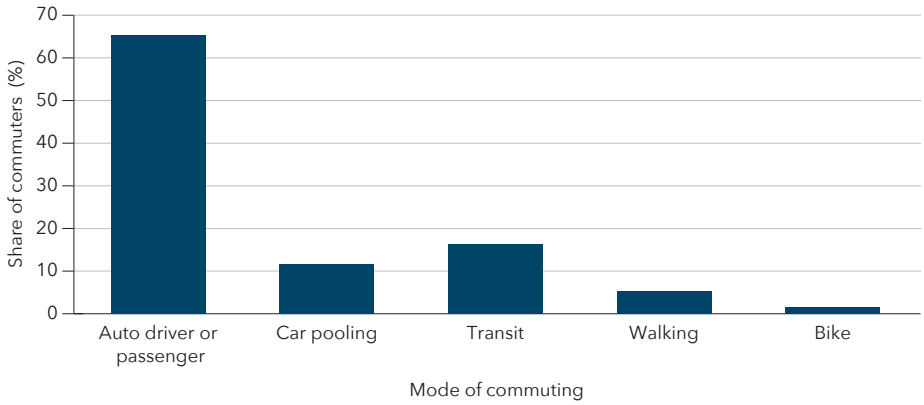
Shared mobility ecosystem

Choice of transportation mode

The long-standing challenge for public transportation is its ability to shift travellers from the low-occupancy automobile to modes of shared mobility. A trip diverted to public transit will reduce urban road congestion, enhance safety and improve the efficiency of transportation. Furthermore, public transit vehicles emit much less pollution and greenhouse gas per passenger per kilometre than personal vehicles do, so increasing public transit ridership is critical to reducing emissions. Key to any strategies and tactics for encouraging a potential rider to choose shared mobility (for those otherwise able choose a private vehicle) is convenient access to public transit, In Canadian Census Metropolitan Areas (CMAs) in 2016, less than 20 per cent of daily commuters were using public transit, compared to over 60 per cent using cars (figure 2). However, the ratio of transit users has improved in larger cities where people have greater access to frequent, reliable fixed transit routes. Panel surveys of Vancouver from 2013 to 2019 show a decrease in car use for commuting to work, but also a noticeable increase in walking and biking (figure 3).

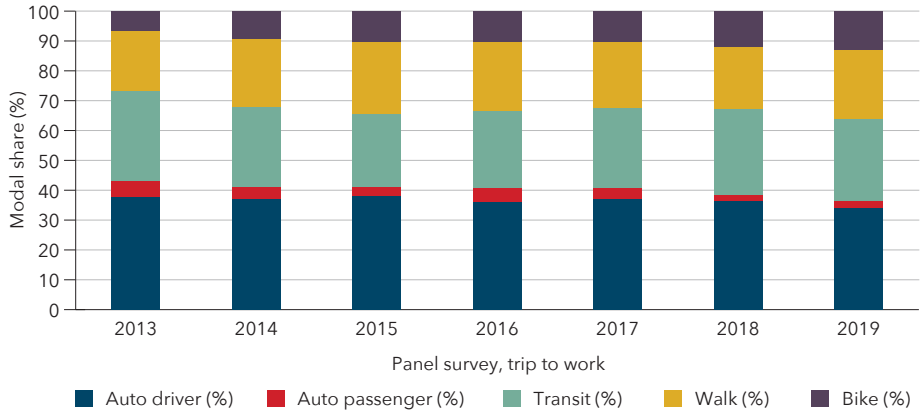
The conventional modes of shared mobility in Canada's largest cities remain regional commuter rail transit, high-capacity rapid rail transit, intermediate capacity rail transit, LRT and fixed-route bus transit. The latter is the main bus-based public transit service in urban areas across Canada and a few cities have modified existing road networks or built access-controlled roadways (transitways) to accommodate BRT operations, or have implemented bus priority signals at traffic lights.

Figure 2. Modal share in Canadian CMAs, 2016



Source: Authors based on 2016 Census data.
Note: The 2021 Census data is not reliable because it was affected by the COVID-19 pandemic. Recent Statistics Canada data show that, as of September 2022, transit ridership recovered to 73 per cent of pre-pandemic levels (measured in August 2019). This is a nationwide, not regional, figure (Statistics Canada, 2022).

Figure 3. Modal share of work trips in Vancouver, 2013-2019



Source: Authors based on panel survey data, City of Vancouver (2020).

Aside from conventional modes, a limited number of new shared mobility modes have been implemented in urban areas in Canada. These include ride-sourcing (or ride-hailing), car-sharing, on-demand microtransit and micromobility (Lauriault et al., 2021). Some municipalities, like Innisfil, Ontario, have incorporated ride-hailing firms like Uber into transit systems. On-demand microtransit can feature many digitally enabled characteristics, such as flexible routing to pick up additional passengers, and while it can be offered with minibuses, vans or sedans, the most efficient option is right-sized vehicles (CUTA & Metrolinx, 2022). Micromobility modes are implemented mainly to improve sustainability and include bikes or e-bikes and e-scooters; along with microtransit, these are relatively new modes of shared mobility in Canada, so ridership data are not available (Fai et al., 2020; Lauriault et al., 2021).

Bus services are the most widespread mode of public transit in Canada, but the majority of buses operating in Canadian cities still run on diesel fuel. In 2019, diesel fuel consumed by urban transit systems in Canada amounted to 562.621 million litres (Statistics Canada, 2021). Not counting small amounts of gasoline and other fuels, this diesel consumption alone resulted in 1.542 million tonnes of CO_2 equivalent greenhouse-gas emissions in one year (CO_2 equivalents calculated using the methodology presented in Khan et al., 2021). It is widely acknowledged that electric buses are necessary to reach zero emissions, but public transit interest groups argue that they need more resources to implement the change (Robson, 2020). Although some transit agencies have begun the process of procuring electric buses, only Saint John, New Brunswick (Moore, 2022), and Oakville, Ontario (Sustainable Bus, 2022), have publicly announced to date the purchase of electric minibuses for on-demand microtransit service. When it comes to rail, the high-capacity rapid rail transit systems of Montreal and Toronto, the ICT system of Vancouver (SkyTrain), and the LRT systems in several cities in Canada are electrified. However, of the regional commuter rail systems in these cities, only Toronto has announced a major electrification and system modernization program (Metrolinx & Infrastructure Ontario, 2022).

Measuring efficiency and effectiveness of public transit

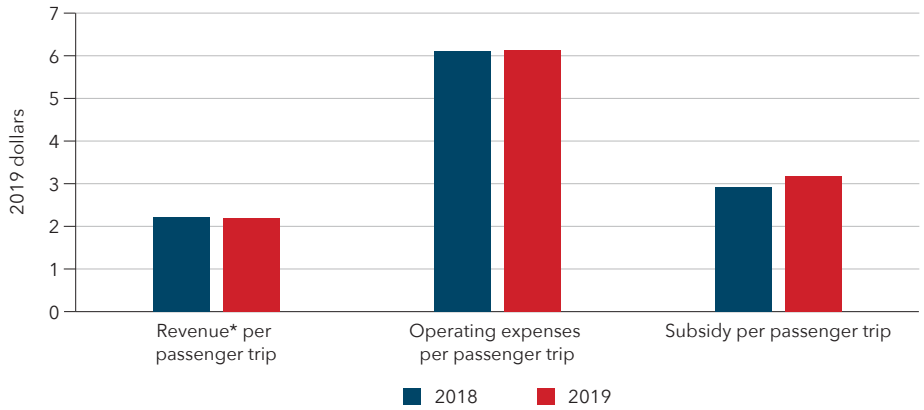
Public transit services in urban areas are assessed according to metrics of efficiency and effectiveness. The former relates resource input (cost, labour, equipment) to service output. Although the ratio of fare-box revenue to operating expenses can differ in other countries, most governments must subsidize the balance of operating costs at public expense in order to keep fares affordable. In Canada, the transit operators are municipal or regional organizations, and yet municipal governments cannot run deficits or raise money through taxes as provincial and federal governments can. In 2018 and 2019, the revenue per passenger accounted for less than 40 per cent of the operating cost per passenger in Canadian urban transit (figure 4).

Achieving effective transit services is also critical (Allen & Farber, 2019; Perrotta, 2021). Notable objectives are real-time information on vehicle arrival and service; travel time reduction; access to public transit; on-demand transit; service quality and frequency; integrated mobility; multimodal connections; fare information and affordability; accessible payment methods; reduced greenhouse gases and other emissions; safety; and favourable economic and land-use developments. As mentioned above, the accessibility of public transit is one of the defining measures of efficacy and equity and merits further elaboration.

Measuring accessibility of public transit

According to the urban mobility readiness index produced by Oliver Wyman Forum and the University of California, Berkeley, Toronto, Montreal and Vancouver have affordable public transit and strong multimodal networks. However, they lack new microtransit and micromobility services (Oliver Wyman Forum & University of California, Berkeley, 2022). These could help overcome service gaps, which is especially important for vulnerable users without alternatives to public transit and inadequate access to existing networks (Allen & Farber, 2019; Perrotta, 2021; Prayitno & Moos, 2022).

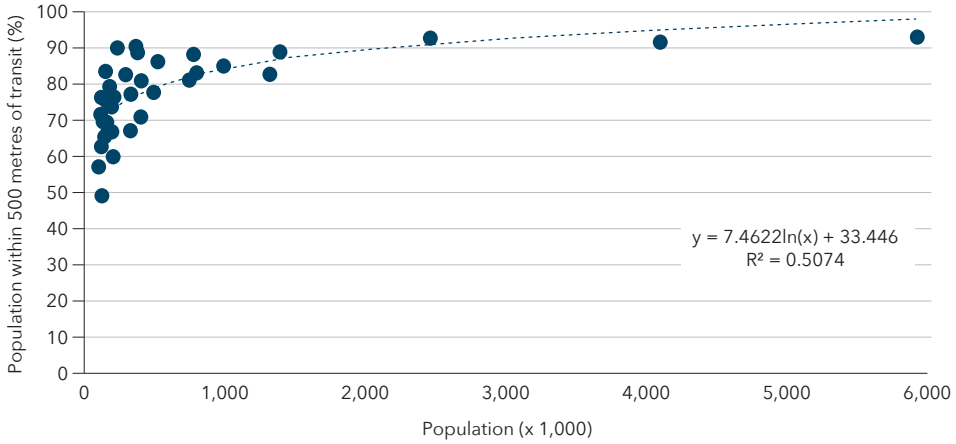
Figure 4. Urban transit financial data (2019 dollars)



Source: Authors based on data from Statistics Canada Table 23-10-0251-01.
Note: * Revenue excludes subsidy

According to Statistics Canada (2020), a 10-minute walk (500 metres) from a bus, tram or under/overground rail stop or station is the international standard to measure convenient access to public transit. Figure 5 measures the accessibility of transit in Canadian CMAs, defined by Statistics Canada as urban areas with a population of at least 100,000, of which 50,000 or more live in the core. It shows that public transit in Toronto, Montreal and Vancouver is accessible to over 90 per cent of residents, while in metropolitan areas with small or low-density populations, transit is generally accessible to between 65 and 80 per cent of residents.

Figure 5. Percentage of population within 500 metres of transit, all CMAs

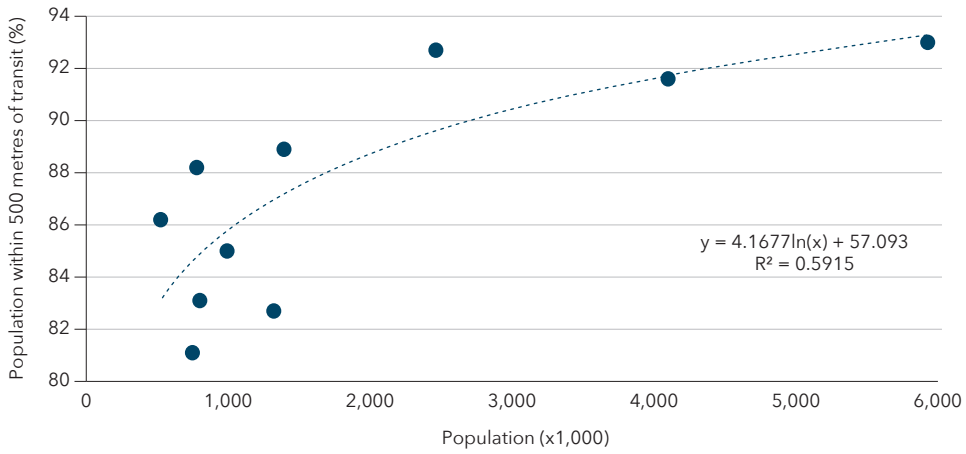


Source: Authors based on data from Statistics Canada Table 23-10-0286-01.
Note: The result of the analysis is shown as a regression model. The strength of correlation is shown as the square of correlation coefficient R^2, which represents the proportion of variance in data explained by the model out of 1.0.

Taking only CMAs with populations over 500,000 into account, between 80 and 95 per cent of residents live within 500 metres of public transit and this higher rate of accessibility correlates to the greater mode share of transit (figure 6 and figure 7). For smaller CMAs, public transit mode share does not correlate with measures of population.

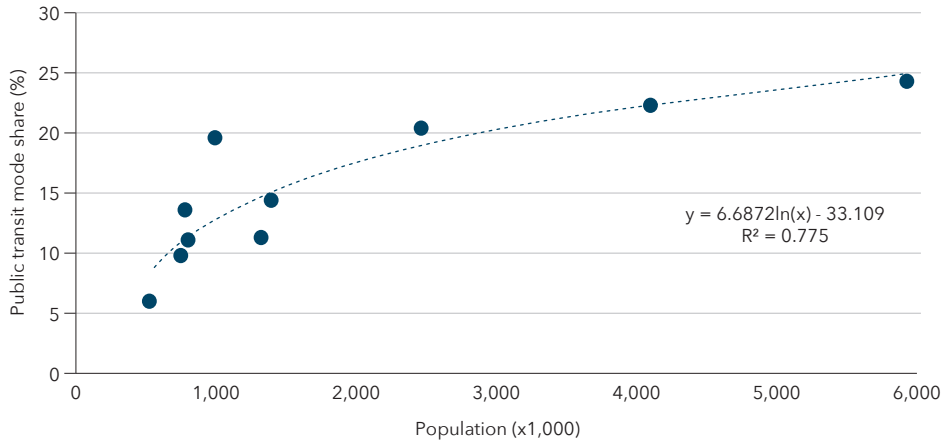
This analysis implies that residents of smaller urban areas are underserved by existing conventional public transit, as most systems allocate routes based on density and therefore function best in large metropolitan areas. Inadequate frequency or coverage of transit in low-density areas occurs in part because fixed-route services are deemed inefficient by transportation providers, since their primary consideration is minimizing operational costs. This suggests that ridership can be improved by offering new on-demand modes of mobility. In particular, microtransit may provide a more reasonable alternative for suburban and rural areas with poor transit access, and for vulnerable users such as those with mobility challenges who may not be served effectively by existing networks such as paratransit. Micromobility options can also improve access to fixed-route services by filling the gap of the last/first mile of travel at any time of day.

Figure 6. Percentage of population within 500 metres of transit, CMAs over 500,000 residents



Source: Based on data from Statistics Canada (2020).
Note: The result of the analysis is shown as a regression model. The strength of correlation is shown as the square of correlation coefficient R^2, which represents the proportion of variance in data explained by the model out of 1.0.

Figure 7. Public transit mode share, CMAs over 500,000 residents



Source: Based on data from Statistics Canada Table 23-10-0286-01.
Note: The result of the analysis is shown as a regression model. The strength of correlation is shown as the square of correlation coefficient R^2, which represents the proportion of variance in data explained by the model out of 1.0.

Integrating microtransit and micromobility alternatives is the responsibility of municipalities and transportation authorities, all of whom have their own budgets and priorities. However, most of them do not have a reasonable level of co-ordination between conventional public transit, microtransit and micromobility. While fixed-route public transit is operated by municipalities and regional governments, microtransit services are often private operations contracted by those governments, and micromobility services are almost all private-sector initiatives. The lack of integration of these options into transit services makes them difficult for users to navigate, leading to less awareness and use.

Public transit must be transformed to increase the availability of equitable, affordable, demand-responsive and integrated mobility options that can supplement fixed-route services. Integrating these options will improve accessibility and decrease travel times, benefiting riders with mobility challenges, low-income groups, underserved communities, non-smartphone users and those in need of medical care.

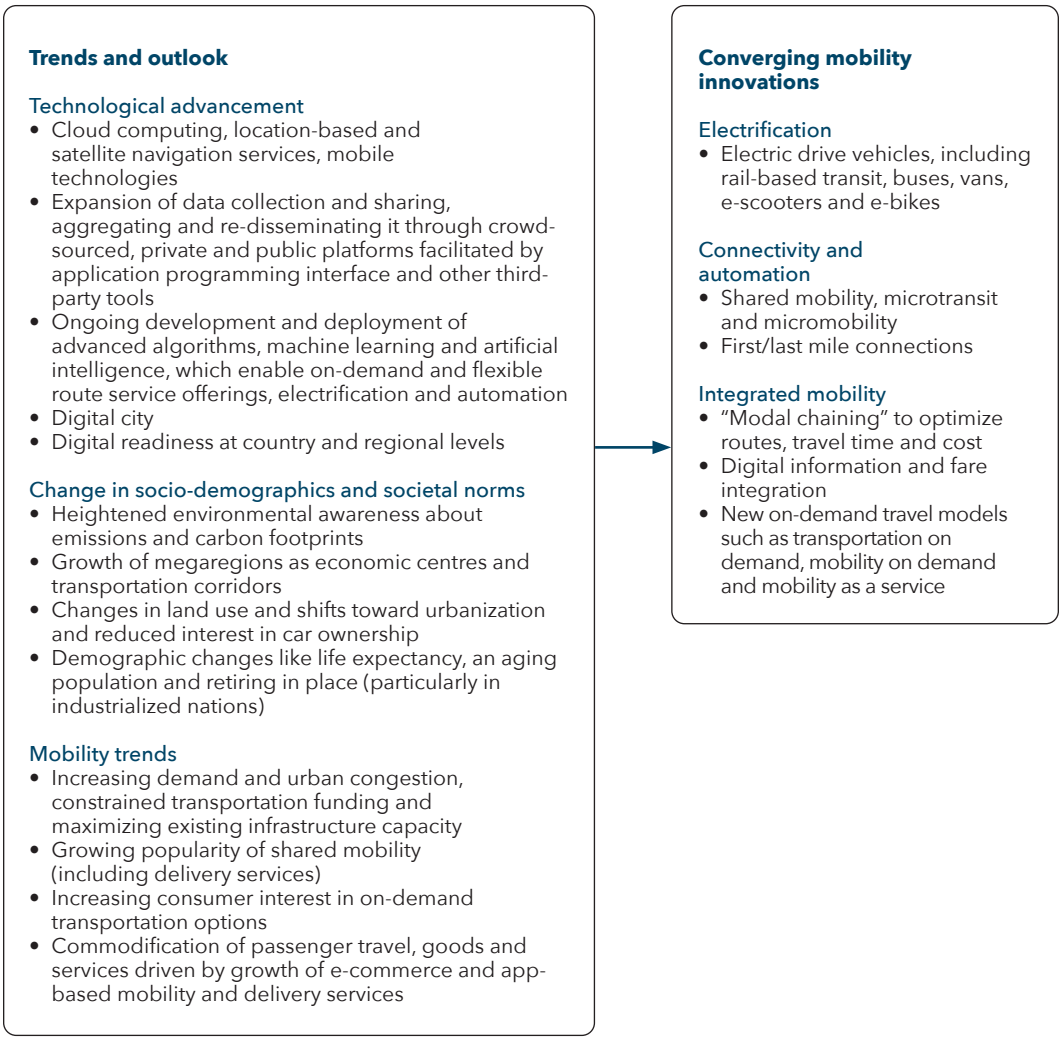
OPPORTUNITIES AND CHALLENGES WITH INCREASED DIGITAL TECHNOLOGY ADOPTION

Technology can play a major role in catalyzing improvements in urban mobility for both transit users and operators. It can support electrification and smart city development that improves planning and reduces traffic congestion, citizen- and consumer-oriented digitalization that enables better route planning and payment options, automation that reduces operating costs, and universal internet connectivity and cybersecurity (De la Cruz et al., 2023; European Commission, 2021). At the World Government Summit of 2020, principles for digital transformation in cities were discussed, including the provision of free internet if warranted and of digital education opportunities (KPMG, 2021). The acceptance of digital transformation in communities is evident in programs implemented in Canada and the United States. For example, the City of Oakville, Ontario, has developed strategies including connected transportation, a responsive transit system, and traffic management measures to reduce congestion (Town of Oakville, 2022).

And yet, though advances like vehicle electrification, increased connectivity and automation, and integrated mobility are being implemented, simply expanding the use of digital technologies will not – on its own – address equity outcomes (see figure 8). Rather, it is the actions municipal governments take to ensure that new technologies increase transit accessibility and affordability for all demographics that will determine whether mobility equity is achieved. For example, introducing distance-based fares would disproportionately burden low-income households, immigrants and racialized Canadians, because these groups experience higher rates of extreme commuting (over 60 minutes) (Allen & Farber, 2019). Meanwhile, systems relying on credit card or digital payments will exclude the 15 per cent of Canadians who do not have bank accounts or have limited access to banking services. This particularly impacts Indigenous and low-income people, who are more likely to have marginal access to financial institutions (Edmonton Financial Empowerment Collaborative, 2016).

Mobility equity will also depend on the governments of smaller and rural areas integrating digital technology to facilitate on-demand transit. Smartphone access does not always equal access to data, as there are often network gaps across rural, suburban and even some urban areas. To help bridge this digital divide among public transit users, there is a need for education and training on smartphone apps, public Wi-Fi and charging stations and improved app security (Golub et al., 2022). For instance, Ottawa's OC Transpo app is designed to help tourists and daily commuters find bus stops and LRT or O-Train terminals, as well as to obtain accurate and real-time arrival times. But for potential travellers who cannot use the app, there are other resources provided with the same information (e.g., a 1-800 number they can call) (Crawford, 2023).

Figure 8. Emerging mobility innovations



Note: Based on Shaheen and Cohn (2022), Khan and Shaheen (2022) and Transport Canada (2021).

Details of opportunities and challenges of electrification and digital technologies when modernizing public transit are discussed for four modes: regional commuter rail, rapid rail transit and light rail transit; fixed-route bus transit and bus rapid transit; on-demand microtransit; and micromobility. Using examples to illustrate the potential real-world impact of opportunities, differential impacts of digital technologies on vulnerable populations are noted.

Applications in rail: opportunities and challenges

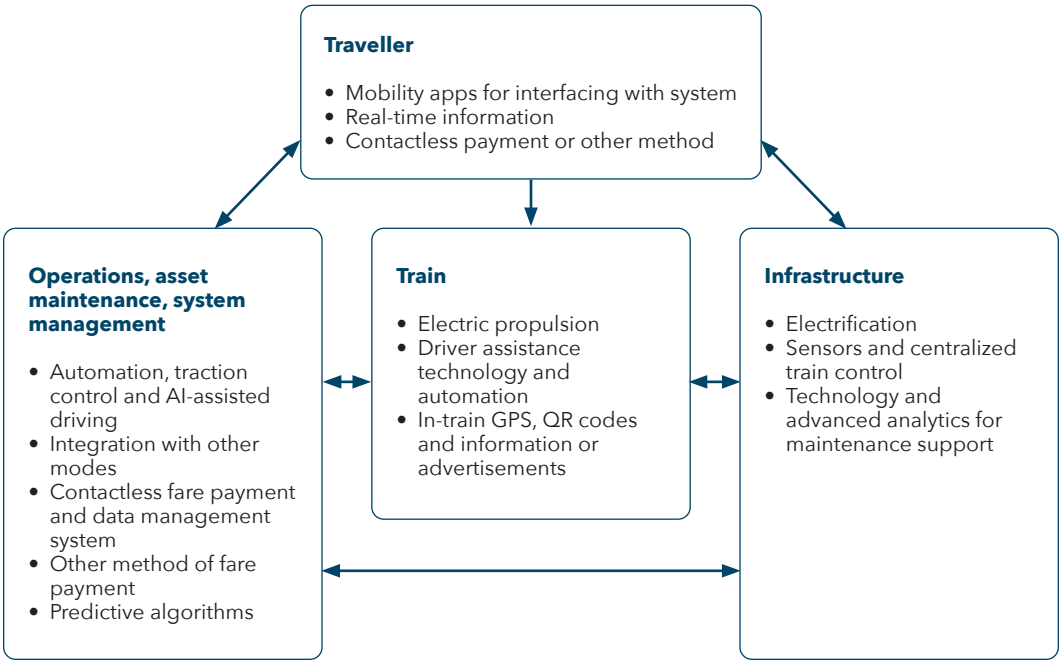
Among existing public rail transit, Vancouver's SkyTrain has the highest level of integrated digital technology: it is fully automated, such that a driver is not needed to manually operate the train. In the rapid rail transit and LRT systems of other Canadian cities, digital technologies assist in operations like traction control. Across all rail modes, digital technologies already assist with all interacting components

of transit (traveller, operations, maintenance and management system, train and infrastructure) (figure 9). Major research, development and demonstration of digital technologies designed for rail have created products either already implemented (in Europe and elsewhere) or ready for implementation. To define possible technology applications for rail in Canada, the findings of major studies in the subject area are taken into account (UITP, 2022a, 2022b).

In regional commuter rail service, diesel engines can be replaced with electric locomotives, and the catenary-type electrification (with overhead wires) of the railway line is commonplace. The efficiency, effectiveness and equity benefits of electrified rail include the following (Metrolinx, 2017):

- Reducing acceleration time and maintaining the top speed for a longer distance
- Storing regenerative braking energy for later use or putting energy back into the grid
- Saving time for customers
- Diverting travellers from vehicles to reduce road congestion and greenhouse-gas emissions
- Increasing service frequency to reduce reliance on scheduled trips and increase available seats
- Using savings from lower operating and maintenance costs to increase service frequency
- Enabling multimodal fare capability
- Introducing special fares for equity and other reasons
- Improving local air quality for customers and residents

Figure 9. Regional commuter rail, rapid rail transit and light rail transit: digital and transportation technologies



The barrier to catenary-based electrification is the high initial cost of the infrastructure and rolling stock (with integrated supporting digital technologies). For instance, the electrification of the GO train requires a multinational team and a multibillion-dollar capital investment. Other technologies that can operate without catenary installation on railway lines are hydrogen-powered fuel-cell engines and battery-powered engines, but these are costly solutions and there is a lack of operational experience in different service environments. In the case of hydrogen fuel cell technology, the cost of obtaining hydrogen from zero- or low-emission sources (or green hydrogen) is a barrier.

Applications for buses: opportunities and challenges

A basic form of urban public transit is the fixed-route bus service and, in some urban areas, fixed-route BRT is offered to respond to higher demand in specific travel corridors (see figure 10). As opposed to rail transit, buses serve lower demand in wider service areas, and flexible routes help enable on-demand service. Beyond eliminating emissions, there are numerous other benefits to implementing electric buses:

- Digital technologies are built into new e-buses (not available in diesel buses)
- Reduced cost of operation and maintenance over a bus's lifespan
- Improved efficiency and reliability
- Improved user services
- Lower noise levels
- Improved equity due to enhanced user interface technologies (e.g., for people with disabilities)

In terms of digital technologies, a bus manufacturer noted that the latest model of a battery-operated electric bus will feature a real-time, cloud-based dashboard to track and maintain performance by providing real-time analytics and support services. Data can be provided on battery charge; outside air temperature trends; GPS location; average speeds; heating, ventilation and air conditioning; energy consumption per kilometre; braking energy returned to the battery; achieved and remaining range of travel; and energy consumption (in kWh/km). Transit company personnel can retrieve these analytics via a computer, tablet or smartphone (Morris, 2019).

Barriers to electric bus transit (including built-in digital technologies) are the initial cost of the bus and charging infrastructure, the space needed to install chargers, and bus-only lanes. In large urban areas, depot space for chargers is limited, prompting some public transit agencies to consider building underground battery charging facilities. According to plan, Montreal's Bellechasse bus garage will be the first depot in North America to make use of underground space for e-bus charging (Yakub, 2023). When planning and designing charging infrastructure, smart energy management systems will be required to control the large amounts of electricity obtained from the grid.

Figure 10. Fixed-route bus transit and bus rapid transit: digital and transportation technologies

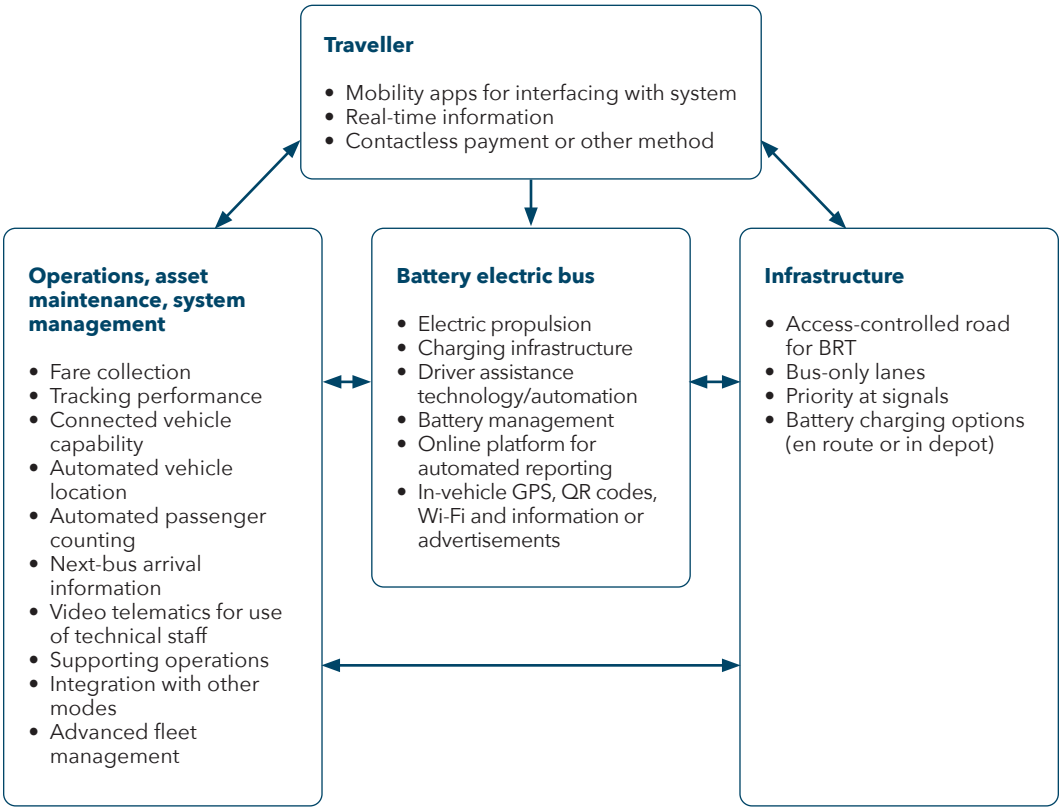
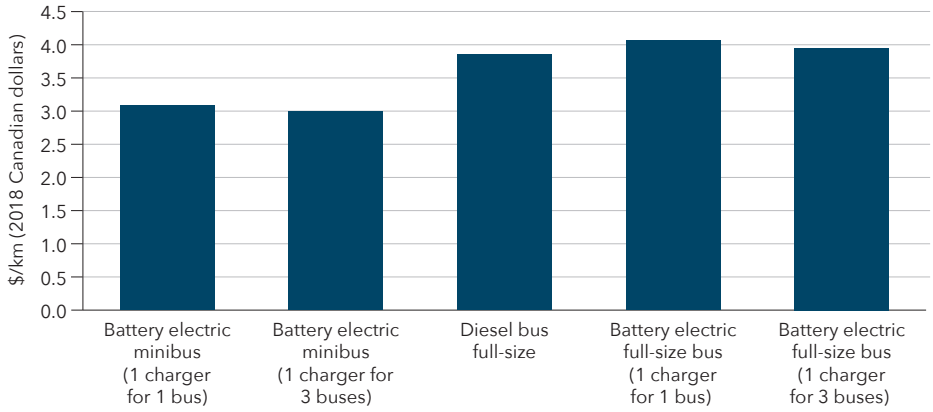


Figure 11. Life cycle cost of transit buses (2018 dollars)



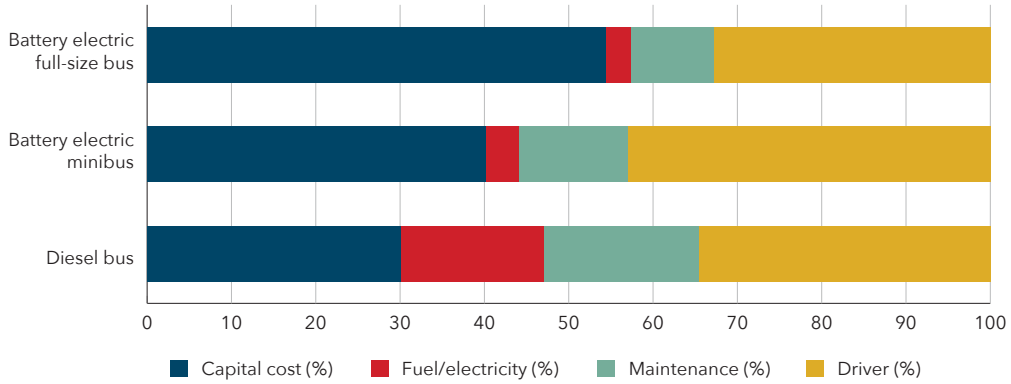
Source: Authors based on various data sources.

To weigh the benefits of implementing electric buses, it is important to understand the life cycle cost of various types of new vehicles. Figure 11 compares a battery electric full-size bus with an in-depot charger, a battery electric minibus with an in-depot charger and a full-size diesel bus. For the electric buses and minibuses, cost estimates for both one charger per bus and one charger for three buses are included. One charger per bus is more convenient but more expensive, while with one charger

for three buses the transit agency has to co-ordinate charging and repositioning buses in a depot. Based on its lifespan, the electric minibus has the lowest cost per kilometre ($/km) in 2018 Canadian dollars, though the driver cost is naturally higher than for full-size buses. The life cycle cost of the full-size battery electric bus is comparable to a new diesel bus, but its purchase price is nearly two times higher.

However, this is partly due to battery cost, which is dropping fast and will likely reach US$80 per kilowatt hour in the near future (U.S. Department of Energy, 2017). Also, battery capacity is improving to the extent that battery electric buses will be able to provide a range equivalent to a diesel bus. The life cycle cost of battery electric buses will also improve if electricity prices decrease (or remain stable at the 2018 price) and the price of diesel fuel increases (see figure 12).

Figure 12. Cost components of public transit buses (one charger per bus for electric)



Source: Authors based on various data sources.

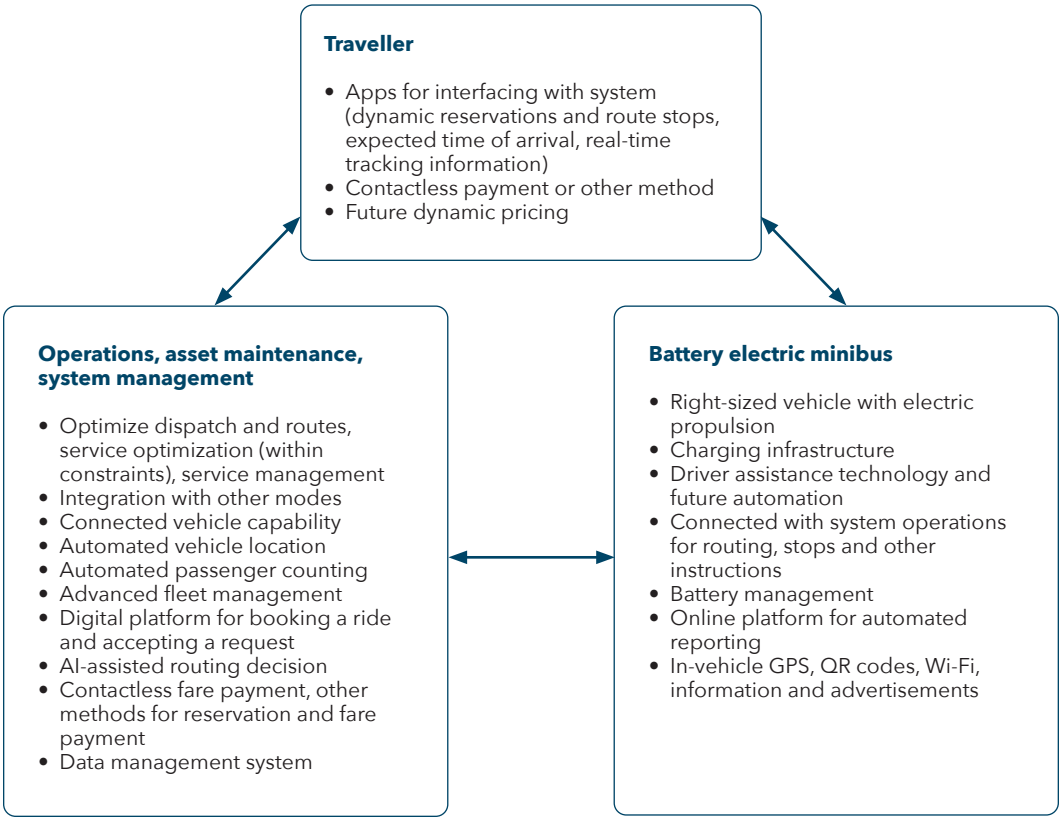
Applications in microtransit: opportunities and challenges

Ideally, cities could strive for a microtransit system that uses electric and technologically advanced vehicles, supported by an operations, management and maintenance centre (figure 13). This system would provide on-demand, right-sized vehicles to travellers who use an app or other method to request and pay for service. The digital technologies would enable the system to provide options like route flexibility (CUTA & Dillon Consulting, 2017; CUTA & Metrolinx, 2022; Park, 2023).

Given the on-demand nature of the service, which could be combined with special fare policies for vulnerable populations, equity of access can be improved in urban, suburban and rural areas.

To provide a right-sized vehicle for various service areas requires detailed research. One survey of transit systems operating on-demand services in the United States showed that most transit agencies used minibuses with capacities ranging from 12 to 26 passengers (Volinski, 2019). Reasons to use smaller vehicles (as opposed to full-size buses) include lower operating costs; ease of access to communities; increased acceptability in residential areas; easier navigation on narrower roads or rights-of-way, especially for door-to-door

Figure 13. Microtransit: digital and transportation technologies



service; better-suited capacity for low levels of ridership; and lower greenhouse-gas emissions (Klumpenhouwer, 2020; Volinski, 2019). Table 1 outlines various types of on-demand transit applications that have already been implemented, reflecting the demand to fill gaps in conventional public transit service.

Implementing on-demand transit in low-density areas will improve equity in shared mobility (Allen & Farber, 2019). Although paratransit service will be necessary in every city, microtransit services can help improve accessibility for those with mobility challenges.

The benefits of integrating digital technologies in microtransit include:

- On-demand service and convenient access to transit
- More sharing of mobility modes
- Provision of right-sized vehicle for the travel market
- Incentivized service (prebooking, discounted fares, variable pricing based on trip time or pickup location, customized pickup/drop-off locations)
- Refined origin and destination data to better understand customer travel needs
- Reduced emissions due to fewer car trips
- Reduced operation and maintenance costs over a minibus/van lifespan (compared to diesel or full-size electric bus)
- Improved service and fleet management

Table 1. Examples of on-demand microtransit (ODT) services

Type	Description	Example
First/last mile travel	Provide riders with connections to existing fixed-route transit hubs	Oakville, Ont. Edmonton, Alta.
Replacing low-performing routes	Replace a fixed-route service with ODT service for a specific catchment area	Calgary, Alta. York Region, Ont.
Off-peak and weekend service	Replace fixed-route service during specific times with ODT service for a specific catchment area	Belleville, Ont. North Bay, Ont. Sault Ste. Marie, Ont.
Overnight service	Provide transit service throughout an urban area during overnight hours, when demand is very low and scheduled fixed-route service does not operate	Durham Region, Ont.
Augment existing fixed route	ODT service to complement existing fixed-route services	Barrie, Ont.
New service	ODT service serving specific catchment areas where no transit systems or service exists	Calgary, Alta. Cochrane, Alta. Okotoks, Alta. Innisfil, Ont.
Overcoming barriers to service area expansion	Use ODT to expand the transit coverage area where a conventional fixed-route service would require additional funding, vehicles and operators	Hamilton, Ont.
Regional cross-jurisdictional service	New ODT service or replace fixed-route service to connect regional hubs across jurisdictions within a larger catchment area	Niagara Region, Ont.
Service to community hubs and centres	New ODT service to community points of interest	Calgary, Alta.
Service for specific populations (seniors, essential workers, etc.)	New specialized ODT service to serve populations with specific needs	York Region, Ont. Edmonton, Alta.
Paratransit and non-emergency transport	Augment service to eligible paratransit customers who do not have mobility aids or devices that require a fully accessible vehicle	

Source: *On-Demand Transit Toolkit*, CUTA & Metrolinx (May 2022).

- Improved equity (better service for people with mobility issues in low-density areas) (Allen & Farber, 2019; CUTA & Dillon Consulting, 2017; CUTA & Metrolinx, 2022)

Barriers to technology integration in microtransit include the initial cost of the electric minibus or van and the charging infrastructure, the limited availability of depot space for installing chargers and the lack of alternatives to apps for booking and fare payment (Klumpenhouwer, 2020). Alternatives are critical for achieving equity of access to a service and preventing a digital divide. Efforts by service providers to provide non-app methods for requesting and paying have been reported, namely call-in options (Volinski, 2019). In Innisfil, Ontario, residents who do not have smartphone access can call a toll-free number, available 24/7, to book their ride, which is then provided by Uber (CUTA & Metrolinx, 2022). For a planned on-demand service in Ottawa, an app, a website and a call-in centre will be available to book a ride (Crawford, 2023).

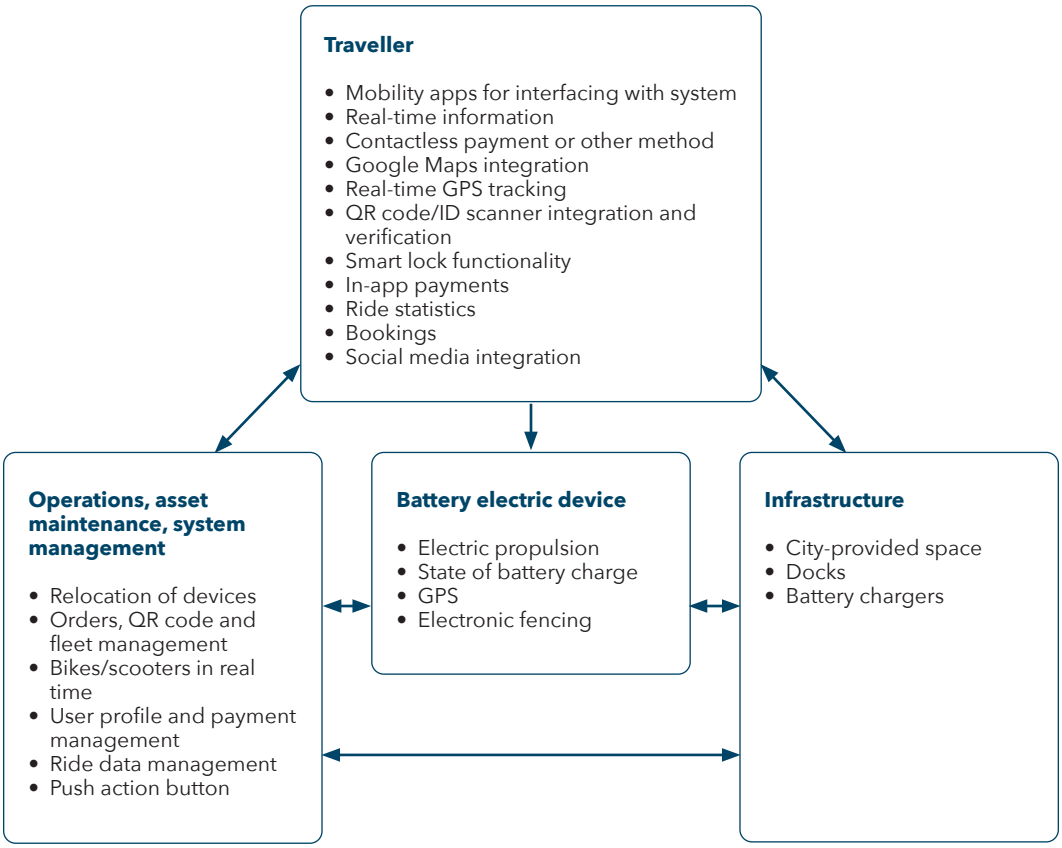
Applications in micromobility: opportunities and challenges

With careful planning, micromobility services can become a part of transportation developments, but the private sector dominates service provision. If allowed by a municipal government, a company sets up, operates and manages the system, and invests its capital in digital technologies such as internet systems, vehicle fleets, vehicle stations and data management systems (figure 14). To improve urban mobility options, municipalities offer public spaces for docking (Lauriault et al., 2021). Micromobility systems already rely heavily on digital technologies, offering e-bikes and e-scooters for rent for short periods of time. These battery-powered devices are internet-enabled and connect to platforms for travel and fleet management. In the dock system, a trip starts and ends at stations.

Other potential benefits of micromobility systems include the following (City of Calgary, 2023):

- Replace automobile trips for short distance travel
- Fill the gap for first/last mile travel
- Encourage taking public transit more often
- Save time on short trips
- Provide access to various transportation options for all demographics

Figure 14. Micromobility: digital and transportation technologies



While bikes or e-bikes and e-scooters are generally regarded as safe and sustainable methods of transportation, provided they are operated according to municipal rules, there are challenges with their implementation. These services use scarce urban space for docking. Also, these services collect sensitive personal data (including financial and movement data), which is vulnerable to attacks or mistakes. Furthermore, Ernst & Young (2022) noted that Canadian cities have been slow to adopt and expand e-bike and e-scooter services because of a lack of municipal micromobility regulations or frameworks; limited collaboration between micromobility operators and cities; neutral or negative public perceptions; harsh weather conditions; and safety concerns related to shared mobility users and pedestrians. Ernst & Young recommend flexible regulatory frameworks, and a data-driven approach to incentivize and penalize operators on their overall performance.

ROLE OF GOVERNMENTS IN ACCELERATING, EXPANDING AND GUIDING TECHNOLOGY ADOPTION

Funding and regulatory authority roles

As previously noted, transportation services for urban areas fall under the jurisdiction of provincial and municipal or regional governments, but substantial funding for infrastructure comes from federal and provincial and territorial governments. For small towns and rural areas, provincial and territorial governments or organizations (regional health associations, regional transit providers) may play a larger role. Direct transit investments are made by federal, provincial and territorial governments and there is also indirect funding (CUTA, 2013).

The latest federal investment in public transit, announced on March 2, 2023, amounts to $14.9 billion over the next eight years. This funding includes $3 billion per year in permanent federal public transit funding, which will be available to support public transit beginning in 2026-27 (Government of Canada, 2023b). The grant is intended for rural transit solutions (including on-demand transit), zero-emission transit and active transportation. Additionally, federal funding is available to accelerate major projects and support the expansion of large urban transit systems. Also, each public transit fund complements Canada's climate plan (Government of Canada, 2023b). There are also several joint federal-provincial funds used by municipalities to cover public transit capital costs, like the Canada Community Building Fund (CCBF, previously the Gas Tax Fund).

Provincial governments support capital and operating costs of public transit. The practice of fund transfer varies from province to province (CUTA, 2013), and Canada's few larger cities are allocated the majority of capital costs. Operating costs are rarely subsidized by higher levels of governments, meaning that it is quite difficult for municipalities with moderate or small populations to expand services. As described in the next section, there are also numerous bylaws, regulations, pilot-testing and public education programs that must be undertaken by municipalities, which means a significant investment in time and resources.

Addressing barriers to micromobility

Given that micromobility is typically a private-sector initiative and requires individual operators to engage with a municipality, provincial endorsement and support are critical. British Columbia and Alberta are examples, where cities as varied as Vernon, Richmond, Kelowna, Edmonton, Calgary, Red Deer, Lethbridge, Okotoks and Cochrane have implemented e-bike and e-scooter programs. For e-scooters, the provincial act governing the use of motor vehicles must allow their use, and the municipality must allow their use on municipal roads by passing a bylaw (City of Vaughan, 2023; Halifax Regional Municipality, 2023). In Vaughan, for instance, the use of e-bikes is permitted on most roads and highways, but not on provincial highways or municipal sidewalks.

Safety concerns have also been major considerations for municipalities adopting micromobility. Provincial regulations therefore typically determine the age of users, the use of helmets and the maximum speed. Calgary's contract with its e-scooter provider specifies a maximum speed of 20 kilometres per hour and prohibits use on major roads and in the winter (Sanderson, 2019). The City of Kelowna requires helmets to operate e-scooters and e-bikes, sidewalk detection technology, a hybrid lock and a floating parking model. Montreal has a shared bike and e-bike system, but did not renew its shared e-scooter program in 2020 because riders were not following regulations, which created a threat to public safety (Ernst & Young, 2022).

In addition to public safety, municipalities need to manage their impact on public spaces, by determining where e-scooters and e-bikes can be parked, and also decide on penalties for improper parking and whether the provider or the user receives the penalty. As noted, municipalities must decide where the vehicles can operate (roads only, roads and sidewalks), but also whether a permit is required, how they will integrate with other vehicles and pedestrians, and whether there should be a limit on the number of devices. They also need to protect themselves from indemnity by requiring that providers insure users.

The equity of micromobility is also an important concern. While micromobility solutions have become ubiquitous, offering short-term solutions and increased mobility access for those without a car and with lower incomes (Aman et al., 2021), they still reproduce inequities across neighbourhoods and populations. For instance, the City of Austin began operating shared electric micromobility in 2019, but an analysis of e-scooter and docked and dockless bike trips found that the services were mostly available in the central city such that 80 per cent of residents had no access to them. The majority of the city's transit-dependent residents had low access to the service and Asian and Black populations had the lowest accessibility, as they mostly live in the city's periphery. Aside from better geographical distribution to serve lower-income and specific racialized communities, municipalities and private operators must also consider how people with mobility challenges could access micromobility services, as well as people without credit cards or smartphones.

Since municipal bylaws usually limit the maximum number of devices, operators tend to maximize profits by providing services for able-bodied, high-income individuals

in central city neighbourhoods. As a counter to this, Provider Spin partnered with the City of Pittsburgh, local non-profits and researchers on a universal basic mobility pilot that offers easy access to transportation services for low-income residents. The project connects mobility services (e-scooters, trip planning, car-share, electric mopeds, carpool matching, charging stations, real-time transit information) into one transit application. Another example is San Jose, California, which requires that 20 per cent of micromobility devices be located in a Community of Concern (defined by the U.S. Department of Statistics); that providers offer discounted memberships to individuals at or below 200 per cent of the federal poverty level and waive any deposit fees; and that services and information be provided in English, Spanish and Vietnamese (University of California, Berkeley, 2023).

Another key aspect of implementing micromobility services is the provision of educational tools. Provincial or territorial and municipal governments already have well-developed programs to educate residents on the use of traditional modes of transportation, but each province has different regulations on the operation of bicycles. Users are more familiar with e-bike practices given their similarity to bikes. However, education on safe and proper use of e-scooters requires the attention of both provincial governments and municipalities. Specifically, according to the Traffic Injury Research Foundation (2022), education is needed on risks related to riding location, time of day, distraction and helmet use. For example, in Ottawa, local police have found that people ride e-scooters on sidewalks rather than remaining on the road, exceed the maximum speed of 20 kilometres per hour and leave them parked haphazardly on sidewalks, where they present a public safety hazard (Vardon, 2021). This is despite a very clear Government of Ontario webpage on e-scooters, and guidelines for municipalities participating in pilot projects (Government of Ontario, 2023).

Broadband service

Transportation technology innovations such as automated fare payment, provision of real-time information and micromobility apps require reliable high-speed internet. Canada's Universal Broadband Fund supports projects bringing high-speed internet across the country, including to rural areas, which currently have at least 5 Mbps download and 1 Mbps upload speeds. The goal is to connect all Canadians to 50/10 speeds, which are needed for cloud-based services and apps. In 2023, only 62 per cent of rural households had these speeds, compared to 91.4 per cent of urban households, and 12.8 per cent of roads and highways still lacked wireless coverage (Government of Canada, 2022, 2023c, 2023d). Connection at 50/10 speeds is expected to reach 98 per cent of Canadians by 2026 and 100 per cent by 2030 (Government of Canada, 2023c, 2023d). The federal government also has targeted funds for the more remote, northern parts of the provinces and territories using satellite services. However, constant demands for innovation and expansion may prove difficult for municipalities to manage without private companies (Brake & Bruer, 2021).

Data governance and privacy

Public and private agencies that contribute to mobility services collect user data using new digital technologies. All levels of government have a responsibility to protect personal information and uphold a user's right to expect safeguards against misuse of their information. For example, the United Kingdom announced a bill in November 2023 applicable to all sectors of the economy, which includes provisions to protect data, and harness the benefits of secure data use through innovation and technology (Prime Minister's Office, 2023). Currently, 27 of the American states have bills regulating data and privacy, and significant digital privacy laws have been passed in California, Virginia and Colorado (Descant, 2021). In Canada, the municipal, provincial and territorial governments have direct responsibility due to their jurisdictional role for mobility in urban areas. Metro Vancouver's Shared Micromobility Guidelines (TransLink Tomorrow, 2019) mention concerns about data collection and storage, including that Canadian Privacy Law requires employers to train employees and other staff about the management of personal information, as defined in *The Personal Information Protection and Electronic Documents Act* (S.C. 2000, c. 5).

The data that shared-mobility digital technologies capture, such as identities and movement patterns, are valuable, but sensitive. If used with well-developed precautions, data can benefit urban and transportation planning, and traffic management. But the privacy and security of identifiable data are paramount. If shared micromobility services are offered by private-sector companies, public agencies should enter into data-sharing agreements with private actors. Unfortunately, socially acceptable data governance approaches are not currently well defined and standards to promote data interoperability need to be updated.

Regulatory actions are required to permit and manage how micromobility technologies and data are deployed and integrated into public urban centres in a way that is collaborative and benefits all stakeholders, including the public (Lauriault et al., 2021). Portland, Oregon, offers an example of one way to minimize data collection. Different operators manage about 1,500 e-bikes and 2,500 e-scooters in the city, but the Portland Bureau of Transportation does not collect data on the whole trip, only on part of it – enough data to use in the bureau's planning purposes (Descant, 2021). Another option is to rely on third-party platforms to store and analyze data, such as SharedStreets, a nonprofit organization being used by cities such as Toronto.

Supporting the diversity of transit users

While most, if not all, municipal public transit agencies provide real-time information on their services, they should all also offer access to travel information using a telephone service for non-smartphone users. Policies regulating the provision of this type of information should be implemented, in addition to federal government plans to ensure all Canadians have high-speed broadband by 2030.

As mentioned early in this paper, there is often inadequate integration between land use and transportation planning because different departments produce land-use

bylaws and municipal or regional transportation plans. Better alignment could augment transportation options, particularly microtransit and micromobility for low-density areas. Some municipalities use land-use plans to designate corridors for future transportation infrastructure, which is necessary for long-term strategies. But rather than leaving implementation of bus lanes to individual municipalities, provincial governments could develop an educational resource to be used by municipalities in public meetings, as community acceptance of bus-only lanes is often contentious. Provincial governments could offer subsidies or technical expertise to municipalities that wish to prepare secondary plans for these areas, bringing together land use, transportation and housing into corridor plans. Municipalities that want to integrate e-scooters or e-bikes to supplement transit options in suburban areas might benefit from provincial subsidies for clean technologies, technical assistance with writing bylaws, as well as co-development of education and training tools on safe operation (aligning with provincial motor vehicles acts). Funding could be available to promote the use of the technologies in racialized and marginalized neighbourhoods, among new immigrants and refugees, and in Indigenous communities.

CONCLUSIONS AND RECOMMENDATIONS

Digital technologies can enable a new era of urban mobility, helping to achieve more equitable, efficient and effective public transportation systems. In combination with changes to land use and transportation planning, as well as improvements to the integration of modes of transportation, consumer-focused apps can improve the accessibility and convenience of public transit, and transit operators can benefit from improvements in the efficiency, effectiveness and sustainability of systems through digitally enabled planning and fleet management.

Public agencies at all levels of government are increasingly receptive to ideas for connected communities and modernized services, with special concern for the needs of vulnerable populations. The digital technologies that are changing urban transportation services are also providing the incentive to overcome the digital divide by ensuring universal broadband access. The electrification of public transportation also relies heavily on digital technologies and it is clear that early adoption of advanced technology-assisted electrification and decarbonization approaches will help achieve the environment and climate initiatives of all levels of government. Federal and provincial capital grants for these technologies are particularly needed in municipalities with moderate and small populations.

The electrification of commuter rail and the use of digital technologies to modernize all rail-based public transportation can improve the equity, efficiency and effectiveness of service. For instance, the savings from more efficient operations can be used to offer reduced fares for low-income commuters who travel long distances. Among other benefits of electrification and modernization are greenhouse-gas reduction, lowered other emissions resulting in improved air quality, and reduced noise levels in low-income neighbourhoods near railway tracks.

The Government of Canada funding programs announced in 2023 (including the Zero Emissions Transit Fund) are intended to help municipalities purchase new electric minibuses and full-size buses (despite the higher upfront cost compared to diesel buses) and associated chargers (Government of Canada, 2023b). These programs are a step in the right direction for addressing funding concerns expressed by public transit interests. For example, according to Robson (2020), more funds are needed to replace all diesel engine buses used for fixed routes, bus rapid transit and microtransit services. Capital funding is needed for both municipalities and regions and their transit operators. To modernize bus-based public transit, operators will need to order digitally advanced battery-electric full-size buses and minibuses, the charging infrastructure and the associated software, while municipal and regional governments and transit agencies need to allocate in-depot charging space. Canadian bus manufacturers and associated software developers will benefit from new demand.

Based on the United Nations metric of a 500-metre distance, accessibility to conventional public transit in Canada's few large metropolitan areas is very high. But accessibility is inadequate in some parts of cities and smaller urban areas. Integrating digitally assisted and on-demand microtransit and micromobility services in the transportation networks of Canadian communities will benefit all potential travellers in their complete trip from origin to destination. Greater collaboration across federal, provincial or territorial and municipal governments, as well as national groups such as the Federation of Canadian Municipalities and the Canadian Urban Transit Association would help ensure different sizes and types of communities are able to evaluate, implement and monitor new mobility services.

Microtransit and micromobility can serve those who lack access to private mobility alternatives or encounter gaps in the first/last mile of travel that cannot be filled by conventional bus transit for economic or other reasons. It is vulnerable groups that are most adversely affected by these gaps, including seniors, people with mobility challenges and low-income populations. Supported by better distribution of coverage, inclusive payment methods and discounted fare policies, microtransit and micromobility services have the potential to improve equity of access to public transit. Policy and planning studies are needed to better integrate mobility options; municipalities need to develop clear micromobility guidelines for safe operation and for parking and docking infractions; and they need to ensure data privacy through agreements with private providers.

For shared mobility to be as efficient and effective as possible, right-sized electric vehicles are needed that feature advanced digital technologies, but such vehicles are in short supply on the market. Several federal and provincial or territorial funding programs are available to help municipalities modernize and electrify their public transit, and the Government of Canada (2023b) has announced a new permanent public transit fund, for which public consultation took place in 2022 and 2023. However, detailed studies are needed to assess if the available money is sufficient to meet goals. Given the uncertainties of the new mobility era, more detailed studies are also needed on various other subjects related to public transit. And yet, from a review of past and present funding practices, it is not clear if there is a provision for a federal capital fund for ongoing research and development. The U.S. Department of Transportation's Transit Cooperative Research Program could serve as a reference.

Recommendations

Two main areas should be addressed:

1. **All levels of government should change their approach to funding and managing public transit to incorporate digital technologies and prioritize the equity and long-term efficiency of services.**
    a. **Municipal:** Review transit decisions through an equity lens. Governments need to do more to determine how vulnerable groups may be adversely affected by transit decisions and develop solutions to ensure the equitable distribution of benefits from transit investments. The impact of digital technology implementation on equity will depend on local decision-making. For example, cities moving to digital transit payment can continue to provide convenient payment options for those who do not have data-enabled phones or bank accounts.
    b. **Provincial/Territorial:** Encourage and enable integrated mobility. Governments should provide financial or regulatory incentives to integrate mobility across different modes of transport, leveraging the potential of digital technologies (e.g., allowing bikes on transit or connecting scooter-sharing options with online route planning). Funding, regulatory frameworks and deployment of digital technologies can help connect different transportation systems, improve user outcomes and reduce operating costs.
    c. **Federal:** Infrastructure funding should support operating costs and digital technologies. Infrastructure funding only supports capital costs, which disadvantages on-demand, right-sized transit options where driver wages represent the most significant cost barrier. Digital technologies should be eligible for funding since they can help optimize dispatch and routes, enable integration with other transportation modes, and improve the user experience through contactless payment, dynamic reservation and real-time tracking of vehicles.
    d. **All levels:** Break down silos in decision-making. Governments must break down silos in decision-making to better align investments and priorities in transportation, housing, infrastructure and land-use planning. Mechanisms should be in place to ensure projects achieve societal outcomes (e.g., regional or provincial emissions goals, equity goals).

2. **Target barriers to the deployment of technologies that can achieve more sustainable, equitable, efficient and effective public transportation.**
    a. **Safety concerns:** Shared micromobility options present various safety concerns. Strong regulation is needed on the age of use, helmets, speed limits and obstruction of sidewalks while also ensuring safer infrastructure. While most of this would be done at the municipal level, best practices could be shared by provincial and territorial governments. Digital technologies can help educate users and promote compliance.
    b. **Electrification of public transit:** Transit authorities and municipalities often lack the information they need to plan and make informed decisions with respect to digital technologies that can enable electrification of bus systems and

commuter rail. In addition to existing funding programs (Canada Growth Fund and Canada Innovation Corporation), enhanced federal and provincial research and development could support electrification in smaller municipalities that lack capacity. Programs aimed at supporting Canadian clean-technology companies can also target economic opportunities in digitally advanced battery electric buses (full-size and mini) along with charging infrastructure and associated software.

c. **Protection of digital information:** Municipal governments and transit authorities need support from federal and provincial governments to implement digitally assisted programs that benefit from collected information but protect data from misuse.
d. **Insufficient broadband service:** Municipalities may need to consider enhanced affordable high-speed internet options to support digital transportation assets such as transit controllers, traffic lights and digitally enabled public transit.

Canada's transportations systems are already transforming in response to technological change and efforts to reduce greenhouse-gas emissions. Governments at all levels have an important role to play in shaping this transformation in ways that improve the equity, efficiency and effectiveness of public transportation.

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