A Tale of Four Canadian Cities:
LRT Systems and the COVID-19 Pandemic

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Light rail transit (LRT) systems have been proposed and implemented in many jurisdictions in Canada and abroad to cope with long-standing problems associated with urban sprawl. LRT systems are presented as an alternative mobility option to automobiles, a solution to alleviate traffic congestion, attract new property developments in existing urban areas close to downtown and enable higher density developments. However, there has been limited discussion and research on evaluating whether the LRT systems achieved their original policy goals and objectives. Thus, this research aims to address the performance of Canadian light rail transit (LRT) systems with respect to ridership and land development, and investigate the impact of the COVID-19 pandemic on meeting the original policy goals and objectives of LRT systems. Four LRT systems in Waterloo, Calgary, Vancouver and Ottawa were chosen as case studies to facilitate the research.

The research identified multiple Key Performance Indicators (KPIs) and created two scenarios to evaluate the LRT system performance and the impact of the pandemic on daily public transit commuting ridership. This research finds that the four case study LRT systems generally had satisfactory performance and mostly achieved their original policy and goals. During the peak of the pandemic, it is estimated that daily public transit commuting ridership decreased by over 40%, while the "new normal" scenario estimated a 20% drop in commuting trips as work from home policies become permanent in some workplaces. However, changes in ridership vary greatly among census tracts (CTs) as some CTs are estimated to experience much larger declines in ridership due to a concentration of industries which has higher potential for telework. While the COVID-19 pandemic is expected to impact the achievement of some policy goals and objectives of LRT systems, the extent of the impact is uncertain due to the ongoing changes of the pandemic.

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1. Introduction

1.1 Background and Research Motivation

Since the 1950s, North American urban development has been dominated by suburbanization and urban sprawl. However, long-standing problems associated with urban sprawl such as automobile dependency and encroachment on agricultural lands have led to the development of alternative approaches to suburbanization in recent years amid the rise of sustainable development concepts and smart growth initiatives. Many cities have rethought their development patterns and are shifting growth towards infill development and intensification as part of strategic growth strategies. Smart growth has been shaped by provincial plans such as Ontario's Growth Plan for The Greater Golden Horseshoe and Places to Grow Act which introduces intensification policies for growth management by focusing on intensification in existing built-up areas, promoting mixed-use development and the provision of auto alternative transportation and improved transit systems.

As part of an effort to support strategic growth and improve transit system performance, light rail transit (LRT) systems have been proposed and implemented in many jurisdictions. They are presented as an alternative mobility option to automobiles, as well as a solution to alleviate traffic congestion, attract new property developments in existing urban areas often close to downtowns and to enable higher density forms of urban development. In North America, LRT systems have experienced several waves of interest, beginning with the energy crisis in the 1970s (Black, 1993) and more recently given an increasing emphasis on sustainable development and smart growth since the 2000s (Higgins & Ferguson, 2012). These LRT systems have varied in performance and have led to very different impacts on patterns of development and urban form (Babalik, 2000). Investigating whether the original policy goals and objectives for different LRT systems have been met is important for future

LRT developments as the case studies could illustrate broader understanding and shed light on other North American LRT systems.

While efforts to impact mode choice and shift from auto to transit have been behind the investments in LRT, there are other forces impacting mode choice as well. Telework and working from home trends have been increasing amid technological advancements in the past decade (Cox, 2020). At the same time, the appeal of living in close proximity to the workplace and entertainment has been very attractive to Millennials and the younger generation as they desire shorter commutes and are "city slickers" who prefer living and working in the city (CBRE Research, 2016). Several cities in Canada with LRT systems have planned and built transit-oriented developments near LRT stations and public transit ridership have increased along LRT corridors.

The COVID-19 pandemic has led to a large decrease in public transit ridership in most cities as a result of restrictions implemented to limit the spread of COVID-19 (Liu et al., 2020). A lot of companies had to implement remote work / work from home policies amid government-mandated shutdowns and Stay-at-Home orders. In June 2020, only 24% of Canadian commuters who used public transit were still using public transit to go to work, while 42% switched to telework (Savage and Turcotte, 2020). As public transit has been associated with higher risks of exposure to COVID-19, there has been concerns and even fear regarding riding public transit even when workers are able to return to the workplace.

Deng et al. (2020) estimate that approximately 39% of Canadian workers are in jobs that could be carried out from home while Gallacher and Hossain (2020) estimate the number at 41%. However, telework capacity varies largely across industries. Therefore, the potential impact of work from home policies on public transit ridership varies considerably between and within cities. As working remotely has become increasingly prevalent, some organisations might introduce telework arrangements in the longer term. The increasing levels of working from home after the pandemic potentially affects the achievement of the goals and objectives of LRT systems as the advantages of residing close to the workplace becomes less important for employees. Understanding the implications of shifts in the workplace is important for transportation planning and helps inform future public transit policy decisions.

1.2 Research Questions and Objectives

This research aims to address the following research questions:

1. How have Canadian light rail transit (LRT) systems performed with respect to ridership and land development?
2. How will meeting the original policy goals and objectives of these LRT systems be impacted by the COVID-19 pandemic?

Four research objectives are drawn from the above research questions.

1. Review the performance of light rail transit systems in four Canadian cities (Waterloo, Calgary, Vancouver and Ottawa)
2. Investigate if the selected LRT systems have achieved their original policy goals and objectives
3. Estimate the impact of COVID-19 induced work from home on public transit ridership at the neighborhood level
4. Assess how the COVID-19 pandemic may impact the achievement of the policy goals and objectives of the LRT systems

1.3 Anticipated Research Contribution

It is anticipated that this research will be beneficial for planning practice and society in several ways. This study aims to provide a comparative evaluation of the selected LRT systems' performance which will provide insight into whether the goals and objectives for the light rail transit systems are met and provide insights for strategic and transit planners. In addition, the study evaluates Canadian LRT system performance and the relationship between the changing nature of workplace locations and commuting needs amid the changes to the workplace induced by the COVID-19 pandemic.

Large amounts of public financial resources are used for LRT system construction – for example, ION rapid transit in the Region of Waterloo and the OTrain in Ottawa had construction costs of over C$800 million and C$2.1 billion respectively. Thus, interest in how the LRT systems are performing compared to their original goals and objectives is high. A comparative analysis among different systems would be beneficial to planning practice and broader society.

The second major anticipated contribution of this study is to further the understanding of how the COVID-19 pandemic is impacting spatial development and activity patterns. This study will bring insights into the longer-term implications of work from home for public transit both at the neighbourhood level and overall transit system perspective.

1.4 Thesis Outline

This thesis is organized into the following chapters and sections.

Chapter 1 (Introduction) provides a general overview for the research, the four selected case systems, and introduces the research questions and key objectives that this research seeks to address.

Chapter 2 (Literature Review) presents literature on the main themes of the thesis. The existing relevant body of literature regarding light rail transit's development and the related land use changes brought by light rail transit systems. The key performance indicators as well as the methods for evaluating system performance are also identified. It also presents how the COVID-19 pandemic has affected transit systems, especially in the Canadian Context.

Chapter 3 (Research Methods / Methodology) explains the research methodology utilized in the thesis. This chapter further highlights the geographic area for the four selected case systems for both the COVID-19 impact and the built form change and transport-oriented development analysis.

Chapter 4 (Findings) presents the findings and results for the case study light rail transit systems by using various key performance indicators, COVID-19 induced work from home's potential impact on public transit ridership and how goals and objectives of LRT systems could be affected by the COVID-19 pandemic.

Chapter 5 (Discussion) discusses the analytical findings of the research as presented in the previous chapter.

Chapter 6 (Conclusions) summarizes the main takeaways from the findings and discussion of the study. The research contributions of the study are highlighted and opportunities for further research are identified.

2. Literature Review

2.1 Definition of Light Rail Transit (LRT)

The definition of light rail transit has slightly varied according to different studies. The Transit Cooperative Research Program (2012) states that the term “light rail” is often misunderstood due to its size and design that could be similar to other railway systems such as heavy rail and commuter rail. The American Public Transport Association (2019) defines light rail transit as a mode of transit service on fixed rails in right-of-way that is often separated from other traffic for part of much of the way, driven electrically. It also expands the definition by adding that it is a system of electrically propelled passenger vehicles with steel wheels propelled along a track constructed with steel rails. European Metropolitan Transport Authorities defines light rail as a rail-bound mode of public transport for cities and urban regions and is principally able to be integrated within public realm, sharing public space with other traffic to some extent (Van der Bijl & Van Oort, 2014).

Schumann (2009) emphasises the flexibility in defining LRT, and his definition of LRT consisted of three descriptions – *“1. Located predominantly on reserved but not necessarily grade-separated rights-of-way; 2. Operating electrically propelled vehicles run singly or in trains; and 3. Providing a wide range of passenger capacities and performance characteristics.”* Schumann’s definition which included streetcars, classic LRT lines and LRT routes that offer private right-of-way was criticized by Higgins & Ferguson (2012) as the definition is too broad and leads to confusion. The viewpoint that streetcars is usually used as another form of transit than LRT is supported by King and Fischer (2016) which states that light rail tends to utilize dedicated rights of way and span longer distances compared with streetcars.

2.2 The Evolution of Light Rail Transit (LRT) in North America

Light rail transit in North America could be traced back to streetcar lines that were first established in the 19th century. Williams (2018) noted with the electrification of streetcars that replaced horse-drawn streetcars, the U.S. had 15,000 miles of electric streetcar lines in the 1920s. By World War I, most towns with more than a population of 10,000 were served by a streetcar system (Slater, 1997). Streetcar usage rose steadily before the 1920s due to rising incomes, low fares and rapid population growth in urban areas. Streetcar ridership peaked at 13.8 billion riders in 1920 and declined from the onset of the great depression till the 1970s. Slater (1997) observed that from the 1930s, buses started to replace streetcars as they had a lower operating cost, were safer and had higher routing flexibility. Public transit ridership dropped significantly by over 50% in the U.S. from 1950 to 1970 from the rise of the automobile and rapid suburbanization (Thompson, 2003). Streetcar ridership as a fraction of transit fell to a mere 3% from 23% in 1950. Many interurban lines became increasingly unprofitable and travel times became longer as traffic was increasingly congested, making streetcars unreliable and slow (Boorse, 2000).

In 1975, only 10 streetcar systems in North America survived according to Schumann & Tidrick (1995). However, since the first modern light rail transit system was built in 1978 in Edmonton, LRT systems have experienced a revival in North America (Topalovic et al., 2012; Culver, 2017). Diamant (1976) attributes the revival of LRT in North America to the reorientation of transportation goals in the 1970s that have emphasized the need to achieve balance among urban transport modes and European successes in adapting LRT to modern cities. Thompson (2003), on the other hand, argues that LRT’s revival and the renaissance was a product of social movements in the late 1960s and 1970s as people were looking for technological and social progress.

North American LRT systems built in the 1970s and 80s were viewed as a natural magnet for development. However, many of these systems had a limited effect on inducing new development and suffered from low ridership as there is a lack of policies for transit-oriented development (Higgins and Ferguson, 2012). In response, a new wave of LRT systems that were influenced by the emergence of the concept of transit-oriented development have been built since the 1990s. These systems were built amid increasing environmental awareness and regional strategies that aimed to reduce auto use, and led the market to start shifting away from post-war suburban development patterns to more sustainable land use patterns (Fogarty and Austin, 2011). Schumann (2009) observed that this phase saw a continued increase of new LRT systems being constructed, and many cities with existing LRT systems expanded LRT coverage amid emerging smart growth initiatives and concerns of automobile dependence.

2.3 Common Goals and Objectives of LRT systems

The goals and objectives of LRT systems have changed through the various periods of LRT development. In the 1970s, LRT systems became more popular in North America as European systems showed that they could provide quality transit service while placing fewer demands on limited financial resources (Diamant, 1976). Transit experts in the 1970s saw LRT systems as a potential solution to alleviate increased traffic congestion and pollution amid the "oil crisis" and a tool to create and guide economic development (Garrett, 2004). Lower initial costs of LRT systems compared to other transit modes such as commuter railways and subway systems was also an underlying reason for LRT development in the 1970s and 1980s as planners were constrained on limited financial resources and government funding amid a strong preference for automobile travel and public antipathy to public transit (Transportation Research Board National Research Council, 1989). Since the late 1990s, sustainable development and environmental goals had also become increasingly prevalent in the construction of LRT systems in the United States with its strong environmental legislation at that time (Mackett & Edwards, 1998).

In recent years, the common goals and objectives of constructing LRT systems include both tangible objectives such as reducing levels of traffic congestion and air pollution, promotion of transit-oriented land use change and intangible objectives such as boosting the image of the city to improve its modernness and competitiveness (Higgins et al., 2014; Higgins and Kanaroglou, 2016). Several main objectives for the introduction of LRT systems include reducing traffic congestion, improving public transport coverage and ridership, improving the environment, and bringing a positive impact on more sustainable land use and urban growth patterns. Other sub-objectives include reducing air pollution, stimulating development in the CBD and declining areas, and helping to change car-oriented urban growth patterns to a more transit-friendly form (Babalik-Sutcliffe, 2002; Mackett & Edwards, 1998).

Cohen-Blankshtain & Feitelson (2011) suggests that there are two predominant goals for LRT systems – to serve existing travel demands as an alternative auto option in areas experiencing congestion, and to induce demand in areas that currently lack transit accessibility by boosting their development potential. These rationales reflect development goals that have different implications for prioritizing and aligning LRT routes as the first rationale prioritizes LRT routes on corridors with the highest existing demand, while the second rationale prioritizes LRT routes that best support the development goals of the city.

Intangible goals have become more common as recent trends indicate that light rail development is shifting away from being a straightforward transportation investment and is rather becoming a spatial growth planning strategy (King and Fischer, 2016). This view is supported by Culver (2017) who points out that new light rail and streetcar projects are formulated through a neoliberal logic, supported by the analysis of proposed and under construction projects which reveals four main themes of these projects. Economic development is the predominant theme, which was mentioned most frequently in the official documents while improved transit, city image and quality of life and sustainability were also overarching themes of new systems. Olesen (2020) further argues that recent light rail projects are blurring the boundaries between strategic spatial planning and transport planning, and the primary goal of new LRT systems is deeply rooted in a neoliberal ideology of promoting economic growth and attracting private investment, and is primarily becoming a means to promote urban development by boosting land values and property prices.

Lane (2008) suggests that cities choose light rail due to the perceived image benefits and political support from upper levels of government which provide funding as it is seen as a permanent mode compared to buses as LRT systems have better security and stronger presence which attracts development. Ferbrache & Knowles (2017) states that LRT construction in a city is a part of image boosterism and enhancement of city quality as LRT is associated with sustainability and livability. In mid-sized cities, LRT has been closely linked to enhancing city reputation and promoting their international image as a 'world city'. Through the introduction of non-bus transport systems, mid-sized cities can promote themselves as an attractive, 'first-tier' city which enhances its competitiveness (McLellan & Collins, 2014). Higgins and Kanaroglou (2016) argue that the intangible goals of rail systems are useful for securing the support of the broader community for new transit projects, and when the intangible justifications are combined with more concrete goals and objectives, they form a political coalition to enable the construction of a new project.

The typical goals and objectives of LRT systems can be divided into four main categories- transit-specific, economic, environmental and social as seen in Table 2.1.

Table 2.1 Common Goals & Objectives of LRT Systems

Category	Specific Goal / Objective
Transit-specific	• Improve and increase use of public transit • Improve access to city centre • Provide higher levels of comfort and service
Economic	• Reduce traffic congestion and saving travelling time • Stimulate development due to its permanence • Accommodating future growth • Image building and boosting city attractiveness
Environmental	• Lower carbon emissions compared to buses and private vehicles • Reduced fuel and salt consumption
Social	• Improve urban aesthetics • Reducing commute time • Expanding transit accessibility for transit reliant residents

Source: Mackett & Edwards (1998); Lane (2008); Ferbrache & Knowles (2017); Cohen-Blankshtain & Feitelson (2011); Higgins et al. (2014); Higgins and Kanaroglou (2016)

Though the introduction of LRT has usually been backed by a range of goals and objectives, these goals and objectives have not always been met. Babalik-Sutcliffe (2002) notes that not all LRT systems have been successful in tackling the economic, environmental, and social issues that they were intended to address. The following section explores the methods and key performance indicators that researchers have used to evaluate the goals and objectives of LRT systems.

2.4 Methods and Common Key Performance Indicators for Evaluating LRT systems

There are multiple key performance indicators to measure and evaluate LRT system performance. Crampton & Hass-Klau (2002) identified direct and indirect factors that could potentially determine whether an LRT system is a success or failure. Direct factors unclude operation factors, demographic factors, geographical factors, hard complementary measures, soft complementary measures cultural and regional differences as well as socio-economic factors. Indirect factors are separated into 5 categories – physical light rail operation, price and marketing of light rail, average accessibility of light rail routes, urban planning and restriction on car use and hours of service.

Transit operators also set out key performance indicators to evaluate the ridership performance of LRT systems. The Santa Clara Valley Transportation Authority (2007) uses three main direct performance standards for evaluating its LRT service regarding ridership: average boardings per revenue hour, minimum boardings per station and average boardings per route mile. However, actual reporting indicators also included total boarding riders and average weekday boarding riders (The Santa Clara Valley Transportation Authority, 2019). In comparison, the Twin Cities Metropolitan Council (2019) evaluates its own transit system by comparing it with a peer group of transit systems with similar sizes and composition of transit service. For ridership performance, indicators include total ridership and ridership per capita. Ridership per route km, per route and per vehicle/km have also been used as indicators for comparing ridership between LRT systems (Currie & Burke, 2013).

More key performance indicators are identified through the study of Jaroszynski & Brown (2014) on eight U.S. Metropolitan Areas with light rail transit backbones. The key performance indicators for the case study included riding habits, service productivity and cost-effectiveness. They also suggested that external factors such as socioeconomic characteristics and planning & design characteristics have a key influence on ridership. Socioeconomic characteristics focus on the population density, employment density, transit commute mode share, median household income and transit commute mode share in neighbourhoods along the LRT lines. Planning & design characteristics include the total number of stations, percentage of an exclusive right of way and park and ride capacity.

Crampton & Hass-Klau (2002) and Currie et al. (2011) conducted international studies on drivers of LRT ridership and discovered that in general, European LRT routes had higher ridership than North American systems. However, while Crampton & Hass-Klau (2002) found that American cities had lower overall densities than European cities, Currie et al. (2011) discovered that European LRT systems' catchment had a lower residential and employment density compared to North American LRT systems' catchment. However, both studies affirmed that North American cities light rail catchments had a much higher private vehicle ownership.

Multiple studies point out there are some important differences between Canada and U.S. LRT systems, including a lack of a federal role in Canadian public transit historically which meant that Canadian transit systems are more cost-effective. Compared to U.S. systems, they have higher rates for cost recovery and cost-effectiveness while having higher reliance on high ridership and farebox revenue (Hubbell & Colquhoun, 2006). In addition, Canadian cities generally also have more centralised planning compared to many U.S. cities that have to deal with multiple municipal governments and regional organizations for transit planning (Higgins and Ferguson, 2012).

Regarding built form impact, Renne (2008) identified several metrics that are useful for identifying if transit-oriented development (TOD) is occurring in a neighbourhood. Metrics such as the number of other transit mode connections and number of mixed-used structures etc. are used as they are easy to survey, while some indicators such as pedestrian activity counts and qualitative ratings of streetscape are not easy to collect by researchers and have not been used. In the Canadian context, Hubbell & Colquhoun (2006) used several indicators such as Central Business District (CBD) work trip modal split and percentage of multi-family housing starts compared to single-family homes to evaluate the performance of the city's TOD policies. Crowley et al. (2009) examined TODs in Toronto's North York City Center and used several KPIs including subway mode share, average household auto ownership and population density over time to evaluate the impact of TOD on public transportation ridership.

Table 2.2 Common Key Performance Indicators of LRT Systems

Category	Common Key Performance Indicators
Physical light rail operation	• Light rail passenger number per urban population • Light rail passenger number per light rail track-km • Light rail passenger-km per light rail track-km • Public transport passenger number per urban population • Annual growth of light rail passengers • Average speed of light rail service
Price and marketing of light rail	• % of light rail passengers using a smart card • Farebox Recovery Ratio • Monthly light rail fare relative to GDP per capita
Average accessibility of light rail routes	• Network density (total light rail track-km per urban population) • Estimated population in 300 m light rail corridor either side of lines per km of track • Average stop distance on light rail system
Urban planning and restriction on car use	• Pedestrian zone length per city population • Number of park and ride spaces per km of light rail track • Number of car parking spaces in the city centre relative to estimated city centre area
Hours of service	• Number of hours run at peak frequency • Total hours of service per weekday
Transit-oriented Development	• Number of other transit mode connections • Number of mixed-used structures • Total number of residential units built during LRT construction till now • Total retail establishments

Source: Crampton & Hass-Klau (2002); Renne (2008); Currie & Burke (2013); Hubbell et al. (1997); Babalik-Sutcliffe (2002); Crowley et al. (2009)

2.5 Land Use Objectives and Urban Development Impacts of Light Rail Transit Systems

Objectives for the construction of LRT systems have often included land use impacts of light rail transit such as enabling better land use planning, stimulating smart growth and encouraging transit-oriented development (Higgins et al., 2014). Nearly half of the existing and planned LRT systems examined by Mackett & Edwards (1998) included the stimulation of urban development as a major reason for the construction of the LRT systems. Some systems are a part of the redevelopment of large city areas while others are to encourage the development in the city centre by providing easier access or in new areas.

Handy (2005) finds that in general, transit systems potentially impact development by reducing transportation costs and by changing relative accessibility. While some other rapid transit systems may increase urban sprawl as they are built on city edges and reduces travel time to the outskirts of the city, most new LRT systems are designed to serve neighbourhoods with existing development and have less impact on travel times. Thus, LRT systems might influence where development occurs in a region as it changes relative accessibilities and helps to focus development on specific corridors and around station areas. It may also serve as a catalyst for redevelopment as ridership increases in the longer term.

The view that light rail transit contributes to the redistribution of development but not a net gain of development in a region is shared by older and newer studies. Cervero & Seskin (1995) finds that urban rail transit investments rarely create new growth and “typically redistributes growth that would have taken place without the investment”, while Knowles and Ferbrache (2016) points out that light rail transit alone is unlikely to be a sufficient catalyst for economic change without supportive policies.

The impact of LRT systems on land development and TOD has varied among different studies. Fogarty and Austin (2011) find that LRT lines brought a significant amount of new residential and commercial development which is often concentrated in existing employment centers and downtowns. In some cities such as Minneapolis, MN in the U.S., the announcement of the full funding grant agreement of the LRT project already brought a clear impact on development activity which increased the number and value of building, before the opening of the system (Cao and Cao, 2014). However, Hurst and West (2014) found that in Minneapolis, proximity to LRT stations during LRT construction and operation periods had minimal effects on land use change through the conversion of industrial properties were observed close to LRT stations, and they concluded that the introduction of LRT did not increase the chance of new developments or redevelopments.

Lavery and Kanaroglou (2012) modelled the impact of LRT on transit-oriented developments and found that regardless of public policy options such as development subsidies that could encourage TOD, the addition of LRT would not have a significant effect on population, employment and transit modal shares for work trips in both LRT corridor zones or non-corridor zones. This result is echoed by Baker and Lee's (2019) study which found that the impacts of LRT stations on gentrification and TOD vary depending on local and regional contexts, and overall, there is no evidence of gentrification in LRT station areas after examining the relationship between LRT stations and urban development.

Since the onset of LRT construction in North America, researchers have found that while major rapid transit improvements have been important inducements to downtown development near rapid transit stations, there were other important factors that supported the development (Knight & Trygg, 1977). Cervero (1984) identified that building an LRT system would not lead to major land use changes or stimulate private investments using Calgary and Edmonton as case studies. It was observed that higher density development, residential construction and mixed-use development have been limited to downtown areas. Higgins et al. (2014) hold a similar view that LRT should not be seen as a primary driver of new growth and land use change on its own. However, it is noted that with other factors the adequate policies and designs such as improvements in accessibility and zoning to promote transit-oriented development, LRT has a much higher chance of success. Cities require some preconditions or external factors such as rising traffic congestion, an economic upswing in the local economy and having net migration gains to make LRT and TOD successful (Lavery and Kanaroglou, 2012). These preconditions and factors would be discussed in the following section, Section 2.6.

2.6 Determining Factors for LRT Systems to Impact Urban Development

Though the potential for promoting transit-oriented land uses has been an important planning consideration for meeting long-term ridership goals, the land use and urban development impacts of LRT systems have varied in different cities (Higgins et al., 2014). Though transit-oriented development (TOD) has become more popular in North American cities in recent years, TOD is not a new concept in urban planning. Knowles (2012) identifies that the earliest examples of TOD started in the last 19th and early 20th centuries before private car ownership. The construction of electrified streetcars and commuter railways that replaced horse-tram routes led to the development of streetcar suburbs in cities such as Boston and Denver and enabled TOD through high-density housing and jobs with frequent and low fare trams (Ward,1964). Knowles (2012) and Knowles et al. (2020) also recognized that throughout the history of TODs, they have been mainly attracting middle to higher-income households. Contemporary forms of TOD are closely related to neoliberalism with urban regeneration and restructuring as main goals thus leading to gentrification amid revitalisation and redevelopment projects with higher property values (Rayle, 2015).

Several important factors enable rapid transit systems to have an impact on land use and transit-oriented development. These factors include the existence of strong demand for new office and retail space, the availability of open or underutilized land for development that is economically viable, placement of transit stations, and other public investments such as government office complexes close to transit stations as well as formal urban renewal projects that simplify land assembly costs (Knight & Trygg, 1977; Fogarty and Austin, 2011; Higgins et al., 2014).

A strong and growing economy is a prerequisite for new development according to (Cervero, 1984; Higgins & Ferguson, 2012, Higgins et al, 2014). Cities such as Buffalo, NY, that are development starved and is undergoing population and employment decline see neglectable change in urban form even as an LRT system is built. Calgary and Edmonton's LRT systems also suffered from similar problems after their LRT systems opened amid Calgary's economic downturn in the early 1980s. According to Cervero (1985), this economic downturn slowed urban development in general and thus in the first few years of LRT operation, led to modest impacts on density, residential construction, and mixed-use development. But as economic growth returned in the cities, the systems have been attracting substantial ridership (Lafleur, 2011). This is similar to the findings of Nelson et al. (2019) where LRT TODs are more resilient during economic downtown and attract more growth during economic recovery. Arrington (2003) argues that LRT lines do not deliver enough passengers to make TOD viable and thus TOD projects should not be transit-dependent – they should be successful even without transit to be successful with transit. Hess and Lombardi (2004) also state that a strong local economy is a key factor for TOD and TOD trends are strongest in high-growth metropolitan areas compared to slow-growth cities. Even in high growth metropolitan areas, TOD mostly occurs in affluent and gentrifying neighbourhoods while limited TOD projects and urban development have been observed in economically distressed and poorer neighbourhoods.

Apart from a strong economy, the alignment of the LRT line also makes a large difference for TOD. Black (1993) explains that separated right-of-way and longer distance between stops for the line alignment enable higher operating speeds. However, policymakers have had to keep costs down for LRT construction and build alignments along existing rail freight corridors, abandoned railroads, industrial belts or along major highways (Cevero, 1984; Nelson et al., 2019). Hess & Lombardi (2004) notes that planners also contribute to a less than ideal alignment as they usually locate transit lines in places with the least resistance and siting decisions are often based on simple land assembly as well as availability and affordability of land. Areas along these alignments are not ideal as they lack concentrations of employment and residences, which limits transit ridership, economic development and negatively impact prospects for new transit-oriented development (Higgins et al., 2014).

A city's historical urban development is also an important factor regarding TOD and urban form change. Cervero (1984) observes that large cities with a long development history such as Toronto and Boston which has heavy rail rapid transit tend to have lower development potential for LRT as heavy rail has a stronger clustering influence. Unless there are large-scale urban renewal developments, land around the urban core in these older cities is usually exhausted and built-up. Porter (1998), however, identifies that urban development that is most supportive of transit and TOD such as mixed uses and walking distance near transit stations are usually found in older cities where urban development was guided by rail transit systems as urban development predated the automobile which leads to high accessibility and short distances to transit. Ohland (2001) also notes that while TOD is a hot development trend in newer cities mainly in the sunbelt, TODs in older cities are customary and seen as a norm. Therefore, TODs are rarely marketed and actively promoted as TODs.

2.7 Impact of the COVID-19 Pandemic on Public Transit Systems

Research on pandemics impact on public transit ridership has been limited prior to COVID-19. During the peak of the severe acute respiratory syndrome (SARS) epidemic in Taiwan, Wang (2014) observed that the daily ridership in Taipei City's underground (subway) system dropped by around 50% at the peak outbreak. However, the SARS outbreak did not cause a prolonged decline in transit daily ridership in Taipei and ridership figures returned to normal in 2004. Other events such as mandated closures of schools and workplaces due to typhoons in the city also caused a similar drop in subway ridership, but these events usually last only one or two days. The COVID-19 pandemic led to an unprecedented major decline in transit demand for public transit systems (Liu et al., 2020). DeWeese et al. (2020) analysed service adjustments in 40 cities in North America amid the pandemic and found that most transit agencies applied major service adjustments to respond to the ridership drop though the adjustments varied. While some cities' adjustments were found to be more sensitive in service adjustments towards vulnerable groups such as lower-income households and visible minorities, other cities had service cuts that disproportionately affected vulnerable neighbourhoods.

In the Canadian context, Armstrong et al. (2020) identified that on average, all forms of mobility such as driving, transit and walking in Canadian cities decreased more significantly than American cities. Savage & Turcotte (2020) examined work commute patterns in Canada in the first few months of the pandemic and found out that the number of commuters significantly decreased - the number of public transportation passenger trips fell by 85% in April following a 42% drop in March. Many commuters are reluctant to use public transit amid the pandemic and more than 40% of public transit users prior to the pandemic switched to telework or while one-third switched to another mode of transportation. The proportion of public transit users switching to telework is higher than overall commuters as they are more likely to live in larger census metropolitan areas, and the type of occupation often allows for telework. Public transit might not be a preferred transportation mode choice even as commuters return to the workplace as a large number of commuters are concerned or even reported fear of using public transit as they associate public transit with higher risks of exposure to COVID-19 and prefer the use of private cars (Labonté-LeMoyne et al., 2020).

Transit agencies have been trying to run public transit during the pandemic and have been adapting to provide service while adhering to public health guidelines (Casello et al., 2020). The Canadian Urban Transit Association (2020) has been preparing guidelines for transit agencies to enhance the safety of passengers and for transit operators. The degree and the capacity of the COVID rules and regulations differ among transit agencies, and some agencies such as OC Transpo and Grand River Transit have placed limits to vehicle capacity to 10 and 20 customers (approximately 25 and 50 percent capacity) respectively. To facilitate social distancing, seat configurations were altered and boarding on buses was restricted to rear doors. Mandatory face covering regulations have also been enforced on board public transit vehicles, adhering to the guidance of provincial governments (Government of Ontario, 2020).

2.8 Introduction of Teleworking / Remote Work

2.8.1 Definition of Telework

Eurofound & the International Labour Office (2017) states that there is no universally accepted definition of telework and different definitions are used depending on the situation but most commonly, it is defined as *"the use of information and communications technologies (ICTs), such as smartphones, tablets, laptops, and/or desktop computers, for work that is performed outside the employer's premises"*. Belzunegui-Eraso & Erro-Garcés (2020) describes telework as a type of work or provision of services done remotely using computer technologies. Alizadeh (2013) argues that the definition of "telework" has changed through time – while older studies classify telework as part of a larger set of flexible work arrangements, newer studies introduce telework as a predominately professional practice for knowledge-workers to work through communication.

2.8.2 Origin & Reasons for Implementing Telework

Teleworking or working from home was first proposed by NIlles (1976) as he believed that it could be a substitution and solution for commuting. The widespread interest in telework in the 1970s was fuelled by the increasing problems caused by commuting, and according to Nilles et al. (1976), brought large workday surges of traffic and contributes to more than 40 percent of all urban trips. The cost of commuting increases as the commuting population grows annually which leads to increased air pollution, more highway construction, more time wasted due to traffic congestion and consumes large amounts of energy.

Apart from tackling the problems that arise from commuting, telework has been promoted for several reasons compared to traditional work from the office. This can generally be divided into three levels: individual, organizational and city-wide.

On the individual level, telework provides greater work time flexibility for workers. Teleworkers have increased time-planning autonomy and are possible to work during the most productive time compared to workers in a fixed working place which leads to better productivity (Nakrošienė et al.,2018). Dockery and Bawa (2018) identify that telework contributes to better couple and parent-child relationships by facilitating a more equitable sharing of household responsibilities associated with childcare. Women are more likely to state family benefits for telework compared to men and though limited mostly to public initiatives, provides a viable and cost-effective method for promoting employment for disabled workers (Bailey & Kurland, 2002).

Organisations could also benefit from telework. Brumma (2016) finds that teleworkers are more engaged compared with working at the office and contributed to reduced turnover rates. Martin and MacDonnell (2012) and Boell et al. (2013) also find positive effects of telework in terms of worker productivity gains and higher working efficiency, increased morale and job satisfaction and an increased ability of organizations to recruit and retain employees, especially among younger employees. Telework also results in lower financial costs and overhead costs from less spending on real estate and utilities.

On the city-wide level, telework provides opportunities for rural communities to grow as telework enables a more decentralized economic structure, and allows local opportunities in rural areas to grow and promote their historical advantages such as rich natural amenities and low housing costs (Gallardo and Whitacre, 2018). Giovanis (2018) explains that implementing telework is a key to alleviate traffic congestion as the number of people driving alone for commuting is decreased and helps reduce vehicle fuel consumption and air pollution. Larson and Zhao (2017) identify that congestion is especially reduced in the commute routes towards the CBD as telework alters the bid-rent curve and enables households to live in different locations. However, the overall energy implications of telework remain uncertain as the decrease in commuting energy per worker the overall per-capita energy consumption rises as housing unit size increases with telework.

Table 2.3 The Potential Benefits of Telework

Level	Potential Benefits
Individual	• Reduced time spent on commuting • Lower travelling costs from commuting • Greater work time flexibility • Fulfilling family responsibilities while working • Enable employment for disabled workers
Organizational	• Overall productivity gains • Improved morale of employees • Facilitate recruitment • Lower turnover rate • Reduced overhead costs
City-wide	• Reduced costs related to congestion • Facilitate rural development • Reduction in air pollution from vehicles

Source: Nakrošienė et al. (2018); Gallardo and Whitacre (2018); Boell et al. (2013)

2.8.3 Telework Trends in North America before the COVID-19 Pandemic

As technological advancements such as personal computers and smartphones have become more common in the developed world, the trend of telework / working from home has been growing since the 1980s. However, Bailey & Kurland (2002) explains that it is not easy for researchers to count the number of teleworkers and estimates of the teleworking population vary due to different definitions and methodologies.

Several studies conducted by futurists such as Handy (1984) were very optimistic about the future of teleworking in the 1980s and estimated that by 1995, around 50% of employees could work from home. The U.S. Department of Transportation (1993) estimated that 1.6% of the total U.S workforce teleworked and predicted that the number would rise steadily to between 5.2% to 10.4% of the U.S. workforce by 2000. Cyber Dialogue (2000) estimates there were 11.5 million teleworkers in 1999, and the gender distribution was 51 percent women and 49 percent men. In the past two decades, telework has continued its growth in the U.S. and in the number of commuters who usually telework increased over 3 million from 2010 to 2019. 2019 marked the first time since the Census Bureau recorded work trip data since 1960 in the U.S. when teleworking became a larger mode than public transit for commuting trips (Cox, 2020).

In Canada, Akyeampong & Nadwodny (2001) report that the number of home-based workers including both employees and self-employed workers rose from 613,000 in the 1971 Census to 1,079,000 in the 1991 Census. However, the proportion of teleworking employees only rose slightly from 4% to 6% as the increase was just slightly higher than the overall workforce. There has been strong growth in telework among employees during the 1990s and the estimated number (and incidence) of employees who did some or all their regular work at home rose from 600,000 (6%) in 1991 to 1 million (9%) in 1995 and to 1.42 million (10.2%) in 2000. However, the number of teleworkers saw an unexpected decrease from 2000 to 2005 despite technological advancements (Akyeampong, 2007). According to Statistics Canada (2019), 4% of the Canadian workforce worked from home (teleworked) regularly in 2018.

2.8.4 Telework & Working from Home Amid the COVID-19 Pandemic

Since the start of the COVID-19 pandemic, telework has become much more common as a part of social distancing measures that help prevent the spread of the virus. Dingel & Neiman (2020) investigated 86 countries and in the US, it is estimated that 37 percent of jobs can be performed at home. People who cannot work at home are more likely to be lower-income, non-white and without a college degree. Deng et al. (2020) estimate that in Canada, approximately 38.9% of Canadian workers are in jobs that can potentially telework. This figure is similar to labour statistics which show that 39.1% of Canadians were teleworking during the late week of March 2020. However, telework potential is different across provinces due to the composition of jobs – larger proportions of workers in the agricultural industry and mining, oil and gas extraction can help explain the lower potential for telework in the Prairies, Alberta and Saskatchewan.

The capacity for telework varies greatly among economies, occupations, and gender. Brussevich et al. (2020) examined 35 advanced and emerging countries for the tele-workability of different economies and occupations. Emerging and developing countries have a lower tele-workability score compared to advanced economies which have relatively developed digital economies. Elementary occupations such as construction workers and janitors are least able to telework. On the other hand, managers and professionals are more able to work from home.

Gender inequalities are also revealed amid COVID-19. Men are on average, less likely to be able to work from home compared to women as men are more likely to work in construction, transportation and manufacturing sectors while women's employment is more concentrated in the education and care sectors. However, Lyttelton et al. (2020) observe that telecommuting mothers have reported more negative emotions such as loneliness and anxiety compared to telecommuting fathers, which can be attributed to the additional time of housework they need to finish apart from working.

In the longer term, it is important to understand to what extent telework arrangements will persist as working from home has become a "new normal" during the COVID-19 pandemic. The pandemic and social distancing forced companies and employees to adopt new ways of working and driven by technological advancements such as videoconferencing and digital collaboration software, many employees have been satisfied with, and enjoy working from home as commute times were much lower and they enjoyed increased work flexibility (Boland et al., 2020). For companies and organizations, the experience of working remotely also means that they can recruit talents with less locational constraints and reduce real estate costs for offices. Bick et al. (2020) found out that a large majority of workers working from home could effectively telework during the pandemic. Beck et al. (2020) examined the two waves of COVID-19 outbreaks in Australia and while the initial work from home arrangements was haphazard, the overall telework experience has become more positive, and a majority of respondents agree that they would like to telework more often, especially for younger age groups. It is expected that even after the pandemic, there will be a sizable increase in the percentage of workers working from home compared to prior levels.

The studies focused on Canada also generated similar results. A survey conducted by ADP Canada (2020) showed that most managers and employees reported that telework did not have a significant impact on productivity and quality of work. 45% of Canadians in the workforce indicated that they would prefer to work remotely at least three days a week, especially among younger workers while more than one quarter would prefer working flexible hours. Angus Reid Institute (2020) found that while around 15% of workers have deemed working remotely as negative for both mental health and productivity, more than half of the respondents currently working from home anticipate that after the COVID-19 pandemic, they can either continue to work from home or work from home more than before.

3. Research Methodology

3.1 Research Methods Overview

3.1.1 Research Philosophy

This study undertakes a pragmatist epistemological approach, as it is problem-centered and focuses on current issues that LRT systems have been facing, especially as part of the impacts of the COVID-19 pandemic. The research questions are answered using this approach to examine whether the case study LRT systems have met their original policy goals and objectives, and how the COVID-19 pandemic will potentially impact the achievement of these policy goals and objectives, which is real-world practice oriented, matching the anticipated contribution of this study (Creswell & Creswell, 2017).

3.1.2 Mixed Methods Approach

A mixed methods study using both quantitative and qualitative approaches is appropriate in addressing the research questions. To evaluate LRT system performance and identify the original policy goals and objectives of LRT systems, a qualitative approach will be used while the identification of how ridership is potentially affected by COVID due to continuing telework / working from home arrangements at the neighborhood level involves statistical and numerical data that requires a quantitative approach.

Different key performance indicators are identified and used to review the performance of the case study systems and to investigate if the LRT systems their original policy goals and objectives. Based on 2016 Census commuting data, the estimated transit (LRT) commuter ridership is calculated according to different scenarios to understand the potential impacts of the COVID-19 pandemic based work from home policies at the census tract level. ArcGIS software is used to identify and define the catchment area of the LRT system to investigate potential commuting ridership change using different scenarios. The results will be visualised using the software to enable better understanding of the potential ridership impacts on the CT level.

3.1.3 Case Study Approach

The purpose of this study is to evaluate the performance of different LRT systems in terms of ridership and land development, and investigate if meeting the policy goals and objectives of these systems would potentially be impacted by the COVID-19 pandemic. To ensure a systematic selection of case studies, a number of criteria are defined to help select systems appropriate for the research questions. The criteria include:

1. The location of the system - Located in Canada, as defined by the research question
2. System has commenced operation - The systems are not in the proposed, planning or construction stage and have commenced operation before the COVID-19 pandemic
3. Data availability - These systems are all within Census Metropolitan Areas (CMAs) defined by Statistics Canada, ensuring a consistent data source
4. Similarities and differences - The systems are located in cities with unique urban forms and planning policies which shaped very different LRT systems (Situated in three provinces with different planning history and ideologies)

Taking into account these considerations, four cities with LRT systems were chosen: Region of Waterloo, City of Calgary, Metro Vancouver and City of Ottawa. Using multiple case studies enable a study to show repeated or variation in patterns and to achieve balance among case studies (Birch, 2012). In this study, the four chosen LRT systems has varying scales and backgrounds, and assessing the performance on these systems allow an understanding of how different light rail transit systems can bring varying impacts on public transit ridership and land development.

3.2 Introduction to Case Studies

The chosen case study systems are located in the Region of Waterloo, City of Calgary, Metro Vancouver, and the City of Ottawa.

Figure 3.1 Locations of the Four Case Study Cities

Source: Google Earth

The Region of Waterloo is comprised of three main cities – City of Waterloo, City of Kitchener and City of Cambridge. The region has a total population of 618,000, and over the past 15 years, has grown an average of 1.59% per year (Region of Waterloo, 2020). Grand River Transit (GRT) is the public transit operator for the region and operates the ION light rail which began service in 2019 (Grand River Transit, 2020).

The City of Calgary is the most populous city in the Prairies. With a population of 1,287,000, the region has added more than 300,000 residents in the past 20 years, an average of 2.1% per year (City of Calgary, 2019). Calgary Transit operates the city's public transit service and the light rail transit system, the CTrain, commenced operations in 1981.

Metro Vancouver is a regional district in British Columbia which is comprised of 23 local of authorities. Home to 2.74 million residents, the region has seen an annual population increase 1.6% since 2001 (Province of British Columbia, 2020). TransLink is the public transit operator in Metro Vancouver which operates the Canada Line (TransLink, 2020a).

Ottawa is the capital city of Canada. With a population of 1,018,000, the city has grown by 1.5% per year since 2001 (City of Ottawa, 2020). OC Transpo, officially the Ottawa- Carleton Regional Transit Commission provides transit service in Ottawa, and started operating the OTrain light rail system Confederation Line in 2019.

Table 3.1 shows the general statistics for the municipality and LRT systems of the four case study cities.

Table 3.1 General Statistics of the Four Case Study Cities

City / Region	Region of Waterloo	City of Calgary	Metro Vancouver	City of Ottawa
Population	618,000	1,287,000	2,740,000	1,018,000
Population Density	451 / km^2	1558 / km^2	949 / km^2	365 / km^2
Percentage of working age population (aged 15 - 64) (2016)	67.8%	69.6%	69.6%	67.9%
LRT System Name	ION	CTrain	Canada Line	OTrain
Year construction commenced	2014	1977	2005	2013
Opening Year	2019	1981	2009	2019
Right of Way	On surface, sometimes shared with cars	Mostly separate, some intersections with cars	Totally separated (elevated / underground)	Totally separated (at grade/ underground)
Number of Lines	1	2	1	2
System Length	19 km	59.9 km	19.2 km	20.5 km
Number of Stations	19	45	16	17

Source: Grand River Transit, Calgary Transit, Translink, OC Transpo

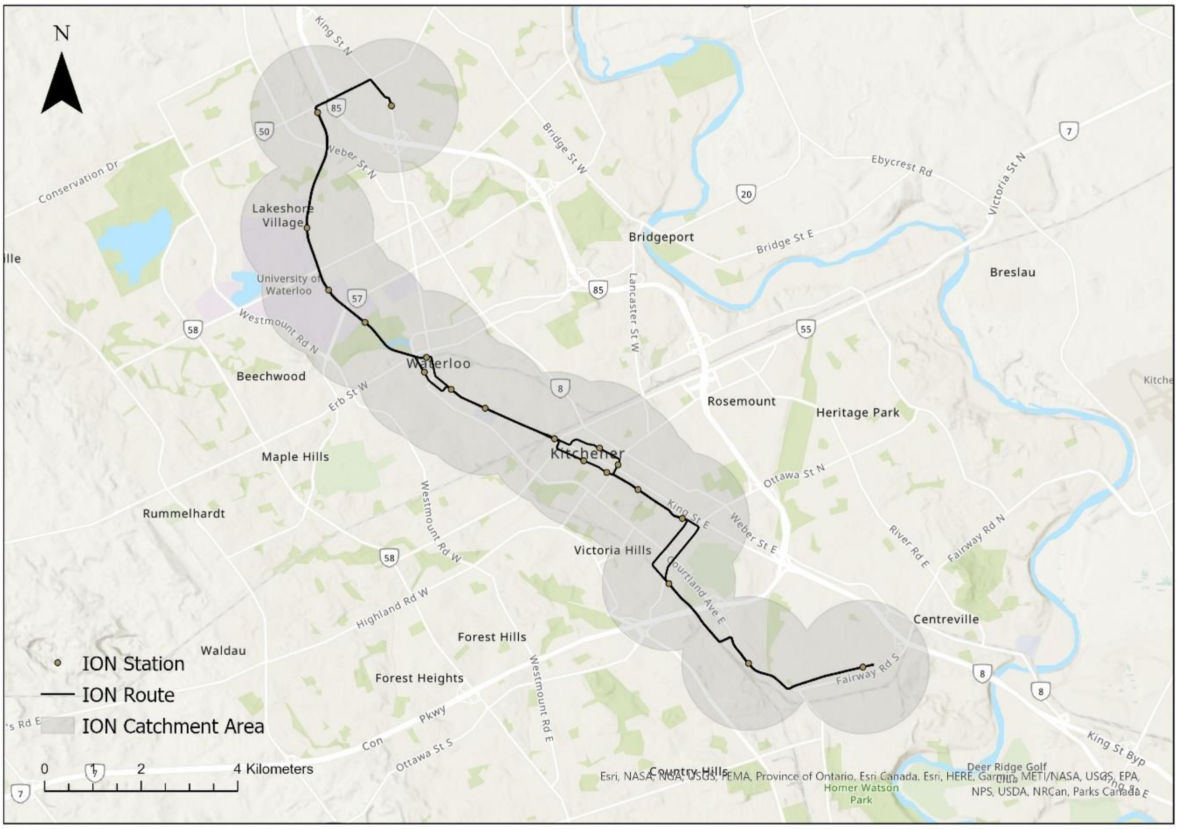
3.3 Defining the Study Area and Catchment Area

The first step in conducting the analysis to define a suitable study area. To evaluate the performance of the case study LRT systems, and whether the original policy goals and objectives of these systems are met, the defined study area for each system should be within reasonable proximity to LRT stations, which covers the area of influence for the LRT line and stations.

Literature suggests public transport catchment areas vary based on the type of transit provided and the built form around the station (Ann et al., 2019). Catchment areas in urban areas tend to be larger than those in suburban areas as suburban areas have lower residential densities and more surface parking space. Catchment areas of various sizes have been used in studies: Crowley et al. (2009) used a 400 m and 800 m buffer for analysing TOD in Canada, which is equivalent to an approximate 5 – 15-minute walk, while Higgins (2016) used an 800 m catchment area and 10-minute functional catchment area using the road network. Lee (2010) applied a 1.5-kilometre buffer around transit stations for capturing changes in residential densities in Toronto. This study would apply a 1-kilometre (1000 metre) buffer around LRT stations as the LRT catchment area as it is a common rule of thumb that most people are willing to walk 1 km to light rail stations in urban stations, which is supported by Ker & Ginn (2003) and O'Connor & Harrison (2012). The detailed methodology and steps for finding the catchment area will be discussed in Section 3.5.2.

This study covers the entire Census Metropolitan Area (CMA) for estimating the impact of the COVID-19 induced work from home on public transit ridership at the neighborhood level. However, the potential change in commuter ridership of the entire CMA will be analyzed within the LRT catchment area.

Figure 3.2 LRT Catchment Area in the Region of Waterloo



3.4 Data Collection & Sources

3.4.1 Potential Data Sources

The various potential sources of data used in the analysis are listed in table 3.2 according to the various objectives of the study.

Table 3.2 Potential Data Sources for the Various Objectives of the Study

Objectives of the study	Potential Sources of data
Review the performance of four light rail transit systems in four Canadian cities (Waterloo, Calgary, Vancouver and Ottawa)	The Planning Act of various provinces (ON, BC, AB), Official Plans of the four selected cities, municipal documents (Municipal Development Plans, Transportation Plans and Land Use Bylaws etc.), transit agency reports, ridership & revenue reports, conference reports, newspaper articles
Investigate if the selected LRT systems achieved their original policy goals and objectives	Project specific documents, public consultation meeting documents, construction progress updates, environmental assessment studies, technical reports, Google Street View
Identify the impact of the COVID-19 pandemic on potential public transit ridership at the neighborhood level	Statistics Canada data, ridership & revenue reports, City council / transit commission updates & reports regarding COVID-19 response, newspaper articles

3.4.2 Unit of Measurement

To identify the impact of the COVID-19 pandemic on potential public transit commuting ridership at the neighborhood level, the census tract (CT) level was chosen as the unit of measurement. Census Tracts are small and relatively stable geographical areas located in census metropolitan areas (CMA) and census agglomerations that usually have a population of less than 10,000 persons (Statistics Canada, 2017). Census Tract is a suitable unit of measurement as it fits the neighborhood level research objective and ensures data consistency for place of work and residence data provided by Statistics Canada.

3.4.3 Data Preparation

The major sources of for evaluating COVID-19 ridership impact is the place of work and place of residence employment and commuting statistics by census tract, and the telework potential by industry. This data is used for identifying neighborhoods in the case study CMAs where ridership could potentially be affected disproportionately during the COVID-19 pandemic.

For place of work, a custom tabulation named: "Selected Labour Force, Demographic, Cultural and Income Characteristics for the Employed Labour Force, by Place of Work at the Census Tract (CT) Level" is used. This data source was made available through the University of Toronto Map & Data Library. Based on the 2016 Census, it provides the employment locations for the employed labour force aged 15 years and over in private households of Census Metropolitan Areas, by Industry using the North American Industry Classification System (NAICS) 2012 with 25% sample data. Variables in the dataset are reported in the Census Tract (CT) level and includes total employment population, employment population according to sector by NAICS 2-digit code, the number of commuters using public transit as the main mode of commuting, visible minority population and employment income.

For place of residence, the dataset on the Census Tract (CT) level is obtained based on the 2016 Census by Statistics Canada. With 25% sample data, the variables include the number of commuters using public transit as main mode for their journey of work and employed population by NAICS 2-digit code sector.

Table 3.3 shows the different employment sectors by both place of work and place of residence, divided into 20 categories using the following 2-digit NAICS codes.

Table 3.3 Different Employment Sectors by NAICS Code for Place of Work and Place of Residence

NAICS sector (2-digit) code	Description of sector
11	Agriculture, forestry, fishing, hunting
21	Mining, quarrying, oil and gas extraction
22	Utilities
23	Construction
31 – 33	Manufacturing
41	Wholesale trade
44 – 45	Retail trade
48 – 49	Transportation and warehousing
51	Information and cultural industries
52	Finance and insurance
53	Real estate, rental and leasing
54	Professional, scientific and technical services
55	Management of companies and enterprises
56	Administrative and support, waste management and remediation services
61	Educational services
62	Health care and social assistance
71	Arts, entertainment, recreation
72	Accommodation and food services
81	Other services (except public administration)
91	Public administration

The data for telework potential by industry is obtained through a Statistics Canada study by Deng et al. (2020), “Running the economy remotely: Potential for working from home during and after COVID-19”. The study estimates the telework capacity of the Canadian economy by industry. The study’s variables are the telework capacity of different industries using 2-digit NAICS codes. The telework capacity of different industries are divided into 19 categories as listed in Table 3.4.

Table 3.4 Different Employment Sectors by NAICS Code for Estimated Telework Capacity

Industry by NAICS sector (2-digit) code	Description of sector	Telework capacity (percent)
52	Finance, insurance	85.3
61	Educational services	84.6
54	Professional, scientific and technical services	83.9
51	Information, cultural industries	68.5
91	Public administration	58.2
41	Wholesale trade	57.3
53	Real estate, rental and leasing	47.8
71	Arts, entertainment, recreation	40.1
22	Utilities	38.6
56	Administrative and support, waste management, remediation	35.1
81	Other services (except public administration)	31.4
62	Health care, social assistance	28.8
48 – 49	Transportation, warehousing	24.5
21	Mining, quarrying, oil and gas extraction	23.9
44 – 45	Retail trade	22.0
31 – 33	Manufacturing	19.1
23	Construction	11.1
72	Accommodation, food services	5.6
11	Agriculture, forestry, fishing, hunting	3.9

To identify urban development and the spatial distribution of transit-oriented developments in the LRT station catchment area, several data sources were used. The sources include municipal documents and maps of development projects and redevelopment applications, real estate websites on information of projects under construction and Google Map's Street view for confirming the locations of redevelopment projects.

3.5 Implementation of Research Methods

3.5.1 Key Performance Indicators for Case Study LRT Systems

The first research objective in the study is reviewing the performance of the case study LRT systems. Section 2.4 of the literature review identified a list of common Key Performance Indicators (KPIs) to understand the performance of LRT systems. Table 3.5 lists the potential

KPIs for evaluating the case study systems that is selected based on the study's research questions and objectives and will be further explored and finalized in the results section depending on the findings of the policy document review.

Table 3.5 Potential Key Performance Indicators for LRT systems

Category	**Potential Key Performance Indicators**
Ridership	• Average daily boardings • Light rail ridership per urban population • Light rail ridership per light rail track-km • Light rail passenger-km per light rail track-km • Public transport ridership per urban population
Network density	• Network density (total light rail track-km per urban population) • Estimated population in 1km light rail corridor catchment
Service	• Average operating speed • Peak service headway in minutes • Number of hours run at peak frequency • Total hours of service per weekday

The second research objective of the study is to evaluate whether the case study LRT systems have achieved their original policy goals and objectives. The original specific goals and objectives of the case study systems can potentially be found using the potential sources of data in Table 3.2 such as project-specific documents, public consultation meeting documents and environmental assessment studies.

A number of common policy goals and objectives of LRT systems are identified in Section 2.2, and to answer the research question, this analysis will focus on transit specific and urban development goals. To indicate if the original goals and objectives of the case study systems are met, certain evaluation criteria are identified. These criteria are evaluated using the potential sources of data in Table 3.2 in Section 3.4.1.

The achievement of transit specific goals is assessed based on the document review of the LRT systems and research. If the goal is deemed to be achieved by the system, a check mark / tick sign would be given. If the system did not achieve the goal, a cross sign would be given. Urban development goals are evaluated using a subjective scaling based on the document review and the mapping of developments. A three-tier system is used to reflect the extent of achievement varies among the case study systems. Systems which had the lowest achievement of the original goals will be given one plus sign, meaning that the performance is weak. Systems with modest achievement would be given two plus signs, while systems with strong performance would be given three plus signs.

Table 3.6 Criteria for the Successful Attainment of Original Goals and Objectives

Goals & Objectives of LRT Systems	**Criteria for Successful Attainment**
Transit Specific Goals: • Increasing public transit usage • Providing alternative transportation options	• LRT system ridership increasing steadily • LRT system ridership is not lower than the initial forecast • Increased modal share of public transit after the completion of the new system • Other transit connections at LRT stations
Urban Development Goals: • Accommodating & redistributing future growth • Urban redevelopment • Intensification	• Construction of transit-oriented developments in downtown / city centre • Construction of transit-oriented, higher density developments along LRT corridor • Indication of redevelopment in inner city neighborhoods

3.5.2 Calculation of LRT Catchment Area

Section 3.3 defined the study and catchment area for the four case study LRT systems. ArcGIS Pro software is used for the calculation of the population, employment and estimated commuting trips within each LRT catchment area. The circular buffer approach for calculating public transport catchment considers the Euclidean distance from a stop where this distance is reasonable to access the transit system (Landex and Hansen, 2006). However, the main limitation of the circular buffer approach is that the actual walking distance from a location to a stop is often longer than the direct Euclidean distance. Barriers and obstacles such as rivers and rail tracks increase the actual walking distance (Andersen and Landex, 2009).

A model is built using the model builder function in the software to facilitate the processes. The first step of the model is to input a coordinate system that is suitable for the case study LRT system for an accurate projection with lower distortion. Table 3.7 lists out the projected coordinate system used for the calculation of the different systems.

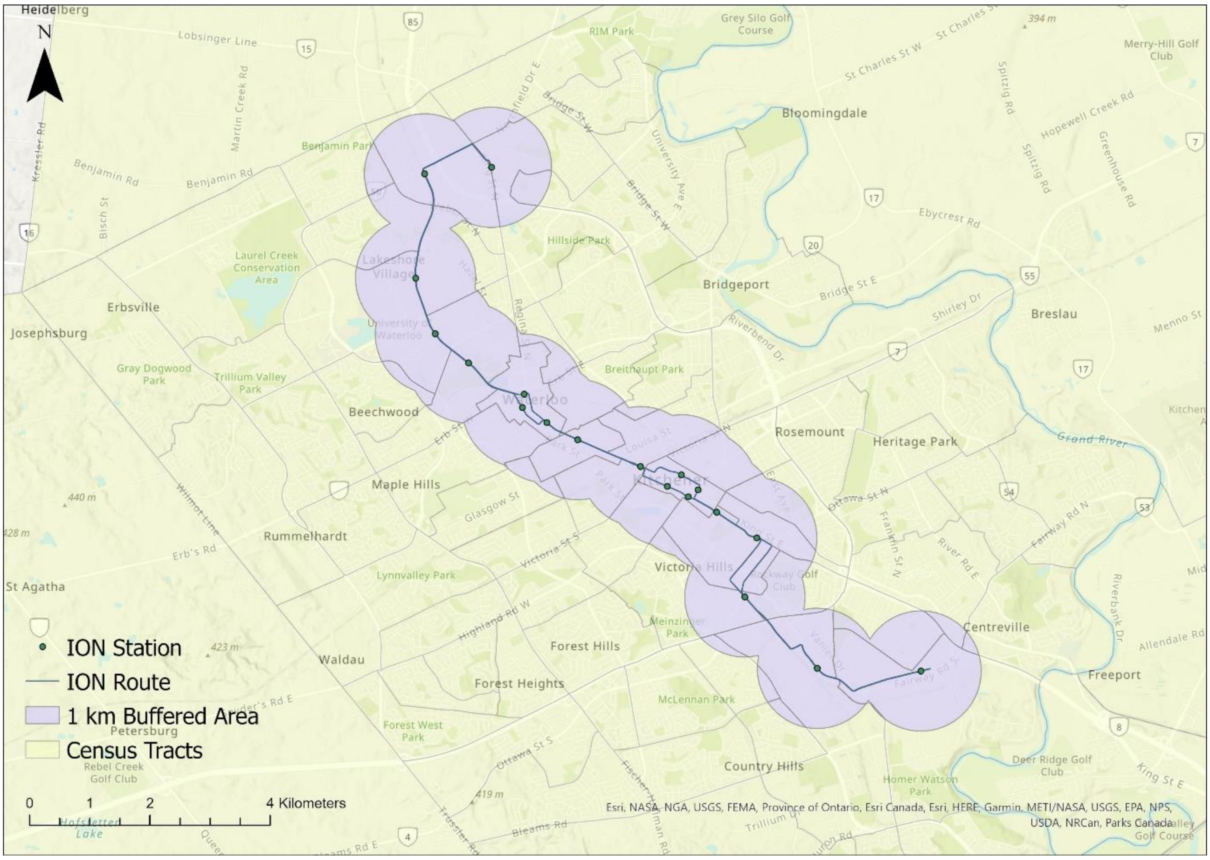
Table 3.7 Projected Coordinate Systems Used for the Case Study Systems

	Projected coordinate system using Universal Transverse Mercator (UTM) Projection
Waterloo	UTM 17N
Calgary	UTM 11N
Vancouver	UTM 10N
Ottawa	UTM 18N

Then, a new field, “Area in square kilometers” of the census tracts is added, and the calculate geometry attributes tool is used to find out the total area of a CT in square kilometers as the total area is reported in square meters in the data source. A new field, “Population density” is then added to find the population per square kilometer in each CT. The points of the LRT stations of the case study systems are then found using ArcGIS Online resources. The points of the LRT stations are then buffered using 1km buffers and dissolved into a buffered layer. The buffered layer is then intersected with the original map layer into a new layer.

A new field, “Buffered area” is then added to the new layer. Then, a new field “Buffered population” is added that calculates the population in the buffered area by multiplying the population density and the buffered land area in the same CT. The sum of the buffered population field is the estimated population, employment and estimated commuting trips in the LRT catchment area.

Figure 3.3 Buffered Area for Calculating Catchment Area Population and Employment



3.5.3 Estimating Potential Change in Public Transit Ridership amid COVID-19

A baseline case and two scenarios have been built for both place of work and place of residence to estimate the potential change in public transit ridership amid COVID-19 on the census tract level. The following table introduces the baseline case and the scenarios. Table 3.9 and Appendix B shows the variables based on different NAICS Sector codes for the scenario calculations.

Table 3.8 Background Information on Scenarios Used to Estimate Public Transit Ridership Change

	Baseline Case: 2016 Commuting Data	First Scenario: Peak of pandemic	Second Scenario: "The New Normal"
Implications	Reflects public transit ridership prior to the COVID-19 Pandemic (2016 levels are used as commuting data is from the 2016 Canadian Census)	Reflects public transit ridership during the peak of the COVID-19 Pandemic (Spring 2020 and Winter 2020) in the case study CMAs amid strict lockdown rules	Reflects public transit ridership in the longer term when COVID-19 restrictions are eased, and workplaces can reopen

Table 3.9 Variables for Scenario Calculations

Variable Description	Variable Symbol
Number of commute trips using public transit as the main mode of commuting by place of work in 2016	$2016TRIP\_W$
Number of commute trips using public transit as the main mode of commuting by place of residence in 2016	$2016TRIP\_R$
Number of total commuting trips using public transit in 2016	$2016TRIP\_T$

Baseline Case

The baseline case reflects the number of current commuting trips using public transit in each census tract (CT), which is derived from the number of workers living in a CT and take public transit to work, and the number of jobs in that CT by which workers commute by transit to work. The total number of commute trips using public transit as the main mode for both Place of Work and Place of Residence is based on 2016 Statistics Canada data in the selected case study CMAs at the census tract (CT) level. The data enables an understanding of the distribution of employment in the case study CMAs and commute patterns using public transit in 2016.

The total number of commuting trips using public transit in a census tract in 2016 $(2016TRIP\_T)$ is calculated by adding the number of commute trips using public transit as the main mode of commuting by place of work ($2016TRIP\_W$) and place of residence ($2016TRIP\_R$).

$$2016TRIP\_T = 2016TRIP\_W + 2016TRIP\_R$$

However, it is important to note that the examined public transit trips are limited to employment (commute) trips and does not include other types of trips such as discretionary trips. In addition, the number of place of work commuting trips is potentially underestimated as the commuters who live outside the CMA and use public transit as the main mode of their commute for work within the CMA is only accounted for one trip instead of two trips (most commuters live in the CMA and two trips are counted for their commute: trip from home to the workplace and trip from the workplace back home). The number of commuters travelling into the CMA from other areas is unsure according to the data provided.

First Scenario: "Peak of Pandemic"

The first scenario represents the commuting situation when strictest measures were in place from governments to curb the spread of the virus during the peak of the pandemic. During that time, provinces of the case studies declared public health and state of emergencies to implement strict measures such as stay at home orders, social distancing regulations, mask mandates and workplace restrictions. Only businesses declared essential were allowed to operate at limited capacity, while other non-essential businesses were required to close in person operations. Most non-essential workers were forced to shift their workplace from the office to home, thus achieving maximum telework capacity.

This scenario implies that "full" telework potential is reached as "stay at home orders" (or its equivalents in other provinces) mandates that only essential businesses can be opened, and trips outside of home should be limited and only for essential purposes. To estimate the impact of working from home / teleworking during the pandemic, the study uses Statistics Canada's estimations on telework capacity in May 2020, reported in percentages for different industry types using North American Industry Classification System (NAICS) 2-digit codes as introduced in Table 3.3 in Section 3.4.3. The percentage of workers that are working in the workplace by industry ($PERC\_WIW_{industry}$) during the peak of the pandemic is identified by deducting the telework capacity for each industry, as shown in Table 3.10, and each industry is a value is an input for later calculations.

% of workers working in the workplace ($PERC\_WIW_{industry}$) = 1 – telework capacity

Table 3.10 Percentage of Workers Working in the Workplace When Full Telework Capacity is Reached

Industry by NAICS sector (2-digit) code	**Description of sector and Variable Name**	**Workers working in the workplace during full lockdown (%)**
11	Agriculture, forestry, fishing, hunting $(PERC\_WIW_{11})$	96.1
21	Mining, quarrying, oil and gas extraction $(PERC\_WIW_{21})$	76.1
22	Utilities $(PERC\_WIW_{22})$	61.4
23	Construction $(PERC\_WIW_{23})$	88.9
31 – 33	Manufacturing $(PERC\_WIW_{31-33})$	80.9
41	Wholesale trade $(PERC\_WIW_{41})$	42.7
44 – 45	Retail trade $(PERC\_WIW_{44-45})$	78
48 – 49	Transportation and warehousing $(PERC\_WIW_{48-49})$	75.5
51	Information and cultural industries $(PERC\_WIW_{51})$	31.5
52*	Finance, insurance $(PERC\_WIW_{52})$	14.7
53	Real estate, rental and leasing $(PERC\_WIW_{53})$	52.2
54	Professional, scientific and technical services $(PERC\_WIW_{54})$	16.1
56	Administrative and support, waste management, remediation $(PERC\_WIW_{56})$	64.9
61	Educational services $(PERC\_WIW_{61})$	15.4
62	Health care, social assistance $(PERC\_WIW_{62})$	71.2
71	Arts, entertainment, recreation $(PERC\_WIW_{71})$	59.9
72	Accommodation, food services $(PERC\_WIW_{72})$	94.4
81	Other services (except public administration) $(PERC\_WIW_{81})$	68.6
91	Public administration $(PERC\_WIW_{91})$	41.8

Source: Deng et al. (2020)

* No sector information on remote work was provided for NAICS sector code 55 (Management of companies and enterprises). Sector code 52 remote work data was applied to that sector.

The estimated number of commuting trips using public transit by place of work during the peak of the pandemic $(LOCKTRIP\_W)$ is the total sum of the percentage of workers working in the workplace in each industry $PERC\_WIW_{industry}$ listed in Table 3.3 in Section

3.4.3 multiplied by the number of commuting trips using public transit by place of work in 2016 by each sector ($2016TRIP\_W_{sector}$).

$$LOCKTRIP\_W = (PERC\_WIW_{11} \times 2016TRIP\_W_{11}) + (PERC\_WIW_{21} \times 2016TRIP\_W_{21}) + \cdots + (PERC\_WIW_{91} \times 2016TRIP\_W_{91})$$

The estimated number of commuting trips using public transit by place of residence during the peak of the pandemic ($LOCKTRIP\_R$) is the sum of the percentage of workers working in the workplace in each industry $PERC\_WIW_{industry}$ listed in Table X in Section 3.4.3 multiplied by the number of commuting trips using public transit by place of work in 2016 by each sector ($2016TRIP\_R_{sector}$).

$$2020TRIP\_R = (PERC\_WIW_{11} \times 2016TRIP\_R_{11}) + (PERC\_WIW_{21} \times 2016TRIP\_R_{21}) + \cdots + (PERC\_WIW_{91} \times 2016TRIP\_R_{91})$$

Subsequently, the total estimated number of commuting trips using public transit in a census tract during lockdown ($LOCKTRIP\_T$) is calculated by adding the number of commute trips using public transit as the main mode of commuting by place of work ($LOCKTRIP\_W$) and place of residence ($LOCKTRIP\_R$).

$$LOCKTRIP\_T = LOCKTRIP\_W + LOCKTRIP\_R$$

Second Scenario: The "New Normal"

The second scenario estimates the commuting trips using public transit in the longer term, when COVID-19 restrictions regarding non-essential workplaces are relaxed and mandatory work from home policies come to an end. This also marks Canadian society returning to a "new normal" and the estimated ridership will be able to illustrate potential long-term changes for telework and commuting. Various research papers, studies and surveys have been attempting to estimate the longer-term implications of telework and working from home after the COVID-19 pandemic.

To estimate how many workers would still be working from home, studies that cover both employers and employees are included. A Statistics Canada study by Mehdi and Morissette (2021) on employees working from home during COVID-19 in Canada indicates that a hybrid workplace is most preferred by workers as 76% of them prefers a hybrid workplace (working both at home and outside the home), while only 9% and 15% of workers preferred working all hours outside the home or at home respectively. ADP Canada's (2020) study reveals the age gap in remote work preferences as younger employees have stronger preferences in favour of telework compared to older employees. Employers' estimates also suggest a significant shift in the location of work activity after the COVID-19 pandemic according to Bartik et al. (2021) in a U.S. study on the firm-level as at least 16% of workers will switch from offices to working at home, which is consistent with the study conducted by Barrero et al. (2020) which projects 22% of full workdays will be supplied from home.

The first scenario uses the study by Deng et al. (2020) on full telework capacity for estimating the percentage of workers working in the workplace. In this situation, it was estimated by the authors that approximately 39% of Canadian workers could be working from home. Based on the above studies' estimates for post-COVID telework, the second scenario assumes the post-pandemic telework percentage of all industries ($PERC\_PWIW_{industry}$) to be halved compared to the peak of the pandemic, which implies that approximately 19.5% of all jobs would be done via telework.

% of workers working in the workplace ($PERC\_PWIW_{industry}$) = 1 – telework capacity

Table 3.11 Estimated Percentage of Workers Working in the Workplace Post-COVID

Industry by NAICS sector (2-digit) code	Description of sector and Variable Name	Workers working in the workplace post-COVID (%)
11	Agriculture, forestry, fishing, hunting ($PERC\_PWIW_{11}$)	98.1
21	Mining, quarrying, oil and gas extraction ($PERC\_PWIW_{21}$)	88.1
22	Utilities ($PERC\_PWIW_{22}$)	80.7
23	Construction ($PERC\_PWIW_{23}$)	94.5
31 – 33	Manufacturing ($PERC\_PWIW_{31-33}$)	90.5
41	Wholesale trade ($PERC\_PWIW_{41}$)	71.4
44 – 45	Retail trade ($PERC\_PWIW_{44-45}$)	89.0
48 – 49	Transportation and warehousing ($PERC\_PWIW_{48-49}$)	87.8
51	Information and cultural industries ($PERC\_PWIW_{51}$)	65.8
52	Finance, insurance ($PERC\_PWIW_{52}$)	57.4
53	Real estate, rental and leasing ($PERC\_PWIW_{53}$)	76.1
54	Professional, scientific and technical services ($PERC\_PWIW_{54}$)	58.1
56	Administrative and support, waste management, remediation ($PERC\_PWIW_{56}$)	82.5
61	Educational services ($PERC\_PWIW_{61}$)	57.7
62	Health care, social assistance ($PERC\_PWIW_{62}$)	85.6
71	Arts, entertainment, recreation ($PERC\_PWIW_{71}$)	80.0
72	Accommodation, food services ($PERC\_PWIW_{72}$)	97.2
81	Other services (except public administration) ($PERC\_PWIW_{81}$)	84.3
91	Public administration ($PERC\_PWIW_{91}$)	70.9

The estimated number of commuting trips using public transit by place of work during the peak of the pandemic ($POSTTRIP\_W$) is the total sum of the percentage of workers working in the workplace in each industry $PERC\_PWIW_{industry}$ listed in Table B in this section is multiplied by the number of commuting trips using public transit by place of work in 2016 by each sector ($2016TRIP\_W_{sector}$).

$$POSTTRIP\_W = (PERC\_PWIW_{11} \times 2016TRIP\_W_{11}) + (PERC\_PWIW_{21} \times 2016TRIP\_W_{21}) + \cdots + (PERC\_PWIW_{91} \times 2016TRIP\_W_{91})$$

The estimated number of commuting trips using public transit by place of residence during the peak of the pandemic $(POSTTRIP\_R)$ is the sum of the percentage of workers working in the workplace in each industry $PERC\_PWIW_{industry}$ listed in Table B in this section is multiplied by the number of commuting trips using public transit by place of work in 2016 by each sector $(2016TRIP\_R_{sector})$.

$$POSTTRIP\_R = (PERC\_PWIW_{11} \times 2016TRIP\_R_{11}) + (PERC\_PWIW_{21} \times 2016TRIP\_R_{21}) + \cdots + (PERC\_PWIW_{91} \times 2016TRIP\_R_{91})$$

Subsequently, the total estimated number of commuting trips using public transit in a census tract in 2020 $(POSTTRIP\_T)$ is calculated by adding the number of commute trips using public transit as the main mode of commuting by place of work $(POSTTRIP\_W)$ and place of residence $(POSTTRIP\_R)$.

$$POSTTRIP\_T = POSTTRIP\_W + POSTTRIP\_R$$

As estimations for longer term telework trends vary according to different studies and is constantly evolving due to the ongoing pandemic, the telework estimations used in this scenario could be adjusted accordingly depending on the changing situation.

4. Results

4.1 The Original Policy Goals and Objectives of the Case Study Systems

4.1.1 Summary of Original Policy Goals and Objectives of the Case Study Systems

The original policy goals and objectives of the case study systems are summarized in Table 4.1 through looking at the original documents during the proposal and construction stage of the LRT systems, including business cases, council documents, environmental assessments, and other studies. The most common objective for the construction of the LRT systems is to accommodate forecasted transportation growth and manage traffic congestion and was stated in all four case study systems. This suggests that LRT systems are mainly built to tackle traffic-related issues. In addition, provide transportation alternatives, efficient transportation and improving travel time is also cited for three of the four systems.

Three out of four case study LRT systems' objectives include stimulating smart growth, improve the vibrancy of urban areas and foster economic development, reflecting the trend which regional and municipal governments guide development towards smart growth and intensification in existing built-up areas. The only system that didn't mention the above objectives was Calgary, probably as their system was planned in the late 1970s, much older than the other LRT systems. Other urban development objectives such as limiting urban sprawl were found in Waterloo and Vancouver.

Environmental goals such as decreasing greenhouse gas emissions and improving air quality are also common and cited as objectives in three of the four systems. In particular, Waterloo's ION rapid transit specifically included protecting agricultural land and preservation of the environment as goals related to the LRT, possibly due to the importance of existing agricultural activity within the region at the urban fringe compared to other LRT systems.

The detailed goals and objectives of each case study LRT system are discussed in Section 4.1.2 to Section 4.1.5.

Table 4.1 Summary of Original Policy Goals and Objectives of the Case Study Systems

	Region of Waterloo – ION rapid transit	**City of Calgary – CTrain**	**Metro Vancouver – Canada Line**	**City of Ottawa – OTrain**
Transit – related goals				
Provide transportation alternatives	✓	✓	✓	
Provide efficient transportation, improving travel time	✓		✓	✓
Reduce transit operating costs		✓		✓
Accommodate forecasted transportation growth	✓	✓	✓	✓
Manage traffic congestion	✓	✓	✓	✓
Improving the quality of the travel experience			✓	
Increasing transit modal share	✓		✓	
Urban development goals				
Limiting urban sprawl	✓		✓	
Stimulate Smart Growth	✓		✓	✓
Improve the vibrancy of urban areas	✓			✓
Foster economic development	✓		✓	✓
Environmental and social goals				
Decreasing emissions and improving air quality	✓		✓	✓
Protecting agricultural land	✓			
Preservation of the environment	✓			
Boosting city image				✓

Source: Region of Waterloo (2012, 2014); Calgary Transportation Department (1976); Kuyt & Hemstock (1978); Translink (2001, 2003); Delcan Corporation (2010)

4.1.2 Region of Waterloo

The construction of ION Rapid Transit is closely related to the Regional Growth Management Strategy (RGMS) entitled "Planning Our Future", developed by Waterloo Region in 2003 (Region of Waterloo, 2003). The strategy identified where, when and how additional residents and jobs should be located to focus growth sustainably. Consistent with the Province's "Smart Growth" principles, the strategy focused on the growth for the next 25 to 35 years in urban areas and rural communities in ways that will preserve and enhance the high quality of life currently enjoyed in these communities. The RGMS includes six major goals for the Region:

- Enhancing our natural environment
- Building vibrant urban places
- Providing greater transportation choice
- Protecting our countryside
- Fostering a strong economy
- Ensuring overall coordination and cooperation

The RGMS recognizes that the traditional development pattern of suburban sprawl and single-occupancy car travel is not sustainable as the Region of Waterloo has to prepare for accommodating additional population growth in the region and Waterloo Region recognizes the need to look at new and improved ways to prepare for the future of Waterloo's community, which led to a push for higher order transit in the region. This is in line with the province of Ontario's Places to Grow legislation and the Growth plan for the Greater Golden Horseshoe which aims to encourage development and growth within existing urban areas. During the Rapid Transit Environmental Assessment (EA) in 2006, 10 rapid transit technologies were evaluated and eventually bus rapid transit (BRT) and light rail transit were shortlisted as the preferred option as it was more likely to achieve the objectives of the RGMS, especially in terms of attracting transit ridership, boosting land values and acting as a catalyst for development and investment compared to BRT.

The business case of the Rapid Transit Project (Region of Waterloo, 2009) states that the project has three main goals: providing transportation choice and meeting future transportation needs, and building a viable, vibrant and sustainable community. The construction of the system is promoted by the region as it was expected to bring a wide range of economic, social, and environmental benefits. These benefits include reduced congestion, increased transit ridership, improved mobility, reduced emissions, reurbanization and intensification, improved public safety and security and building a prosperous community.

More specifically, three of the fundamental goals of ION are: moving people more efficiently in and around our community, limiting urban sprawl and saving our farmland through the protection and preservation of the environment (Region of Waterloo, 2012). By focusing development and investment in the core, Waterloo Region can build up, instead of out to limit urban sprawl and protect the environment (Region of Waterloo, 2014).

4.1.3 City of Calgary

Calgary started to plan for rapid transit in the 1960s as the development of the Alberta oil industry made the city into a “boomtown” with massive downtown construction developments and unprecedented population growth. With centralized employment areas and fast-growing suburbs dominated by low-density housing, the transportation system experienced high levels of directional and temporal peaking during workdays (Belobaba, 1982). Calgary’s actual planning for rapid transit started in 1966 with preliminary plans for an extensive network with four legs and two express bus lines. However, the economic downturn in the early 1970s led to slower population growth and lower population density that anticipated while construction costs for the proposed grade-separated rapid transit system increased rapidly. Initial studies for a potential light rail in Calgary started in 1975 as the city’s South corridor was expected to exceed transportation capacity over the next 20 years (Kuyt

& Hemstock, 1978). The Calgary Transportation Improvement Priority Study by the Calgary Transportation Department (1976) found that existing road and transit systems were incapable to accommodate the forecasted growth in travel demand, especially in the MacLeod Trail corridor, South of the downtown core. Rapid transit construction was preferred compared to buses on reserved lanes and even high-quality express bus service as comparative analyses determined that building an LRT system had the highest ability to defer significant costs associated with road construction, increase travel by transit and attract more compact transit supportive land development at station locations (Hubbell et al., 2009). It was also expected that the long-term capital costs of a rapid transit system was lower than a “bus now, rapid transit later” alternative. However, a formal alternatives analysis was not conducted while selecting the route alignment as the use of the existing railroad right of way in the existing MacLeod Trail corridor was deemed necessary due to less property acquisition, lower capital and operation costs and minimal environmental impact.

Belobaba (1982) states that the motivation and decision of Calgary to build rapid transit in the 1970s was a response to a capacity deficiency in one corridor of the city’s transportation network, a change in transportation policy to develop public transit as an alternative to road construction for private vehicles and a land use planning decision to influence urban form and guide land development. Chumak & Bolger (1984) explains one of the goals for LRT is to manage traffic in the downtown and inner city that face increasing congestion and to improve the physical environment of these areas by reducing unnecessary vehicle traffic. Bakker (1992) find that the underlying real reason LRT was built in Calgary was the rivalry between the city and Edmonton, and as Edmonton has started building an LRT system, Calgary could not stay behind Edmonton for LRT construction. On the other hand, the northwest line extension was motivated by the 1988 Winter Olympics amid community opposition according to Hubbell & Colquhoun (2006) and Whitson & Macintosh (1993) as several important venues such as the Athletes' Village and McMahon Stadium that were used for the opening and closing ceremonies were located at the University, and a public transit connection between the downtown core which hosted other venues and the university area was needed.

4.1.4 Metro Vancouver

The planning of rapid transit systems in Metro Vancouver started in the late 1960s amid debates of freeway construction and projections of a rapid population boom from 1 million residents in 1970 to 2 million in 2000. The Rapid Transit Study conducted by Greater Vancouver Regional District (1970) proposed four main corridors in the city for rapid transit construction, including the Arbutus Corridor which links up Downtown Vancouver and Richmond, similar to the Canada Line today. Rankin (1971), a long time Vancouver City Councillor who supported rapid transit construction instead of freeways, stated comprehensive goals that a rapid transit system can achieve, including monetary savings to the individual, travel time savings, reduction in air and noise pollution, reduced traffic congestion, planned community development and the creation of new jobs.

The main goals and objectives of the current Canada Line are shaped by the Livable Region Strategic Plan (LRSP) and "Transport 2021" Medium and Long-range Transportation Plan for Greater Vancouver formulated by Greater Vancouver Regional District (1993). The LRSP was based on four fundamental strategies including: protecting the green zone (which includes natural assets such as major parks, watersheds and ecologically important areas), build complete communities, achieve a compact metropolitan region and increase transportation choices. The Transport 2021 Medium-range Transportation Plan for Greater Vancouver identified three corridors that could support some form of Intermediate Capacity

Transit System (ICTS) by 2006, and concluded that the Richmond Vancouver ICTS had the greatest projected intensity of usage and improving transport efficiency but ranked third on its ability to shape land use and urban development. On the other hand, the current light rail segment from Vancouver International Airport – Richmond was only recommended for bus lanes instead of ICTS.

The Multiple Account Evaluation for the Richmond / Airport-Vancouver Rapid Transit Project by IBI Group and Price Water House Coopers (2001) supported an earlier implementation, 2010 in-service date for the line as it can better encourage higher transit usage and transit-oriented development and contribute to regional land use goals and Transport 2021 transit mode share goals. Moreover, it stated that transit has the ability to shape and direct growth to areas which have become more accessible by new transport links. Specifically, some under-developed sites were identified in the Vancouver/ Richmond corridor near the airport, shaping development which can contribute to the wider region goals.

TransLink (2001) advanced the Richmond/Airport-Vancouver Rapid Transit Study amid strong development trends in Downtown Vancouver and Richmond City Centre. The study added an airport connection compared to original proposals as passenger and employment growth on Sea Island greatly exceeded LRSP estimates. It concluded that rail investments would offer benefits that would help achieve transportation, land use, economic, and environmental policy objectives, including:

- Provide transportation choice
- Provide capacity, particularly in the region’s primary corridors
- Manage congestion

- Concentrate population and employment growth in regional town centres and provide high quality transit between them
- Foster a strong regional economy
- Improve local air quality and control greenhouse gas emissions

During the public consultation process, it was stated that the main problem the new line aims to address is the increasing traffic congestion along the North/South Corridor between Richmond, the Airport and Vancouver, meeting demands of population growth and provide broader travel options (Translink, 2003). Moreover, the community consultation guide listed the primary objective for the line as "increasing transportation capacity in the corridor in a sustainable way". Specific transit-related objectives for the project include:

- Increasing transportation choice
- Improving travel times
- Improving the quality of the travel experience
- Improving the regional transportation network
- Improving travel within Vancouver and Richmond
- Addressing congestion
- Increasing transit ridership (in the Richmond/Vancouver corridor and region wide)
- Increasing the percentage of total trips by transit

Other objectives include:

- Decreasing greenhouse gas emissions and improving local air quality, over the long term
- Providing infrastructure to improve the movement of goods and people in the region, and to improve the economy generally
- Improving overall quality of life in the region

4.1.5 City of Ottawa

The first LRT line in Ottawa, the Trillium line, was proposed in 1998 as a pilot project for light rail along a small segment of track on existing Canadian Pacific Railway rails with a small budget of $16 million. According to City of Ottawa (2002), the objectives of the light rail pilot project set out in 1999 were to: assess the technical feasibility of using an existing freight rail corridor for rapid transit, validate the projections for ridership, cost and performance, and allow proper analysis of larger scale implementation. Other objectives include improving transit access to key markets and diverting transit trips from the Central Area.

Ottawa's Confederation Line, formerly referred to the Downtown Ottawa Transit Tunnel (DOTT) project was recommended in the Transportation Master Plan in 2008. With tunnels beneath the downtown core, it replaces the downtown Bus Rapid Transit Transitway into an LRT system with total grade separation. The City of Ottawa (2009) recommended the City Council to approve the LRT project as it supports objectives of the City Strategic Plan such as improving the city's transportation network for ease of mobility, keep pace with growth, attain transit goals of 30% modal split by 2021, require walking, transit and cycling oriented communities and employment centres etc.

After the City of Ottawa (2012) identified that the main reason for LRT construction is due to the existing transit system being pushed to its maximum capacity, particularly the downtown BRT sections reaching its limits which will negatively impact the reliability and quality of public transit. Along with City of Ottawa (2012), Croft (2011) listed out the benefits of the LRT project which include:

- Accommodating future ridership growth and Increasing transit capacity
- Increasing the speed, comfort and reliability of transit
- Time savings by preventing congestion
- Reducing transportation-related air quality impacts
- Greenhouse gas reductions and reduced salt use
- Reducing transit operating costs

- Improving the downtown area and providing economic development
- Encouraging transit-oriented development and focusing growth of new employment and residential clusters around LRT stations

The Business Case of the DOTT Project by Metropolitan Knowledge International and Delcan Corportation (2010) also states that the main reason for building LRT is that travel access into downtown Ottawa is approaching capacity and cannot handle any further growth and road expansions are not feasible, and a transit tunnel provides additional capacity. The planning objectives of the DOTT project are as follows:

- Increase Transit Ridership and Mobility
- Enhance Ottawa's Urban Character and National Stature
- Stimulate Smart Growth
- Create Successful Rapid Transit Stations
- Provide Safe and Efficient Linear Infrastructure
- Provide a Safe and Efficient Tunnel and Compatible Portals
- Be Compatible with Adjacent Communities
- Maintain or Improve Natural and Physical Environments
- Showcase Sustainable Design Best Practices
- Manage Construction Disruption and Risk
- Result in a Wise Public Investment

4.2 Performance of the Case Study Systems

4.2.1 Overview

The case study LRT systems were introduced in Section 3.2. In general, the case studies are mid to large sized cities in Canada with operating LRT systems. The population density of the case study cities varies with Calgary and Vancouver having higher densities than Waterloo and Ottawa. These cities also have a slightly higher percentage of working age population. Waterloo has a much lower public transit ridership and annual public transit trips per capita compared to the three other cities, possibly due to its smaller urban size and shorter history of higher order public transit.

Table 4.2 Characteristics of the Urban Areas Served

	Waterloo	Calgary	Vancouver	Ottawa
Population (2019 / 2020 estimates)	618,000	1,287,000	2,740,000	1,018,000
Population density (persons per km^2)	451	1,558	949	365
Percentage of working age population (aged 15 - 64) (2016)	67.8%	69.6%	69.6%	67.9%
Annual public transit ridership (in thousands) (2019)	21,962	164,453	435,882	97,400
Annual public transit trips per capita (2019)	35.5	127.8	159.1	95.7

Sources: Region of Waterloo (2020), City of Calgary (2019), Province of British Columbia (2020), City of Ottawa (2020), Statistics Canada (2016), OC Transpo (2021), American Public Transport Association (2020), Translink (2020c), Region of Waterloo (2020)

The physical and operating Key Performance Indicators are presented in Table 4.3. Calgary's LRT network is most extensive as it has the longest system length and the highest number of stations among the systems. However, it also has the highest average station spacing and highest average operating speed among all systems, possibly reflecting the LRT network which extends beyond the urban area into the suburbs. On the other hand, Waterloo's ION LRT system provides lower service levels and has a much lower transit unit and line capacity compared to other LRT systems.

Table 4.3 Physical and Operation Key Performance Indicators

	Waterloo	**Calgary**	**Vancouver**	**Ottawa**
System length (km)	19.0	59.9	19.2	12.5
Number of routes	1	2	1	1
Number of stations	19	45	16	13
Average station spacing (km)	1.00	1.33	1.20	0.96
Segregation from other traffic	partial	partial	complete	complete
Transit unit (TU) capacity	200	800	400	600
Line capacity (Passengers per hour per direction) (pphpd)	1,200	8,000 (Red Line)	8,000	10,700
Average operating speed (km/h)	24.8	35.4	34.8	32.6
Peak service headway in minutes (Before COVID-19 service adjustments)	10	6	3	4
Peak hour frequency	6	10	20	17
Number of hours run at peak frequency	11	6	13	6.5
Total hours of service per weekday	18	20	20	20

Source: Keolis (2020); Grand River Transit (2020); Calgary Transit (2020); Translink (2020); OC Transpo (2020)

The ridership Key Performance Indicators are presented in table 3. The estimated population and employment in the 1km station catchment area in Calgary is the highest which also has the highest average daily ridership among all systems. Employment density is also a major KPI to measure potential ridership, and Vancouver has a much higher median employment density compared to the other systems, while Calgary has the highest employment density in a census tract, possibly reflecting the high concentration of employment in the downtown Calgary. External factors also affect the estimated ridership impact, as the case study systems were built for different purposes and have a different structure, which impacts transit performance. For example, Calgary's employment which is concentrated in downtown and its city planning policies such as limiting downtown parking spaces and ample park and ride facilities have led to a high share of workers using public transit in the downtown core (Higgins & Ferguson, 2012).

Table 4.4 Ridership Key Performance Indicators

	Waterloo	Calgary	Vancouver	Ottawa
Estimated population in 1km LRT station catchment area	59,863	247,638	172,887	88,253
Estimated employment in 1km LRT station catchment area	32,119	147,006	103,568	50,485
Median employment density in catchment area census tracts	1,219	450	4,316	2,069
Range of employment density in catchment area census tracts	26 – 2,522	29 – 52,542	24 – 24,318	27 – 44,786
Average daily ridership (2019 Q4)	20,000	250,972	137,597	100,000
Estimated annual light rail transit trips per capita *	11.8	71.2	18.3	35.9

Source: Grand River Transit (2020); Calgary Transit (2020); Translink (2020c); OC Transpo (2020)

* Annual light rail transit trips are estimated based on 2019 Q4 ridership data

4.3 Have the Case Study Systems Achieved their Original Policy Goals and Objectives?

4.3.1 Summary of the Case Study Systems in Achieving their Original Policy Goals and Objectives

Section 3.5.2 outlined the specific key performance indicators (KPIs) which can indicate success or failure in achieving the related objectives of LRT systems and the original policy goals and objectives for the four case study LRT systems identified in Section 4.1 are in line with the KPIs.

Table 4.5 Summary of LRT Systems' Performance in Achieving their Original Policy Goals and Objectives

	Waterloo	**Calgary**	**Vancouver**	**Ottawa**
LRT system ridership increasing steadily	✓*	✓	✓	✓*
LRT system ridership is not lower than the initial forecast	✓	✓	✓	×
Increased modal share of public transit after the completion of the new system	✓*	✓	✓	✓*
Other transit connections at LRT stations	✓	✓	✓	✓
Construction of transit-oriented developments in downtown / city centre	+ +	+ + +	+ +	+
Construction of transit-oriented, higher density developments along LRT corridor	+ +	+	+ + +	+ +
Indication of new development in inner city / declining neighborhoods	+	+	+ +	+
Diversity mix of developments within 1km LRT catchment area (commercial/ residential/ mixed) based on floor area	9:73:19	38:46:16	9:29:62	6:43:51

Plus signs indicate the performance of the LRT system: weak (**+**)/ modest (**++**) / strong (**+++**) performance

* Based on limited data as ridership was impacted by the COVID-19 pandemic within one year of operation

4.3.2 Region of Waterloo - ION Rapid Transit

LRT system ridership increasing steadily

As the COVID-19 pandemic led to a significant decline in ridership since March 2020, ridership data is limited for The Region of Waterloo's ION LRT system. However, initial ridership figures show that LRT ridership has risen since the opening of the ION LRT system in July 2019 and ridership trends were positive (Weidner, 2019). The ION LRT system has also attracted more public transit trips - the half-year passenger revenue and ridership of Grand River Transit rose 7.4% from July to December 2019 (after the opening of ION) compared to July to December 2018. In particular, the number of boardings in the Central Transit Corridor with LRT service increased by 45% or 7,000 more weekday daily passenger boardings (Region of Waterloo, 2020).

LRT system ridership is not lower than the initial forecast

Initial boarding stood at 17,000 passengers daily in September 2019, two months after the opening of the system, which is lower than the initial expectation of 27,000 daily passenger boardings on opening day in the Business Case of the Region of Waterloo Rapid Transit Project (2009). However, ION ridership has been significantly affected by the COVID-19 pandemic shortly after its opening, which has affected the ridership numbers in 2020.

Increased modal share of public transit after the completion of the new system

The mode share of public transit in the Central Transit Corridor (CTC) was 5% in 2015, and the Region has not updated the modal share information after the opening of the ION system. However, the share of active transportation (pedestrian and cycling) in the CTC rose from 5% to 9% from 2011 to 2016. The percentage of daily average transit activity within the CTC in the region lowered from 67% in 2011 to 59% in 2019, reflecting transit ridership has grown faster in suburban areas compared to the CTC (Region of Waterloo, 2020).

Other transit connections at LRT stations

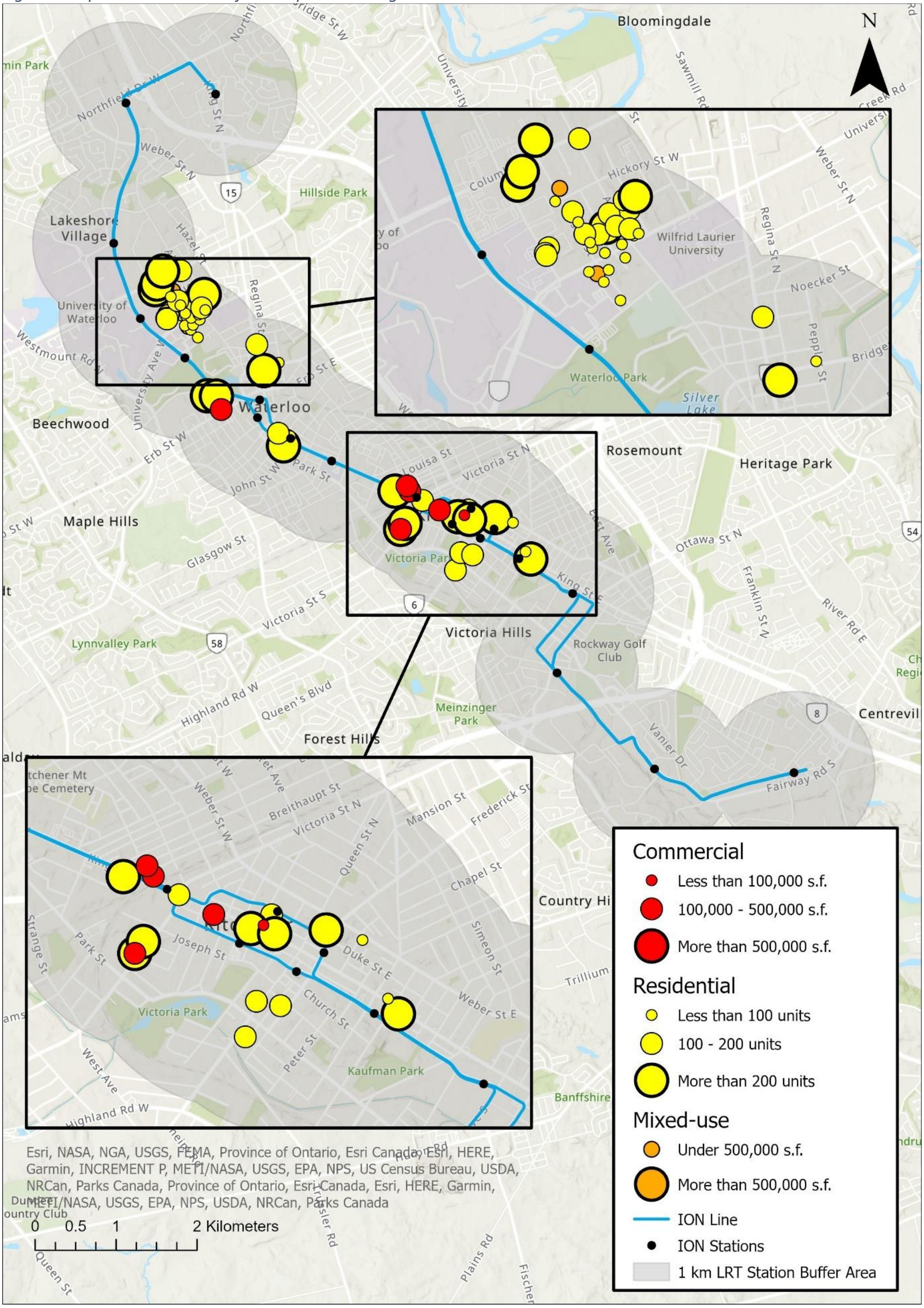
Grand River Transit's network which was based on a bus system was changed significantly amid the opening of the ION LRT system to better connect to ION service (Grand River Transit, 2019). The Charles Street Transit Terminal was closed upon the launch of the LRT system and, and buses were rerouted to provide connections as feeder lines for the ION LRT service in each LRT station.

Construction of transit-oriented developments in downtown / city centre

A significant number of transit-oriented developments have been constructed or are under construction along the LRT route, mostly in Downtown Kitchener and Uptown Waterloo, the regional centers of the Region of Waterloo. These TODs are mostly condominiums with some retail space at the ground or lower levels. Within the Central Transit Corridor (CTC), 12,300 apartments and 2.76 million square feet of commercial usage were constructed from 2011 to 2019. The total cumulative building value for both residential and non-residential developments in the CTC from 2011 to 2019 was $3.2 billion (Region of Waterloo, 2020). The inset maps in Figure 4.1 show the concentration of developments in downtown Kitchener and the University district.

Spatial distribution of developments along LRT corridor

Figure 4.1 Spatial Distribution of Developments along the ION LRT Line



Note. Includes complete and approved developments since 2010.
Source: Google Maps, City of Kitchener

Construction of transit-oriented, higher density developments along LRT corridor

The developments in the Central Transit Corridor, especially Downtown Kitchener and Uptown Waterloo have seen increasing density. Nine out of the ten tallest buildings in the Region of Waterloo were built after ION construction commenced and are all located within the Central Transit Corridor. These high-density developments such as Duke Tower Kitchener and Charlie West in Downtown Kitchener as shown in Figure 4.2 and 4.3, are mainly used for condominiums, which is different from previous high-density developments which were used for office or long-term rental apartments. Higher density development could also be reflected in the housing type of the new residential units built in the Central Transit Corridor – among the 13,100 units built, 94% (12,300) of the units were multi-storey apartments (Region of Waterloo, 2020).

Figure 4.2 (left) Duke Tower Kitchener in Downtown Kitchener which will become the tallest building in the Region upon completion
Source: Urban Toronto

Figure 4.3 (below) Street-level rendering of Charlie West in Downtown Kitchener under development showing the ION LRT line in front of the building
Source: Momentum Developments

Indication of new development in inner-city / declining neighborhoods

Outside the downtown core, several sites have been subject to redevelopment along the ION light rail. The most prominent development is the 27-acre former Schneiders Meat Processing Plant Site close to Mill Station which has been proposed for 2,800 residential units, office space and a retail hub (GSP group, 2019). Several older and low-density buildings have also been demolished, mainly for mid to high-density mixed-use redevelopment along main roads such as the Station Park development on King Street.

Transit-induced gentrification has been observed and is increasingly evident in the Region of Waterloo (McDougall et al., 2020). With condominium prices and median income increasing in the central transit corridor, low-density commercial buildings and vacant land in the downtown core have been replaced with high-rise residential towers that cater to younger residents and higher income groups.

4.3.3 Calgary

LRT system ridership increasing steadily

Since the completion of the first phase of CTrain in 1981, the ridership of CTrain has been steadily increasing. Annual LRT boardings rose from 10 million to 90 million from 1981 to 2019 amid ongoing expansions of the system (Lafleur, 2011; American Public Transport Association, 2020). The CTrain carried 313,800 passengers on an average weekday in 2019, becoming the highest ridership of LRT systems in North America. However, the ridership of the system is unbalanced in peak periods as three quarters (75%) of trips are inbound and outbound commuting trips from the downtown core.

LRT system ridership is not lower than the initial forecast

The initial forecast ridership of 40,000 boarding passengers per day was soon met after the opening of the system (Hubbell & Colquhoun, 2006). While there were dips in ridership during economic downturns in the early 1980s, early 1990s and 2008, the overall ridership for the system have met forecasts. In more recent LRT expansions, actual LRT ridership has continued to meet ridership estimates. The West LRT that opened in 2012 achieved a ridership of 32,400 per weekday during the first year of its operation (Calgary

Transit, 2014). This meets weekday ridership estimates of 32,000 to 37,000 in the costing report of the extension (Calgary Transit, 2006).

Increased modal share of public transit after the completion of the new system

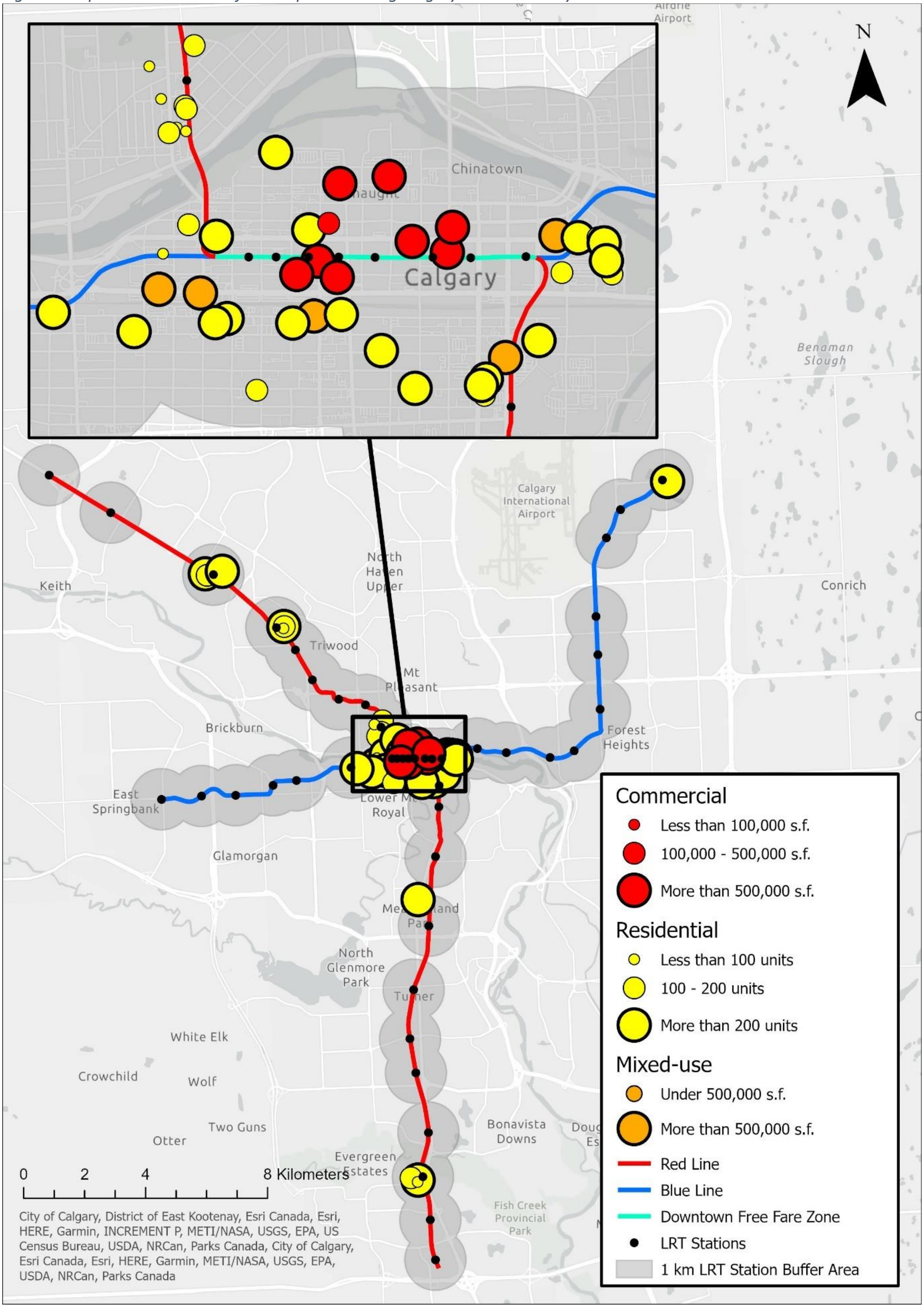
A large concentration of employment is located in downtown Calgary which houses over one-fifth of all Calgary jobs. The two lines of the LRT system provide fast access to the downtown from other parts of the city and a free-fare zone under 7th Avenue was established in several downtown stations. This has resulted in a transit modal split which has increased significantly from 34% in the early 1970s to 42% in 2005 in the downtown core. The modal split for public transit in downtown is particularly high during the inbound AM peak period and has risen from under 30% in the early 1970s to around 50% in the 2010s due to the large number of commuters travelling into the Central Business District (The City of Calgary Transportation Planning, 2012).

Other transit connections at LRT stations

The CTrain system is closely integrated with the MAX bus rapid transit (BRT) system which has four routes (MAX Orange, MAX Yellow, MAX Teal, MAX Purple). They form Calgary Transit's rapid transit system which aims to provide more frequent and higher quality service compared to conventional bus routes, and transfers between BRT and LRT are direct as each BRT route has a terminus at an LRT station (Keating, 2018). LRT riders can also transfer to local bus routes in a larger number of LRT stations. Apart from transit connections, Calgary's LRT system provides 17,500 park and ride spaces for the LRT system, much more than other major Canadian transit systems. 15 percent of customers access LRT service using park and ride services, especially in suburban CTrain stations where connecting bus services are insufficient or of lower quality in terms of frequency and operating span (The City of Calgary Transportation Department, 2016).

Spatial distribution of developments along LRT corridor

Figure 4.4 Spatial Distribution of Developments along Calgary's CTrain LRT System



Note. Includes complete and approved developments since 2010.
Source: City of Calgary, Google Maps

Construction of transit-oriented developments in downtown / city centre

Calgary's have allowed zoning bonuses and other incentives to encourage station-area development since the early days of LRT development. In the downtown stations, density bonuses are given to new construction projects that provide better connectivity such as pedestrian arcades, public open spaces, direct access to LRT stations and interconnected elevated skywalks (Cervero, 1985). The skywalks link into the extensive pedestrian walking system, Plus 15 network, which links up more than 60 buildings in the downtown core with LRT stations. Higgins and Ferguson (2012) suggest that the cornerstone of Calgary's transit plan is the reduction of minimum parking requirements for long term parking spaces in downtown office developments by requiring one parking space for every 140m^2 of net floor area which in turn promotes transit ridership in the downtown. The inset map in Figure 4.4 shows the concentration of developments in downtown Calgary, including several large-scale mixed-use developments with a floor area of over 500,000 square feet, such as the 5th and Third development shown in Figure 4.5 close to City Hall LRT station which includes a podium which provides 178,000 sq ft of retail space and two residential towers with approximately 500 units.

Figure 4.5 (right) 5th and THIRD mixed-use development in East Village, Downtown Calgary
Source: Skyrise Calgary
Figure 4.6 (below) University City Development in Brentwood, a suburban neighborhood in Northwest Calgary
Source: GEC Architecture

Construction of transit-oriented, higher density developments along LRT corridor

Transit-oriented development is mainly concentrated in the downtown core despite high levels of ridership of the CTrain and a downtown with multiple transit-oriented commercial developments and a high transit modal split. This could be attributed to the automobile-oriented design for many CTrain Stations further away from the downtown core which provides large park and ride lots for commuters using the LRT system. In addition, some LRT stations are located in the middle of highway medians (Higgins and Ferguson, 2012). With 17,500 park and ride spaces, Calgary's CTrain provides much more parking facilities compared to other major Canadian Transit systems (The City of Calgary Transportation Department, 2016).

Several notable new transit-oriented residential developments have occurred close to suburban stations in Northern Calgary neighbourhoods such as Brentwood, Dalhousie and Saddletowne. Figure 4.6 shows the University City project located near Brentwood station which was redeveloped from a suburban strip mall into four buildings with over 700 residential units. Meanwhile, not much transit-oriented development has been observed in the southern segment of the LRT. White (2019) argues transit-oriented development in Calgary has been lagging other cities in Canada as the city has focused on creating plans and policies that favour density near transit stations but is slow to approve development plans. In addition, high costs of single-family homes in cities such as Vancouver has brought high demand for higher density development, while Calgary's low housing costs and abundance of land for urban sprawl has led to lower demand for new condos.

Indication of new development in inner city / declining neighborhoods

Amid the booming economy of the city, Calgary's population increased from 879,000 in 2001 to 1.24 million 2016. However, population growth has mostly concentrated in the outer suburbs and the downtown core (Babin, 2016). On the other hand, several inner-city suburbs with such as Canyon Meadows in the Southwest, Scenic Acres and Silver Springs in the Northwest have seen population declines of over 10% between 2000 and 2018 (City of Calgary, 2018). Limited new development has occurred amid suburban-redevelopment conflicts such as community resistance towards proposed higher density transit-oriented developments and the lack of undeveloped land.

Redevelopment for transit-oriented development in inner-city neighborhoods started in the mid-2000s. Close to City Hall Station, several mid to high rise condominiums with retail on lower floors have replaced a few low-rise commercial buildings in East Village. A notable large-scale redevelopment is The Bridges project located at Bridgeland/Memorial Station, which occupies a 14.9-hectare site of the former Calgary General Hospital which closed in 1998 (Figure 4.7). Under the Bridgeland-Riverside Area Redevelopment Plan that was approved in 2003, it was redeveloped into a master-planned mixed-use neighbourhood (The City of Calgary, 2003). CMHC's (2009) case study illustrates that the development has successfully increased LRT ridership at Bridgeland/Memorial Station while providing open space and community facilities for the development and surrounding neighbourhoods (Figure 4.8).

Figure 4.7 The demolition of the former Calgary General Hospital
Source: Calgary Herald

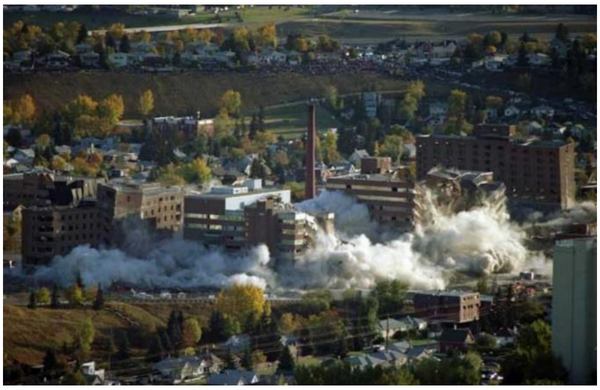


Figure 4.8 The Bridges Development
Source: Google Maps

Other inner-city neighbourhoods such as Hillhurst/Sunnyside, an inner-city area located right across the Bow River from Downtown Calgary have also experienced redevelopment in recent years. Approved by the city in 2009, the Hillhurst/Sunnyside Area Redevelopment Plan has driven the redevelopment of low-rise commercial buildings near Sunnyside Station into mid-density residential buildings (White, 2019).

4.3.4 Metro Vancouver
LRT system ridership increasing steadily

Since the completion of the Canada Line in 2009, the system has seen ridership increasing steadily from 38.4 million annual trips in 2010 (its first year of full service) to 50.2 million annual trips in 2019. Average weekday boardings during the same period rose from 83,000 to 152,400. 4 new trains have been purchased and commenced operation through the Public Transit Infrastructure Fund in 2019 as the line was reaching its maximum capacity during peak hour operations (Chan, 2020a; Government of British Columbia, 2020).

LRT system ridership is not lower than the initial forecast

Ridership of the Canada Line has exceeded initial forecasts. Original projections expected 31 million passengers in 2010 that would grow gradually to 45 million passengers in 2021. In its first full year of operation (2010), ridership already exceeded initial estimates. As ridership has continued to rise steadily, 2021 ridership target was achieved in 2017, four years ahead of the initial projections (Chan, 2020b). This has caused overcrowding in trains during peak hours in 2018 and 2019, as the passengers per hour per direction (pphpd) between the busiest segment from King Edward Station to Broadway-City Hall Station had an average of 6,500 pphpd during the AM peak, exceeding the system's maximum capacity of 6,100 pphpd.

Increased modal share of public transit after the completion of the new system

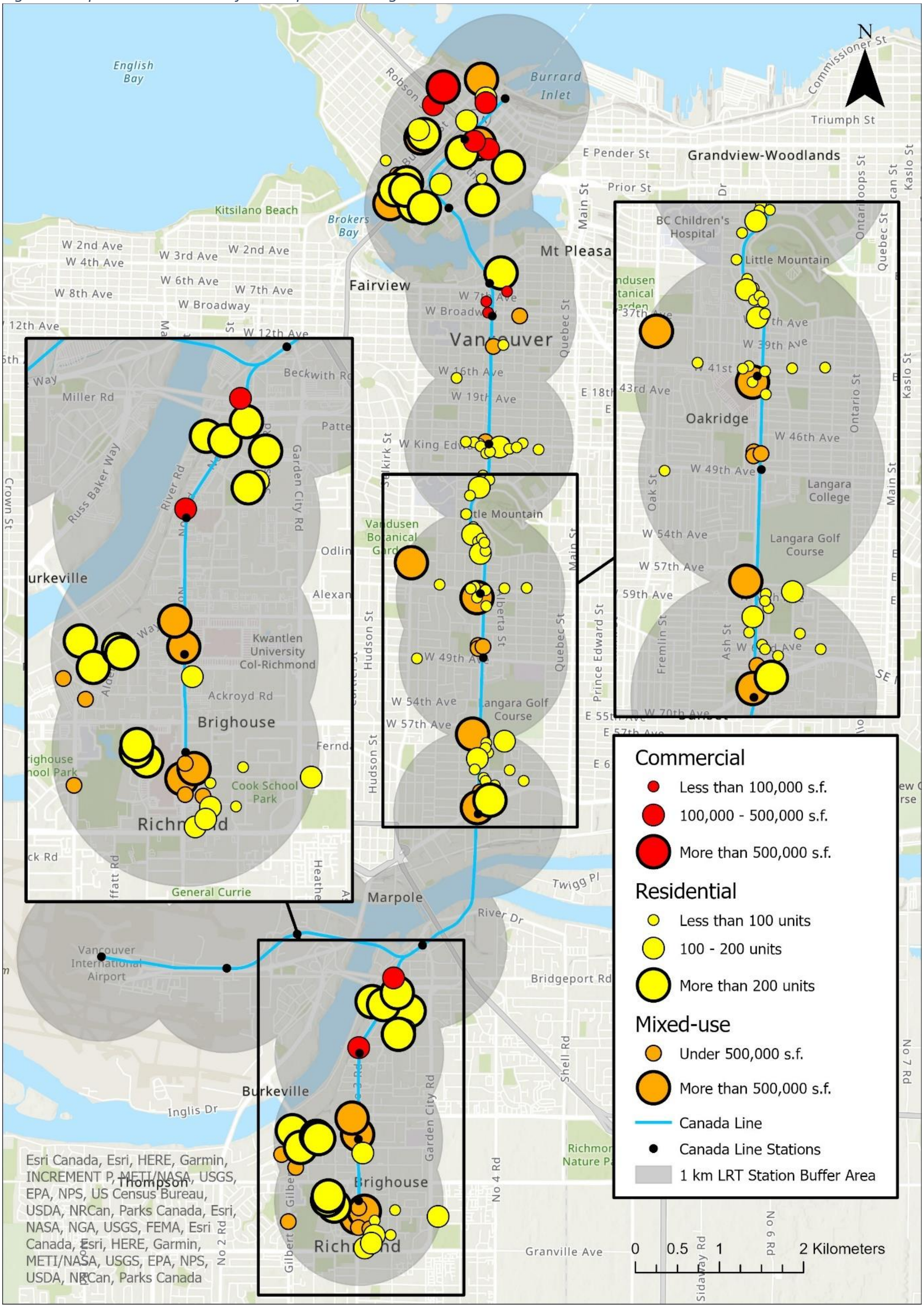
The Metro Vancouver Regional Trip Diary Survey conducted by Translink shows that Richmond's percentage of trips using transit rose from 5.2% in 2004 to 12.5% in 2017 (Translink, 2017). Trips by driving automobiles reduced in particular after the opening of the Canada Line, from 60.7% in 2011 to 54.7% in 2017. However, In Vancouver South - the neighborhoods along Cambie Street, the Canada Line alignment, not much change in modal share of transit has been observed according to the annual transportation panel surveys. While the share of automobile driver and passenger trips declined from 57% to 52% from 2013 to 2019, significant growth was observed in cycling that rose from 3% to 11%.

Other transit connections at LRT stations

The Canada Line is closely integrated with other modes of transit operated by Translink. The Northern Terminus of the line, Waterfront Station provides direct connections to the SeaBus, the passenger ferry connecting North Vancouver, the West Coast Express, a commuter railway serving other parts of Metro Vancouver and the Fraser Valley Regional District as well as The Skytrain Expo Line. Other stations of the line provide multiple connections to the bus system of Translink, including the trolley bus routes, RapidBus routes and other local buses (Translink, 2021).

Spatial distribution of developments along LRT corridor

Figure 4.9 Spatial Distribution of Developments along Vancouver's Canada Line



Note. Includes complete and approved developments since 2010.
Source: City of Vancouver, City of Richmond, Google Maps

Construction of transit-oriented developments in downtown / city centre

There has been significant transit-oriented development in Downtown Vancouver. The neighborhoods surrounding Yaletown-Roundhouse station and Vancouver City Center station witnessed high-density mixed-use development, mostly retail space on the lower floors and multi-story condominiums on the upper floors. However, some of these developments predate the construction of the Canada Line. The large-scale redevelopment plans of the area started in the late 1980s as the former industrial lands surrounding False Creek used for Expo 86 were sold to developers in 1988 for the redevelopment of the 200-acre site into a new community with multiple residential towers (Proctor, 2016).

Construction of transit-oriented, higher density developments along LRT corridor

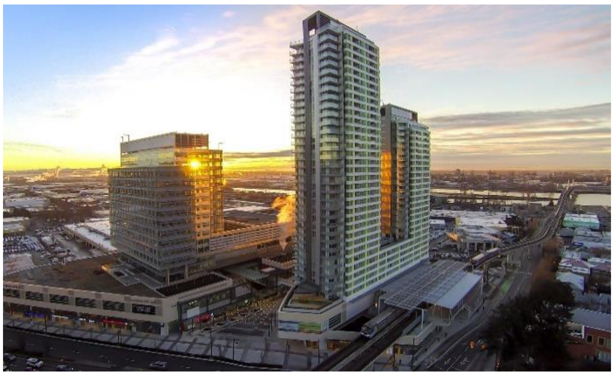
The Cambie Corridor was identified amid the opening of the Canada Line along Cambie Street. The City Council approved the Cambie Corridor Plan in 2010 amid the opening of The Canada Line which is a long-term framework to guide the development of complete communities within the corridor, enabling the corridor to become the biggest growth area outside of downtown and add over 30,000 new homes (City of Vancouver, 2018). A monitoring report on the Cambie Corridor Plan by the City of Vancouver (2020) indicates that 5,300 new residential units have been approved in Phase 1 and Phase 2 of the Plan from 2011 till 2019. Phase 1 and 2 of the project (2010 – 2018) have led to major transformation to the Corridor. Mid density residential development and new townhouse projects that replaces larger, single detached homes built in the post-war period have been ongoing along main arterial roads near King Edward, Oakridge-41st Avenue and Langara-49th Avenue Stations.

Commercial development has also increased in the corridor, with 327,800 square feet of retail space and 272,300 square feet of office space have been approved. Market data from MLA Canada (2020) shows that Cambie corridor has seen robust sales of presale units – from

Q4 2012 till Q3 2020, a total of 2,764 condominium units were presold which represents 90% of the housing supply during the period. In addition, there are 7,600 units under application for development as of Q4 2020.

Figure 4.10 New high rise condominium developments under construction in Richmond Centre
Source: Google Maps Street View

Figure 4.11 Mixed-use transit-oriented developments on the Cambie Corridor in Marpole, Vancouver
Source: Marine Gateway on the Canada Line



In Richmond, significant transit-oriented development projects have been completed since the early 2000s along the LRT corridor on No.3 Road in anticipation of the construction of the Canada Line. In the Richmond City Centre neighbourhood (Figure 4.11), 7,904 new units started construction since 2010 (CMHC, 2021). In particular, Capstan Station that is currently under construction was funded though the Capstan Station Funding Agreement signed in 2012 that enabled the City of Richmond to collect funds from developers in the area in exchange for density bonuses for transit-oriented developments (City of Richmond, 2017). A total of $28 million was raised from 2012 to 2018, eight years ahead of the original anticipated time frame. From 2012 to 2019, 3,336 new housing units started construction near Capstan station, with over 95% of new dwellings being multi-story condominiums. With this ongoing pace of development and new building activity even during the COVID-19 pandemic when over $1.0 billion in construction approvals and building permits were issued, it is anticipated that the city will meet the Official Community Plan 2041 target of 280,000 residents (City of Richmond, 2019; City of Richmond Economic Development, 2021).

Indication of new development in inner city / declining neighborhoods

The area around 41st Avenue and Cambie Street has been designated as a Municipal Town Centre in the Metro Vancouver Regional Growth Strategy. It is home to two large scale redevelopment projects – Oakridge Centre, a large shopping mall built in the 1950s and Oakridge Transit Centre, home to the operating fleet and maintenance facilities of the Coast Mountain Bus Company. The first phase of the mixed-used redevelopment of the 28-acre Oakridge Centre commenced in 2019 and will provide 2,600 residential units (including 290 affordable housing units), over one million square feet of new retail space, 290,000 square feet of office space and 100,000 square feet community centre housing multiple facilities such as a performance hall and a public library branch, is scheduled for completion in 2026 (Chan, 2019).

Canada line runs along Cambie Street in the City of Vancouver, and Vancouver Vest neighborhoods surrounding the LRT stations have generally been regarded as affluent neighborhoods. Marpole which is one of the earliest settlements of Vancouver and a former industrial centre, however, is an exception: the population below the National Poverty Line in 2016 stood at 25%, higher than the city average; its median household income was $54,000 in 2016, the third lowest neighbourhood in Vancouver (City of Vancouver, 2020). In recent years, new high-density mixed-used developments such as Marine Gateway (Figure 4.11), which include retail, offices and condominiums has been replacing older low-rise rental units and commercial strip malls close to Marine Drive station.

4.3.5 Ottawa

LRT system ridership increasing steadily

Ridership data is limited for Ottawa's LRT system as the COVID-19 pandemic led to a significant decline in ridership since March 2020. Despite operational challenges during the opening months of the Confederation Line, overall public transit ridership has continued to rise by 3.7 and 3.2 percent in the first two months of LRT operation compared to the previous year (Britneff, 2020).

LRT system ridership is not lower than the initial forecast

In the final business case for the Confederation Line (then known as the Downtown Ottawa Transit Tunnel Project), it was estimated that the ridership on the line would be at 51 million trips in 2021, and 76 million trips in 2031 (Metropolitan Knowledge International & Delcan Corporation, 2010). Meanwhile, it is projected that the total system ridership would increase from 93 million to 166 million trips per annum. In Q4 2019, the first quarter with full operation of the Confederation Line, the daily ridership was at 159,000 while first month ridership stood at 3 million. Ridership will unlikely meet original 2021 projections as the COVID-19 pandemic led to drastic decreases in ridership since March 2020 in Ottawa amid lockdown restrictions and ridership has not recovered to pre-COVID-19 levels in early 2021.

Increased modal share of public transit after the completion of the new system

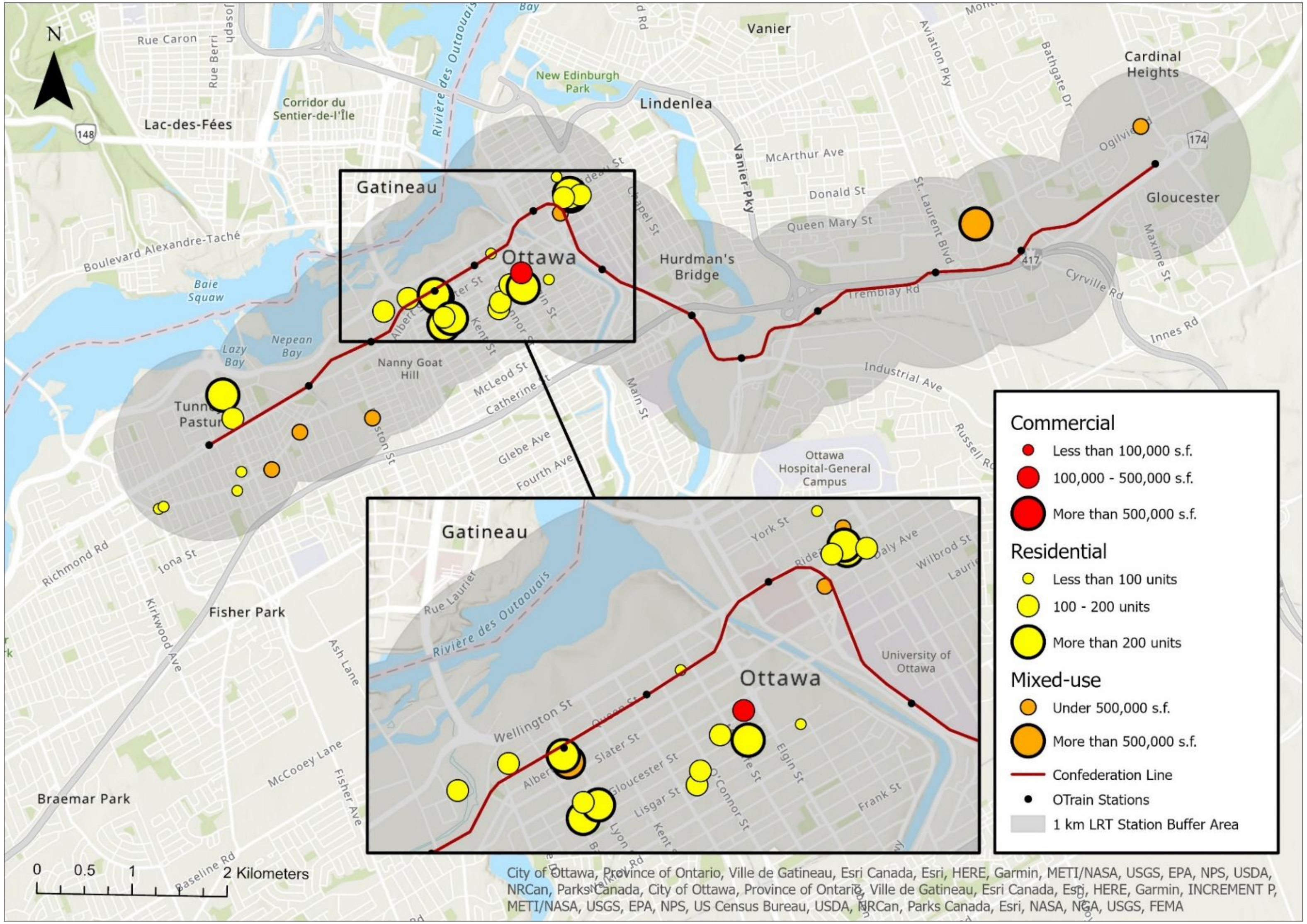
Few months after operation commenced on the Confederation line, COVID-19 caused a significant impact on ridership and there is limited data of modal share for the confederation line. During the operation of the Trillium Line pilot project, a modal shift of 600 peak period vehicles from the congested north-south Bronson Avenue corridor was observed (Transport Canada, 2005). In addition, the non-car-drive share in Ottawa during the morning peak period is 45.3% (22.4% public transit) in 2011, which reflects the success of the Transitway in transit and the less auto-centric culture in Ottawa compared to other cities in North America (Barrie, 2019). Thus, it is expected that the Confederation Line has a large potential to increase public transit mode share.

Other transit connections at LRT stations

All LRT stations except for uOttawa and Cyrville Station provide transit connections to OC Transpo buses. In addition, Tunney’s Pasture, Hurdman, Blair and Greenboro Station serves as transfer stations to the Transitway network, the bus rapid transit network of Ottawa. Tremblay Station is located next to Via Rail’s Ottawa Station, allowing transfers to inter-city trains.

Spatial distribution of developments along LRT corridor

Figure 4.12 Spatial Distribution of Developments along Ottawa's Canada Line



Note. Includes complete and approved developments since 2010.

Source: City of Ottawa, Google Maps

Construction of transit-oriented developments in downtown / city centre

Several transit-oriented developments, mostly high-end high-rise condominium and rentals are currently underway in downtown Ottawa, close to Lyon station and Parliament station. This includes the 27-storey condominium building Claridge Moon, the first residential development to be directly connected to an LRT station in Ottawa (Claridge Homes, 2021). Other ongoing real estate projects also include the conversion of older office buildings into mixed-use developments such as InterRent REIT's 473 Albert Street project (Ottawa Business Journal, 2020b).

Construction of transit-oriented, higher density developments along LRT corridor

Despite several transit-oriented development plans being developed by the planning department during the construction of the Confederation Line for Lees, Hurdman, Tremblay, St. Laurent, Cyrville and Blair stations, no significant development has occurred yet and most developments are still in the planning stage. One of the first developments that were completed is the Frontier Towers at Blair Station, which provides over 400 high-end rental units. Near Cyrville Station, Ottawa City Council approved a mixed-use development proposal on a vacant 3.8-acre site that includes 850 rental apartment units in three high rise towers with 25, 27 and 36 storeys and an 8-storey hotel that houses 175 suites for extended stay guests (Ottawa Business Journal, 2020a).

Along the O-Train West Extension which is currently under construction and is expected to start operations in 2025, transit-oriented developments have started to take shape. The largest transit-oriented development that has been planned in Ottawa is the 16-acre mixed-use redevelopment of the former Lincoln Fields Shopping Centre, located next to the upcoming Lincoln Fields station (Ottawa Business Journal, 2019).

In 2019, a total of 9,426 residential unit building permits were issued in Ottawa with 3,034 of these issued building permits in designated intensification target areas according to The Official Plan. From 2015 to 2019, a total of 7,587 units were built within 600 metres of rapid transit stations, which accounts for 22.6% of total residential units built in this period (City of Ottawa, 2020). The number of new residential unit build permits near rapid transit stations has increased since the approval of the Confederation Line from 1,291 in 2012 (20.6% of total units) to 2,029 (21.5% of total units) permits issued in 2019 (City of Ottawa, 2016).

Indication of new development in inner-city / declining neighborhoods

Dow's Lake (formerly Carling) station on the Trillium Line (currently under construction for upgrades), has seen several transit-oriented developments from the redevelopment of low rise residential and light industrial buildings (Hickman et al., 2020). In particular, the Claridge Icon tower which comprises of condominiums and ground-level retail space became the tallest building in Ottawa when it was topped out in 2019. The new Civic campus development of the Ottawa Hospital has also been proposed right across the station, and the new hospital campus will be connected to the LRT station by a covered and accessible walkway (The Ottawa Hospital, 2020). In Westboro, an inner-city community that was mostly developed in the early 20th century, several high-rise condominium redevelopments are under construction or in the planning stage close to the future LRT station (Ottawa Business Journal, 2020c). This is especially evident on Scott Street where low-density commercial and light industrial buildings have been replaced by mixed-use high-rise towers, as seen in Figure 4.13 which illustrates the significant change of the neighborhood in anticipation of the West LRT extension which is currently under construction.

Figure 4.13 The intersection of Scott St & McRae Ave near the future Westboro LRT station in 2009 (left) versus 2020 (right)
Source: Google Maps Street View

Not far from downtown Ottawa, the Little Italy – Chinatown neighbourhood, West of downtown Ottawa saw its population decrease by 15 percent between 2011 and 2015. This has been attributed to the displacement of old residential houses that were emptied and fenced off for new development amid gentrification attributed by residents to the construction of the new LRT line (Harrap, 2017). Several new infill developments have been approved with higher densities and re-zoning by the city council (Willing, 2020).

4.4 The Impact of the COVID-19 Pandemic on Potential Public Transit Ridership on the Neighborhood Level

4.4.1 Overview

As identified in Section 2.7 of the literature review, the COVID-19 pandemic led to a significant drop in public transit usage as lockdowns and stay-at-home orders were imposed as an effort to reduce mobility to curb the spread of the disease. Most companies switched their operations from the office to remote work / work from home under government regulations, leading to a large reduction of commute trips. The first scenario introduced in Section 3.5.3 estimates the number of commuting trips during the peak of the pandemic as maximum telework potential is achieved. The scenario estimates that the number of commuting trips using public transit as the main mode dropped by more than 40% in the case study Census Metropolitan Areas (CMAs) compared to 2016. In particular, Ottawa has the largest estimated drop of trips (47%) which reflects that the CMA has a larger proportion of jobs with a high telework potential compared to other case study CMAs.

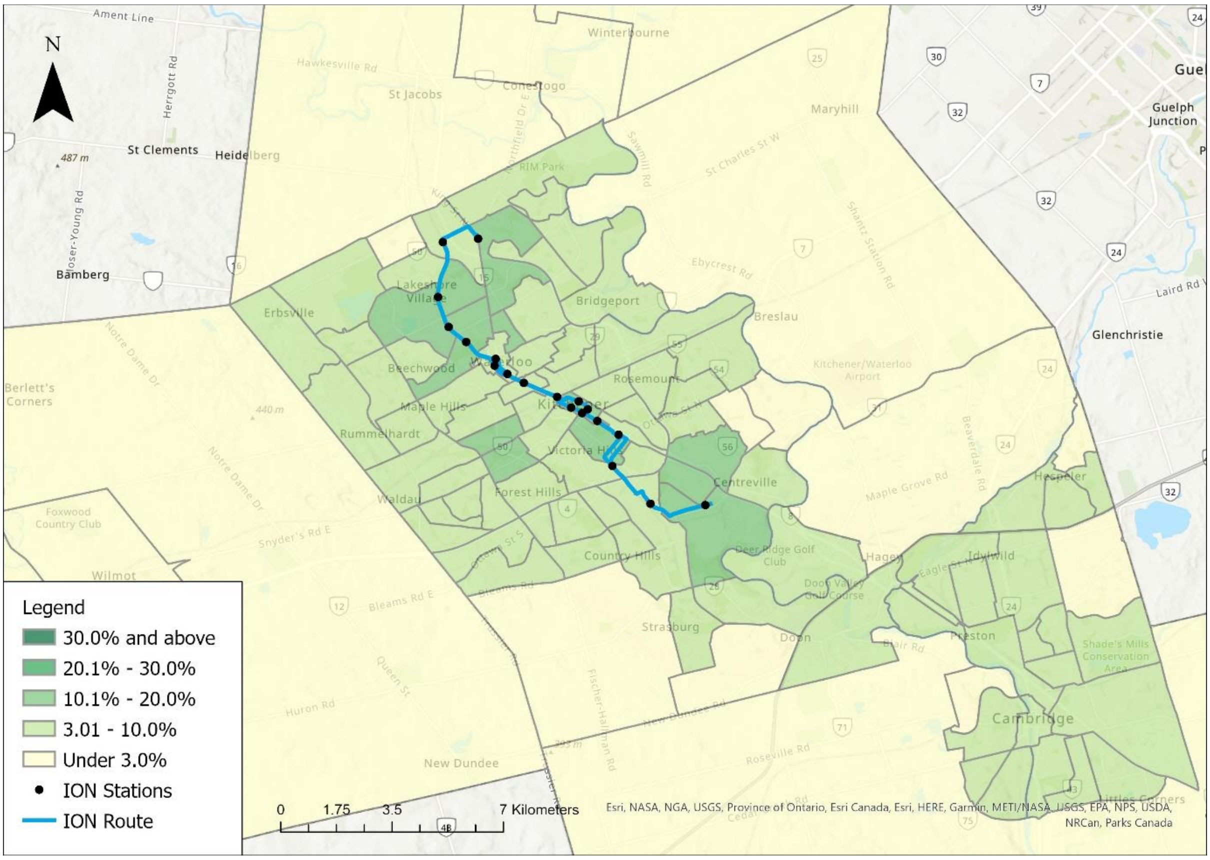
Table 4.6 Summary of Impact on Potential Public Transit Ridership of the Case Study Systems

	Waterloo	**Calgary**	**Vancouver**	**Ottawa**
Total daily public transit commuting trips in 2016 (Baseline)	29,570	188,990	451,615	227,435
Estimated daily public transit commuting trips during the peak of the pandemic (First Scenario)	16,837	111,362	255,737	119,814
Change between 2016 and the peak of the pandemic (%)	– 43%	– 41%	– 43%	– 47%
Estimated daily public transit commuting trips in the “new normal” (Second Scenario)	23,222	150,267	353,694	173,655
Change between 2016 and the “new normal” (%)	– 21%	– 20%	– 22%	– 24%

The estimated ridership impact of the pandemic on the four LRT systems will be discussed in detail in the sections below.

4.4.2 Region of Waterloo

Figure 4.14 Percentage of commuters using public transit in Kitchener-Cambridge-Waterloo CMA based on 2016 census data

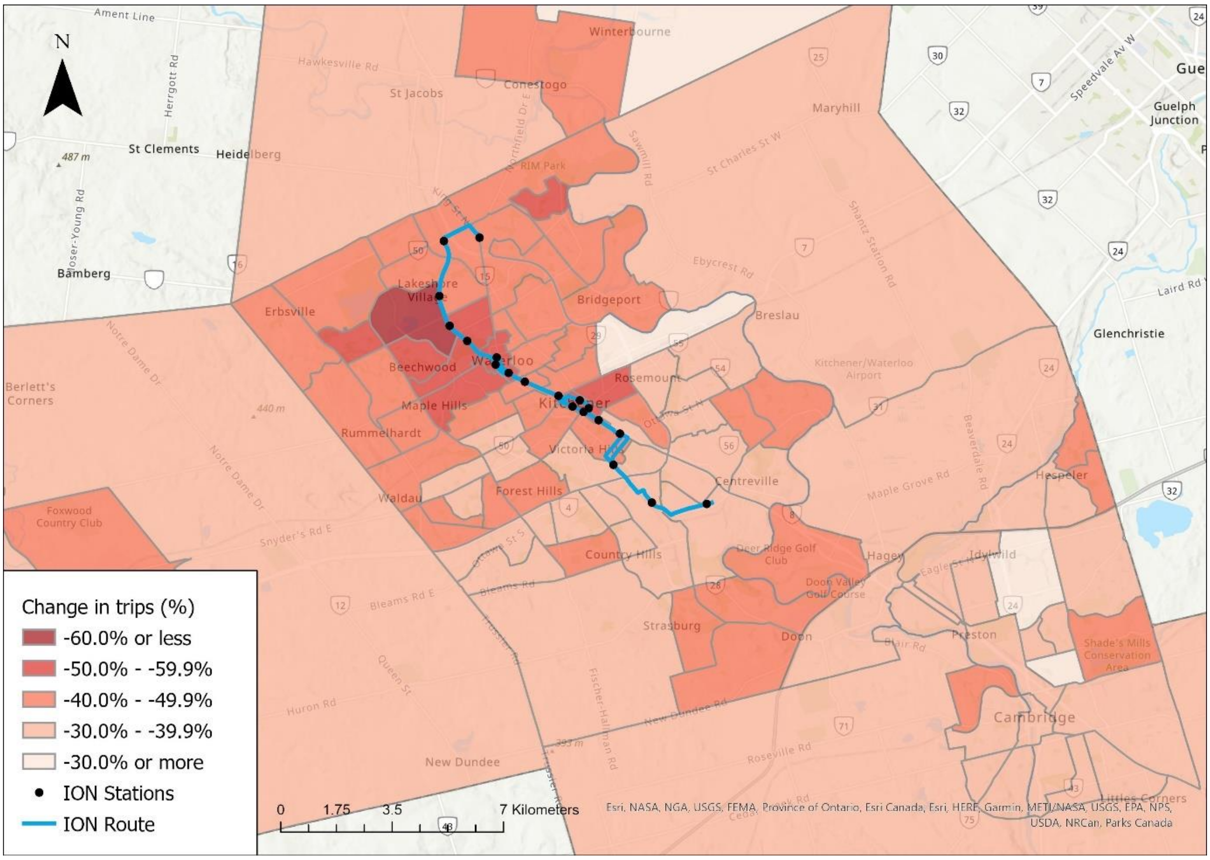


The 2016 census data indicate that 6.2% of commuters in the Kitchener – Cambridge – Waterloo census metropolitan area (CMA) used public transit as the main mode of transportation for their commute, which is the lowest percentage of the four case study cities. As shown in Figure 4.9, census tracts (CTs) that were more rural and further away from the city center had a lower percentage of commuters mainly using public transit (mostly under 3.0%) while CTs in the Central Transit Corridor with the ION light rail transit line saw a larger number of commuters mainly using public transit. In particular, CTs in university campuses, downtown Kitchener and large malls (Fairview Park Mall and Contestoga Mall) had the highest percentage of commuters using public transit at around 15%.

First Scenario: Peak of pandemic

It is estimated that the number of total commuting trips using public transit in the Kitchener – Cambridge – Waterloo CMA decreased from 29,570 to 16,837 during the peak of the pandemic (based on 2016 data). This translates to an estimated 43% drop in commuting trips. Within the CMA, the degree of reduction of trips varies, with most trip reductions observed in the University District in Waterloo and Downtown Kitchener census tracts (CT) with a loss of more than 600 commuting transit trips per day, implying an estimated drop of more than 50% in trips. This could be attributed to a large concentration of jobs that have high telework potential in the university and downtown core CTs. On the other hand, CTs covering more rural areas of the CMA experienced less change in transit trips as public transit was not a main mode of transportation in those areas even prior to the pandemic.

Figure 4.15 Estimated Percentage Change in Daily Commuting Transit Trips at the Peak of the Pandemic in Kitchener-Cambridge-Waterloo CMA

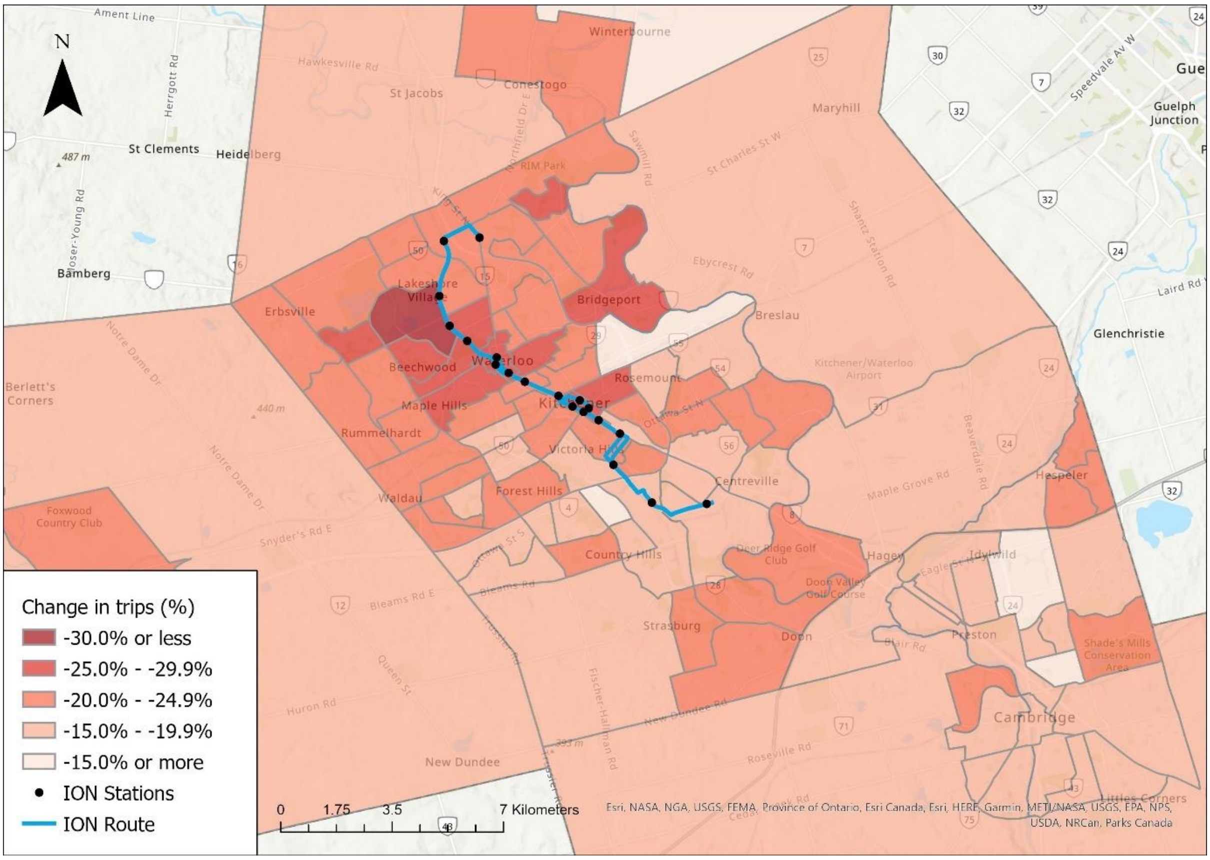


Note. Based on 2016 Canadian Census commuting data.

Second Scenario: The "New Normal"

In the second scenario, it is estimated that the total number of commuting trips using public transit in the Kitchener – Cambridge – Waterloo census metropolitan area (CMA) increased from the peak of the pandemic's 16,837 trips to 23,222 trips (based on the first scenario). However, this is still a 21% drop from 2016 public transit commuting trips. The university district CT in Waterloo experienced the largest drop even in the "new normal" scenario with a drop exceeding 30%. It can also be observed that within the municipalities in the CMA, the city of Waterloo's CTs are estimated to experience a larger percentage of trip decreases, possibly due to the city's employment structure that allows for a higher proportion of remote work.

Figure 4.16 Estimated Percentage Change in Daily Commuting Transit Trips during the New Normal in Kitchener-Cambridge-Waterloo CMA



Note. Based on 2016 Canadian Census commuting data.

4.4.3 Calgary

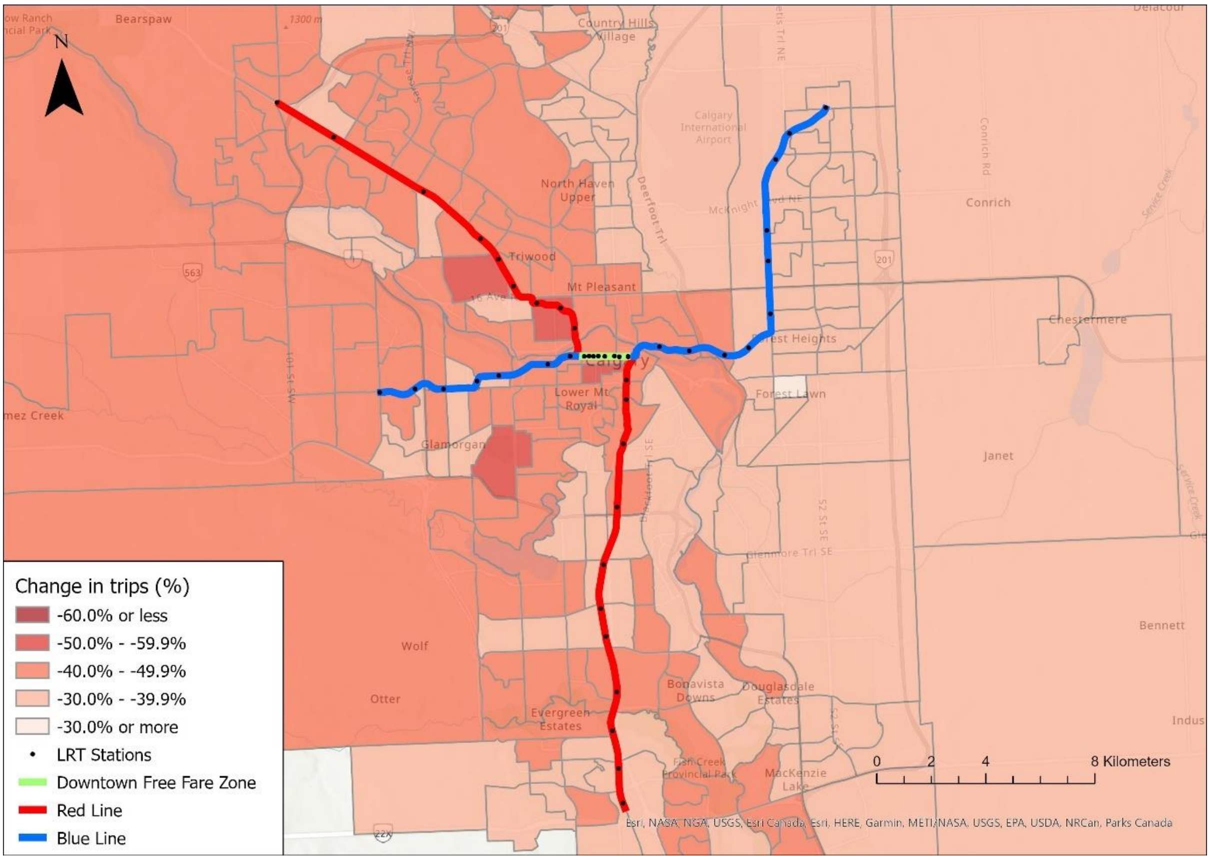
Figure 4.17 Percentage of commuters using public transit in Calgary CMA based on 2016 census data

14.9% of commuters used public transit as the main mode of transportation in Calgary census metropolitan area (CMA) to work according to the 2016 census. Generally, rural CTs further away from the downtown core had a lower percentage of commuters using public transit, while CTs close to the LRT systems had a higher percentage of the population using public transit at around 10 – 20%. Downtown Calgary's CT had the highest percentage of commuters in the CMA using public transit at 40%. Southeast Calgary had a lower percentage of commuters using public transit in Calgary CMA, possibly due to a lack of an LRT line currently (the approved Green Line LRT is expected to start operations in 2027).

First Scenario: Peak of pandemic

In Calgary CMA, it is estimated that the total number of daily public transit commuting trips declined by 41% (based on 2016 data), from 188,990 trips to 111,362 trips during the peak of the pandemic. In general, the west side of the CMA had larger decreases in trips compared to the east side. Census tracts in downtown Calgary and tertiary education institutions such as the University of Calgary and Southern Alberta Institute of Technology (SAIT) experienced the highest decreases of over 50%. On the contrary, industrial area CTs located in Southern Calgary along the red line is estimated to experience a slightly lower decrease in trips, possibly due to the larger proportion of workplaces that are deemed as "essential" and have lower telework capacity.

Figure 4.18 Estimated Percentage Change in Daily Commuting Transit Trips at the Peak of the Pandemic in Calgary CMA

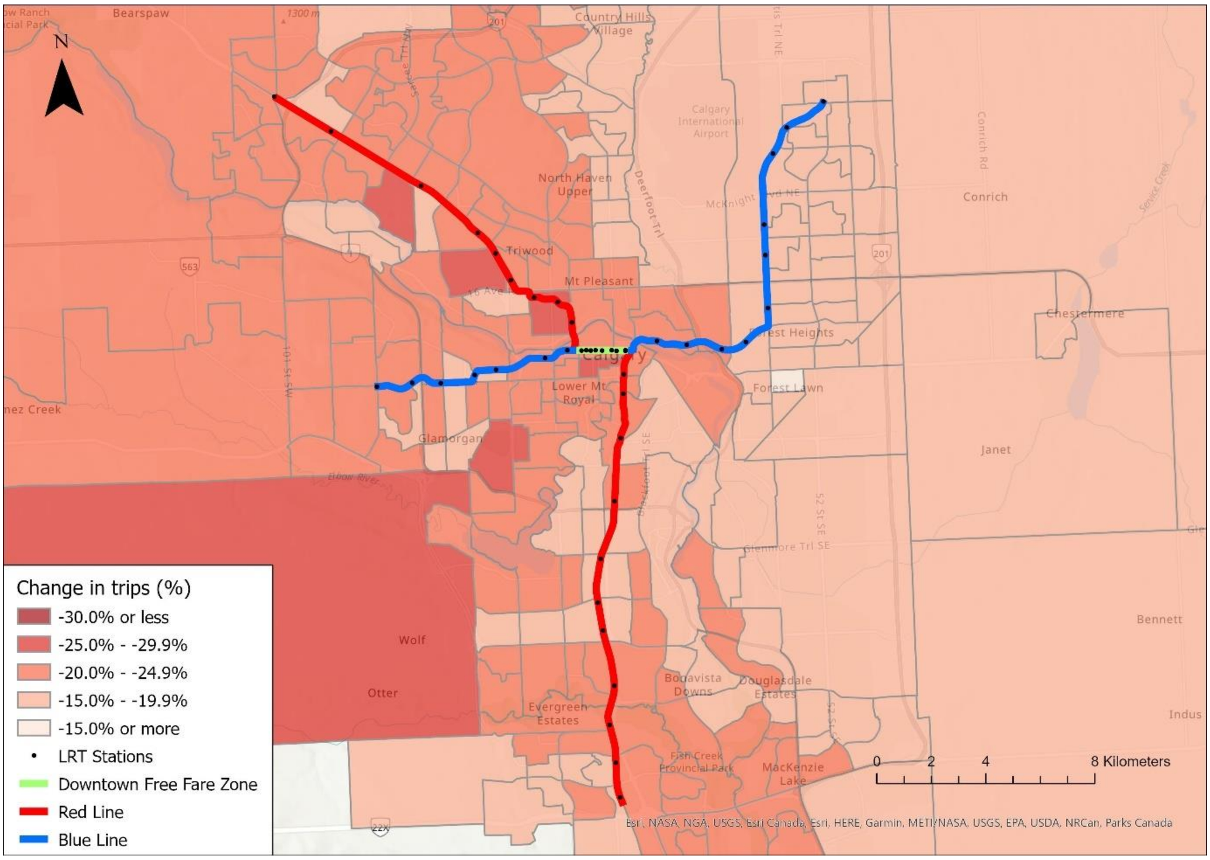


Note. Based on 2016 Canadian Census commuting data.

Second Scenario: The "New Normal"

In the Second Scenario, it is estimated that the number of public transit trips will increase from the peak of the pandemic to around 150,000 trips per day. However, this still represents a 20% drop (based on 2016 data). The east side of Calgary shows a lower change in trips compared to the Western part, even in CTs along the blue line which had similar public transit usage among commuters as shown in Figure 4.12.

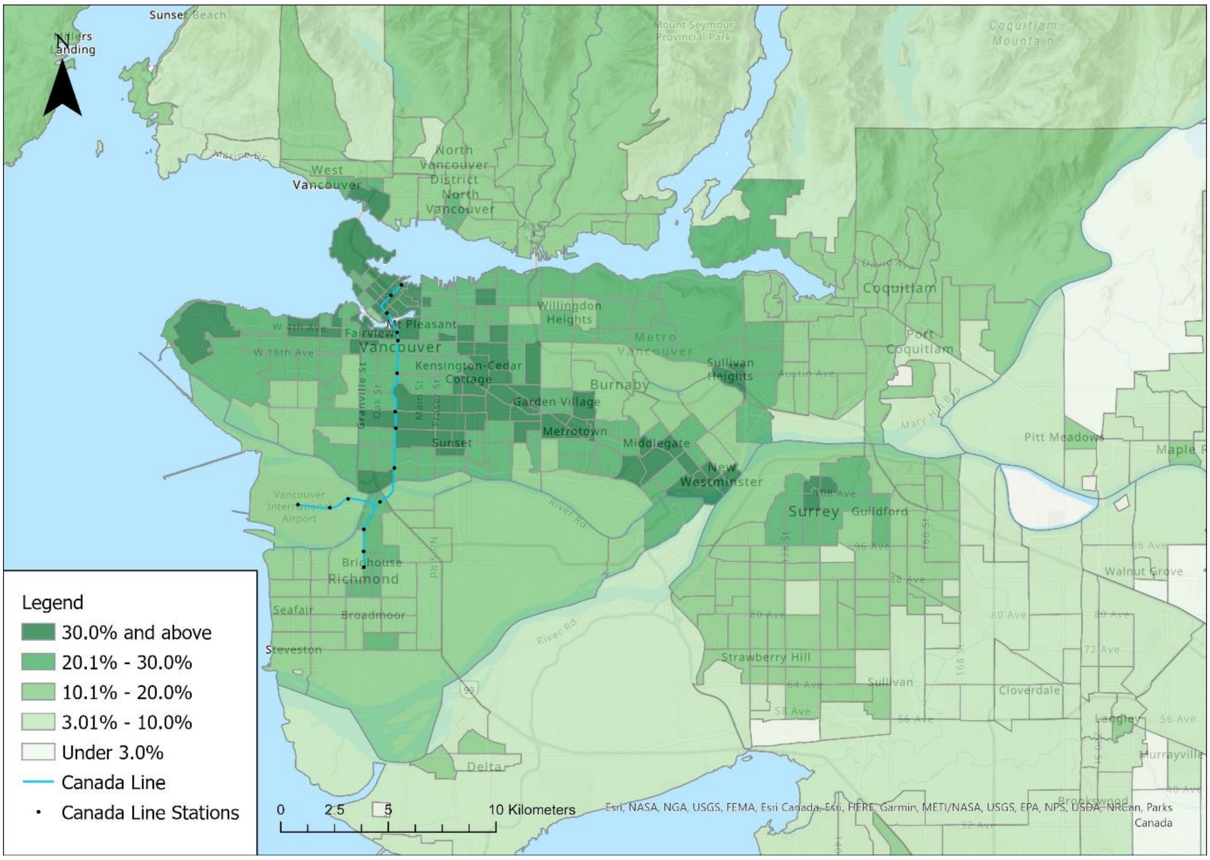
Figure 4.19 Estimated Percentage Change in Daily Commuting Transit Trips during the New Normal in Calgary CMA



Note. Based on 2016 Canadian Census commuting data.

4.4.4 Vancouver

Figure 4.20 Percentage of commuters using public transit in Vancouver CMA based on 2016 census data

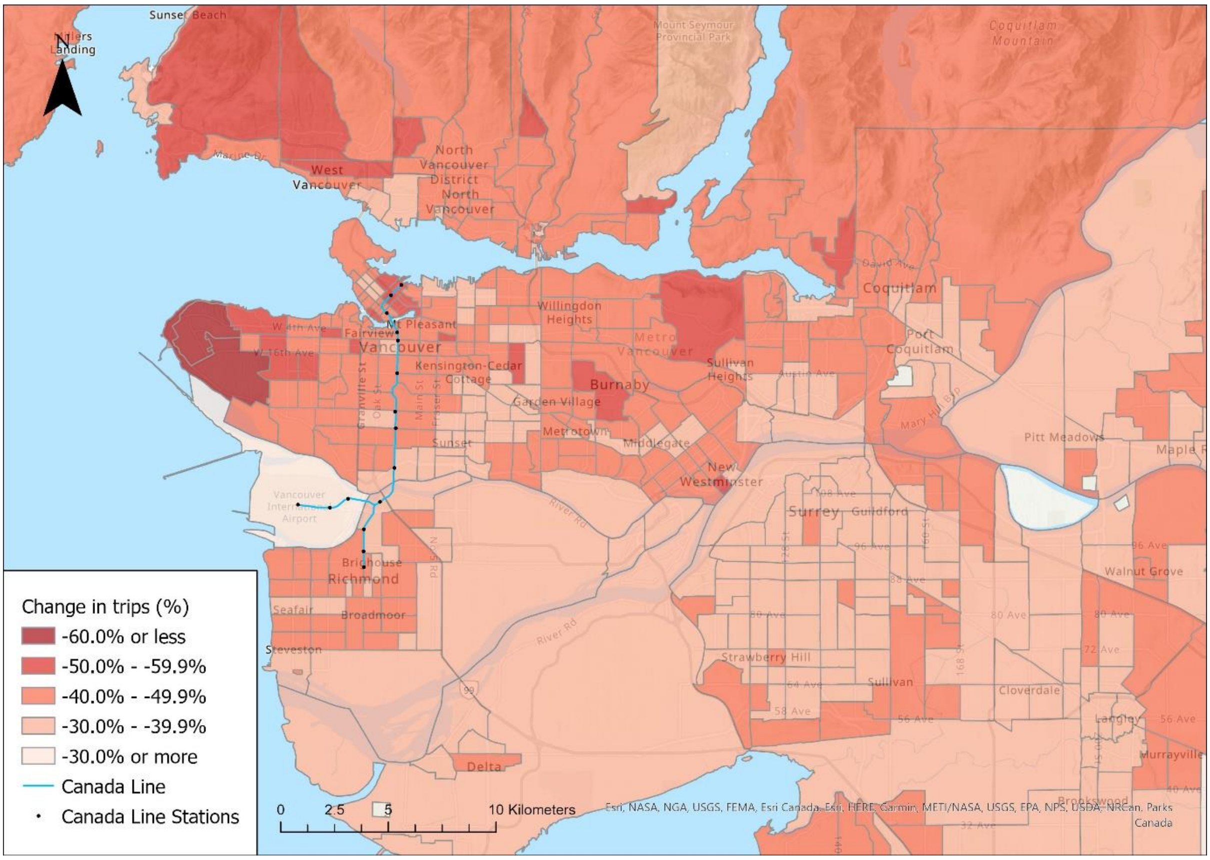


Vancouver CMA had the highest percentage of commuters using public transit as their main mode of commute among the four case study cities with 20.9% of commuters using public transit as the main mode of transportation in the 2016 census. A large number of CTs close to downtown Vancouver and along the Skytrain rapid transit line such as Metrotown in Burnaby and New Westminster had over 30% of commuters using public transit as the main mode. On the other hand, the CTs along Canada Line had moderate public transit usage for commuters, especially in the City of Richmond which is more suburban compared to the City of Vancouver.

First Scenario: Peak of pandemic

In Vancouver CMA, it is estimated that the total number of daily public transit commuting trips fell 41%, from 452,000 to 256,000 (based on 2016 data). The trend of a 40% to 50% drop in commuter trips was widespread in the CTs closer to downtown Vancouver. The largest decreases in commuting trips (over 60%) are estimated to be in the University Lands area CTs which is home to the University of British Columbia (UBC). On the other hand, the CT which is estimated to experience the lowest decrease is home to Vancouver International Airport.

Figure 4.21 Estimated Percentage Change in Daily Commuting Transit Trips at the Peak of the Pandemic in Vancouver CMA

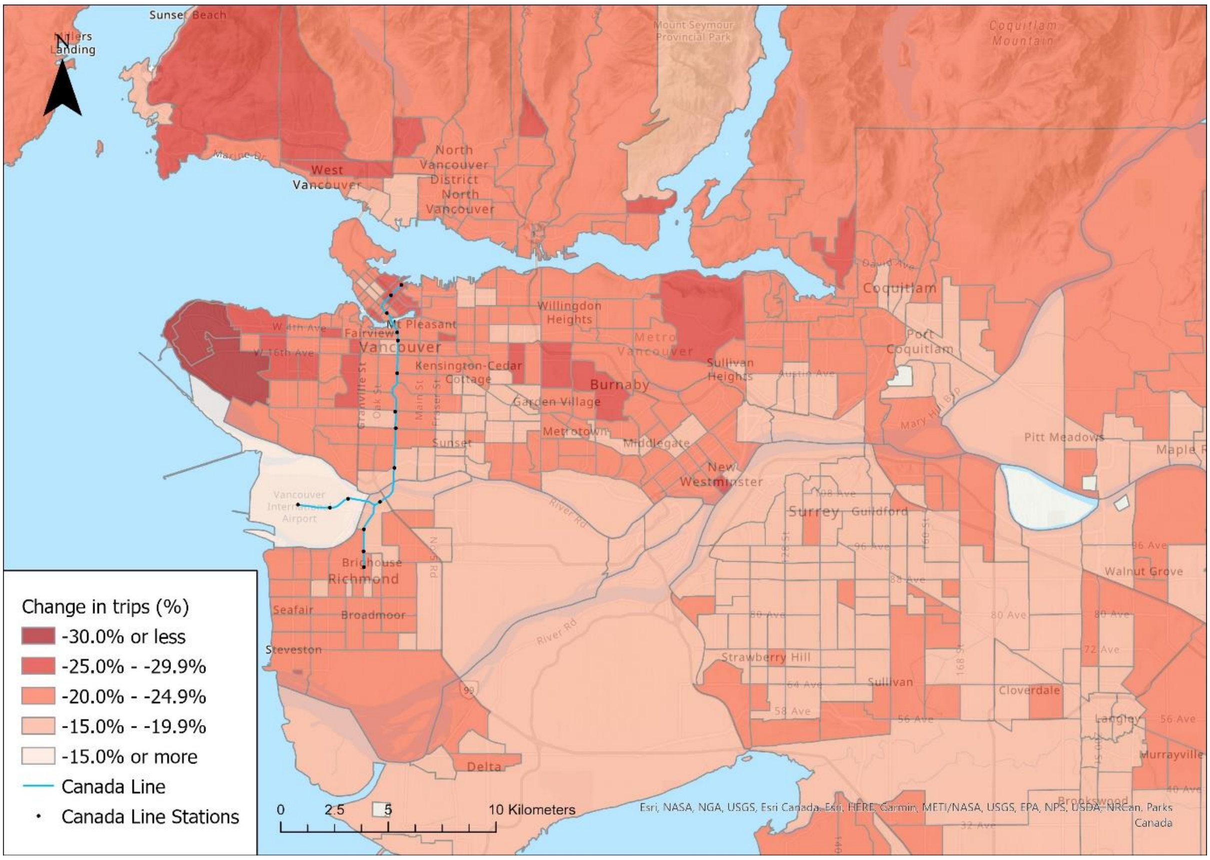


Note. Based on 2016 Canadian Census commuting data.

Second Scenario: The "New Normal"

In the "New Normal" scenario, the total number of commuters using public transit as their main mode of commute in Vancouver CMA is projected to rise back to 354,000 daily trips from the pandemic lows of 256,000. CTs along the Canada line is generally estimated to experience a drop in commuter trips of around 20% (based on 2016 data). The several CTs in the CMA that are projected to experience larger declines (over 25%) in commuting trips are mainly home to large tertiary institutions such as UBC, British Columbia Institute of Technology and Simon Fraser University.

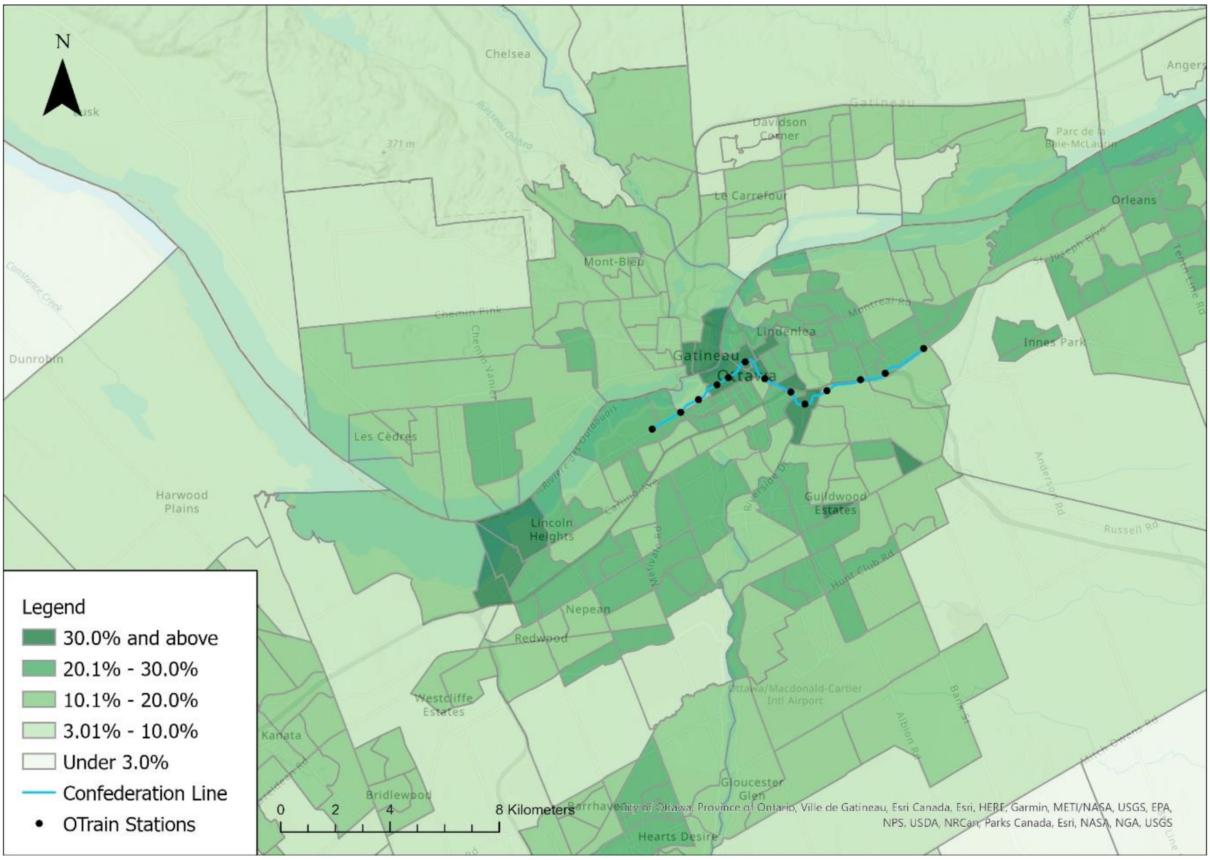
Figure 4.22 Estimated Percentage Change in Daily Commuting Transit Trips during the New Normal in Vancouver CMA



Note. Based on 2016 Canadian Census commuting data.

4.4.5 Ottawa

Figure 4.23 Percentage of commuters using public transit in Ottawa-Gatineau CMA based on 2016 census data



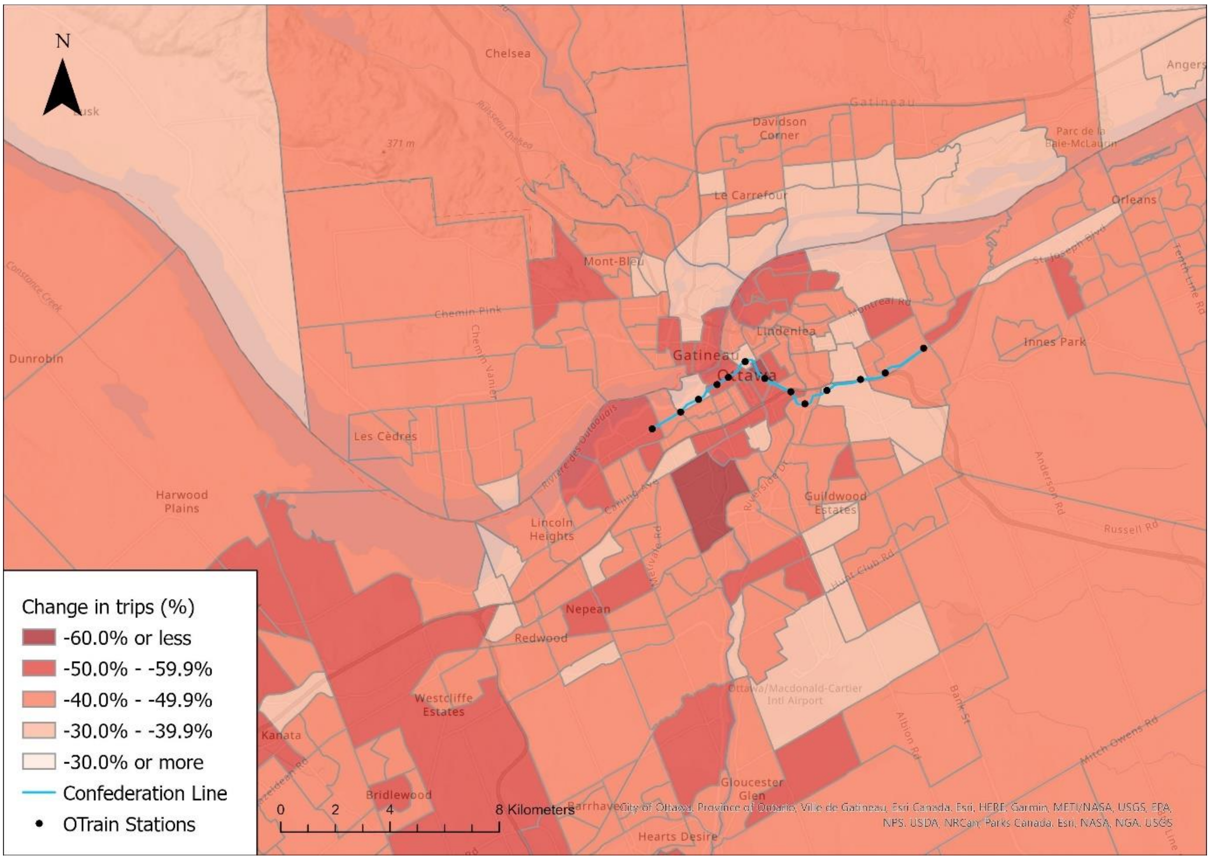
18.6% of commuters in Ottawa-Gatineau CMA used public transit as the main mode of commute in the 2016 Census. Like other case study CMAs, CTs closer to the downtown core tend to have a higher share of public transit commuters whereas increasingly rural CTs had a lower percentage of commuters using public transit. A large number of CTs in Ottawa recorded a public transit usage of over 10%, possibly attributed to the extensive bus transitway networks in the city.

First Scenario: Peak of pandemic

In the first scenario, it is estimated that the total number of daily public transit commuting trips in Ottawa-Gatineau CMA decreased 47% from 227,000 to 120,000 (based on 2016 data), which is the largest percentage drop among the four case study CMAs. The large decrease in trips reflects that the CMA has a higher proportion of jobs that have a higher telework ability compared to other case studies. In general, the drop in trips is widespread and are not limited to the downtown area. The two CTs with the highest drops in trips (over

60%) are home to the two universities in the city, University of Ottawa and Carleton University. On the other hand, the indusial park area in Eastern Ottawa showed a lower change in trips.

Figure 4.24 Estimated Percentage Change in Daily Commuting Transit Trips at the Peak of the Pandemic in Ottawa-Gatineau CMA

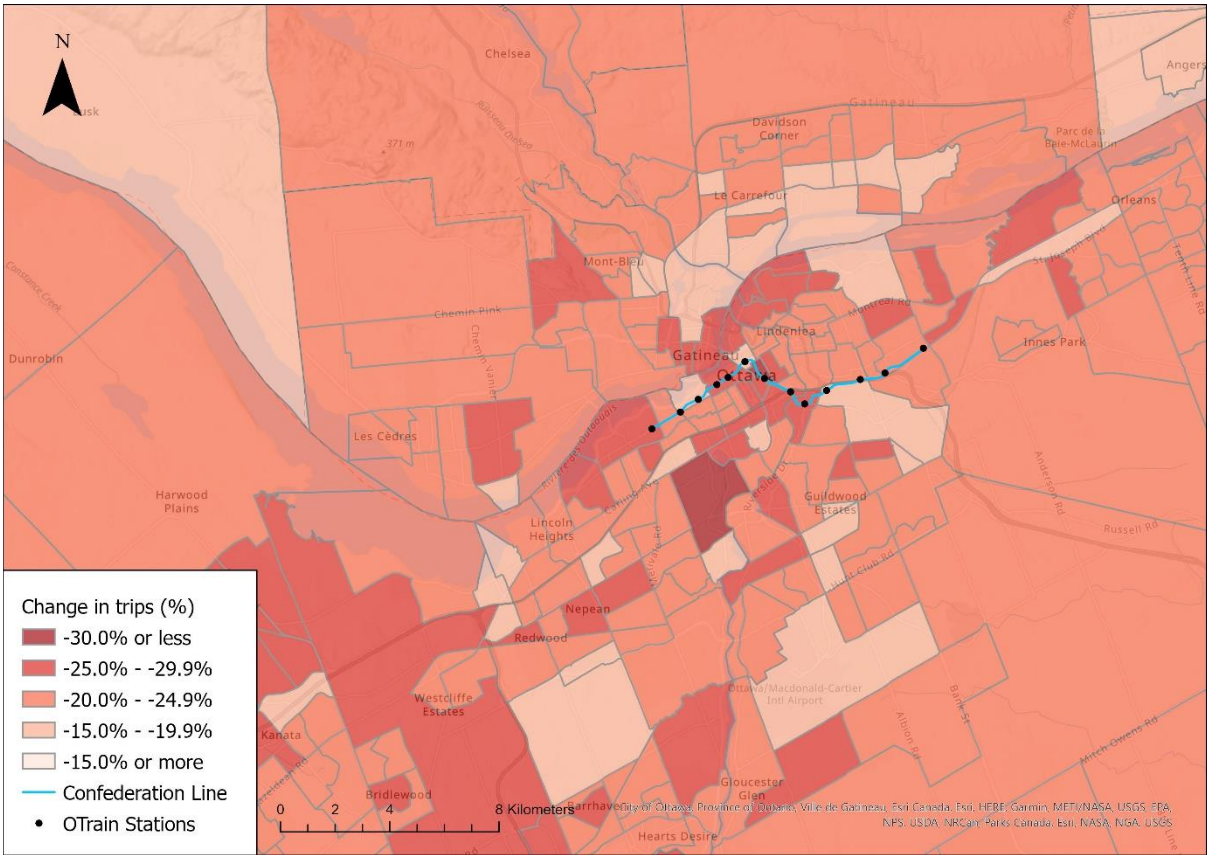


Note. Based on 2016 Canadian Census commuting data.

Second Scenario: The "New Normal"

In the "New Normal" scenario, the total number of commuters using public transit as their main mode of commute in Ottawa-Gatineau CMA is projected to rise to 174,000 daily trips from the pandemic lows of 120,000. While many CTs in the CMA saw a drop in commuting transit trips by 25% or above, Several CTs on the Northern shore of the Ottawa river in Gatineau saw a relatively modest decrease in trips.

Figure 4.25 Estimated Percentage Change in Daily Commuting Transit Trips during the New Normal in Ottawa-Gatineau CMA



Note. Based on 2016 Canadian Census commuting data.

4.5 The impact of the COVID-19 pandemic on the achievement of policy goals & objectives of the LRT systems

Various prior studies have investigated the goals for the construction of LRT systems, and a consensus on several common goals and objectives were identified in the literature review. While Section 4.3.1 demonstrates that the four case study LRT systems have generally met their original goals and objectives, literature showed that the ongoing COVID-19 pandemic has had a significant impact on public transit systems. Section 4.4 explores the impact of the pandemic on short-term (peak of pandemic) and long-term (post-pandemic / "new normal") commuting activity. Based on this analysis, LRT systems might be in danger of not being able to meet their policy goals and objectives. Therefore, Section 4.5 will investigate, in short-term and long-term, how the pandemic might affect the achievement of policy goals and objectives of the LRT systems.

4.5.1 Transit Specific Goals: Increasing Public Transit Usage, Providing alternative transportation options

Short Term

As illustrated in Section 4.4, though changes in public transit ridership for commuting varies across neighbourhoods in the four case study cities, all cities have been facing significant decreases in public transit ridership due to lockdown measures and work from home policies amid the COVID-19 pandemic. This has directly impacted the LRT systems' goal to increase public transit usage. Waterloo's Grand River Transit (GRT) experienced a monthly ridership reduction by 66% in April 2020 compared to April 2019. While the drop in ridership slightly improved in Summer 2020, second wave lockdowns led to a 68% Year-Over-Year drop in ridership in February 2021. GRT projects transit ridership in 2021 will be 55% of 2019 ridership (Region of Waterloo, 2021). Routes serving universities / college locations have seen the largest decrease in boardings compared to pre-COVID levels while routes serving industrial areas have seen less COVID-19 impact. Service adjustments have been made in the 2021 GRT Service Plan to reduce service frequencies, especially peak trips and late-night trips for routes serving universities. Calgary Transit faced significant ridership drops since March 2020 due to the COVID-19 pandemic. In 2020, total ridership was approximately 52 million compared to 106.4 million in 2019, a 51% year-over-year decrease (Pike, 2021). During the peak of the pandemic in April 2020, ridership dropped by 90% compared to 2019 levels. Calgary Transit reduced service levels by approximately 30 percent by temporarily removing routes and service frequency reductions (Calgary Transit, 2020).

Vancouver's Translink experienced a 60% decline in ridership compared to pre-COVID levels from March 2020 till November 2020 (Chan, 2020c). To adjust to the significant decline in ridership, Translink reduced service levels and deferred planned service expansions (Translink, 2020b). OC Transpo, the City of Ottawa's Transit Operator, witnessed a 58% ridership decline in 2020 compared to 2019 (City of Ottawa Transportation Services Department, 2021a). Multiple service adjustments have been made since March 2020, including service reduction measures such as temporary suspension of certain peak-period routes, frequency reductions and shortening routes, especially for routes primarily from suburban areas to downtown. On the other hand, service improvements are provided for routes that have seen relatively small ridership compared to pre-pandemic levels, main routes that serve hospitals, shopping districts and some employment locations (City of Ottawa Transportation Services Department, 2021b).

During the pandemic, some consumers have avoided using public transit and shared mobility services due to perceived health and safety concerns and have indicated that they will use private cars more frequently despite little evidence that mass transit poses a risk of COVID-19 outbreaks (Joselow, 2020). Capgemini Research Institute (2020) found that nearly 70% of respondents agree that the reasons to buy a car are due to greater control of hygiene in a self-owned vehicle and a reduced chance of infection compared to public transport, ride-hailing or carpooling. These views on public transit and the shift towards private cars are contrary to LRT goal of providing alternate transportation options and increasing public transit usage.

The equity aspect has been brought up from the service changes associated with the COVID-19 pandemic. As mentioned in Section 2.7, a study by DeWeese et al. (2020) illustrates that different cities in North America had a wide range of service outcomes as some transit agencies adjusted their services based on vertical equity (less service reductions in lower income areas) while others focused on horizontal equity (adjusting service equally across all income groups). Liu et al. (2020) also reveal that communities with higher proportions of essential workers and ethnic minorities maintain higher public transit demand levels during the pandemic. Some cities such as Ottawa also specified some criteria to select service cuts, which includes avoiding cuts that would have a disproportionate impact on vulnerable parts of the population which are “captive” and not “choice” transit riders (The City of Ottawa, 2021). For people with disabilities, the reduction of paratransit services during the pandemic is also exacerbating difficulties accessing transportation and services (Cochran, 2020).

Some cities such as Edmonton are taking steps to try increasing ridership post pandemic (Riebe, 2021). Safety measures such as mandatory mask wearing, robust cleaning and other practices have been implemented, and the bus network resign was launched in April 2021 as an effort to modernize the transit system, providing more direct and frequent express bus services as week as on demand bus services (City of Edmonton, 2021).

Mid to Long Term

The mid to long term impacts of the COVID-19 pandemic on transit-specific goals in post-pandemic times are still uncertain. As mentioned in Section 2.7, transportation behaviour returned to pre-pandemic levels within few months in some Asian cities during past pandemics such as SARS and MERS. However, the past pandemics were shorter and had a less significant impact (Casello et al., 2020). The unprecedented prevalence of working from home during the pandemic might become more permanent, especially in some sectors such as technology, finance and media where some companies such as Twitter and Shopify have announced switching to remote work permanently (Stoller, 2021). As pandemic restrictions ease in different provinces of Canada, the extent of remote work that becomes more permanent will affect public transit ridership of commuters in the longer term.

A survey conducted by Durham Region (2020) showed that mode choice during the pandemic impacted different modal types, with transit seeing the largest decrease in the number of transit trips. In comparison, active transportation modes such as walking and cycling experienced fewer declines in mode share as some respondents reported they started using these modes during the pandemic. IEA (2020) suggests that a major determinant of whether active transport modes' popularity will persist depends on the relative cost of different transport options as the shifts to active transport modes during the pandemic are out of necessity from social distancing measures and more attractive cycling environments such as empty streets and better roadside air quality, and better active transportation infrastructure could lead to longer term modal shift in the post-pandemic world. In Wuhan, China, where the COVID-19 pandemic first emerged, bike sharing services soared in popularity after the city lifted its lockdown and travel restrictions (Zhao, 2020).

4.5.2 Urban Development Goal: Accommodating & redistributing future growth

The lockdown measures and stay at home orders have forced many companies to switch to remote work during the COVID-19 pandemic. In addition, multiple studies have indicated that work from home policies will continue after the COVID-19 pandemic as identified in Section 2.8.4 and Section 3.5.3, though the extent of remote work is still largely uncertain. As a result, the vacancy rate of offices in Canada rose from around 8% in Q1 2020 to 11.4% in Q1 2021. However, the vacancy rates in different cities vary among the case study cities. Before the pandemic hit (Q1 2020), the vacancy rate for offices in Waterloo, Calgary, Vancouver and Ottawa was 14%, 24%, 3% and 6% respectively. As of Q1 2021, Vancouver still has the lowest vacancy rate of 6.0%, followed by Ottawa with 9.4%, Waterloo's 15.7% and Calgary's 27.8% (Colliers Canada, 2021). It is expected that the new construction of transit-oriented developments in the downtown core in cities with a higher vacancy rate will be slowed down, contrary to the urban development goal of the LRT systems.

Among the case study cities, Calgary's office vacancy rates are the highest, with an underperforming economy compared to the rest of Canada since 2014 (The City of Calgary, 2021). In 2020, Calgary saw its highest unemployment rate since 1983, with an unemployment rate of 11.7%. Calgary's downtown, a key economic hub for the region which saw several large-scale commercial and mixed-use developments completed or under construction since 2010 (refer to the inset map of Figure 4.4), had an unprecedented vacancy rate of 31.2% in Q1 2021 (Colliers Canada, 2021). To tackle the high vacancy rates, the City of Calgary approved a one-time capital grant in early 2021 for its rapid affordable housing pilot which enabled an office to residential conversion in the downtown core for 108 affordable residential units (The City of Calgary, 2021a). The Calgary city council also approved a new Greater Downtown Plan for the longer term which acknowledges that Calgary's downtown "will not go back to the way it was before the pandemic" (The City of Calgary, 2021b; Smith, 2021). The Plan raises several policies and strategies to tackle the problem of office vacancies and excess office capacity in downtown Calgary, including the conversion of commercial, office or hotel buildings to residential or other uses. Initial investments have also been approved for a $450 million investment incentive / grant over 10 years for office to residential conversion, redevelopment, or adaptive use. This investment incentive aims to eliminate six million square feet of downtown office space as is projected to reduce vacancy rates to 14.3% by 2031 (The City of Calgary, 2021c).

On the federal level, the 2021 Budget proposes a $300 million funding for the Rental Construction Financing Initiative which will be allocated to support the conversion of vacant commercial property into housing. The initiative will target the conversion of excess commercial property space into 800 units of market-based rental housing as demand for retail and office space has changed due to COVID-19 (Department of Finance Canada, 2021). As commercial properties, especially those in urban cores have a lowered demand and an uncertain future, the goal of redistributing growth of commercial activities from the suburbs to the LRT corridor might be hindered.

4.5.3 Urban Development Goal: Urban redevelopment (Indication of redevelopment in inner city / declining neighborhoods)

Another common urban development goal of the case study LRT systems in urban redevelopment as cities try to focus growth on existing built-up areas along LRT corridors that are currently underutilised. Section 4.3 identified some redevelopment projects along the LRT corridors of the four case study cities. Two urban redevelopment trends were identified amid the ongoing pandemic.

Co-living spaces was a rapidly growing type of real estate in North America before the pandemic, expanding from less than 100 beds in 2014 to more than 7,000 in 2019. However, the pandemic led to a negative impact on the coliving market as shared spaces and amenities such as gyms and resident living rooms were closed (Cushman & Wakefield, 2020). Despite the ongoing pandemic, some developments in Canada have continued, such as Node's co-living project in Kitchener Market station near Downtown Kitchener that is under construction (Node Living, 2021). However, as the pandemic lowered the appeal of shared amenities, regular cleaning by staff and living in a small space close to downtown (Franklin, 2020). It is expected that the expansion of co-living developments will slow down in the short term, which might negatively impact the urban redevelopment goals of LRT systems.

Foot traffic in shopping malls had been declining in Canada even before the COVID-19 pandemic (Deloitte, 2020). During the pandemic, government-mandated lockdown restrictions forced the closure of non-essential businesses and shopping malls across the country. Even after malls could eventually reopen, mall operators are concerned that shoppers have embraced e-commerce compared to traditional brick and mortar stores (Bickis, 2020). With some anchor stores and retail stores in shopping malls choosing to close in the short term and longer-term concerns, the trend of repurposing malls into other types of uses have accelerated. Pisciotta (2020) identifies two main types of mall repurposing – conversion of disused malls into industrial spaces such as warehouses, and redevelopment of malls into mixed-use developments. In the case study cities, the latter seems to be an emerging option for mall owners along LRT lines. Two high rise residential rental buildings providing over 400 units have been built in Ottawa's Gloucester Centre, a suburban mall adjacent to Blair LRT Station (McLean, 2020). Along Vancouver's Canada Line, large-scale suburban mall redevelopments such as Landsdowne Centre and Oakridge Centre (refer to section 4.3.4 for details) have been approved to be transformed into complete communities which will be home to retail and office space, residential condominiums, affordable housing, urban parks and community facilities (Lanthier, 2021). If the trend of mall redevelopment continues in the longer term along LRT corridors, the urban redevelopment and intensification goal is likely to be achieved.

4.5.4 Urban Development Goal: Intensification

Urban development has remained robust in Canada as property prices have risen to record highs despite the ongoing pandemic (CBC News, 2021). Canadian housing starts hit a record high in March 2021 with 335,000 units, and much of the growth was contributed by multiple urban starts which grew much faster than single-detached urban starts (Thomson Reuters, 2021). The City of Richmond, which has been home to a large number of new high-rise developments along the Canada Line as mentioned in section 4.3.4, recorded a similar number of development applications in 2020 compared to 2019 which totalled over $1 billion in combined construction approvals and anticipated building permits, with single family homes and multiple-family dwellings exceeding 2019 permit applications (City of Richmond

Economic Development, 2021). These figures show that the COVID-19 pandemic seems to have a limited impact on the achievement of the intensification urban redevelopment goal as there has been ongoing construction of transit-oriented, higher density developments along the LRT corridor.

However, several factors might hinder the achievement of the urban development goal of intensification along LRT corridors. The pandemic has brought a negative impact on the demand for density as the need of living close to the workplace and the value of accessing consumption amenities such as restaurants were lowered amid social distancing measures, and has led to a diminished demand for central locations (Liu and Su, 2020). Even as housing sales fully recovered, the reduced demand for density continued and new listings and inventory in central cities soared compared to the suburbs. CIBC Economics (2021) also pointed out that there has been a notable increase in demand for detached houses compared to high-rise units in Canada. In particular, single family houses in smaller and more remote centres have surged in prices due to the increased ability to work from home and low affordability in large urban centres. The urban development goal of redistributing residents to more central locations with LRT service instead of sprawling suburbs in the urban fringe might be negatively affected if work from home policies is continued post-pandemic, which is in line with the trends introduced in section 2.8.4. Though there will likely be more workers working remotely on a regular basis compared to pre-COVID levels, the extent of work from home trends is uncertain as many employers expect workers to go back into the office to some extent as identified in section 3.5.3. In addition, while housing starts in Canada have seen strong activity in early 2021, it might be hard to keep the ongoing momentum as builders have encountered supply disruptions, shortages of skilled workers and rising material costs amid the pandemic, which might slow down construction activity (Hussain, 2021).

4.5.5 Scenarios For the Future

The mid to long term impact of the COVID-19 pandemic is still uncertain as the pandemic is still evolving in Canada and the World. Several scenarios have been outlined by various studies since the start of the pandemic to envision how transit systems would look like post pandemic (City of Calgary, 2020; Shaheen and Wong, 2021; Emerson, 2020). The scenarios identified in the studies can generally be categorized into “optimistic”, “slow recovery” and “transformational” scenarios. The optimistic scenario projects a fast recovery as the city returns to normal after vaccination efforts and economic growth encourages public transit usage. The slow recovery scenario indicates slow economic recovery and a prolonged pandemic which significantly reduces ridership for the long term, while the “transformational” scenario envisions remote work becoming the norm in the future.

5. Conclusion

This research focuses on evaluating the performance of LRT systems and the potential impact of COVID-19 pandemic on the achievement of the original policy goals and objectives of LRT systems. Using four Canadian LRT systems (Waterloo, Calgary, Vancouver and Ottawa) as case studies, this study addresses two research questions:

1. How have Canadian light rail transit (LRT) systems performed with respect to ridership and land development?

2. How will meeting the original policy goals and objectives of these LRT systems be impacted by the COVID-19 pandemic?

Section 5.1 summarizes the main findings of the study based on the four research objectives. Section 5.2 outlines the limitations of the research. Section 5.3 discusses the research contribution of this research and recommendations for planning practice. Lastly, Section 5.4 suggests the opportunities for future research.

5.1 Summary of findings

The study first identified the original policy goals and objectives of the four case study systems. Among the three types of goals, transit-related goals were mentioned most frequently. Specifically, transit-related goals such as accommodating forecasted transportation demand due to population growth and managing traffic congestion were the most common goals and were found in all the case study systems while transit-specific goals of providing transportation alternatives, providing efficient transportation, Urban development goals and environmental and social goals were mentioned in three of the four case studies. The second most mentioned types of goals were urban development goals, specifically goals for stimulating smart growth and fostering economic development which were found in three of the four case studies. Environmental and social goals were less mentioned in the case studies, with the exception of the goal of decreasing emissions to improve air quality which was found in three of the four case studies. In general, Waterloo's ION system had the most goals among the case study systems, covering all three types of goals. Calgary's CTrain system only mentioned transit-related goals, without mentioning any urban development, environmental and social goals.

The evaluation of the performance of the case study systems started with physical, operation and ridership key performance indicators. Calgary, which is the oldest LRT system among the case studies, had the most extensive system with a system length of nearly 60 km and was the only system to have more than one route. Calgary, Vancouver and Ottawa's LRT systems had similar line capacities (8,000 – 10,700 passengers per hour per direction) with a frequent peak service headway (3 – 6 minutes) and high average operating speeds. On the contrary, Waterloo's LRT system had a much lower line capacity (1,200 passengers per hour per direction), peak service headway (10 minutes) and operating speed. In terms of ridership, Calgary had the highest average daily ridership and estimated annual LRT trips per capita, while Waterloo's system had a much lower daily ridership than other case study systems.

Several key performance indicators were used to evaluate the case study systems' performance in achieving their original policy goals and objectives. In general, the transit specific goals were met by all systems, except for Ottawa's OTrain system which did not meet the initial forecasted ridership. The achievement of urban development goals varied among the case study systems. Region of Waterloo observed a modest performance for construction activity with the development of several projects in downtown Kitchener and the University District. Urban development near LRT stations in Calgary is focused on downtown with limited development in other neighbourhoods along the LRT corridor. Vancouver's Canada Line had a strong performance overall in terms of the construction of transit-oriented high-rise developments along the LRT corridor and the line attracted a large amount of development in neighbourhoods close to the city centre and the suburbs. Ottawa had a weak performance in developments near downtown but had a modest performance in transit-oriented developments in neighbourhoods along the LRT line.

The study then estimated the impact of the COVID-19 pandemic on potential public transit ridership based on daily commuting trips using public transit as the main mode of commuting reported in the 2016 census. Two scenarios, one representing the peak of the pandemic and another one representing the "new normal" were created. The "peak of the pandemic" scenario showed a large decrease in trips in all four case study CMAs, and it is estimated that the number of daily commuting trips fell by 41 to 47% compared to 2016 levels in the different case studies, reflecting the effect of extensive work from home policies during the government mandated lockdown. The "new normal" scenario showed a rebound in commuting trips as the cities reopened, but as work from home policies are expected to continue in the longer term for some jobs, it is estimated commuting trips still dropped around 20 to 24% compared to 2016 levels. Out of the four case study CMAs, the Ottawa-Gatineau CMA is estimated to experience the largest decreases in commuting trips, possibly due to the higher concentration of jobs that allow telework compared to other CMAs. On the census tract (CT) level, considerable differences in commuting ridership were observed when comparing different CTs. CTs closer to downtown and tertiary education institutions saw larger drops in estimated commuting ridership while CTs in industrial areas tend to have lower decreases.

While the original policy goals and objectives were generally met by all four case study LRT systems, the COVID-19 pandemic led to huge changes in people's daily lives. Therefore, the study investigated how the pandemic would potentially impact the LRT systems' achievement of the original policy goals and objectives. In the short term, the achievement of transit specific goals such as increasing public transit usage and providing transportation options was negatively impacted by the pandemic as lockdown measures led to a huge decrease in public transit ridership across Canadian cities, and concerns of contracting COVID-19 led to fear in riding public transit and prompted riders to drive private vehicles. While the extent of telework in the future is still uncertain now, continued work from home policies would likely lead to fewer commuting trips compared to pre-pandemic levels and negatively impact transit specific goals. Amid high property prices and a booming real estate market, the achievement of urban development goals of intensification and redistributing future growth are uncertain as mixed trends emerged amid the ongoing pandemic. While downtown areas might accommodate some future population growth as municipalities encourage the conversion of commercial spaces into residential uses, work from home and social distancing policies led to higher demand for lower density detached housing in the suburbs and more remote locations compared to high rise condominiums close to the urban core.

5.2 Research limitations

While this study evaluates the performance of LRT systems and examines the potential impact of the COVID-19 pandemic on achieving original policy goals and objectives, several research limitations and research constraints are identified which readers should note before interpreting research findings.

The first research limitation focuses on the data discrepancies for evaluating the case study LRT systems which affects data consistency. Different transportation agencies have varying methods of reporting ridership data which impacts the comparison of ridership information. In addition, the case study cities had variations in providing information for new real estate developments, which potentially affects the accuracy of including new developments. Thus, other data sources such as real estate agencies and street view maps have been used to verify the construction of new developments.

A limitation was also identified regarding the completeness of data of the case study LRT systems. The detailed original plans and documents were obtained relatively easily as they were well documented for systems that were completed recently. On the other hand, some documents were harder to access and less complete for Calgary's LRT system as they are from the late 1960s to early 1970s. This limitation is addressed by the information provided by other data sources on Calgary's system as it is the most examined LRT system among the four systems.

In addition, it is important to note that the commuting data is based on 2016 census data, and commuting data is temporal as demographic changes in the case study systems would affect trip making activities. Cities with a higher proportion of working age population tend to have more commuting trip activities, and as many Canadian cities are experiencing an ageing population, behavioural changes of residents should be considered as they move from young adult to family retirement stages of life in the longer term.

The two scenarios used to estimate the change in daily commuting trips have several constraints. Firstly, the number of transit trips only include commuting transit trips, and other types of trips such as school and discretionary trips are not included in the analysis. Furthermore, the scenarios did not account for the loss of jobs and unemployment during the pandemic. Therefore, some CTs, especially CTs with jobs that are more affected due to the pandemic might experience a greater change in ridership activity as employment activity is reduced due to employment layoffs. In addition, as the number of daily commuting trips on the census tract (CT) level is based on the 2016 census, some CTs experienced some growth or decline in employment in the past few years. Thus, the commuting data might not totally reflect the commuting levels in early 2020, before the onset of the pandemic.

Finally, it is important to note that this study is a high-level analysis of the performance of the case study LRT systems and focuses on whether the systems achieved their goals and objectives, and opportunities for further research would be discussed in Section 5.4.

5.3 Research contribution and recommendations

Several Canadian cities have proposed and implemented light rail transit (LRT) systems and these systems play an important role in supporting strategic growth and improving transit systems. This study provides a comparative evaluation of the selected LRT systems' performance and insight into the achievement of the goals and objectives for the light rail transit systems. Based on the findings of this study, other cities can replicate this study to estimate the potential impacts of longer-term work from home trends on transit ridership.

As the ongoing COVID-19 pandemic brought unprecedented changes to the workplace, this study uses two different scenarios which provides further understanding of spatial patterns of commuting on the census tract level in the short term and in the longer term. The scenarios provide a preliminary snapshot of the implications of work from home on overall transit system design and public transit ridership.

Several recommendations are raised for different stakeholders. For strategic planners, it is recommended that they should revisit their urban development and public transit goals in light of the pandemic which has potentially changed the preferences and lifestyles of citizens. It is recommended that land use planners conduct a more detailed analysis on increasing capacity for family living in the LRT corridor. Transit planners should conduct further analysis on ridership by looking at other trip making activities such as discretionary and educational trips to better understand the ridership changes on the census tract level, and factor in the employment changes on commuting activity during the pandemic. Finally, given the uncertainty of the ongoing pandemic, planning practitioners should continually monitor and evaluate how the pandemic impacts ridership and urban development trends.

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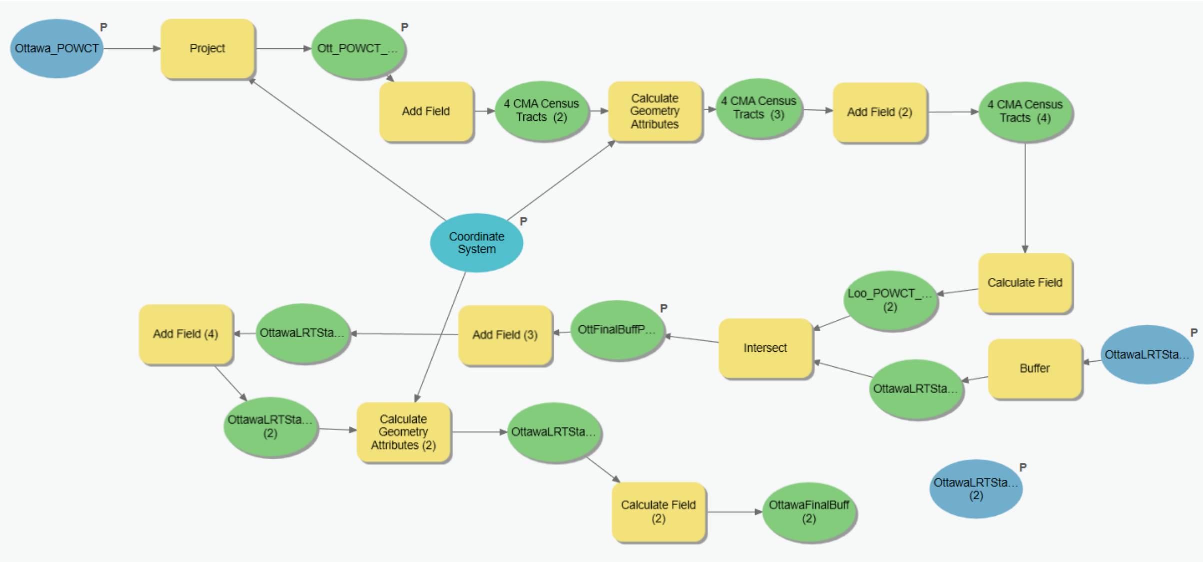
Appendices

Appendix A: Model Builder for finding catchment area information in ArcGIS



Appendix B: Model Builder for finding catchment area information in ArcGIS

NAICS sector (2-digit) code	Variable name for place of work	Variable name for place of residence
11	$(2016TRIP\_W_{11})$	$(2016TRIP\_R_{11})$
21	$(2016TRIP\_W_{21})$	$(2016TRIP\_R_{11})$
22	$(2016TRIP\_W_{22})$	$(2016TRIP\_R_{11})$
23	$(2016TRIP\_W_{23})$	$(2016TRIP\_R_{11})$
31 – 33	$(2016TRIP\_W_{31-33})$	$(2016TRIP\_R_{31-33})$
41	$(2016TRIP\_W_{41})$	$(2016TRIP\_R_{41})$
44 – 45	$(2016TRIP\_W_{44-45})$	$(2016TRIP\_R_{44-45})$
48 – 49	$(2016TRIP\_W_{48-49})$	$(2016TRIP\_R_{48-49})$
51	$(2016TRIP\_W_{51})$	$(2016TRIP\_R_{51})$
52	$(2016TRIP\_W_{52})$	$(2016TRIP\_R_{52})$
53	$(2016TRIP\_W_{53})$	$(2016TRIP\_R_{53})$
54	$(2016TRIP\_W_{54})$	$(2016TRIP\_R_{54})$
55	$(2016TRIP\_W_{55})$	$(2016TRIP\_R_{55})$
56	$(2016TRIP\_W_{56})$	$(2016TRIP\_R_{56})$
61	$(2016TRIP\_W_{61})$	$(2016TRIP\_R_{61})$
62	$(2016TRIP\_W_{62})$	$(2016TRIP\_R_{62})$
71	$(2016TRIP\_W_{71})$	$(2016TRIP\_R_{71})$
72	$(2016TRIP\_W_{72})$	$(2016TRIP\_R_{72})$
81	$(2016TRIP\_W_{81})$	$(2016TRIP\_R_{81})$
91	$(2016TRIP\_W_{91})$	$(2016TRIP\_R_{91})$