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Research Report

AN INTEGRATED APPROACH TO TRANSIT SYSTEM EVOLUTION

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An Integrated Approach to Transit System Evolution

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EXECUTIVE SUMMARY

About the Project

Recent transformational trends are changing the way we think about transportation and land use interaction in cities. On the one hand, technological innovations appear to be promoting rapid and potentially disruptive changes in transportation infrastructure and services. This includes the rise of new electric mobility modes and mobility service providers offering ride-hailing, carpooling, bikesharing, and other means of transportation. Looking ahead, connected and autonomous vehicles and highly integrated Mobility-as-a-Service (MaaS) platforms also stand to reshape how we travel. On the other hand, the global COVID-19 pandemic is also impacting the way we think about transportation and land use. Early evidence suggests the pandemic has dramatically altered travel behaviour and settlement patterns in many communities.

This knowledge synthesis project provides an up-to-date perspective on the transportation-land use system and the role of public transit within it. To do so, we first revisit the core works that inform the ways in which we think about the transportation-land use connection in cities. Second, we review recent literature on new transportation technologies and trends associated with the COVID-19 pandemic with a focus on how they have changed, and may potentially change, the transportation-land use connection. Third, we complete the synthesis of previous works through a reinterpretation of the transportation-land use connection through the lens of new technology to provide a conceptual basis for more integrated systems planning. In addition to the review activities, the project benefits from the co-creation of knowledge facilitated through three workshops with public, private, and not-for-profit sector stakeholders.

Key Findings

Compared to previous research into the transportation-land use connection, our reinterpreted system is rooted in an activity-based approach, generalizes the transportation system around mobility services, and incorporates new thinking on the links between transportation accessibility, travel behaviour, activity potential, and activity participation. We use the reinterpreted system to answer several thematic questions related to public transit's role within it considering the changes that have, and are likely to occur, over the next decade in Canadian communities.

First, can public transit alone affect land use change? Probably not – but the combination of transit service that offers accessibility benefits relative to other travel options with supportive planning and policy can create a compelling development context for realizing land use change.

Second, is there a role for land value capture for financing transit? Probably – while transit can create land value uplift, there are challenges associated with implementing large-area value capture strategies related to the timing, spatial extent, sources, and amount of uplift that can be captured. Still, smaller-scale joint development projects have the potential to offset some project costs.

Third, can we balance the transport and land use benefits from transit with social outcomes? We should try – land value uplift from transit can result in the least advantaged residents in society paying proportionately more of their income to live near transit or being displaced to areas where transit is less competitive. However, policy supports for affordable housing in new and established station areas, business stabilization plans, and community benefits agreements for transit projects can help in this regard.

Fourth, will new mobility technologies and trends lead to more suburbanization? Possibly – autonomous vehicles may contribute to suburbanization by decreasing transportation costs associated with more regional travel patterns. On the other hand, micromobility modes and services might help to urbanize the suburbs by better connecting individuals and households to more local destinations and improving first/last-mile connections to transit.

Fifth, do we need to rethink future planning for sustainability? Perhaps – information communication technologies, work-from-home and social distancing policies, and new transportation technologies can lead to more decentralization and driving. Nevertheless, face-to-face communication will continue to be an important driver of agglomeration in many sectors and as traffic congestion returns, mass transit and active modes will maintain their competitive advantage for moving people. Cities are also about more than work, and greater emphasis can be placed on planning to improve local accessibility.

Policy Implications

The review has revealed that we "know a lot" about transportation-land use interaction and the need for an integrated approach to achieve improved social, economic, and environmental outcomes. However, several barriers prevent major changes from occurring, including a largely private sector-driven land development process, a culture of automobility, fractured planning responsibilities, insufficient knowledge mobilization, and a lack of visioning and political will.

Nevertheless, we can use leverage points to intervene in the transportation-land use system and achieve meaningful improvements in system performance. These include treating all new greenfield development sites as an opportunity for master-planned complete communities, identifying suburban contexts with strong opportunities for urbanization such as shopping centres and arterial commercial strips, intensifying underutilized lands, using infrastructure interventions and computational approaches to improve transit performance and relative accessibility, and experimenting with mobility services and MaaS platforms to improve accessibility and transport equity in urban and suburban areas.

Such initiatives must be undertaken while recognizing feedbacks within the larger regional transport-land use system and pursued in partnership with developers and the public so that individual costs and benefits are balanced with a better understanding of improvements to society and the public good.

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INTRODUCTION

Transport systems have a significant impact on the efficiency, equity, sustainability, resiliency, and health of communities in Canada and around the world. We rely on transport systems to move people between locations where they carry out their daily activities. They also provide firms with access to labour markets, goods movement, and enable both the intensification and outward growth of cities. As such, the transport system is fundamentally intertwined with the use of land. For public transit, research has shown that it performs best when closely integrated with land use planning. This makes understanding the role of public transit in the wider transport-land use system of great importance for guiding effective policy and planning at all levels of government.

While there is a consensus around the relationship between transit and land use, recent transformational trends are changing the way we think about transportation and land use integration. On the one hand, new technologies are producing opportunities to make transportation systems more flexible, seamless, accessible, and affordable. On the other, technological change can be disruptive, leading to changes in transport mode usage and presenting challenges for multimodal and multi-ownership (public and private) system integration. Similarly, other trends may produce structural changes that affect preferences for particular modes or alter travel patterns, such as the ongoing COVID-19 pandemic. Within an interconnected system like transport, such changes can have ripple effects that alter outcomes ranging from land use planning and real estate markets to affordable housing and equitable access.

Considering these factors, an integrated approach is required for governments and transit agencies to conceptualize, manage, and plan transport systems over the next several decades. To that end, the proposed project reviews and synthesizes knowledge around several key questions: What are the theoretical foundations of how transportation shapes land use (and vice-versa)? What is the current state of knowledge on transportation and land use interaction? How are new technologies affecting modal shift and multimodal integration? What does the evidence show about the benefits that arise from synergies between transportation and land use? How have these synergies affected property markets and the potential for land value capture, as well as impacts on housing and social equity? How have travel patterns changed due to new technologies and the recent COVID-19 pandemic?

Although there have been academic debates over the strength and directionality of relationships in the transport-land use system in the past, an up-to-date perspective on this system through the lens of new transportation technologies does not yet exist. In response, this project revisits core theories, reviews recent research, and reinterprets the transportation-land use relationship in light of the challenges and opportunities that have occurred and are likely to occur over the next decade in Canadian communities.

The objectives of this synthesis are to first assess the state of knowledge about the transportation-land use connection, identifying research strengths and gaps. Second, the project team evaluates the quality, accuracy, and rigour of the reviewed works. Third, we use the results of the synthesis as a foundation for mobilizing the perspectives and expertise of academics and stakeholders in government and the private and not-for-profit sectors on the role of public transit in Canadian communities in the future. In doing so, this work fills a critical gap in our knowledge regarding the role of public transit in the face of new and potentially disruptive changes to the transportation system.

METHODOLOGY

Literature reviews in the field of transportation have been criticized for often lacking specificity and rigour in their methods (van Wee & Banister, 2016). To overcome this, the present work organizes its review and synthesis around three research modules: revisiting the transportation-land use connection, reviewing recent literature regarding new technologies and trends, and reinterpreting the transport-land use relationship for integrated systems planning. For the first module, we engaged in a targeted review of major works by drawing on the knowledge bases of team members to select relevant works. Where appropriate, this list was expanded to include information on new methods, techniques and debates. This synthesis is presented in Part 1 of the report.

The second module adopted a much wider approach to reviewing the literature on new transportation technologies and trends. The review activities were organized around key concepts relevant to each theme. For new transportation technologies, we utilized Google Scholar to search for papers focused on keywords such as autonomous vehicles, ridehailing, micromobility, on-demand transit, and information-communication technologies. For new trends, we focused on research relating to the COVID-19 pandemic's effects on travel behaviour, including keywords such as mode and location choices, remote work, and face-to-face communication. When they were available, we utilized findings from existing literature reviews, synthesizing them to this project's more aggregate transport-land use system narrative. To fill in remaining gaps or update some reviews, research papers were only selected for review if they focused on transportation and/or land use issues. Moreover, due to the deluge of substandard research associated with the pandemic (Bramstedt, 2020), we placed significant emphasis on papers published in major high-quality peer-reviewed journals. Grey literature is also used to contextualize some information where appropriate. Finally, Part 3 of this research engages in a value-added synthesis consisting of a critical appraisal of results and the formulation of forward-looking conclusions.

KNOWLEDGE MOBILIZATION ACTIVITIES

To mobilize knowledge in this project, we engaged in three workshops with stakeholders from the public, private, not-for-profit, and academic sectors. Each workshop was planned around the three major themes of the project: *1. Revisiting the Transportation-Land Use Connection*, *2. Reviewing New Technologies, Trends and the Transport-Land Use System*, and *3. Reinterpreting Transport and Land Use for Future Integrated Systems Planning*. All together we welcomed 64 unique attendees from 23 different entities (Appendix 1) across all three workshops with 39, 36, and 23 attending workshops 1, 2, and 3 respectively. Workshops 1-2 began with the dissemination of findings obtained from the review and synthesis activities outlined within the individual modules. Following this, we shifted to a collaborative forum where participants engaged with the material through roundtable discussion sessions led by project team members that were oriented to topical questions. Finally, report-back activities summarized the key points raised in the roundtables, enabling the co-creation of synthesized knowledge that was instrumental in shaping the outcomes of this project. Workshop 3 adopted a similar structure, but rather than a roundtable discussion, we summarized the major findings of the synthesis and hosted an open plenary discussion about the challenges and opportunities associated with realizing integrated systems planning in the Canadian context.

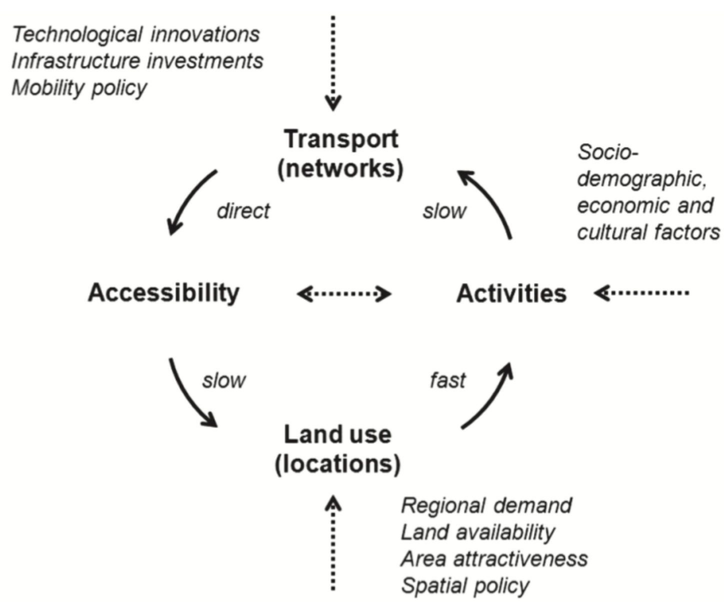
PART 1. REVISITING THE TRANSPORTATION-LAND USE CONNECTION

The first objective of this research synthesis is to revisit the core theories and methodological frameworks that inform the way we think about transportation and land use as an integrated system. Decades of research suggest that changes in transportation networks influence the location choices of households and firms and patterns of development. Likewise, land use patterns influence the design of the transportation network (including its modal composition and level of service) and impact the number and type of trips made on it. This relationship is known as the transportation-land use connection and it rests on core works that cover a variety of topics.

The Transportation-Land Use Connection

Transportation and land use exist within an integrated system (Figure 1). This makes it particularly difficult to examine one aspect in isolation of the other. At a high level, Giuliano (2004) discusses the characteristics of the urban system where transportation infrastructure reduces travel impedance or the transportation costs associated with the friction of distance and improves accessibility to destinations. This accessibility impacts the location of land uses and the activities they contain. The combination of transport accessibility and land uses affects travel patterns and manifests as flows on the network. Giuliano notes that although this model details the interdependencies between transportation and land use and how changes in one aspect affect the others, it does not imply anything about the strength of these relationships.

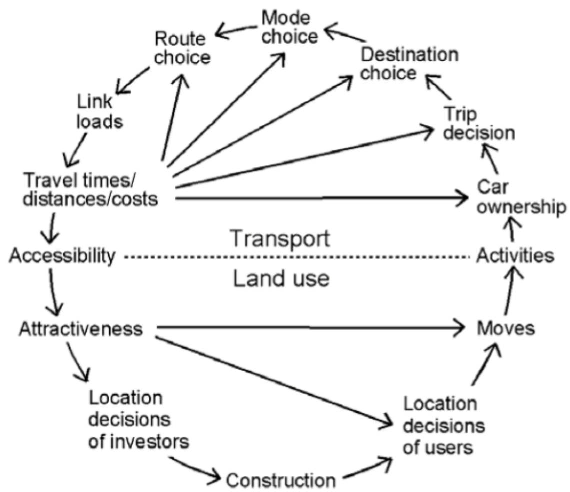
Figure 1. The Transportation-Land Use Connection



Source: Bertolini (2012)

Other researchers have offered versions of the urban system graph. Bertolini's (2012) graphic shown in Figure 1 offers more detail on the factors that affect different aspects of the urban system, including the role of technological innovations, infrastructure investments, and policy choices on the development of transportation networks, factors influencing the land development process, and the socioeconomic, demographic, and cultural factors that influence the availability of activities. Bertolini also includes some indications of the temporal dynamics involved in system change. In contrast, Wegener's (1996) version shown in Figure 2 is more oriented to travel behaviour and locational decisions within a more static transportation system. The report will draw on both examples in proposing a reinterpreted transportation-land use system in Part 3.

Figure 2. Land Use Transport Feedback Cycle



Source: Wegener (1996)

A key concept within this framework is *transportation accessibility*. As summarized by Geurs & Van Wee (2004), accessibility has been defined as "the potential of opportunities for interaction" (Hansen, 1959), "the ease with which any land-use activity can be reached from a location using a particular transport system" (Dalvi & Martin, 1976), or "the benefits provided by a transport/land-use system" (Ben-Akiva & Lerman, 1985). Geurs & Van Wee (2004) define accessibility as "the extent to which land-use and transport systems enable individuals to reach activities or destinations by means of a transport mode".

Whichever definition one adopts, a key determinant of accessibility is the friction or cost associated with travel. Such travel costs are typically measured in terms of distance, time, or money, and accessibility measures capture the elements of spatial or spatio-temporal proximity through the travel costs associated with travel on the transportation network and the attractiveness of opportunities available at destinations reachable from the origin. While accessibility measurement and accessibility planning constitute an active area of scholarship that we cover in more detail further below, the concept of accessibility is essential to more general urban economic models of the city that underpin our understanding of why cities exist, how they develop, and how they are shaped by transportation technologies and integrated planning.

Urban Economic Foundations: Transportation Costs and Spatial Structure

In traditional urban economic models of the city, urban forms and functions are fundamentally shaped by accessibility, which is often framed in terms of transportation costs and transportation technologies (Glaeser & Kohlhase, 2003). Early firm location models from Christaller (1933), Lösch (1944), and Isard (1956) assume that the primary force shaping economic decisions is the cost of moving goods over space. Similarly, transportation costs are key aspects of the foundational models of urban economics. This includes the monocentric city models of Alonso (1964), Muth (1969), and Mills (1972), hereafter referred to as the AMM model, where urban land uses and development intensity are a function of transportation costs (see Box 1 below). Per Glaeser and Kohlhase (2003), transportation technologies are implicit in the AMM model with transportation costs consistent with cities built around walking and transit for moving people to the central business district.

These models capture the essence of historical urban forms and economies at the turn of the 20th century when transportation costs were high. While the friction of distance has fallen dramatically over the past century, transportation costs and technologies still shape cities with respect to four concepts from urban economics that underpin our understanding of the relationship between transportation and land use in cities: spatial or locational equilibrium, agglomeration economies, transportation technologies, and government policy (Glaeser, 2008).

Box 1. The Standard Urban Model

The spatial equilibrium model of Alonso (1964), extended by Muth (1969), and Mills (1972), seeks to explain the patterns of urban land use. Miron (1982) and Brueckner (1987) offer summaries of the fundamental aspects of these models. The theory is built on a foundation of spatial equilibrium and land uses are determined in a competitive land market where a parcel is allocated to the highest bidder. The use of a particular parcel is thus a function of willingness to pay amongst business, industrial, residential, and agricultural uses. All parcels in a city have *site advantages* in terms of the internal characteristics of the site such as its ease of development, and *locational advantages* such as accessibility to markets, labour pools, or proximity to major transportation facilities. Firms consider their *normal profit*, or the profit that is required long-term to maintain the business, and *excess profit* above and beyond the required normal profits. For commercial and industrial uses, firms bid up the price of land at different sites to the point at which their excess profits reach zero, and the site is ultimately allocated to the highest bidder. This highest bidder is the firm whose excess profits at that parcel would be maximized due to the match between their business and the site and locational advantages of the parcel.

Box Figure 1. Hypothetical Monocentric and Polycentric Urban Structures

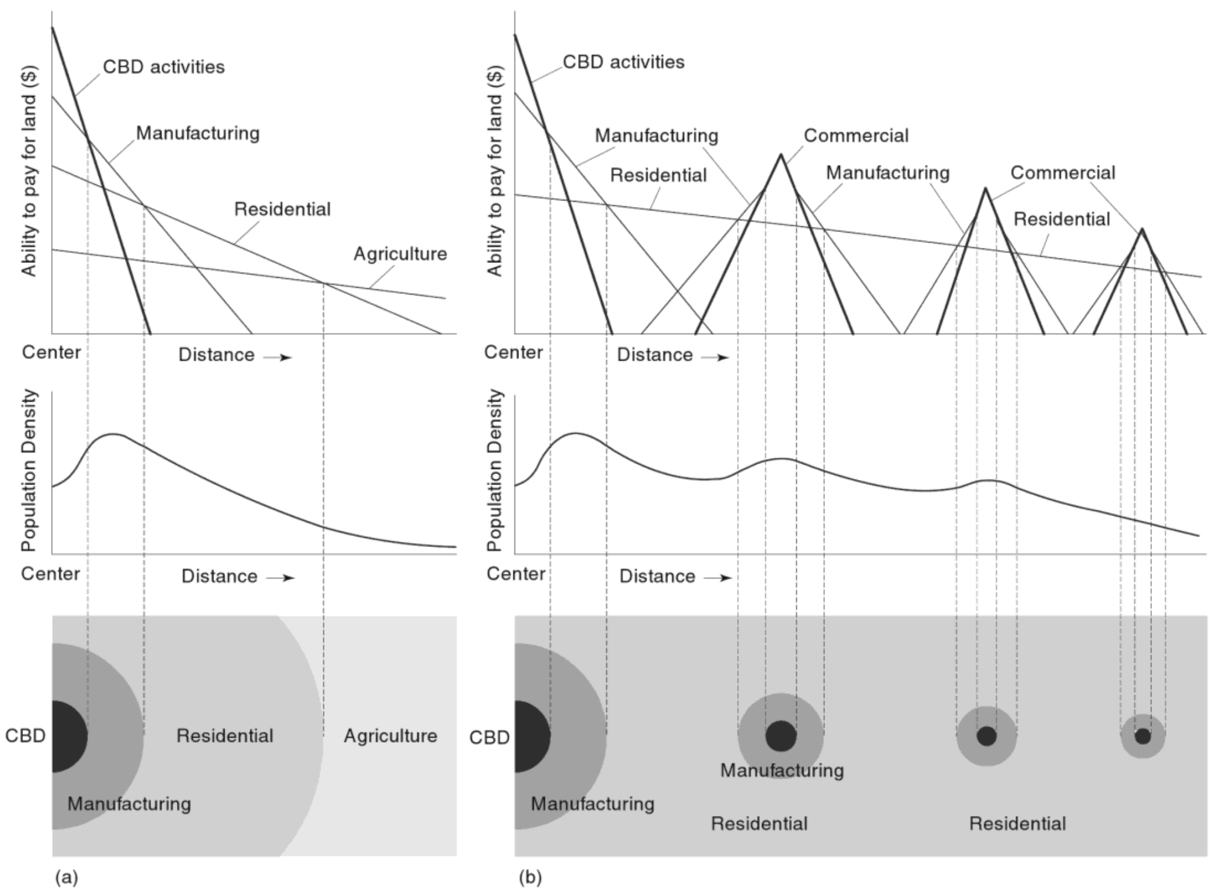


Figure from Clark (2000), a: adapted from Bourne (1981); b: adapted from Cadwallader (1996). Reproduced with permission from Wiley-Blackwell.

On the household side, households consume land, measured in terms of lot size or living area, and other goods such as food and clothing. The purchase of land and other goods is assumed to generate a level of utility or satisfaction. Households also spend some proportion of their income on commuting to jobs in the central business district. Like firms, households compete for land and will bid up prices where the attainable utility level is high. Assuming the price of goods is constant across the city, for a particular group of households with the same utility level and income, the price bid for a given location is a trade-off between living area and commuting costs. This trade-off emerges, in part, from residential developers maximizing their profits in accessible locations by building more densely. In suburban areas, this leads to housing that is lower in cost per square metre of living space and larger homes on bigger lots. However, commuting costs absorb a larger part of the household budget and less is spent on other goods and services. In more urban settings, greater accessibility leads to lower commuting costs and more income spent on goods and services, but these commuting savings are offset by a higher per square metre cost of housing and smaller homes. With transportation costs a key component of the model, the result is an urban form with different uses competing for locations high in accessibility and higher density uses on more expensive land (Box Figure 1 Panel A).

The Alonso-Muth-Mills model can be criticized along several dimensions. Perhaps the biggest criticism is that the monocentric assumption of the model is at odds with a world in which cities are increasingly polycentric and major employment centres are located far away from the old central business district (e.g. Giuliano and Small (1991)). In response, researchers have extended the Alonso-Muth-Mills model to include more than one employment node (Box Figure 1 Panel B) and the prediction is that in cities that are more decentralized, the relationship between distance from employment nodes and housing prices is flatter (Fujita & Ogawa, 1982; Glaeser, 2008; Henderson & Mitra, 1996). Other criticism includes its simplified views of urban land markets, a reliance on spatial equilibrium, and assumptions of utility-maximizing behaviour (Miron, 1982), as well as its ignorance of the urban transportation system and treatment of housing based on a single attribute (Brueckner, 1987). However, despite its limitations, the Alonso-Muth-Mills model maintains a great deal of attraction. According to Glaeser (2007), the model's strength lies in its ability to make predictions that hold generally, not in its ability to explain the exact peculiarities of particular places.

Spatial Equilibrium

First, the concept of spatial or locational equilibrium is that all locations around a city offer an equivalent level of utility given their prices. Prices adjust to achieve locational equilibrium for people and firms and as a result, no entity has an incentive to change locations. While spatial equilibrium is never quite achieved in constantly changing cities, this simplifying assumption provides a foundation on which the other aspects of the urban economic models of cities are built. In practice, the concept of spatial equilibrium relates to trade-offs that occur when selecting a location. This could mean a household trading off between living in a costly apartment in the urban core that offers shorter travel times to a variety of destinations reachable by transit, bicycle, or foot, or a larger house in a suburban area that requires longer travel times to reach amenities. In both scenarios, the utility the household derives from living at either location is assumed to be equal.

Agglomeration

Second, agglomeration economies exist whenever individuals and firms become more productive through proximity to one another. The centripetal forces of agglomeration economies arise due to centrality, or that the nature of the city as a place of closeness negates much of the friction of distance for transporting goods and information, which in turn facilitates lower costs and higher productivity. However, transportation costs in terms of the physical movement of goods have less of a role in creating and maintaining agglomeration economies in modern cities. Innovations in transportation technologies, which will be discussed further below, have reduced the importance of traditional transport hubs such as ports or railroads. But while agglomerations based on transport costs for goods have all but disappeared, Glaeser (2008) notes that agglomeration based on reducing the transport costs of people and ideas remains (and indeed has increased over time). As a result, today's cities are increasingly oriented to high-value business services and innovation where face-to-face contact still matters. This need for face-to-face contact, alongside transportation costs for people movement, still acts as a centripetal force for higher density development.

Transportation Technologies

Third, transportation technologies have had a fundamental impact on the shape and character of cities for as long as cities have existed. For example, the shape of the monocentric city is largely a function of pre-20th century transportation technologies, with both New York and Chicago growing around their ports and later their rail hubs. When moving goods by sea or rail was more cost-effective than road, proximity to sea or rail terminals offered a locational advantage for firms to be more productive. However, innovations in transportation technologies over much of the 20th century, such as trucks and cars, led to dramatic declines in the cost of shipping goods and moving people (Glaeser & Kohlhase, 2003). Glaeser and Kahn (2003) argue that the dominance of the automobile over other modes was essentially complete by the turn of the century. Per the Alonso-Muth-Mills model, this reduction in transportation costs should result in an erosion of the agglomerative properties of the monocentric city with lower transportation costs causing the spatial extent of the city to expand and densities to fall. Indeed, this reduction in transportation costs has been cited as one of the key drivers of the dispersion of households and firms into suburban areas throughout the second half of the 20th century (Glaeser & Kahn, 2003; Handy, 2005).

Government Policy

Fourth, government policy can have a profound effect on shaping growth in cities. This can come through enabling transportation technologies and the construction of transportation infrastructure. For example, Baum-Snow (2007) notes the case of federal highway construction in the United States and its role in facilitating the dispersion of people and jobs to sprawling suburban areas. Land use planning is just as important as one of the primary tools governments use to shape how, where, and when growth occurs (Glaeser, 2008). Other government policies have also been identified as factors contributing to urban decentralization and locational dispersion in the United States, including subsidies for highways and sprawl (Glaeser & Kohlhase, 2003), market failures regarding the social benefits of open space, the true cost of infrastructure required to service suburban developments, and the social costs associated with commuting behaviour (Brueckner, 2001), as well as zoning controls that prohibit intensification in cities and push development to the urban fringe (Glaeser & Kahn, 2003).

Transportation-Land Use Connection in Practice

While these models provide general insight into why cities exist and the characteristics that influence their spatial structure, researchers have long questioned the strength and mechanisms of the transportation-land use connection in shaping urban form, travel behaviour, and other social, economic, and environmental outcomes. This section provides an overview of major debates in the field and the current state of knowledge regarding different elements of the transportation-land use connection depicted in Figure 1.

Transportation Costs and Decentralization

The 1990s and early 2000s saw increased debate around the strength of the transportation-land use connection. While urban economic models noted the strong role of transportation costs in shaping cities, these models tend to be crafted under the assumption of high costs for the movement of people and goods associated with travel primarily by rail and by foot. However, the 20th century saw a dramatic decline in transportation costs due to the invention, miniaturization, and widespread adoption of the engine to power cars and trucks. For industry, these reduced absolute costs combined with a shift to high-value goods production has meant that firms are not likely to place a significant value on transportation costs when selecting a location, with Glaeser and Kohlhase (2003, p. 199) stating "it is better to assume that moving goods is essentially costless than to assume that moving goods is an important component of the production process." In addition to reducing movement costs, Glaeser and Kahn (2003) note how cars and trucks eliminate the scale economies associated with the fixed costs of older transportation technologies like rail and shipping, further reducing the agglomeration benefits of locating around terminals.

In line with what the AMM model would predict, reductions in transportation costs are associated with urban spatial expansion and sprawl. Brueckner (2000) argues that in addition to falling transportation costs, excessive spatial expansion in the United States also results from population growth driving demand for development and rising incomes causing households to demand more living space and bigger dwelling sizes (see additional discussion related to demographics further below). This combines with three market failures to drive suburbanization: a failure to take into account the social value of open space, a failure to recognize the social costs of congestion, and the failure of the development process to account for the public infrastructure costs generated by peripheral development projects and making development artificially cheap. To this Glaeser and Kahn (2003) add environmental externalities like air pollution and greenhouse gas emissions from driving and note the role of zoning in restricting new housing supply in built-up areas and driving decentralization in many cities.

This reduction in transportation costs and the underperformance of large investments in urban rail transit in the 1970s and 1980s (e.g. Cervero and Landis (1997)) led researchers to question how strong a role transportation costs play in contemporary locational decisions and the ability of transit to shape cities. Guiliano (1995) argues there is overwhelming evidence that public transit projects alone are not an efficient means for affecting land use patterns within this context. Reasons for this include modern metropolitan areas having well-developed transportation systems so that even large investments in new infrastructure will only have an incremental effect on accessibility, the durability of the built environment, and that transportation costs are so low that transportation considerations are of declining importance in the locational decisions of households and firms.

Transportation Costs and (Re)Centralization

Although much of the narrative about cities in the late 20th century was regarding urban sprawl, the turn of the 21st century saw the reversal of urban flight and disinvestment in several cities across the United States. This process has been referred to as the "back-to-the-city" movement (Sturtevant & Jung, 2011), the "fifth migration" (Fishman, 2005), and the "great inversion" (Ehrenhalt, 2012), amongst other names (see Hyra (2014)). This section discusses some of the forces related to transportation costs informing centripetal growth in cities, including traffic congestion and the importance of face-to-face contact in the knowledge economy.

First, while the decline in transportation costs over the 20th century has had a decentralizing effect on cities, the personal automobile and the urban form associated with it can also act as a contradictory force for centralization and intensification. The ascendancy of the automobile is based on time savings and flexibility. However, by impacting the monetary, as well as the travel time (duration and variance), physical, and mental costs of transportation, congestion can increase transportation costs and reshape the form of cities. Part of this relates to the concept of constant travel time budgets that imply an upper bound on time spent commuting and suggest that traffic congestion is to some degree "self-limiting" as delay causes individuals to make alternative travel mode and locational choices (Metz, 2021). As the costs of moving people and goods by automobiles and trucks increase, both firms and individuals may again find an economic advantage in density and agglomeration. There is some evidence that traffic-related increases in transportation costs are affecting the locational decisions of individuals and acting as a centripetal force for urban growth. Ehrenhalt (2012) offers the example of Atlanta, where the most frequently cited reason for moving away from suburban areas to the central city amongst the middle-class is traffic.

The second factor affecting contemporary urbanization is agglomeration benefits that arise from face-to-face contact in the post-industrial city. At their most basic, cities are density or the absence of physical space between people and firms that minimizes the friction of distance in the movement of people, goods, and ideas (Glaeser & Gottlieb, 2009). As discussed above, innovations in transportation technologies have eroded the benefits of agglomeration for people and goods movement, although congestion remains an important cost. Likewise, observers such as Friedman (2007) have argued that innovations in information communication technologies (ICTs) such as e-mail, mobile phones, and the internet have lowered barriers to communicating ideas over space, leading some to predict the "death of distance" as a factor impeding the transmission of information (Cairncross, 1997). In this sense, it is not that the costs of physical transportation will continue to fall, but rather that ICTs will cause activities to become "footloose", physical transportation to become redundant, and agglomeration economies to disappear (Rietveld & Vickerman, 2004).

But despite the proliferation of ICTs, it appears that cities still offer agglomeration advantages based on the exchange of ideas or tacit knowledge. At a higher level, several authors have depicted a new geography of employment in the knowledge, creativity, and innovation sectors, driven by high levels of human capital and with workers drawn to cities rich in urban amenities (e.g. Florida (2002), Glaeser and Kolko (2001), Moretti (2012), Storper and Scott (2009)). The notion that cities exist to expedite the flow of ideas and create knowledge spillovers that facilitate innovation has long been recognized (Jacobs, 1969). At a smaller scale, the success of firms engaged in the innovation economy depends both on human capital and proximity, resulting in what Glaeser (2011, p. 6) calls the "paradox of the modern metropolis", wherein the density of knowledge and human interaction has become ever more valuable even as the cost of transporting goods, people, and information over long distances has fallen.

Part of this stems from differences in how the different types of knowledge used in the process of innovation are shared. Based on the work of Polanyi (1966), a distinction is made between *explicit knowledge* (or codified knowledge) and *tacit knowledge* (or scientific knowledge). Explicit knowledge is more formal and can be transmitted in systematic language and has a singular meaning and interpretation. In contrast, *tacit knowledge* is "vague, difficult to codify, and often only serendipitously recognized." (Audretsch, 1998, p. 21) According to Gertler (2003, p. 89), Polanyi "conceives of tacit knowledge as an understanding of 'know-how,' acquired through experience. It is cognitive in the sense that it defies conscious articulation – meaning that (i) we may not even be aware of it, or the way it influences our behaviour, and (ii) even if we are, when we try to articulate or explain it to someone else, communicating this knowledge in verbal, written, or diagrammatic form will never be fully equal to the task. For these reasons, tacit knowledge must be learned by demonstration, imitation, performance, and shared experience."

As a consequence, the sharing of tacit knowledge is highly dependent on spatial proximity and face-to-face communication and, in contrast with codified knowledge, does not lend itself to easy communication via ICTs. Similarly, Rietveld and Vickerman (2004) argue that face-to-face contact will remain important for fostering trust between parties. With trust being a foundation of many types of social and commercial interactions, this will result in significant distance decay effects on the dispersion of particular activities. Extending this within the framework of the AMM model, the costs involved in the transmission of tacit knowledge and building relationships through shared trust should act as a force for agglomeration in contemporary cities.

Transportation, Land Use, and Travel Behaviour

Researchers have long been interested in whether, and to what extent, different aspects of the transportation-land use connection influence travel behaviour and the social, environmental, and economic outcomes associated with how people travel in cities. This research area considers the left-hand side of the transportation-land use connection depicted in Figure 1, where the transportation system and land use combine to influence the activity and travel patterns of individuals. However, emphasis in this section is on transportation or land use initiatives in isolation.

On the transportation network side of this relationship, evidence has shown that increases in transportation mobility can have a profound, but complex effect on the transportation-land use system. On the one hand, as detailed above, new transportation infrastructure such as a new highway can increase mobility, reduce travel times, and spur more decentralized patterns of growth and development. But in terms of how these changes manifest into travel behaviour, research has found some interesting relationships. First, while improvements to the transportation network can lead to increases in mobility, research into travel time budgets suggest a near-universal time spent commuting at around 1 to 1.3 hours per person every day, on average (Ahmed & Stopher, 2014). Within this context, researchers such as Metz (2008) have questioned the role of travel time savings in cost-benefit analysis, as it appears that any travel time savings from new infrastructure simply cause individuals to consume more distance rather than save time, at least in the aggregate.

Second, the ability of transportation infrastructure investment alone, such as building new highways or adding lanes, to solve complex transportation-land use issues such as traffic congestion and sprawl seems limited due to induced demand. This is because over the long-run, new and improved roads divert traffic from other links and modes, awaken latent demand in the form of additional travel that otherwise would not have occurred, and generate new trips through development along new roads (Noland & Lem, 2002). The combination of induced demand as the "fundamental law of traffic congestion" (Downs, 1962) and constant travel time budgets suggests that even if new highways or transit lines reduce traffic in the short term, it will soon return to fill the available road capacity up to some equilibrium point at which congestion levels are just tolerable for drivers.

Shifting auto trips to public transit or active modes has long been considered one way to reduce traffic congestion and improve social outcomes in cities. However, it has been argued in the past that despite higher purchase and operating costs than other modes, reliance on the car for commuting in the United States is essentially "complete" (Glaeser & Kahn, 2003). Part of this stems from more suburban forms of development essentially requiring cars for travel - in auto-dependent countries, automobile ownership is a strong predictor of activity participation (Morris et al, 2020). Another aspect is the low cost of automobile travel, with Glaeser and Kahn (2003) arguing that the mode offers tremendous time-saving advantages compared to transit when viewed across the United States. However, car travel is heavily subsidized, whether through drivers not paying for the pollution and the congestion they impose on others, the use of property taxes to pay for road maintenance, the widespread provision of free parking, and low operational taxes such as the gas tax (Giuliano, 1995). In this environment, Giuliano (1995, p. 9) argues "We should not be surprised that efforts to shift travel to other modes, either by promoting higher-density land use patterns or building massive rail systems, are doomed to fail if current automobile pricing policies are maintained."

While many cities pursued large-scale investments in public transit in the 1970s and 1980s, researchers were beginning to recognize the shortcomings of these projects in terms of achieving their transportation and land use goals. The Bay Area Rapid Transit (BART) system was the focus of much of this work, with Webber (1976) noting that the system failed to meet its stated objectives related to strengthening downtown, eliminating traffic congestion, and densifying suburban areas in pursuit of a more polycentric development. Research conducted on the BART system 20 years later arrived at many of the same conclusions (Cervero & Landis, 1997). Other papers examined the failure of contemporary transit investments to shape land use development (1977a) and meet cost and ridership projections across the United States (Pickrell, 1992).

On the land use side, previous research has explored the role of urban growth boundaries or "greenbelts", zoning controls, and tax policies in the decentralization of urban growth. In the United States, Pendall (1999) found that land use controls that shift development costs onto developers rather than the public, such as development charges or other mechanisms to make growth "pay its own way", tend to reduce subsidies for sprawl and limit decentralization. On the other hand, and unsurprisingly, low-density zoning and subsidies for sprawl tend to produce more decentralization.

There is some debate over the efficacy of urban growth boundaries and greenbelts in reducing sprawl. More than 100 cities and counties in the US had adopted urban growth boundaries by 2004 (Jun, 2004). But in terms of empirical research, the presence of urban growth boundary was not a statistically significant predictor of sprawl in the Pendall (1999) study. In one popular example of Portland, OR, the city's urban growth boundary was shown to be ineffective in slowing suburbanization as it likely led to spillover growth into nearby counties without contributing to any shift away from automobile commuting within the boundary (Jun, 2004). Similarly, growth-limiting policies like greenbelts have yielded unintended consequences like more inter-city commuting over longer distances and greater congestion (Bae & Jun, 2003). In theory, strong urban growth boundaries supported by zoning ordinances that permit higher-density development and preclude low-density development should lead to intensification.

However, piecemeal adoption of growth boundary policies and related zoning may lead to "leapfrog" development beyond the boundary (Pendall, 1999). Furthermore, by not addressing the market failures that contribute to sprawl, Brueckner (2000) argues that urban growth boundaries might be a draconian approach to limiting spatial expansion that "needlessly limit the consumption of housing space" and depress the standard of living of consumers (Brueckner, 2000, p. 89). Still, Brueckner recognizes that a growth boundary may be more politically feasible than alternatives such as congestion charges and development charges. While isolated land use and transportation policy initiatives appear to have mixed effects, previous experience does suggest that land use and transportation issues are best understood and addressed through an integrated approach.

Integrated Transportation and Land Use Policy: Planning for TOD

Planners and policymakers are increasingly pursuing integrated transportation-land use policies to shape urban growth and development and address problems such as urban sprawl, traffic congestion, and greenhouse gas emissions. While in the past, authors such as Giuliano (1995) have questioned the strength of the transportation-land use connection and the ability of transit investments alone to guide growth in a context of ubiquitous car infrastructure, established settlement patterns, and low travel costs for automobile trips, others have argued that the link between transport and land use remains sufficiently strong to influence travel patterns. In particular, Cervero and Landis (1995) argue that while transportation infrastructure alone can no longer shape urban form, integrated transportation-land use planning through the combination of investments in infrastructure and supportive policy and planning can play an important role in shaping growth, development, and travel behaviour. This emphasis on integrated transit and land use planning culminated in the concept of transit-oriented development (TOD) (Calthorpe, 1993) or "transit villages" (Bernick & Cervero, 1997) that calls for creating higher-density, mixed-use, and pedestrian-friendly built environments as a strategy for promoting transit and alternative mode use.

Within the context of the failure of transit projects to achieve their ridership and development goals, researchers were recognizing the importance of land use and the built environment in shaping travel by alternative modes to the private automobile. For example, in terms of automobile dependency, Newman and Kenworthy (1989) produced a widely-cited study that found increasing urban densities were associated with decreases in fuel use across many cities around the world. This paper highlighted the environmental sustainability issues associated with the more decentralized cities of the United States relative to those in Europe and Asia, sparking a significant debate (Newman & Kenworthy, 2021) and contributing to the popularization of the need to re-urbanize and reorient transportation priorities.

For transit specifically, Pushkarev and Zupan (1977) estimated minimum density thresholds for different types of transit service and Knight and Trygg (1977a) drew on experiences in Toronto to detail how supportive policy and planning can shape and intensify development around rapid transit in the right market conditions. The relationship between the built environment and travel behaviour associated with public transit, walking, and cycling became popularized through research into the 'D' variables and the concept of transit-oriented development (TOD). For example, Cervero and Kockelman (1997) examined how the '3Ds' of urban *density*, land use *diversity*, and pedestrian-friendly urban *design* affect trip rates and mode choices using travel diary data from 1990 for the San Francisco Bay Area. While effects for the D variable constructs were marginal in isolation, when combined they could be expected to meaningfully influence travel by reducing VKT and promoting alternative mode use.

A synthesis of the literature on travel and the built environment from Ewing and Cervero (2001) found that vehicle trips and VKT are negatively associated with density, land use diversity, neighbourhood design, with reductions in VKT also affected by regional accessibility. A later literature review and meta-analysis of more than 200 studies conducted by Ewing and Cervero (2010) increased the list of "D" variables by adding destination accessibility, distance to transit, demand management, and demographics. However, the role of built density has been the subject of debate. Compared to Newman and Kenworthy's (1989) aggregate metropolitan-level approach to the relationship between urban density and gasoline use, the disaggregate approach of the studies reviewed by Ewing and Cervero (2010) found that density only explains a small fraction of the variation in VKT. Instead, reductions in VKT were associated most strongly with accessibility to destinations and street network design. Walking and transit use was associated with factors such as street design, accessibility, and mixed-use development rather than density. Similar findings regarding the role of density were reported in Ewing et al. (2017). Nevertheless, this evidence has supported an emphasis on transit-oriented development and design as a means of achieving policy goals related to reducing automobile dependency and increasing transit and alternative mode use.

Research into property markets has also offered indications of the demand for transit accessibility and more transit-oriented forms of urban development. The rationale for examining property values is that rooted in the predictions of the AMM model where accessibility is a key input into the value of land and intensity of development. All else being equal, more accessible locations with lower transportation costs should attract higher prices per square metre of living space and higher-density development. By extension, new transportation infrastructure that lowers transportation costs around access points should create a locational advantage due to increased accessibility that is priced into the land market. This process is often termed land value uplift. But if transportation costs are low and new infrastructure does not entail much of an accessibility benefit, then no land market effects should be detectible. Previous research has explored the relationship between highways and property values (see Ryan (1999) for a review) and generally found positive price effects associated with better highway access.

For transit, hundreds of studies have examined how access to transit stations affects home prices and many do find positive effects associated with being close to transit stations (Debrezion et al., 2007; Higgins & Kanaroglou, 2016; Mohammad et al. 2013) as well as price effects associated with different transit-oriented development contexts (Higgins & Kanaroglou, 2018). Still, some studies also find negative or insignificant effects that may result from transit not offering meaningful accessibility benefits or reductions in transportation costs compared with other modes or other factors such as high-income households not valuing transit access or emphasizing nuisance effects such as noise (e.g. Bowes and Ihlanfeldt (2001)). However, deriving generalized conclusions is made difficult by the differing data and methods used across papers and it is only recently that researchers have adopted quasi-experimental methods to better examine potential causal relationships in land value changes over time (Higgins & Kanaroglou, 2016). The existence of land value uplift from the locational advantages that transit can produce is a prerequisite for land value capture, where policy tools such as tax increment financing are used to recapture some of the land market benefits that result from public investments in infrastructure but would otherwise accrue to private individuals (Medda, 2012; Suzuki et al., 2015).

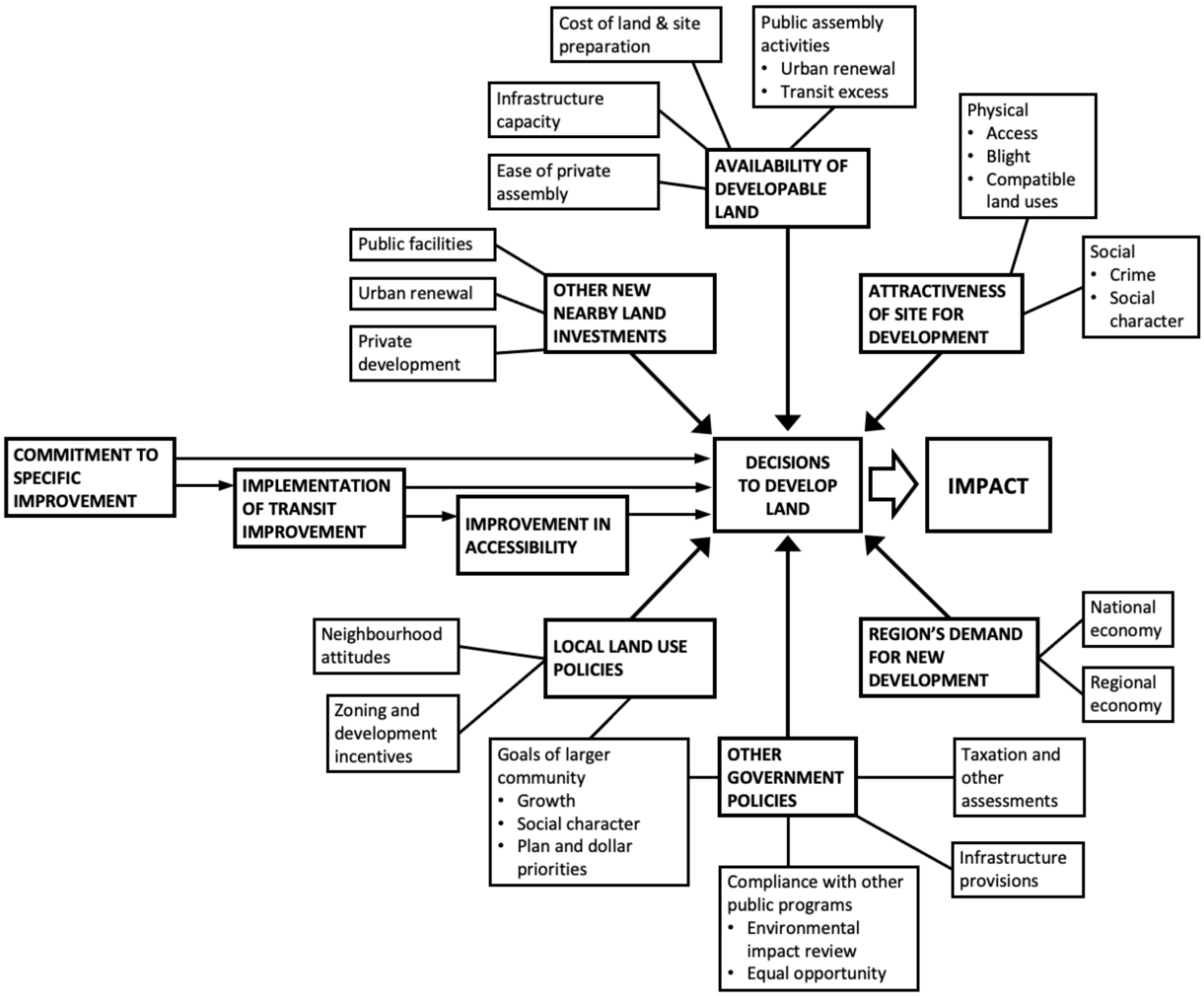
However, by pushing up property prices, land value uplift also suggests the potential for an “affordability paradox” where households that rely most on public transit may be priced out of living close to it, potentially leading to the suburbanization of transport poverty amongst low-income households (Allen & Farber, 2021). This can occur through the process of transit-induced gentrification where higher-income households outbid low-income households for transit access (Dawkins & Moeckel, 2016). Nevertheless, while the theoretical arguments surrounding the gentrification process are strong, and research has typically found that those moving to transit station areas are younger, wealthier, and highly educated (Delmelle, 2021), empirical evidence relating to displacement has thus far been mixed (e.g. Grube-Cavers and Patterson (2015); Baker and Lee (2019)). In a commentary about the state of knowledge in this rapidly advancing area of scholarship, Delmelle (2021) suggests that compared to more aggregate approaches that examine gentrification at the neighbourhood level, more individual-level studies can potentially offer greater insight into how local contextual factors affect neighbourhood change.

Part of affordability also relates to transportation costs. While the AMM model predicts that land value uplift results from lower transportation costs, do more transit-oriented and accessible locations actually lead to reductions in household transport expenditures? Housing and transportation are typically the two largest expenses for families in Canada, making up 29.3% and 18.5% of average household expenditures respectively in 2019, with the transport portion primarily driven by vehicle ownership and operational costs (Statistics Canada, 2021). In this regard, shifting trips to transit and requiring fewer vehicles to meet household travel needs can potentially be a significant source of savings. However, in line with induced demand, people living in more accessible areas may also make more trips (Thill & Kim, 2005). Some research has shown that families living within transit-oriented neighbourhoods tend to own fewer cars and drive less and therefore, likely spend less on transport, although the magnitude of these relationships varies widely and likely depends on individual, household, and built environment factors. Self-selection, wherein households choose neighbourhoods that meet their preferences for less car travel, also plays a confounding role (Cao & Cao, 2013). However, only a handful of studies have directly examined the relationship between TOD and household expenditures. In this regard, a recent longitudinal study by Dong (2021) found that, after controlling for a number of covariates, California households living in TODs spent more on transit trips but saved about $1,200 per year on transport expenditures compared to similar non-TOD households with similar demographics, largely due to owning fewer cars.

Investments in transit, when coupled with supportive policy and planning, can also lead to greater development and redevelopment in transit station areas. However, the relationship between transit access and urban development is also not a straightforward one. While the AMM model predicts higher property prices and a greater intensity of development on more accessible land, and research has shown higher property values associated with transit access and transit-oriented development, the actual process of land use change is a complex one. Based on interviews with developers and planners, Knight and Trygg (1977b) detail how an improvement in accessibility is just one factor alongside regional growth and demand for development, the physical and social characteristics of station areas, the availability of land, and supportive policy and planning in the decision to develop land (Figure 3). This highlights how transit accessibility, and indeed TOD planning and policy, are necessary but insufficient precursors to development and land use change in station corridors.

In terms of the demand for TOD, beyond the studies of property values, other research has shown that there is significant demand for the characteristics of TOD amongst individuals and households (e.g. Levine & Frank (2007); Lewis & Baldassare (2010); Luckey et al. (2018)). Research has also found evidence of “residential dissonance”, wherein individuals and households do not live in a neighbourhood that matches their preferences for features such as walkability, transit access, and transit-oriented urban design (Huang, et al., 2021; Kamruzzaman et al., 2013; Liao, et al., 2015; Myers & Gearin, 2001; Schwanen & Mokhtarian, 2004). Such results also highlight the potential for significant latent or unmet demand for more transit-oriented forms of urban development.

Figure 3. Factors Influencing Land Use Impact



Source: adapted from Knight & Trygg (1977b)

Planning for Accessibility

While the "D" variables proposed by Cervero and Kockelman (1997) and expanded upon by Ewing and Cervero (2001; 2010) have helped to bring discussions of urban form and function into the mainstream, the "D" variables have been criticized for confusing and simplifying the synergistic relationships between different aspects of the built environment and travel behaviour. Handy (2018) argues that the focus on the D variables as independent constructs is not strongly supported by travel behaviour theory as we would expect synergistic effects between characteristics such as density, mixing of uses, urban design, and good transportation network connectivity and their ability to influence trip rates and mode choices. In effect, the focus on the D variables in much of contemporary research has resulted in epistemic circularity, or a tautological literature with a teleological reliance on the Ds as proxies for the complexity of built form that may be over- or under-estimating built form impacts on travel.

Instead, Handy (2018) argues that there is a much stronger conceptual basis in focusing on transportation accessibility as an integrated measure of urban form and its relationship with travel behaviour. While accessibility can be defined in several ways, the general concept of transportation accessibility refers to the ease of travelling from an origin to destinations of value using the transportation network. In this regard, the primary role of the transportation system is to provide accessibility so that people and businesses can engage in activities and exchange goods, services, information, and knowledge.

Academics have been advocating a shift from mobility-oriented planning to an accessibility-oriented approach (Deboosere et al., 2018; Handy, 2020; Proffitt et al., 2019; Yan, 2021). As Handy (2020) notes, accessibility is appropriate for planning practice: "What matters to people is how easy it is for them to get to where they need to be, how easy it is to access the services they need or want, which is exactly what accessibility measures". But while many regional plans now cite accessibility as an important goal, tension remains between planning for accessibility versus the more traditional "predict and provide" approach to planning for mobility through increasing levels of service on the transportation network (Owens, 1995). In the latter view, congestion remains the predominant concern and the preferred solution in many jurisdictions has been to enhance mobility by increasing highway capacity. Although such increases in mobility can increase accessibility, the accessibility-oriented approach does not view the transport system in isolation but regards land use change and provision of opportunities over space as a more effective and environmentally friendly solution (Handy, 2020).

Nevertheless, despite fundamentally capturing the relationship between land use and transportation, accessibility remains an elusive concept in transportation planning (Miller, 2018). Perhaps the largest challenges associated with accessibility planning are measuring and interpreting the concept of accessibility. Accessibility is typically measured through four broad approaches: distance to the nearest attraction, cumulative opportunities within an access distance or time threshold, gravity or entropy model formulations, and expected maximum random utility-based measures (Geurs & van Wee, 2004; Miller, 2018). Typically, the more simplified distance or cumulative opportunities measures are easiest to understand, however, they are generally inconsistent with the ways people minimize travel costs.

In this regard, the selection of the indicator for travel impedance (travel time or distance) and level of attractiveness of a certain location in terms of a specific activity, spatial and temporal scale, and heterogeneity in the perception or preference of agents may all lead to inaccurate accessibility measurement. Here researchers have also moved beyond distance, time, and monetary costs to consider measures of energy expenditure (e.g. Páez et al. (2020)), cognitive costs (e.g. Mondschein et al. (2010)), and spatio-temporal accessibilities (e.g. Miller (1991)), as well as how accessibility is affected by competition (e.g. Shen (1998)), the mobility characteristics of the individual (e.g. Kwan (1998)), user satisfaction (e.g. Chaloux et al. (2019)), or perceptions of accessibility (e.g. Lättman et al. (2018)). Recent research has found that different software packages and routing algorithms used for network analysis and accessibility measurement can produce different results (Higgins, et al., 2021).

On the conceptual side, crafting useful, meaningful, and robust standards for accessibility remains a significant challenge (Miller, 2018). Unlike levels of service measures, practitioners have little in the way of official guidance or standard methods to use when navigating the complexity of accessibility measurement (Handy, 2020). Similarly, van Wee (2016) comments that the challenges of accessibility research lie in not only the concept and measurement methodology, but also in expressing accessibility in terms of factors like inequality and social exclusion (e.g. Lucas et al. (2016)) and their evaluation along different dimensions, such as the expression of accessibility in monetary terms.

Beyond the Transportation-Land Use Connection

While the above sections have discussed the elements and dynamics of the transportation-land use connection, it is important to also add that there are many other factors external to the urban system that affect transportation and land use. Many of these are included in Figure 1 from Bertolini (2012). However, demographic and population-geographic factors play a significant role in many of these relationships, and we expound on some of them here.

The relationship between socioeconomic and demographic characteristics and the transportation-land use connection can be distilled into four subprocesses that all act to generate trips and extend travel distances (Holz-Rau & Scheiner, 2019). First, higher incomes tend to lead to greater levels of car ownership and longer distance travel; second, higher education and increased occupational specialization tend to increase trip distances; third, increasing equality for women can lead to more car ownership and longer distance tripmaking; and fourth, virtualization of some activities can result in people making fewer trips, but trips that do occur happen over longer distances. Indeed, Brueckner (2000) argues that in addition to falling transportation costs, much of the sprawl seen over the 20th century in the United States can be attributed to a growing population and rising incomes that lead to greater demand for more space and separate tax jurisdictions at the urban fringe.

However, urban centralization and intensification can also be driven by demographics. Foot (1998) explains individuals typically maintain a set of locational preferences in life that shift from urban to suburban: people generally enter the labour force after the age of 20 and seek rental housing, and many of these young people maintain a preference for city living. By thirty, many have saved enough money to afford a down payment on their first home, and due to children, choose to move away from the central city to suburban areas. Near the age of forty, these individuals sell their first home for a larger one, where they will remain until they downsize around the age of seventy. This process is formalized in housing theories relating to the upward movement of repeat homebuyers that can see households, on average, moving from older urban and suburban areas for newer suburban and exurban ones (Bier & Howe, 1998). These preferences, when combined with macro-scale demographic trends, have had a profound effect on the shape of cities in North America. For example, as the baby boomer generation entered the labour market in the late 1960s, cities in Canada and the United States witnessed a boom in demand for urban housing, resulting in the imposition of rent control measures in many areas. By the 1980s, growth had generally switched back to the suburbs (Foot, 1998).

Nevertheless, writing on more recent trends observed through the United States Census, Ehrenhalt (2012) argues that cities in the US are in the midst of the “Great Inversion” – a migration of the affluent back to the central city and mass gentrification of declining areas combined with a shift in settlement patterns of immigrants and minorities to outer suburban areas. Canadian cities have similarly witnessed the shift of higher-income people towards transit-rich urban cores, and lower-income people into suburbs (Hulchanski, 2010; Ley & Lynch, 2012). But where Foot (1998) argues that preferences for city living are temporary and concurrent with the youth in their 20s and early 30s, Ehrenhalt (2012) sees the recent patterns emerging in cities across the United States as a more fundamental and permanent shift in locational preferences wherein the rich will continue to live in the central city and immigrants and the poor will relocate to the outer suburbs. Ehrenhalt (2012, p. 22) attributes these demographic trends to a change in values, habits, and living preferences between the echo or millennial generation and those before it, based in part on urban economic considerations such as the monetary and time costs of commuting from suburban areas to jobs in the central city as well as a strong “pro-city sensibility” within this demographic cohort, particularly among its elite.

These trends are also helped by an improvement in central cities themselves, such as the reduction or elimination of environmental factors because of deindustrialization and a decrease in violent crime, generally making these areas nicer places to work, live, and raise a family. In the aggregate, millennials do appear to travel less, own fewer cars, and use alternative modes more than prior generations (Garikapati et al., 2016). The wave of millennials has also contributed to a reversal of longstanding trends of urban decline in many cities and many maintain preferences for higher-density, transit-oriented, and walkable neighbourhoods (Moos, 2016). But how the younger millennial generation travels, and whether they will adopt the same travel and locational preferences of previous generations over their life course, remains a topic of significant research interest.

Immigration and cultural factors have also been found to influence travel. Recent studies have noted that more affluent new immigrants tend to settle in newer suburban areas while less affluent newcomers tend to settle in older inner-suburban neighbourhoods. In Canada, this has meant that many immigrant families are moving to areas where public transit is not competitive (Lo et al., 2011). Relatedly, research into the settlement and travel patterns of Syrian refugees in Durham Region found that many live in areas with poor transit accessibility that negatively impacts their participation in social and discretionary activities, leading most survey respondents to link their transportation situation with feelings of loneliness and sadness (Farber et al., 2018). While not an explicit focus of this research project, this overview suggests that it is important to remember that socioeconomic and demographic factors play a significant role in shaping some of the larger-scale transportation and land use trends in cities.

PART 2. NEW TECHNOLOGIES, TRENDS AND THE TRANSPORT-LAND USE SYSTEM

Public transit operates in a larger system of transportation infrastructure and service technologies, and current trends suggest many of these technologies are undergoing rapid and potentially disruptive change. Moreover, some ongoing and emerging trends related to the COVID-19 pandemic are also shaping the way we think about transportation and land use. This section reviews recent literature on new transportation technologies and trends with a particular focus on their implications for our understanding of the transportation-land use system and public transit's role within it.

New Transportation Technologies

Researchers interested in exploring new transportation technologies and their role in the transportation-land use system are confronted with a wealth of terminology to describe different systems, vehicles, and service types. This includes mobility services, mobility on-demand, mobility-as-a-service (MaaS), and flexible transportation systems, ridehailing, ridesharing, ridesplitting, ridesourcing, bikesharing, and carpooling systems, microtransit and demand-responsive transit, connected, autonomous, and electric vehicles, and micromobility. Not to mention how more traditional modes such as public transit, personal bikes or cars, taxi services, and paratransit fit alongside these terms in our understanding of the transportation system. To structure the review, this section presents a framework for understanding the different types of new transportation technologies organized around physical networks, physical modes, mobility services, and mobility-as-a-service. This framework is based on the reviews conducted by Calderón and Miller (2020; 2021).

Physical Networks

The travel modes discussed below operate on or within physical networks – the physical infrastructure of roads, rails, bike lanes, and sidewalks that enables point-to-point travel using a transport mode. Some modes can share rights-of-way, such as roads being used by many different types of vehicles. These modal networks can also be represented graphically as a multimodal "hyper network" – a system of interconnected links and nodes that have measures of capacity, impedance, and flow and can be modelled for research, policy, and planning purposes. Transport network innovations often go hand-in-hand with modal technology innovations, such as rail-based public transit. While urban tunnels for vehicular traffic or tube-based "hyperloops" could constitute future network innovations that decrease the friction of distance, literature on their potential impacts is scant. As such, our focus in this report remains on more modal and service innovations.

Physical Modes

The physical modes of transport consist of the combination of vehicle and control system technologies for moving people and/or goods. Typical transportation modes encountered in cities include automobiles and trucks, public transit modes, active modes such as walking and cycling, as well as more non-traditional modes like scooters. We can also think of modes in terms of what Calderón and Miller (2021) refer to as "sub-modes", including driven vs. autonomous vehicles, internal combustion vs. electric engines, or pedalled vs. electric bikes. Various transit sub-modes include minibuses or full-size buses, light-rail transit (LRT), heavy rail transit (HRT), and commuter rail transit (CRT), each of which entails various capacities and cost performance (see Table 4.2 in Vuchic (2007)).

Innovations in travel modes have long been a source of increases in mobility and decreases in transportation costs. This includes examples such as the transit-oriented streetcar cities from the late 1800s to the further spatial expansion facilitated by the automobile post World War Two. Walking aids such as elevators, escalators, or travelators could also be considered travel modes. Building heights are also partly a function of transportation technology, with the elevator helping buildings to grow beyond the height limits associated with staircases (Glaeser, 2008). This section discusses modal innovations associated with autonomous vehicles. Micromobility is a concept that is also partly oriented to modes. However, because these vehicles are often utilized in a shared system, we save their discussion for the mobility services section below.

<u>Autonomous Vehicles</u>

Autonomous vehicles (AVs), or autonomous and connected vehicles, have been hailed as a potentially transformative transportation innovation that will affect mobility and land use in cities. AV technology is described according to six levels of automation (0-5). Briefly, a Level 0 vehicle has no automation features; Level 1 features driver assist aids such as adaptive cruise control; Level 2 features driver aids for steering in addition to speed, although the driver must monitor the system at all times. At Level 3, the vehicle is capable of fully driving itself in limited circumstances, although the driver is required to monitor the system in a "hands-off" manner. Level 4 vehicles can drive themselves in most circumstances while Level 5 vehicles can drive themselves in all conditions without any human intervention. Despite the enthusiasm for AVs in many sectors, there are significant legal, ethical, political, security, privacy, behavioural, transportation network, and computing hurdles to be overcome (Fagnant & Kockelman, 2015). In response, researchers generally see a long time horizon to realize full autonomy. A review of different sources by Martínez-Díaz and Soriguera (2018) found most researchers believed Level 4 could be achieved by 2030, Level 5 autonomy between 2030 to 2050, and realizing a fully connected and autonomous transportation system with vehicle-to-vehicle communications by 2050 to 2080.

Nevertheless, researchers see many potential benefits in AV technology for transportation mobility, including increased safety, providing mobility to populations with mobility challenges, increasing road capacity through vehicle-to-vehicle or vehicle-to-infrastructure communication, and reducing household transportation costs by eliminating vehicle ownership. If AVs are electric, they may also reduce or eliminate transportation-related emissions (depending on the source of energy, see Réquia et al. (2018)). In terms of travel behaviour, a fully realized system of AVs might increase travel speeds by reducing congestion and travel time uncertainty through more reliable and predictable routing (Heinrichs, 2016). Taking an AV could theoretically free passengers from focusing on driving and enable them to do other productive activities in the car, which can make long car commutes less of a burden than they are at present (Hawkins & Habib, 2019).

But while AVs can provide mobility for individual or household tripmaking, this change can affect the transportation system in several ways. For example, the adoption of AVs may lead to increases in trips and VKT, which can lead to greater energy use and may result in more traffic congestion in the near-term (Fagnant & Kockelman, 2015). On the other hand, high-level autonomy with AV mobility services could reduce household vehicle ownership and lead to fewer vehicles on the road (Soteropoulos et al., 2018). Still, if AVs are largely privately-owned in practice, these benefits would be greatly reduced.

On the land use side, the adoption of AVs may also influence the built environment, land use, and urban form over the long run. One aspect is that by reducing the need for parking, AVs can free up land for other uses (Soteropoulos et al., 2018). However, many researchers expect AVs to promote decentralization by decreasing the costs of long-distance travel (Hawkins & Habib, 2019). Still, both of these effects are premised on several assumptions. Parking reductions assume high levels of fleet ownership of AVs operated as mobility services or part of an integrated MaaS paradigm. If AVs are privately-owned, this could result in greater VKT as more trips are made by empty vehicles. Enabling more productive use of time could also reduce the disutility of travel time and increase trip distances. But as Hawkins and Habib (2019, p. 69) argue, an AV will remain a "cramped space for conducting work or enjoying leisure activities" and suggest these potential time use benefits are overblown.

There are also debates about whether AV technology will change the public transit system. At the extreme end, some have argued that AV technologies will make public transit obsolete (Lutin, 2018; Wiseman, 2018). Others expect that the adoption of AVs could complement public transit by making it more efficient (Soteropoulos et al., 2019). It could do this by potentially solving first- and last-mile issues (Fraedrich et al., 2019). Nevertheless, researchers emphasize that the potential impacts of AVs on public transit are very sensitive to model assumptions that are still very uncertain (e.g. the perception of time in AVs and the level of AV technology) (Soteropoulos et al., 2019). Others argue that public transit will still retain its essential role in providing mobility for those who cannot afford costly AV services (Buehler, 2018). In dense urban areas and during rush hours, public transit will provide more efficient services than AVs. Public transit agencies and operators can integrate public transit services with AV services to better coordinate transportation services (Fraedrich et al., 2019). Beyond transit, it has also been argued that, if fully realized, AVs can potentially make roadways safer for cyclists and pedestrians (Botello et al., 2019).

Nevertheless, there is still a strong role for policy and planning in shaping the impacts of AVs, and scholars argue that because of this, the impacts of the technology are likely to vary by locality (Botello et al., 2019). On a macro level, federal and state governments will play a role in encouraging innovation and regulation. Still, local governments will ultimately determine how AVs are integrated into the transportation network. For example, when Uber first entered Canada, it operated either illegally or outside of regulations (Brail, 2018; Tabascio & Brail, 2021). Adopting AVs also needs regulations, but few local governments have begun planning for AVs. Freemark et al. (2019) reviewed existing transportation plans of the largest U.S. cities and surveyed transportation and planning officials from 120 cities about their plans for AVs. They found that cities with larger populations and higher population growth are more likely to be prepared for AVs. Local governments still need to understand the impacts of AVs before implementing regulations. The City of Toronto's AV Tactical Plan is an example in this regard. It is also necessary to explore the preferences towards AVs and how political ideology, per capita government expenditures, and population density influence adoption (Freemark et al., 2019). Equity concerns are also important for planning and policy, although Cohn et al. (2019) note that the potential equity impacts of AVs remain understudied in general.

Mobility Services

In contrast to physical modes and networks, Calderón and Miller (2021) define a mobility service as an operational entity that provides a way for tripmakers to contract for a transportation service. Ridehailing and bikeshare services are new examples of mobility services where users typically utilize mobile applications to request, pay for, and complete a trip. However, public transit and taxi services, which are commonly treated as modes, can also be defined as mobility services. Like the new mobility offerings, users pay a fare to contract for the transportation service and then board or enter a vehicle to travel. Extending this framework further, the use of personal modes such as driving your own bicycle or car, can also be thought of as mobility services that the user supplies. In this sense, these personal self-supplied and external public or private mobility services offer alternative and competing means by which a tripmaker's travel needs can be met. However, to summarize the recent literature, this section focuses on external mobility services including ridehailing, micromobility sharing, and demand-responsive transit.

Ridehailing

Several characteristics make ride-hailing attractive. The literature has shown several benefits associated with cost and time, ease of payment, safety, and convenience. Most of the trips are observed in high-density, mixed land use areas. According to evidence from the United States and Canada, the primary user has been shown to be young, educated, and of higher income (Conway, Salon, & King, 2018; Young & Farber, 2019), mainly using it for occasional and leisure trips.

Despite these overall geographical and sociodemographic characteristics, US evidence on ride-hailing has also demonstrated significant equity impacts. This transport alternative provides mobility options for low-income, racialized, and outer neighbourhoods and the physically and cognitively disabled (Brown, 2019; Tirachini, 2020). A recent study in Toronto, Canada, showed that accessibility benefits of ride-hailing in Neighbourhood Improvement Areas (NIAs) are higher compared to the rest of the city, improving access to jobs for residents of Toronto's NIAs by 30% and 5% for local and regional employment, respectively (Abdelwahab et al., 2021).

Another critical dimension of ride-hailing is its role as a complement or substitution to other modes. The evidence worldwide is mixed. For example, research in San Francisco has shown that ride-hailing services can complement transit by providing last-mile connections (Rayle et al., 2016). In contrast, a recent study in Toronto found that most ride-hailing trips were directly competing with or supplementing transit trips (Young et al., 2020). Overall, the most recent studies show a trend where the substitution effect of public transit trips is stronger than the complementarity effect (Tirachini, 2020). In this regard, Young et al. (2020) recommend planners and policymakers consider a tax upon ridehailing trips where transit alternatives are of similar duration. However, the type of transit service matters, with Li et al. (2021) finding a positive association between subway ridership and ridehailing trips in Toronto, but a negative association between ridehailing and surface transit ridership.

When we look at traffic externalities, ride-hailing has shown consistent evidence from 2017 onwards related to an increase in VKT and congestion. The induced demand introduced by ride-hailing has been highlighted in the majority of studies, and recent studies show worrying environmental and energy consumption effects that must be further studied (Tirachini, 2020). Finally, as Tirachini (2020, pp. 2036) summarizes, ride-hailing has "the potential to reduce car ownership and encourage a car-free lifestyle, but current evidence of the matter is inconclusive", and future work should be focused on better understanding this relationship in the medium and long term. As of now, the US has shown some evidence that negatively correlated car ownership with ride-hailing use and non-car ownership being linked with more frequent use of ride-hailing in California (Conway et al., 2018; Circella et al., 2018).

Micromobility Sharing

Micromobility is a term that encompasses a number of different transportation modes that can increasingly be found in cities. A broad definition of micromobility includes human-powered vehicles such as traditional bicycles or kick scooters, as well as a new category of "electromobility" vehicles such as e-bikes and e-scooters. A strict definition adopted by the International Transport Forum is based on the kinetic energy of the vehicles, with micro-vehicles having a kinetic energy limit of 27 kJ based on a mass of no more than 350kg and a top speed not exceeding 45km/h. In this sense, micromobility can also encompass vehicles such as unicycles or skateboards (Oeschger et al., 2020). Micromobility modes can be privately-owned or shared through the use of mobility services. This section discusses micromobility sharing first in terms of bikesharing and then through other sharing systems, touching on both the general modal benefits of micromobility vehicles as well as the potential benefits of their integration into a mobility service.

In general, micromobility modes and services are seen to have potential for helping to solve transportation problems in cities, including promoting modal shifts away from private automobiles and greater transit use. The main potential of micromobility modes lies in their potential to solve first/last-mile problems associated with access to public transit. The integration of micro modes with transit within a single trip chain can combine the accessibility offered by the transit network with the door-to-door convenience of a micro mode, potentially realizing a degree of access, speed, and comfort that can compete with the private car (Kager et al., 2016). Micromobility systems can also improve social equity by increasing access to services and opportunities (Abduljabbar et al., 2021; Oeschger et al., 2020).

Of the shared micromobility services, bikesharing systems provide bicycles for shared use in cities. There are two main types of bikesharing modes: dockless and station-based. Dockless bikesharing is an emerging transportation mode and does not require docking stations. Station-based bikesharing has many stations and ready-to-use bicycles and can be provided for users to easily pick up and return bikes in the city (Lin & Yang, 2011). Much of the benefit of bikeshare systems for cities can be derived from the benefits of urban cycling as an activity and transport mode. This includes individual health benefits such as increased physical activity, lower obesity rates, and morbidity (Pucher et al., 2010).

Many factors influence the adoption and use of bikesharing and the realization of the associated benefits. The characteristics of the natural environment are the most important factors that influence trip demand for bikesharing and cycling in general. Rain and snowfall at low temperatures are generally considered the most adverse weather conditions that negatively influence bikesharing demand (Hyland et al., 2018; Kim, 2018; Sun, Chen, & Jiao, 2018). In addition, wind speed, humidity, seasonality, and climate all influence bikesharing demand with the highest use expected between temperatures of 20-30 °C (Eren & Uz, 2020). The provision of cycling infrastructure is also a significant factor in cycling use (Pucher et al., 2010) and cycling safety in cities (Reynolds et al., 2010). Employment, population density, and mixed land use are correlated with bikesharing demand (Eren and Uz, 2020). Electric bikes, or e-bikes, also appear to be popular for users due to their higher speeds and reduced energy expenditure requirements and the global trend of e-bike adoption could lead to what Kazemzadeh & Ronchi (2021) refer to as a potential paradigm shift in mobility patterns that could lead to massive modal substitution for trips by transit, car, and traditional bike.

A bikesharing system can be integrated with public transit and provide solutions to first- and last-mile issues by offering more sustainable modes than driving and covering more distance than one could by walking. An online survey with bikesharing users in the US and Canada showed that most think the bikesharing system strengthens public transit and improves transit connections (Shaheen et al., 2013). Integration with public transit will also stimulate bikesharing demand. Studies found that using the same payment system as public transit will increase the use of bikesharing (Eren and Uz, 2020). Bikesharing can also complement public transit in low-density areas or low transit demand (DeMaio, 2009).

Some researchers argue that the benefits of bikesharing are not equally distributed. Studies have found that bikeshare members are more likely to be male, young, educated, employed, and high-income people (Fishman et al., 2014; Ricci, 2015; Shaheen et al., 2013). Survey results found that barriers to bikesharing include cost, liability concerns, needing to use a credit card, lack of computer access, time limits, and lack of knowledge. Some studies find that people of colour using bikesharing are more likely to be casual riders than members. People of colour may be more concerned about bike theft or damage, and they know less about rules and facilities of bikesharing (Dill & McNeil, 2021). Studies also highlight the importance of social networks: knowing more friends and family who bike will encourage bikeshare trips (Dill & McNeil, 2021). In addition, some studies found that racially diverse neighbourhoods have lower accessibility to bikesharing services. With the exception of Hamilton, most bikeshare systems in Canada were not found to improve access for people living in disadvantaged areas (Hosford & Winters, 2018).

Other sharing systems encompass the range of alternative micromobility mode share systems that are emerging in cities around the world. Due to technological advancements and system improvements, micro modes such as e-scooters have emerged that operate in either docked- or dockless service designs. Like bikesharing, the sharing of micromobility modes is seen as a way of increasing their convenience, particularly for first/last-mile trips that connect to transit. However, due to concerns about micromodes related to safety, such as parking e-scooters on sidewalks, some cities have defined specific zones where these vehicles can be parked (Oeschger et al., 2020) while others, such as Toronto, have elected to ban these systems for the time being. While Riggs et al. (2021) found that very few communities were actively regulating e-scooters, experiences from communities that are regulating them provide some early best practices in terms of pilot programs, vendor limits, and equity policy.

In terms of usage, e-scooters were found to overlap with the service areas of transit in Washington, DC with only about 10% of trips taken to connect with the city's subway service. However, e-scooters were found to enhance mobility for places underserved by transit (Yan, et al., 2021). The introduction of other micro modes may result in increased competition for bikeshare systems. In Chicago, IL, Yang et al. (2021) found that the introduction of e-scooter service led to a decrease in bikeshare usage by 10%, although peak-period use remained similar. Research has found that the characteristics of the built environment around transit stations influences the use of micro modes for trips integrated with transit (Oeschger et al., 2020). Like cycling, there are also health benefits associated with the use of non-electric micromobility modes that stimulate physical movement. However, the provision of dedicated infrastructure is also seen as a key intervention for increasing safety and confidence in the use of micro modes by reducing potential conflicts with motorized vehicles (Oeschger et al., 2020).

Nevertheless, research into micro modes beyond cycling and their role in the transportation-land use system is in its infancy. Much of the research into micromobility modes and their integration with transit considers the preferences and mobility patterns of users. However, few have quantified the larger impacts of these systems on outcomes such as modal shifts from private vehicles, increasing social equity, or improved environmental outcomes, suggesting there are large gaps in our knowledge at present (Oeschger et al., 2020).

On-Demand Transit

On-demand transit is a form of transit that provides service using fleets of vehicles scheduled to pick up and drop off people according to their needs. When public transit incorporates demand-responsive technologies, it can use smaller vehicles that are not bound to a fixed schedule but react to real-time demand. On-demand transit also has lower operational costs to provide services in low-density areas or during off-peak hours (Shaheen & Cohen, 2020). This form of public transportation is becoming more actively adopted by many countries and regions, for example, Singapore (Oh et al., 2020), Amsterdam (Coutinho et al., 2020), and Canada (Klumpenhouwer et al., 2020).

Several studies have investigated the impacts of on-demand transit. Bürstlein et al. (2021) analyzed operational scenarios of on-demand transit in Markham, Toronto. They found that on-demand transit can solve Markham's primary public transit stations' first- and last-mile issues. Using a van-based on-demand transit system, passengers can reduce car use and transportation expenditures without significantly increasing time costs. Zhang et al. (2021) explored the social impacts of on-demand transit in Belleville, Ontario. They found that on-demand transit can provide affordable nighttime transit services for low-income people and carless households and encourage residents to participate in more nighttime activities.

Mobility-as-a-Service

While there is no generally agreed-upon definition of mobility-as-a-service (MaaS), and indeed some argue it would be premature to impose a strict one at this time (Sochor et al., 2018), the concept generally refers to a centralized platform that offers mobility solutions for tripmaking to individuals by gathering a range of different mobility services within a centralized platform (Calderón & Miller, 2020). Calderón and Miller (2020), working from Kamargianni et al. (2016), outline three key aspects of a MaaS system: seamless ticket and payment integration across mobility services, mobility packages that can include a wide range of alternatives, and strong integration with ICTs for real-time information. In this way, the concept of MaaS can produce a user-centric personalization of mobility services that optimizes multimodal tripmaking.

However, the concept of MaaS is currently best understood according to a continuum of features and integrations. Based on a review of different MaaS descriptions and definitions and a multi-stakeholder expert workshop, Sochor et al. (2018) propose a typology of services that MaaS platforms can or might encompass organized into five levels from 0-4: Level 0 corresponds to no integration and reflects single service providers such as transit, taxi, ridehailing, or bikesharing operators. Level 1 features the integration of information, including route and modal options without booking or payment features. An example of a Level 1 MaaS is a multimodal trip router like Google Maps. Level 2 features the integration of booking and payment services for different modes alongside routing features. A Level 2 MaaS provider would take responsibility for integrating different mobility service suppliers and for ensuring valid tickets and accurate bookings. However, the Level 2 provider would not be responsible for the actual travel services.

Level 3 features further integration of the services on offer, such as through the bundling of mobility services and possible subscription payments. This type of offering focuses on meeting the total transportation needs of an individual or household to provide lifestyle mobility over a long period of time rather than short-term trip mobility and entails full two-way responsibility for the services on the part of the provider. Compared to a Level 2 operation where the MaaS platform is the product, for a Level 3 service, the ICT platform facilitates a larger business of working with and integrating mobility suppliers for different modes and mobility solutions.

A Level 4 MaaS is one that builds on Level 3 to integrate the ability to achieve societal goals. With payments and mobility services integrated into the MaaS platform, there becomes an opportunity for public authorities to influence travel behaviour to achieve goals such as reductions in congestion or greenhouse gas emissions and higher transit ridership and alternative mode use, or to pursue objectives related to achieving a more accessible and equitable transportation system. This could be accomplished through dynamic pricing or incentives to choose more sustainable modes of transport. The rationale for Level 4 interventions lies in the fact that the physical network infrastructure that mobility services operate on is, more often than not, public space, and that public authorities also generally control public transit as the backbone of the MaaS system. In this regard, the public sector can use its monopoly position to ensure that the mobility solutions offered through the MaaS platform achieve public goals.

Many studies have discussed the potential outcomes of MaaS. First, for users, MaaS can offer improved access to mobility by offering personalized and seamless bundles of mobility services. For transport providers, potential benefits are profitable markets for mobility services, the potential for new markets and sales channels, simplified payment management, and richer data on travel demand patterns. For the public sector, researchers expect that the adoption of MaaS may reduce car ownership, per capita VKT, and the need for parking spaces (Butler et al., 2021; Mulley, 2017). MaaS can also potentially improve social equity by offering disadvantaged groups greater freedom to satisfy their mobility needs using shared services and forgoing the need to rely on public transportation or private transport. This potential is significant in low-density areas where public transit providers have traditionally found it difficult to provide services that meet the community's varying needs (Hensher, 2017).

However, while MaaS is a compelling concept, researchers argue there are a number of barriers that might prevent the realization of highly integrated MaaS platforms. From Butler et al.'s (2021) review, these include a lack of cooperation among public and private sector stakeholders, business and political support, service coverage, and shared vision, as well as data and cybersecurity concerns on the supply side. Demand-side barriers include a lack of appeal to older generations, public transit users, and private vehicle users, as well as concerns about the attractiveness of the digital platform and reduced willingness-to-pay for MaaS relative to existing transport services. On this last point, while discounts or subsidies may effectively attract more users, they also put financial pressure on operators.

Early experience with MaaS platforms suggests that a culture of private vehicle travel presents a significant challenge for MaaS. Previous studies have found it difficult for car users to switch to alternative travel modes, particularly for leisure trips (Storme et al., 2020). In this regard, promoting a more multimodal culture could stimulate the adoption of MaaS (Mulley, 2017). Moreover, researchers emphasize the importance of adopting tailored policies according to different cultures and landscapes. For example, differences in modal split in Asian and North American cities are likely to be associated with different users and operational costs in these contexts (Butler et al., 2021).

Some studies found that existing MaaS implementations are disproportionately by more privileged populations. High-income levels, car availability, high education level, nondisabled status, and younger age are all positively associated with the early adoption of MaaS in the Netherlands (Caiati et al., 2020; Zijlstra et al., 2020). Realizing reductions in car use might also prove challenging. A pilot study in Ghent, Belgium found that while participants were eager to explore MaaS for public transit and car sharing, clear reductions in car use were difficult to achieve, particularly for leisure trips, suggesting that MaaS should be regarded as a complement rather than a substitution for private car use in the near term (Storme et al., 2020).

Furthermore, although there is the potential to gain subscribers of MaaS and reduce private car use, it may be difficult for MaaS to be profitable. A MaaS pilot project in Sydney, Australia bundled public transit, rideshare, carshare, and car rental services with financial discounts and monthly subscription fees. After running for two years, researchers found that it is difficult to attract users to register a monthly or periodic bundle, and people might reduce their willingness to use the MaaS service if there is no subsidy (Hensher et al., 2021). Moreover, MaaS has higher costs than traditional transit services, and the revenue can barely cover these costs (Mulley, 2017), which would make it difficult to attract business interest and investments. In this regard, it is helpful to provide training and improve user satisfaction to make the MaaS platform easy to use (Butler et al., 2021). Although this research provides early insight into MaaS platforms and their use, such pilots do not reflect fully-realized high-level MaaS concepts that may be realized in the future.

Digital Infrastructure and ICTs

While the sections above have discussed the transportation network in terms of its physical attributes that facilitate flows of people and goods, digital or virtual transportation networks are also critical for the transmission of information. Information communication technologies (ICTs) play a key role in the urban system by decreasing the relevance of physical distance through connections in virtual space, making them intertwined with traditional transportation infrastructure. Per Salomon (1986), ICTs can have three transportation-related direct effects. First, they can generate new travel by acting as a complement to the existing transportation system by, for example, making trips easier through routing applications. Second, ICTs can modify or substitute transportation for trips that would have occurred anyhow, such as through online shopping or telecommuting that reduces the need for physical travel. Third, ICTs can have a neutral effect by changing the location and timing of activities without an overall increase or decrease in activity frequency. ICTs can also have indirect effects, such as through the growth of new ICT-oriented economic sectors (Miller, 2007).

Considering these potential outcomes, ICTs can affect short- and medium-term decision-making with respect to travel and travel demand. Over the short term, ICTs can affect trip and activity generation. Based on a review of the literature up to 2009, Mokhtarian (2009) concludes that the complimentary effect is the dominant one and discusses why ICTs do not always lead to reductions in travel. This includes all activities not having an ICT counterpart; if an alternative does exist, it may not be practical or feasible; the alternative may not be desirable; ICTs can free up time or money for other activities; ICTs can make travel more efficient and less costly; ICTs can make travel more enjoyable; and travel itself can be associated with positive utility. However, ICTs can also reduce travel by substituting for making a trip; time spent using ICTs can consume time or money that might otherwise be spent travelling; ICTs can reduce unnecessary travel, such as through more efficient routing; and ICT alternatives can be more appealing if travel is more difficult or dangerous. Over the medium-term, ICTs can affect outcomes like automobile ownership, lifestyle, and home and work locations.

The combination of physical networks with virtual networks supported by ICTs adds an extra layer of complexity to our understanding of the urban system. In Toronto for example, telecommuters were found to make more trips by car for non-work-related travel outside of peak periods, a travel context where transit is least competitive (Miller & Shalaby, 2003). Reviewing the literature on how ICTs are affecting the urban system, Yousefi and Dadashpoor (2020) conclude that by decreasing spatial and temporal constraints, ICTs increase accessibility to physical and virtual activities. Combined with the ubiquity of ICTs, the increasing prevalence of activities like online shopping, remote work technologies that decrease the need for face-to-face contact, and online social relationships and entertainment in virtual space offers a high degree of spatio-temporal flexibility. This affects travel patterns and the transportation network and, by extension, such changes also affect land use decisions related to housing and activities. However, writing in pre-COVID timeframe, the authors note that while they are important, it is not clear that ICTs have fundamentally altered the connection between transportation and land use. The following section builds on this to consider the role of the COVID-19 pandemic in the transportation-land use connection.

The COVID-19 Pandemic

In Triumph of the City, Glaeser (2011, p. 6) argues that "Cities are the absence of physical space between people and companies. They are proximity, density, closeness." However, the COVID-19 pandemic appears to have drastically altered this conceptualization, with social distancing policies potentially leading to a "rapid fire de-urbanization of the world" (Glaeser, 2021). Setting aside research into how urban features like population density (e.g. Hamidi et al. (2020); Páez (2021)) or public transit (e.g. Browne et al. (2016)) may or may not play a role in the spread of respiratory or coronaviruses, this section focuses on the changes associated with the COVID-19 pandemic as they relate to our understanding of the transportation-land use system.

Initial Impacts

Nathan (2021) argues there are two ways in which cities were "deactivated" due to COVID-19: economic deactivation, which refers to the economic upheaval associated with the loss of urban industries and employment opportunities, and surface deactivation associated with drastic declines in urban activities. However, there are enormous disparities associated with *where* these "deactivation" effects have occurred, as well as in *who* or *what* has been most affected.

Labour market effects have been significant. Survey research in the US showed that half of people employed pre-COVID-19 were working from home by April-May 2020, including 35.2% who reported commuting and switched to working from home during early lockdowns (Brynjolfsson et al., 2020). In addition, 10.1% report being laid-off or furloughed since the start of COVID-19. In Canada, researchers found that the lockdown did not cause any substantial increase in unemployment. Still, it did force a majority of residents to telecommute and practice flexible office hours (Habib et al., 2021).

These labour market effects have been unequally felt across society. Facilitated by advances in ICTs, many professional and business service activities such as finance and insurance have largely moved online. Regions with a higher share of employment in information work, including management, professional and related occupations, were more likely to shift toward working from home and had fewer people laid off or furloughed (Brynjolfsson et al., 2020). On the other hand, the pandemic has also shone a light on all the essential workers whose jobs ensure the functioning of different aspects of society. This includes positions like healthcare and workers, truckers, delivery drivers, and warehousing and retail employees (Kim & Kwan, 2021).

On the economic side, Ramani and Bloom (2021) utilize data from the US Postal Service and Zillow to detail a "donut effect" within large US cities with economic activity moving from higher-density city centres to the suburban ring. This includes declining real estate demand (sales and rents) and outflows of households and businesses relative to each city's suburban areas. The donut effect is more muted in medium-size cities and almost nonexistent in smaller cities. Furthermore, the authors do not find strong evidence of migration between cities, suggesting the potential rise of exurban "Zoom towns" may not materialize on a large scale. Similarly, Gupta et al. (2021) find that house prices and rents declined in city centres but increased father away from the centre, corresponding to a flattening a flattening of the bid-rent curve in large metro regions across the United States since the start of the COVID-19 pandemic.

Research is starting to detail the differential effects of economic deactivation on commercial real estate submarkets, with Hoesli and Malle (2021) finding retail, hospitality, and, to a lesser extent, office buildings were most affected by the pandemic in Europe while industrial and warehousing demand remained steady. This largely echoes grey literature findings about commercial real estate across Canada during the early stages of the pandemic. In terms of spatial trends, Haider and Moranis (2021) use data from the CoStar Group to detail the urban-suburban divide in how COVID-19 is impacting commercial real estate. In line with the shift of more CBD-oriented jobs in finance, law, and insurance to work-from-home, major Canadian cities have seen a decline in the demand for downtown office space. However, suburban office markets have largely remained steady. For the post-COVID recovery, the authors suggest downtown real estate will rebound with the return of many face-to-face activities in early 2022.

In terms of what Nathan (2021) refers to as surface deactivation, the COVID-19 pandemic and associated control measures have had a significant effect on travel demand in Canada and around the world. Some researchers argued that the fears of exposure to the virus were high in shared modes and would reduce ridership (Beck & Hensher, 2020). Public transit ridership was particularly hard-hit, with transit operators across North America reporting dramatic reductions of up to 93% during the first wave of lockdown measures in April-May 2020 (Kamga & Eickemeyer, 2021). Using recent data from the Canadian Perspectives Survey Series 3, Harris and Branion-Calles (2021) found that the use of public transit prior to COVID was the strong predictor of commuting mode change during the pandemic.

In line with the donut effect, ridership declined more in areas with more commercial lands and areas with higher percentages of white, educated, and high-income individuals in Chicago (Hu & Chen, 2021). In contrast, areas with higher proportions of essential workers working jobs in food and agriculture, transportation and warehousing, and utility sectors presented smaller declines, as did regions with more coronavirus Google searches and more COVID-19 cases/deaths (Hu & Chen, 2021; Liu et al., 2020).

During the COVID-19 pandemic, compared to high-income households, lower-income households also had fewer travel choices, as their usual reliance on mass transit may be affected by lower service frequencies and fear of transmission risk (Basu & Ferreira, 2021; Palm et al., 2021). Studies found that many people increased car use during the pandemic (Basu & Ferreira, 2021; Palm et al., 2021; Wang et al., 2021) and some found that lower-income households are more susceptible to being forced into auto-dependence, as their usual reliance on mass transit may be affected by lower service frequencies and fear of transmission risk (Basu & Ferreira, 2021).

The Post-COVID Recovery

While it will take more time and research to fully understand the implications of COVID in the urban system, early evidence is starting to emerge about post-COVID recovery with respect to transportation and land use. On the employment side, data from Statistics Canada suggests many individuals may wish to continue working from home, at least part of the time (Mehdi & Morissette, 2021). These preferences, and the willingness of corporate leaders to partially acquiesce to them (PwC, 2021), may affect demand in the urban core.

Nevertheless, questions are being raised about the quality of online interactions facilitated through virtual meeting platforms. In line with past arguments about the transmission of information versus tacit or scientific knowledge, Glaeser (2021) suggests that from their own experience as a university instructor, it is difficult to inspire students due to the lack of an emotional bond. Similarly, such effects might result in lower productivity in the private sector over the longer term. Reades and Crookston (2021) agree, arguing that although ICTs are a great enabler, face-to-face contact will still be integral for maintaining relationships, confidence, and commitment. By extension, the authors argue there will continue to be advantages in agglomeration. But while such agglomeration effects may shape longer-term trends, preferences and arrangements for working from home will continue to affect travel demand in the short term.

Although travel demand is starting to recover as restrictions are gradually lifted in many cities, significant questions remain about the shape this demand will take. One such question concerns modal choices, and early research seems to suggest that car travel is rebounding faster than transit ridership. In Australia, Beck and Hensher (2020) found that aggregate travel was recovering since initial COVID restrictions, but car travel was the quickest to recover and concerns about public transit remained high. Survey results from Australia suggest transit ridership will return, but at a level about 20% lower than the pre-pandemic period (Currie et al., 2021). Moreover, a shift from transit to driving, particularly for CBD-oriented trips, is expected to result in significant peak-period traffic congestion. Still, sustained work-from-home policies are estimated to reduce commuting to the CBD by about 20%, but this level does not offset the expected growth in car trips.

Elsewhere, Rasca et al. (2021) found strong negative impacts on transit patronage associated with lockdown and distancing measures implemented over different “waves” of the pandemic across four cities in Europe. But since restrictions were eased, ridership recovered faster in the mid-size cities studied. In Toronto, car traffic had rebounded significantly faster than transit ridership by late 2021 resulting in the return of traffic congestion (Spurr, 2021). Survey research by Palm et al. (2022) found that of those in Toronto and Vancouver that frequently used transit before the pandemic, individuals aged 18-29 and recent immigrants were more likely to be attracted to driving during the pandemic. Moreover, catching COVID-19 or living with someone who did was associated with purchasing a car and plans for less transit use after the pandemic.

A frequently cited reason for a lack of transit trips during the pandemic is a concern about safety. In this regard, there is a risk that if the public transportation sector is perceived as poorly transitioning to post-pandemic conditions, the view that public transportation is unsafe may persist (Tirachini & Cats, 2020). The provision of hand sanitizer and the requirement of face-covering may encourage individuals to use sharing services. However, a survey shows that respondents expect these measures and improvements to be implemented but maintain the same pre-COVID-19 prices (Awad-Núñez et al., 2021). The uncertainty associated with the timing and magnitude of a return to transit will likely necessitate different service and operational plans on the part of transit operators (Shaheen & Wong, 2021).

Along these lines, some researchers argue that we should treat COVID-19 as a window of opportunity (Schmidt et al., 2021) or "circuit-breaker" (Basu & Ferreira, 2021) for policy and planning to reverse historically increasing car ownership trends and promote sustainable mobility alternatives. Part of the rationale for this stems from increases in more sustainable mode choices during COVID. Based on expert observations and interviews, Zhang et al. (2021) detail how most of the modal shift away from public transit went to car travel in various countries around the world. However, significant percentages also shifted from transit to walking and cycling. For example, Teixeira and Lopes (2020) found that while both subway ridership and use of New York City's CitiBike bikeshare were significantly down during initial COVID restrictions, bikeshare use recovered at a faster pace and there is some evidence of mode shift from the subway to the bikeshare system. Another aspect is building on the successes of many of the active travel-oriented urban design interventions that were implemented around the world (Combs & Pardo, 2021; Vecchio et al., 2021), including Toronto's popular ActiveTO program.

Looking ahead, some researchers have attempted to forecast different travel demand and mode choice scenarios and found that facilitating active mode use might be required to meet post-COVID travel demand in a context where transit is not at full service levels. Wang et al. (2021) studied transit ridership trends in New York City and found that a full reopening with 100% transit capacity may only attract up to 73% of pre-COVID ridership while the number of car trips increases by as much as 142% compared to the pre-pandemic period. Limiting transit capacity to 50% would further decrease transit ridership to 64% while car trips increase to 143% of pre-pandemic levels. The authors argue that during reopening, a transit capacity restriction policy needs to be accompanied by support for micromobility modes and restrictions to alleviate congestion. A similar conclusion is drawn from Ciuffini et al.'s (2021) research on several European and North American cities. Here the authors argue that mitigating an increase in driving in the context of reductions in transit capacity will require substantial increases in active mode share, particularly in cities with high transit ridership in the pre-COVID period. To help contextualize how such changes might occur and how planners can approach the role of public transit in the post-COVID recovery, the next section builds on the prior reviews to reinterpret the transportation-land use connection.

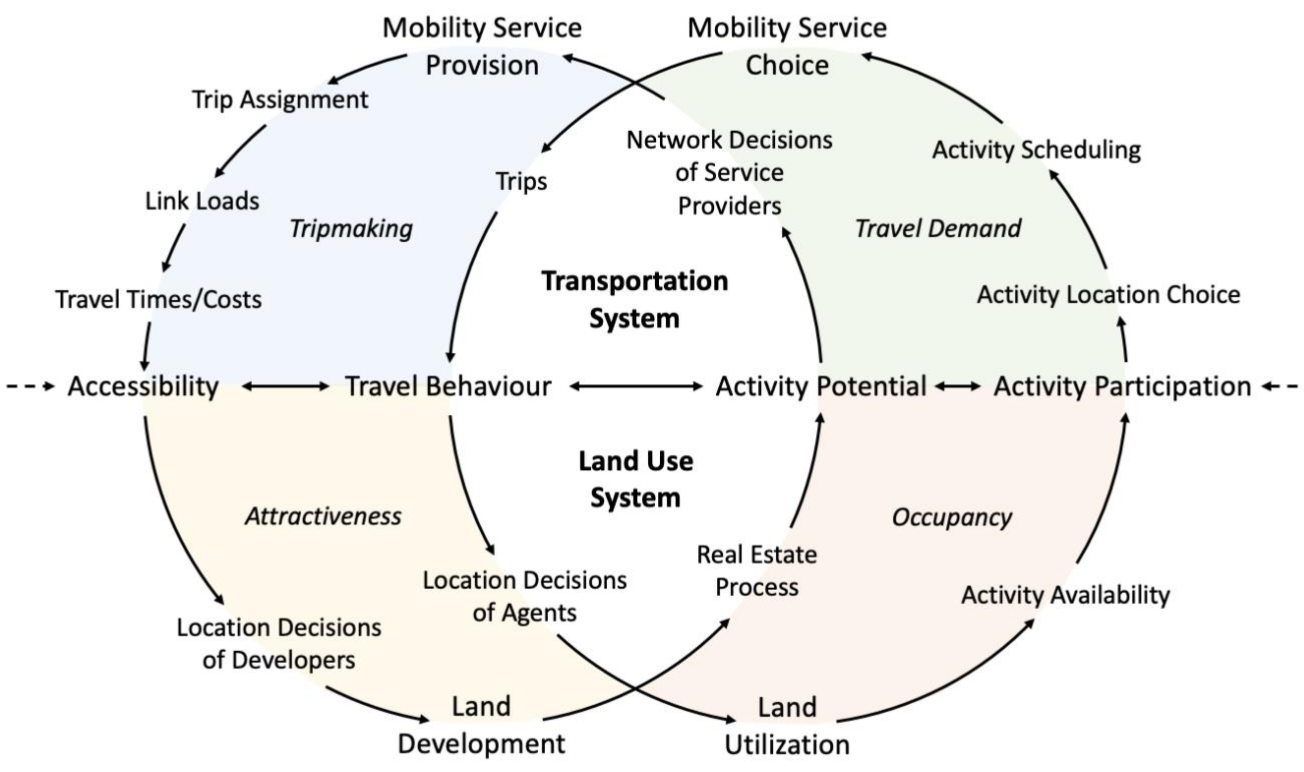
PART 3. REINTERPRETING TRANSPORT AND LAND USE FOR FUTURE INTEGRATED SYSTEMS PLANNING

The third objective of this report is to add value to the literature review through a synthesis and reinterpretation of the transportation and land use connection through the lens of new technology. Next, we identify gaps in our knowledge through the discussion of several thematic conclusions related to transport and land use and public transit's role within this system considering the changes that have, and are likely to occur, over the next decade or more in Canadian communities. In addition to the academic literature, we draw on a wealth of knowledge gained from three workshops held over the past year with stakeholders from different levels of government and the private/non-profit sectors. Together, these two objectives propose a modern and integrated approach to thinking about public transit and its role in facilitating improved social, environmental, and economic outcomes.

Reinterpreting the Transportation-Land Use Connection

Building on the core theoretical works concerning the transport-land use connection and our review of recent literature on new transportation technologies and trends, Figure 4 presents a reinterpretation of the transportation-land use system schematic. The top half of the schematic refers to the transportation system, made up of the physical networks, physical modes and sub-modes, and external or self-supplied mobility services that are potentially integrated within a MaaS paradigm. The bottom half corresponds to the land use system, which can be understood in terms of characteristics such as development density, diversity, and design.

Figure 4. A Reinterpreted Transport-Land Use System



Along the equator, the four concepts of accessibility, activity potential, travel behaviour, and activity participation are linked. *Accessibility* considers the potential to engage in activities using the transportation network, *activity potential* considers activity locations available for interaction, *travel behaviour* considers the observed trips that households make between origins and destinations to participate in activities, and *activity participation* reflects realized interactions that occur at a location over time. Each circle of the schematic has slightly different "poles" that reflect, to some extent, supply or demand in the transportation-land use system. The left-hand circle corresponds to more supply-side considerations including the provision of mobility services and land development, while the right-hand circle corresponds to more demand-oriented aspects like the use of mobility services and occupancy of activity generators in particular locations.

Within the schematic are four domains. In the *travel demand* domain, individuals and households make choices about the activities they will engage in and how they will be scheduled into activity episodes. Individuals then select a mobility service option that best meets their travel needs and engages in the trip. This aspect of the graph draws from Wegener's (1996) graph in Figure 2, but rather than the four-step modelling approach employed in the original figure, this reflects a more activity-, episodic-, and tour-based perspective that is sensitive to factors like household constraints related to modes and scheduling (Miller et al., 2015) as well as mobility services rather than modes (Calderón & Miller, 2021). Also within this domain, mobility service providers make decisions about where to supply and price mobility services on the network to meet potential and actual service demand for trips to activity locations.

Trips occur in the *tripmaking* domain, reflecting mobility service choices and travel behaviour associated with participating in activities. In the *attractiveness* domain, accessibility and observed travel patterns interact to influence the demand for locations. This can result in the supply of new development at particular sites by developers and influence the locational decisions of households and firms looking to utilize the developed land for activities. Finally, in the *occupancy* domain, households and firms take occupancy of the developed sites and utilize them for activities (e.g. one's home or setting up a business).

Accessibility is a key element that interacts with several aspects of the schematic. It is affected by tripmaking behaviour on the network that can alter travel costs on links through congestion or demand-based pricing. Accessibility can also directly influence the attractiveness of particular areas, with greater accessibility reflecting lower transportation costs involved in reaching potential jobs, amenities, employees, or customers. In line with the Alonso-Muth-Mills model, these lower transport costs should be reflected in higher land costs and a tendency to develop the site at higher densities.

Accessibility also affects travel behaviour and activity participation. For accessibility and activity participation, there is debate in transport modelling regarding whether travel is a derived demand – that travel occurs to enable participation in activities – or whether it should be treated as induced demand as households consume travel within their travel time or composite time and monetary cost budget (Thill & Kim, 2005). In the latter case, higher accessibility is assumed to reflect lower transportation costs or reductions in the friction of distance that produce higher rates of trip generation and greater participation in out-of-home activities.

To better understand the links between accessibility, travel behaviour, and activity participation, van Acker et al. (2010) argue that a distinction should be made between objective measures of spatial accessibility and subjective individual characteristics. In the former case, while traditional measures of place-based accessibility can capture the potential for interaction, person-based accessibility measures can better capture the space-time dynamics associated with travel behaviour and the potential for activity participation (Patterson & Farber, 2015). In this regard, the link between access and activity participation is stronger when viewed through the lens of time geography concepts that treat time as an essential element alongside special considerations when examining accessibility and travel behaviour (Fransen et al., 2018). This includes considering three constraints: authority constraints related to the availability of activities or transportation options throughout the day (e.g. transit scheduling, a store's opening hours), capability constraints related to individual mobility characteristics, physiological needs, or available resources such as mobility services, and coupling constraints related to the scheduling of activities with others in space and time throughout the day (Hägerstraand, 1970). In the latter case, socio-psychological factors including lifestyle, attitudes, perceptions, preferences, and habits are understood to play important roles in how such objective measures of time-geographic accessibility relate to individual perceptions of access and realized patterns of travel behaviour (Van Acker et al., 2010; van der Vlugt et al., 2022).

Beyond the graph itself, there are a number of external forces that shape, and are shaped by, the different aspects of the reinterpreted transportation-land use system in Figure 4. Following Bertolini (2012) for example, the supply of activities is affected by socioeconomic, demographic, and cultural factors, the transportation system is affected by technological innovations, infrastructure investments, and transport policies, and land use is affected by regional demand, the availability of land and attractive sites, compatible adjacent land uses, and land use policy. In terms of time effects, the shift to transportation options defined through mobility services and MaaS could change the feedback effects from slow in Bertolini's formulation to fast as mobility brokers or platforms respond to existing or potential activity patterns, although the rapidity of such changes would still subject to transport technologies and policy context.

There are other important linkages that can be drawn in, including housing affordability, social equity, and environmental outcomes that cannot be fully covered here. As one example, the link between travel behaviour and activity participation also extends beyond the schematic to individual satisfaction both in terms of satisfaction with daily travel as well as cognitive evaluations of one's satisfaction with life (De Vos & Witlox, 2017). Within this framework, the characteristics of the urban system affect one's ability to participate in activities such as work and leisure, enable social relationships, and contribute to individual health through physical activity. These "pathways" in turn affect life satisfaction, emotional wellbeing, and eudaimonia (Mouratidis, 2021). On the other hand, when transport disadvantages related to low mobility combine with social disadvantages such as a lack of employment, low income, or poor health, they can lead to inaccessibility and social exclusion (Lucas, 2012; see also the KSG project by Linovski et al. (2021)).

Beyond the transportation-land use connection depicted in the figure, there are also virtual networks and ICTs that facilitate information exchange. However, such digital infrastructure can play a complex role in the urban system by substituting trips and abstracting distance, changing existing trips, or by generating more trips by making travel easier. In this regard, there is ongoing interest in conceptualizing and measuring virtual and hybrid (physical-virtual) accessibility (e.g. Cavallaro and Dianin (2022)).

Thematic Conclusions

Building on the literature review and reinterpreted transportation-land use connection proposed above, this section reflects on what we know and do not know from the literature relative to the changes that are likely to impact the system and public transit's role within it over the next decade or more. The commentary is organized around five thematic questions that consider public transit and land use change, land value capture, social outcomes, new mobility technologies, and future sustainability planning.

1. Can public transit alone affect land use change?

Probably not. The connection between transportation and land use has been strong enough for public transit to influence land use change in the past. Much of the early spatial expansion of cities can be attributed to public transit innovations such as horse-drawn and electric streetcars. Within a transportation context that was largely defined by how far one could walk, these new transportation technologies enabled faster travel and allowed people to move further away from their jobs in the city. In some cases, streetcar lines were constructed by land developers who knew that new transit service would unlock the development potential of their land. The land development pattern that emerged was essentially transit-oriented development with clusters of higher-density development within walking distance of transit stops.

But this context has long since passed. Consistent with the academic literature, there was consensus in our workshops that transit, and transportation more generally, is a necessary but insufficient part of what makes a particular site appealing for land use development and change. There are many examples where new transit infrastructure has been built, often at significant cost, but the expected changes in development did not naturally occur. Part of the reason why could be a lack of change in relative accessibility. Compared to the streetcar cities of old, the transportation-land use context of contemporary cities is one where innovations in transportation technologies such as the car, alongside massive investments in supporting infrastructure like highways, have led to dramatic declines in transportation costs and generally high levels of accessibility across a city or region.

The ubiquity of roads has meant that high-order transit may not result in much of an increase in accessibility for particular sites. There are exceptions to this – consider a new transit line that runs parallel to a congested highway. If the transit line offers a decrease in travel times, we would expect it to offer meaningful accessibility benefits and compete for trips. Other transportation cost characteristics can also be considered, such as money. Congestion tolling on roads or high parking prices in the urban core can alter the transportation cost calculus in favour of a cheaper transit trip, even if the ride would be slightly longer. The greater the magnitude of transit's comparative transportation cost savings and accessibility benefits for connecting people to destinations of value, the stronger the link between transportation and land use. This reinforces that transit infrastructure should be built in the right place – where it fits in with the network and the other land uses this network connects to.

However, even if a new transit project is associated with relative accessibility benefits, transportation cost savings alone are not likely to spur land use change. This is because land use in cities is, more often than not, heavily regulated. If a new rapid transit station serves a neighbourhood zoned for single detached homes, we should expect this land use pattern to persist, even if the transit service offers a step-change in accessibility benefits. On the other hand, the evidence supports the conclusion that there is a strong role for government to support and capitalize on the transportation-land use connection through integrated land use and transportation planning. The combination of policy that promotes higher-density, mixed-use, and pedestrian-friendly development with high-quality connections to a transit service that offers accessibility benefits offers a much more compelling development context for realizing land use change. Consistency in policy and planning also matters – promoting transit-oriented intensification while also prioritizing highway expansion can create a situation where policy and planning are at cross-purposes, with the efficacy of "pull" factors undercut by policies that can "push" activities further into decentralized areas.

Nevertheless, it is important to remember that much of the development activity that occurs in cities is conducted by the private sector. While transportation accessibility and supportive policy are significant, they are only two of many aspects that affect the decision to develop land by private developers. Previous research also highlights that factors such as regional growth and demand, the availability of land and attractive sites, compatible adjacent land uses, and land use policy (Figure 3).

2. Is there a role for land value capture?

Probably. Transit projects can create locational advantages in the right accessibility, policy, and developmental contexts. Within the framework of the AMM model, an improvement to transportation infrastructure such as a new rapid transit line that decreases transportation costs and increases accessibility should lead to higher land prices for locations around transit station access points. If individuals value the accessibility offered by transit, this should in theory translate to demand for locations around access points. But the land value effects of transit can be distributive. By increasing accessibility in suburban areas, we might then decrease the relative locational advantages of existing urban land, flattening the bid-rent curve and increasing the spatial extent of the city.

In practice, we might reasonably expect land value increases associated with a transit line that produces accessibility benefits relative to other modal options by reducing transportation costs associated with travel to destinations that people value. While we can study land values directly, one indication of the demand for transit accessibility is ridership – if the station or line is heavily trafficked, this indicates that the service offers value to riders that might translate to locational premiums.

But in addition to transit accessibility, land value uplift is also fundamentally a question of the demand for more transit-oriented lifestyle contexts. Research has shown significant latent demand for transit-oriented development amongst certain segments of the population – latent in the sense that existing housing options mean that this demand is not currently met and that some households experience locational dissonance with respect to the match between their current versus ideal housing and travel context. Previous research into the land value effects of transit has not often recognized this aspect or attempted to decompose the issue to consider both transit access and built environment context and here more research is required. Furthermore, there has been little work conducted towards better understanding the link between personal or household preferences, household socioeconomic and demographic profiles, and willingness to pay for transit-oriented development.

In this regard, there is a rationale for pursuing land value capture associated with rapid transit projects, at least in theory. Land value uplift has in the past been referred to as an "unearned increment" or "windfall" for private land owners that benefit from public investments in transportation infrastructure. However, many factors should be considered when determining if this is worthwhile. Ideally, a value capture tool would be applied to offset some or all of the unearned increment, but in order to do this, planners and policymakers must have some expectations of what that increment is. Determining the spatial extent and rate of decay in the increment as distance from station access points increases is also critical so that some property owners who do not benefit are not unduly taxed. Typically, we might expect this value increment to decrease within a station catchment area defined by walking distance or time to a station. However, new micromobility modes that improve first/last segment connections to transit could act to further spread this land value uplift effect further over space. The timing of the uplift benefits is also a critical consideration. Land value uplift may already be priced into neighbourhoods in anticipation of a project due to speculation, and this process can occur as soon as planning documents are released and station locations are publicized.

There is also a question of what accessibility benefit is being valued in the property market. While land value capture works from the premise of recapturing the accessibility benefits afforded by a new transit project, transit access alone may not be what is driving land value uplift. As discussed above, some households value transit-oriented urban contexts featuring higher-density, mixed-use, and amenity-rich development with urban designs that afford high-quality connections to transit, but also designs that make these neighbourhoods more conducive to walking, cycling, and other uses. In this regard, transit-oriented development entails both local accessibility benefits, such as the ability to reach local amenities within walking distance of one's home, as well as more regional access benefits such as access to job markets or other destinations reachable on the transit network.

Determining and capturing the value of transit accessibility alone constitutes a significant challenge. Consider a long-term tax increment financing district around a new transit stop where policy and planning changes promote TOD. What drives the tax increment? Is it transit? Or transit-oriented development? Is there a rationale to extract value from not only transit planning but land use planning through TOD? Determining the value placed on regional versus local accessibility benefits entails decomposing the interdependencies between transportation, land use, accessibility, and travel behaviour in the urban system. There is a clear need for further research in this area.

The choice of value capture policy tool is also critical. Some policy tools such as tax-increment financing can be more flexible in this regard, allowing for the market to determine the incremental price appreciation through buying and selling. This is in comparison to policy tools such as benefits or special assessment districts where fees are levied to properties that are determined to benefit from the transportation improvement. But if applied in isolation, large-scale value capture policy may not align with larger policy and planning goals. Applying value capture policy to transit station areas where planning wants to promote more sustainable patterns of growth may penalize or disincentivize that growth from occurring, particularly when overt or hidden subsidies for urban sprawl persist.

Compared with more large-scale strategies for capturing value benefits within transit station areas, smaller-scale opportunities for value capture through joint development, land banking, air rights, or even station-area retail can provide interesting avenues for offsetting the costs associated with new transit projects. The magnitude and timing of expected uplift will also determine how much funding could potentially be raised while considering costs like administrating the joint development program. Engaging in public-private partnerships for smaller-scale transit joint development projects can entail staffing or transaction costs for the partners that might offset some or all the funds raised if the program cannot scale. For joint development to be fully realized, this also suggests that real estate and development considerations should play important roles in the planning process for determining the alignments of new transit lines and station locations.

3. Can we balance the transport and land use benefits from transit with social outcomes?
We should try. The literature suggests that the most acute potential adverse impacts of new transportation infrastructure are either small in magnitude (evictions) or mitigatable (business failures), offering hope that these impacts can be addressed. In the former case, the long-term value uplift effects of transportation infrastructure, a positive impact for some, can mean the least advantaged residents in society paying proportionately more of their income to live near transit or are displaced to areas where transit is less competitive. But evidence on acute impacts in residential mobility and displacement is limited, and current findings are mixed. The existing research suggests that the construction of new transit infrastructure is generally not associated with increased evictions due to real estate market changes. However, in areas already under pressure to gentrify, transit-related investments may add to this burden. Data on all residential moves reflects a reality that low-income people are more likely to move than other households in general, regardless of whether they live near new transit infrastructure. At the same time, wealthier people are also more likely to move into TODs (Delmelle, 2021). That said, the expropriation of properties required to construct a transit right-of-way or stations can directly lead to the displacement of people and businesses.

Nevertheless, such results must be contextualized in terms of the cities, transit corridors, station areas, accessibility contexts, and time periods inherent to each study. Moreover, existing quantitative research conducted at aggregate scales needs to be complimented with more individual-level qualitative work. Other effects require more research, including more gradual changes in housing costs and whether these expenditures are balanced by a household’s transportation cost savings. Here, the limited research suggests households may realize some savings when locating in a TOD neighbourhood, largely due to owning fewer cars, although these savings tend to be reduced by making more trips on transit. As such, these conclusions should be interpreted with caution and may not be relevant to particular examples in Canada.

In the latter case, there is also little evidence that public transit systematically induces commercial gentrification, although businesses may report higher rents. Still, like the residential side, it is unclear whether the potential attractiveness benefits associated with travel patterns and accessibility, such as greater foot traffic and potential customers, are balanced by the higher rental costs. Impacts from construction are particularly relevant for more disruptive construction techniques such as cut-and-cover that reduce foot traffic and vehicle access. However, researchers conclude that business impact mitigation and business retention plans can assist in minimizing these impacts. Stronger measures may be needed depending on the relative affluence of the retailers being impacted. A policy suitable for national chains may not be effective for racialized owners of small businesses.

Examples of mitigation strategies for displacement include setting aside land for affordable housing, requiring inclusionary zoning, or waiving parking requirements in exchange for affordable housing (PolicyLink, 2008). Moreover, while much of the research has focused on changes to the socioeconomic and demographic characteristics of neighbourhoods with new transit, there may be important opportunities to intensify around existing transit stations where land values are already high. Rather than gentrifying, such projects could help to produce more equitable outcomes in neighbourhoods that already feature good transit access. Mitigation impacts to businesses can include introducing business stabilization and retention plans, requiring local hiring in construction, and creating a community stake in joint ventures on contracts (PolicyLink 2008; BMO, 2019). The joint venture established to ensure community benefits from light rail in Toronto’s Golden Mile is a compelling example of what is possible

(BMO, 2019). Future research can identify the relative efficacy of these interventions to help further guide policy.

4. Will new mobility technologies and trends lead to more suburbanization?

Possibly. The connection between transportation and land use weakened over the past century, with the reduced transportation costs associated with the personal automobile contributing to urban decentralization and sprawl and questions about the efficacy of achieving more sustainable patterns of growth and development through investments in transit alone. In theory, if transportation gets faster, cheaper, or more convenient, we would expect individuals to travel more, relocate to more distant locations, and make longer trips. Moreover, if people commute less, we might also expect more trips over longer distances.

In this regard, new transportation technologies and services will continue to affect the urban system. But it is important to first consider the spatial and temporal scales of these potential impacts. In terms of space, on the one hand is the regional or metropolitan scale while on the other is the local or neighbourhood scale. The other dimension reflects the temporal scale at which we might expect these changes to occur.

To return to the question, new transportation technologies such as AVs may contribute to suburbanization by decreasing transportation costs associated with more regional travel patterns, though not as unidirectionally as the automobile did. Autonomous implies the cognitive burden on the driver associated with navigation and operation is decreased, allowing one's attention to be placed elsewhere. If this is paired with ICTs, we might see travellers become more productive on trips which in turn could change the individual calculus related to travel time budgets towards more long-distance travel for some people. Nevertheless, there is reason to be suspect of the claims that connected AVs will reduce traffic congestion as there is potential for such vehicles to lead to more VKT. This could be through empty trips in the case of privately-owned AVs, or, for example, different mobility services competing for trips by placing more vehicles on the road to decrease wait times. Downward price pressure from competition can decrease costs and lead to more travel. Moreover, COVID-19-related changes to the built environment, such as road closures, alongside demands to increase the safety and convenience of micromodes that divide limited urban road space for use by more types of vehicles, all stand to limit access by private vehicle – autonomous or not – in more urban settings.

On the other hand, micromobility modes and services might reasonably be expected to have a positive impact on transportation accessibility at the neighbourhood scale by better connecting individuals and households to more local destinations. Much of the potential of micromobility is rooted in first/last-mile connections to transit. In doing so, micromobility modes and services can reduce transportation costs associated with some legs of a multimodal trip chain and extend the spatial catchment area of transit accessibility associated with station access points. This can also act to spread out or smooth the locational benefits of transit that have typically been confined to walking distances, such as land value uplift, that could result in greater development potential. In this sense, rather than contribute to suburbanization by decreasing more regional-scale commuting or transportation costs, micromobility may help to urbanize the suburbs. However, micromobility modes are not likely to contribute to any meaningful changes in more regional-scale accessibility related to longer-distance travel to major employment or activity centres.

The COVID-19 pandemic adds a layer of complexity to these conclusions. While there was consensus in our workshops that much of the pandemic-related effects will not be permanent, COVID-19 has undeniably altered the relationship between land use and transportation over the short- to medium-terms in ways that complement urban decentralization. In terms of work, the pandemic has demonstrated the effectiveness of work-from-home technologies at a scale not previously seen. COVID-19-related control measures have also contributed to significant changes in travel behaviour. Transit use has significant declines that appear to persist relative to other modes with some riders questioning the safety of transit within the context of social distancing. Many previous transit riders have also fallen into new routines that prioritize other modes. This includes increases in driving, but also greater amounts of walking and cycling.

Looking ahead, these changes will alter travel in cities along the who, where, when, why, and how dimensions. While work-from-home has not been an option for many whose jobs are classified as essential, most of those in white-collar jobs working remotely strongly desire to continue doing so post-pandemic. If employers partially acquiesce, the “donut” effect associated with declines in demand for space in the central business districts of cities may also persist. However, there is always going to be a role for face-to-face contact. Although further innovations in ICTs such as virtual reality might be promoted as a means of better communicating in virtual space, the undefinable properties of tacit knowledge and importance of face-to-face contact in building trust and maintaining relationships mean that the benefits of agglomeration will persist for some activities. On the other hand, ICTs that largely accommodate a firm’s business functions could result in these firms being more “footloose”, causing them to relocate to lower-cost suburban areas where transit is not competitive, or switch entirely to virtual work models.

On the travel side, if AVs are fully realized, we might see some workers make fewer trips over longer distances in AVs to their knowledge-sector jobs in the CBD. But what will not persist over the short term is the reductions in traffic congestion due to COVID-19. While remote work will continue to reduce peak-period CBD-oriented trips, these reductions will be more than offset by the increases in car use associated with shifts away from transit and the longer car trips that result from the relocation of households to more suburban areas. This congestion will continue to impede movement and act as a force for centralization that is likely to result in continued demand for more urban locations that facilitate transit and micromobility use.

Moreover, it is critical to consider how such changes will alter why people travel in cities and when. While much of the discussion above has focused on commuting, cities are about far more than work. Already, some major cities like Vancouver saw weekend transit ridership reach near pre-COVID peaks while ridership at the former ‘peak hours’ remain depressed, reflecting the importance of amenities, culture, and nightlife as urban centripetal forces. For white-collar workers at least, proximity to amenities, and not work, may play a bigger role in residential location decisions. While such changes may lead to greater demand for more travel and suburbanization, there is also a clear role for planning and policy in shaping many of these outcomes. We discuss these in the next section.

5. Do we need to rethink future planning for sustainability?

Perhaps. Based on the experiences of cities like Toronto over the 20th century, much of planning for sustainability since the 1990s has been about the promotion of TOD or, more recently, planning for accessibility. However, the COVID-19 pandemic has raised questions about the return to cities for many people and activities, as well as the return to transit. Likewise, new transportation technologies are already influencing the ways in which people travel and may promote more decentralization over the coming decades. The previous conclusions discussed some of these effects in more detail through the question of suburbanization; this section takes a wider view. While we expect the current COVID-19-related “donut hole” of urban activity to be filled through the reactivation of economic and “surface” functions, the transportation-land use dynamics that inform how we plan for sustainability may look different from the pre-pandemic period.

New mobility technologies and services can make travel easier in cities, and this should result in a smoothing of the bid-rent functions and locational advantages associated with accessibility. On the one hand, AVs and telecommuting could lead to fewer but longer trips, acting as a push factor that promotes decentralized growth. On the other hand, requirements for face-to-face contact will continue to exert pull effects for certain sectors and activities. Traffic congestion will resume its self-limiting tendencies, causing people and firms to make alternative mode and locational choices. This suggests an enduring role for transit-oriented development where self-supplied or external micromobility services can make first/last-mile access to transit easier, spreading the benefits of transit accessibility to major job centres over a larger area. Still, many jobs are already not located in urban centres and, going forward, more functions may also suburbanize due to ICTs.

Although safety concerns about transit are likely to persist and hamper the return of ridership over the short term, there is no denying the critical role of transit and active modes in the pursuit of urban sustainability over the longer term. Much has been made about the potential of electric automobiles and AVs to reduce emissions in the transportation sector. Reducing and ultimately eliminating fossil fuel use is of paramount importance. But even if the primary energy source for cars and trucks switches entirely from fossil fuels to electricity, moving a relatively small number of people using large vehicles will always be more space and energy-intensive than the sheer passenger throughput potential of higher-order transit or the space and energy optimization of active modes for travel in higher-density contexts.

The COVID-19 pandemic's effect on work and commuting is of great interest – much of the research into the transportation-land use connection focuses on work-related travel, and workplaces traditionally act as important "anchors" that impact time-geographic conceptualizations of accessibility. Nevertheless, travel for work purposes makes up only a small proportion of all trips in North America. Travel for non-work purposes made up 80% of all trips in the US in 2017, and this proportion has increased over time. Combined with the workplace-related effects of COVID-19, this suggests a potential rethinking about how to plan for accessibility and travel behaviour in cities with less of an emphasis on regional accessibility and a greater emphasis on what can be reached locally. The 15-minute City concept (Moreno, 2019) has done much to highlight and popularize the role of neighbourhood accessibility and "living locally".

Rather than the more traditional view of cities and agglomeration as the engines of production and the "pull" forces employment hubs exert on commuting, viewing cities as centres of consumption, entertainment, and social functions will be crucial. In this regard, planning for local accessibility and quality of life should involve placing greater emphasis on local amenities such as the grocery store as a hub for trips that drives foot traffic, the attractiveness of sites, and the density of development. Similarly, even if many workers are telecommuting from the suburbs, there will always be demand for agglomerations of amenities closer to home that increase quality of life, such as shared workspaces and meeting rooms or coffee shops for when one wants to leave the home office as well as other amenities that fulfil critical social functions.

On the one hand, innovations in transportation technologies combined with lasting effects from the COVID-19 pandemic may continue to weaken the transport land use connection and promote suburbanization. But on the other, there are still agglomerative forces for many activities. This suggests planning for sustainable growth and travel might take the form of higher-density, mixed-use development around regional express rail stations supported by transit and micromobility modes and MaaS platforms that connect residents to the node. Certainly, such plans for polycentric development are not new. All that might change is a greater emphasis on new transport technologies for spreading the benefits of such development over a larger area.

That said, what will be new is the context in which these plans are made. While decreasing transportation costs can result in push factors that favour more trips over longer distances and potential relocations to decentralized areas, many forces external to the transportation-land use connection will shape urban sustainability over the coming decades. Socioeconomic and demographic shifts associated with the life course of the millennial generation, as well as the aging of their parents in the baby boom generation, will impact many facets of the urban system in the near term. Other general trends impact travel, with increasing incomes a major driver of the demand for suburbanization in the past. However, in the context of a weakening transportation-land use connection, policies that attempt to limit urban growth or shape travel may be perceived as restricting individual mobility and quality of life. In this sense, planning for sustainability may need to better consider the political economy of political and planning processes.

Over the short term, and given the pressing need to rapidly decarbonize and meet climate goals, increasing the environmental sustainability of suburban built environments can be accomplished through

EVs to reduce or eliminate emissions associated with existing land use and travel patterns. There is also a role for on-demand transit and ridehailing, as well as micromobility, although the adoption of micro modes can be limited by factors such as a lack of safe infrastructure and long trip distances. Nevertheless, these options can be used for increasing access in areas that are poorly served by existing transit routes and to improve social equity in access. Due to existing transportation and land use patterns, increasing accessibility and promoting more sustainable travel patterns in suburban environments is best accomplished through land use changes that increase the number of amenities reachable by alternative modes. But because of the durability of the built environment, land use changes that urbanize the suburbs will occur over a longer timeframe and will require supportive planning and policy.

There is also a need to promote greater intensification, land use diversity, and local accessibility – as well as greater social inclusion and economic opportunity – in more urban settings through changes to zoning. This includes revisiting zoning ordinances that prohibit medium (missing-middle) or higher-density development in areas that already exhibit relatively higher levels of accessibility by transit, walking, and micromobility modes. Other zoning ordinances such as parking minimums, setbacks, and single-use zoning can limit accessibility to diverse opportunities by transit and alternative modes. In many cases, zoning has codified aspects of automobility and made it difficult or impossible to replicate the higher-density and mixed-use urban forms that facilitate the greatest levels of walking and alternative mode use in cities. In this regard, sustainability planning must include greater attention on how finite urban space is implicitly/explicitly allocated or re-allocated for particular modes and functions.

Longer-term, although current planning paradigms offer valuable pathways for promoting more sustainable development and travel, current planning paradigms are fundamentally growth-oriented. Significant questions remain about how to plan for sustainability in a context of slowing growth or even the “degrowth” associated with population decline over the coming decades. Such effects are not likely to be evenly distributed across, nor within cities. Moreover, climate change resilience and the potential for climate-associated migration will also need to be considered. Finally, whether the “consumer city” can ever be socially just or truly environmentally sustainable or ethical also remains to be seen.

PART 4. TOWARDS FUTURE INTEGRATED SYSTEMS PLANNING

To conclude the synthesis, this section first reflects on issues and challenges surrounding the implementation of policies and plans to achieve improved outcomes. Second, we close with some commentary on opportunities for a more integrated approach to systems planning in the future.

Challenges: System Context

As demonstrated by this review, we "know a lot" about transportation-land use interaction and the need for an integrated approach to the planning, design, and operation of both the transportation and land use systems. Much of this knowledge of the urban system has existed for decades. However, one of the big challenges facing integrated systems planning in the future is a lack of integrated transportation-land use planning in the past. A question then arises as to why this theoretical knowledge often seems to have so little impact on actual policy and on-the-ground implementation. Based on feedback from the third workshop associated with this project, a number of reasons for this state of affairs arguably exist.

First, in Canada, land development lies largely in the private sector, with development plans being driven by developer profitability rather than broader societal goals, transportation or otherwise. While public sector levers for influencing this aspect of the urban system exist, including zoning and official plans, these are often overly malleable in implementation. They may also in some instances be counter-productive in terms of locking-in outdated design concepts or providing scope for innovative design experiments (Blais, 2010).

Second, while calls for more environmentally sustainable and socially just transportation systems and urban designs are ever-increasing, a "culture of automobility" still exists within our society with strong vested economic interests in the status quo, including the automotive, energy, and land development sectors. Similarly, while widespread public support exists in principle for more sustainable options, strong cultural preferences for low-density, single-family housing (as well as automobility) exist that continue to drive many development decisions.

Third, planning responsibilities and capacities are overly fractured, both between land use / urban planning on the one hand and transportation system planning on the other, and across levels of government (municipal, regional, provincial, and federal). This makes an integrated, systematic public sector approach to problem definition, generation and comprehensive assessment of solutions, and coherent decision-making challenging, and, often, impossible.

Fourth, insufficient effort has gone into "knowledge mobilization" in terms of translating this theoretical knowledge into intelligible "stories" that are understandable by politicians and the public alike. While we all experience our urban systems daily, most people generally do not perceive or understand the interconnections that have been described in this report. As a result, there is generally an under-estimation of the risks of the status quo (and, hence, for the need for change) on the one hand, and an over-estimation of the risks of change (and, hence an unwillingness to change) on the other. People need to be able to understand how an alternative future, while different, can be better. Further, people need to be shown how they can individually benefit from a more sustainable future, not just society as a whole. Improved visualizations and other communication mechanisms need to be developed that translate sound technical analysis in ways in which both the individual and collective good can be seen to be improved.

Given all the above, political will is too often lacking to undertake new, improved land use or transportation options (let alone their coordinated implementation) given the strong economic and social inertias on the one hand and (too often) a lack of compelling, implementable policies possessing strong public support on the other. This can prevent policy interventions that can be highly effective – such as congestion charging or ending subsidies for sprawl – from being realized, while potentially far-off and uncertain technological innovations such as AVs attract significant attention. "Visionary leadership" is always an ideal, but it is difficult to achieve without coherent public support pushing the vision.

Opportunities: Systems and Leverage

The transportation-land use system depicted in Figure 4 is a complex one, but there is great potential for making changes to achieve better social, economic, and environmental outcomes. In her excellent, very accessible book on systems theory, Donella Meadows argues that a systems approach is essential to understanding complex socio-economic phenomena such as cities (Meadows, 2008). But understanding the structure and processes of the system (road and transit systems operations, land development processes, etc.) is only the beginning. We must then use this understanding to identify the "system traps" – the behaviours within the system which are generating sub-optimal, unwanted and even perverse outcomes. Some of these system traps have been listed above.

Then we need to look for the "leverage points" within the system where we can effectively intervene to achieve a meaningful improvement in system performance. This may well include improving "structural elements" of the system, such as building more public transit or imposing higher density development targets. But these, in themselves, are rarely sufficient, and, indeed, may be ineffective. For example, as discussed in this report, building high-order transit in low-density, auto-oriented land uses is unlikely to be effective without, at a minimum, significant other supporting changes in local land uses (increased mixed-use, new micromobility options, etc.), changes in existing travel patterns that might make use of such investments, and changes in public attitudes towards both mobility options and local urban form.

Other possible leverage points might include: first, treating <u>every</u> new greenfield site as an opportunity to develop a "complete community" that has a variety of uses (residential, commercial, recreational, employment) and supports a variety of travel modes (walking, biking, and transit – but also the automobile for trips that cannot be served otherwise). Both the local neighbourhood design and the interconnectivity of the community with the rest of the municipality and the region need to be explicitly considered.

Second, opportunistically looking for suburban neighbourhoods that are most "susceptible to change" for urbanization. Not all suburban neighbourhoods are capable of transforming to more "urban" configurations, for a variety of reasons. But many are. Shopping malls and suburban office parks, in particular, are prime candidates for densification and "urbanizing" into more complete and higher-quality neighbourhoods. They are prime candidates to become nodes in enhanced transit networks. Relatedly, wide suburban arterial commercial strips are often superb candidates for LRT or BRT routes, with wide rights-of-way able to accommodate more cost-effective surface rapid transit and sites with potential for medium- to high-density mixed-use redevelopment.

Third, Canadian cities are also rife with high-rise "towers in the park" built on spacious sites in the 1950s, '60s and '70s in the Le Corbusier style. The City of Toronto is perhaps the ultimate example of this, with more such developments than anywhere else in North America outside of New York City (ERA Architects, 2009). The "parks" within which these towers sit are sterile, vastly under-utilized land parcels that are ripe for densifying with new homes, shops, stores, and other uses that would immeasurably improve their residents' accessibilities and quality of life, promote fair greater neighbourhood walkability and bikeability, and enhance transit ridership potential. These tower complexes are also home to some of the city's poorest populations who possess some of the worst accessibilities.

Fourth, aggressively looking for ways to systematically and comprehensively improve surface transit networks and their operational performance. This can include using modern ICTs and artificial intelligence to provide much-improved priority for on-street transit operations to maximize roadway throughput for all trip-makers; using modern computation capabilities to optimize bus network design, stop spacings, and service frequencies to provide much better service for actual travel demand patterns; and looking for opportunities to make use of wide suburban arterials to implement BRT and LRT services.

Fifth, creatively experimenting with new mobility services and MaaS models in a variety of urban and suburban contexts. Complementing and supporting transit should always be a primary concern – but this might in some cases mean replacing a very inefficient and ineffective fixed-route bus service with a more nimble, cost-effective, and attractive mobility service of one form or another. The interaction of such new services and technologies with the land uses being served – and the potential for evolution of these land uses given the presence of these new services – also needs to be always considered.

Note that in all these cases, an integrated perspective and balance between land use and transportation elements is maintained. Also, the focus in each case is a "bottom-up" one in which individual communities, transportation corridors, etc. are identified for potential improvement, but always within the overall municipal and regional context. While actions are locally focused, they should never be piecemeal or undertaken without understanding the larger spatial context. No neighbourhood is an island, and every transit line and road segment exists within an integrated network. The urban region changes over time through one development project and one transportation system change at a time, but the cumulative effects of these individual events must be understood and are what ultimately lead (or not!) to enhanced urban equity, sustainability, and other macro goals.

Finally, all such initiatives need to be taken in partnership with private sector partners (developers, mobility service providers, etc.) and the public through knowledge mobilization activities such as have been briefly discussed above. Developers must understand how new land development models can be feasibly and profitably constructed while benefitting society. The public similarly must understand how changes in their neighbourhoods and mobility options can improve their personal accessibilities and quality of life while "improving the social good".

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APPENDIX 1. WORKSHOP ATTENDEES

The project team is grateful for the attendance of representatives from the following public, private, and not-for-profit sector entities. Input and feedback from attendees across the 3 project workshops was crucial for contextualizing and co-creating this synthesis.

Canadian Urban Institute
Canadian Urban Transit Association
City of Toronto
City of Vancouver
Durham Region
Durham Region Transit
Environics Analytics
Ford of Canada
General Motors Canada
Infrastructure Canada
Infrastructure Ontario
Metrolinx
Ministry of Infrastructure
Ministry of Transportation
Northcrest Developments
pointA
Smart Commute NTV
Strategy Corp
Toronto Transit Commission
TransLoc, Inc.
ULI Toronto
York Region
York Region Transit

An Integrated Approach to Transit System Evolution

University of Toronto
Transportation Research Institute

December 2021