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# Evaluating the accessibility benefits of the new BRT system during the COVID-19 pandemic in Winnipeg, Canada

Suraj Shirodkar Singh<sup>1</sup>, Reyhane Javanmard<sup>2</sup>, Jinhyung Lee<sup>3,\*</sup>, Junghwan Kim<sup>4</sup>, Ehab Diab<sup>5</sup>

<sup>1</sup> Department of Computer Science, Western University, Canada

<sup>2</sup> School of Surveying and Geospatial Engineering, University of Tehran, Iran

<sup>3</sup> Department of Geography and Environment, Western University, Canada

<sup>4</sup> Center for Geographic Analysis, Institute for Quantitative Social Science, Harvard University, USA

<sup>5</sup> Department of Geography and Planning, University of Saskatchewan, Canada



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## ABSTRACT

Recently, in Winnipeg, the implementation of new bus rapid transit (BRT) system in the middle of the COVID-19 pandemic has raised many concerns, challenging the rationale behind the untimely release. However, the new BRT service can benefit low-income, socio-economically vulnerable, and transit captive passengers who must travel to essential services and work opportunities during the pandemic. This study evaluates whether the new BRT system has positive impacts on accessibility to such essential services during the pandemic. Isochrones with different time budgets as well as times of a day are generated based on high-resolution public transit network via the General Transit Feed Specification (GTFS) data and used for evaluating accessibility benefits before and after the BRT construction. The new BRT service in Winnipeg demonstrates varying accessibility impacts across different parts of the BRT corridor. Areas near dedicated lane-section show a significant increase, whereas areas near non-dedicated lane sections show a decrease in accessibility. Nevertheless, across the whole BRT corridor, the new BRT service presents an overall increase in accessibility to essential services. This demonstrates the positive accessibility benefits of the new BRT service to residents seeking essential services during the COVID-19 pandemic. A decrease in accessibility along some parts suggests the necessity of using local transit improvement strategies (e.g., dedicated lanes) to improve service speed when planning BRT services within urban areas.

## 1. Introduction

In December 2019, COVID-19 was detected in Wuhan, China, and it has since been one of the most unprecedented challenges in the world (Sohrabi et al., 2020). In Canada, as of March 12, 2020, many provinces have implemented stay-at-home orders or lockdowns to control the spread of the disease. Many schools, universities, and businesses have been closed, and many people were required to work from home. These new policies, along with the fear of infection, have decreased the level and frequency of human mobility in cities, resulting in a decline in public transit demand and its ridership level (Central News Agency, 2020). For example, in Canada, the transit ridership decreased to almost half (-45.6%) in March 2020 and more than 80% in April and May (Statistics Canada, 2021). In Västra Götaland, Sweden, as a second example, the ridership of trains, trams, and buses saw a drop of 60%, 40%, and 30%, respectively in June 2021 compared to the same time in the previous year (pre-COVID-19) (Jenelius and Cebecauer, 2020).

In the face of the general reduction in mobility and ridership level, some public transit providers have halted specific services and have diminished service span and frequencies (Gkiotsalitis and Cats, 2021). In Canada, all of the largest 25 transit agencies immediately reduced the offered service frequency and capacity in March 2020, while implementing other physical and communication measures to reduce the risk of infection (Diaz et al., 2021). Additionally, almost none of the transit agencies implemented supplemental services or provided access to paratransit services between March 2020 and June 2020 (Diaz et al., 2021). In contrast, Winnipeg Transit unveiled a new public transit service just after 12 days from the stay-at-home order and started running to full capacity (CTV News Winnipeg, 2020a). Although it was welcomed with controversial remarks due to its untimely release (Elisha Dacey 2020), this new BRT service can serve to benefit some people who do not have the luxury of working from home, including low-income, socio-economically vulnerable, and transit-captive essential workers (Zimmerman, 2005; Gallagher et al., 2021). Not being able to afford a personal car, essential workers have continued to commute by public transit and have maintained their transit ridership levels despite the potential risk of infection and public health warnings (Liu, Miller and Scheff, 2020; Farber, 2021; Justin George, Kate Rabinowitz, 2021; Kim and Kwan, 2021). Given that low levels of accessi-

\* Corresponding Author

E-mail address: [jinhyung.lee@uwo.ca](mailto:jinhyung.lee@uwo.ca) (J. Lee).

bility can exacerbate the socio-economic and health disadvantages for these groups (Lee and Miller, 2018), it is vital to enhance spatial accessibility, even during a pandemic when the overall ridership declines.

This study aims to investigate the impacts of Winnipeg's new bus rapid transit line (BLUE) on accessibility to essential services during the COVID-19 pandemic. We classify essential services into four categories: 1) health, 2) grocery, 3) finance, and 4) accommodation. The paper examines accessibility to these destinations from centroids of dissemination blocks, which is the smallest geographic unit used by Census Canada<sup>1</sup>, that are located within a 500-meter catchment area of the BLUE rapid transit line. This was done to explore the local impacts of the new BRT service on local residents' accessibility along the BRT corridor. We employ a space-time constrained cumulative measure to calculate accessibility benefits pre- and post-BLUE implementation within different time windows on weekdays. Specifically, we consider morning peak, mid-day off-peak, early evening peak, and late evening off-peak hours as our departure times to account for fluctuations in transit schedules (e.g. frequency and headway). Using this detailed approach will help us not only to assess the effects on different segments along the BRT corridor, but also to understand the benefits of offering dedicated bus lanes at some locations.

The rest of the paper is structured as follows: Section 2 will provide discussions on recent research studying the COVID-19 impacts on mobility and accessibility. The following section will describe Winnipeg's new public transit service Section 4 presents the research methodology and explores the impacts of the new BRT service on accessibility Section 5 provides the results, and finally, Section 6 concludes the paper and discusses the limitations and the future steps.

## 2. Literature review

The COVID-19 pandemic has prompted governments to restrict residents' mobility to mitigate the spread of the virus. The government-imposed restrictions have included the closure of borders, travel bans, lockdowns, and urging people to work and study from home. These governmental interventions as well as people's perceived risk of the disease contributed to behavioural changes in human movement (Warren and Skillman, 2020). Generally, the COVID-19 pandemic has profoundly affected the trip frequency around the world. For example, a study conducted in the United States revealed that the number of out-of-country trips dropped from 28% to 23% and per-person trips fell from 3.7 to 2.7 trips (Lee et al., 2020b). This reduction was also observed in France in both recreational and work-related trips, particularly during peak hours (Pullano et al., 2020). In Canada, since April 2020, there has been a considerable decrease in the number of trips to transit stations, workplaces, and retail and recreational opportunities, while there was a slight increase in the number of trips to essential services such as grocery and pharmacy stores (Google 2021a). The pandemic has also resulted in a dramatic drop in travel distances. For instance, the median of the maximum distance mobility in Hong Kong dropped from 2.3 to about 0.2 kilometers and the average trip distance in the US dropped from around 64 to 30 kilometers (Lee et al., 2020b; Warren and Skillman, 2020). Also, movement restrictions during the pandemic have reduced traffic congestion and therefore resulted in a considerable rise in the spatial extent and average level of personal vehicle speeding relative to the before COVID-19 speeding pattern (Lee, Porr and Miller, 2020; Stiles et al., 2021).

Recent studies have examined the travel mode choice during the pandemic and observed a shift away from public transit (Abdullah et al.,

<sup>1</sup> A dissemination block, for which population and dwelling counts are disseminated, is defined as a region bounded on all sides by roads or boundaries of standard geographic areas (Statistics Canada, 2018).

2020; Bhaduri et al., 2020; Dingil and Esztergár-Kiss, 2021). They indicate that most passenger's preference has shifted from public transport to private vehicle and non-motorized vehicles (Anwari et al., 2021). For example, there has been a significant increase in bike trips and cycling kilometers per day in Switzerland (Molloy et al., 2021). As a result of the overall decline in public transit use, ridership has notably decreased (Ahangari, Chavis and Jeihani, 2020; Jenelius and Cebecauer, 2020; Wilbur et al., 2020). For instance, in New York, there has been an 80% drop in subway and commuter rail ridership, and a 50% drop in bus ridership (Gao et al., 2020). Although the mode preference has shifted to personal cars, public transit has been remained popular in some trips during the pandemic (Anwari et al., 2021). Considering low-income people who are most reliant on public transportation to reach their destination (Liu, Miller, and Scheff, 2020), it is important to enhance the accessibility by public transit during the pandemic (Wilbur et al., 2020).

*Accessibility*, which is a key concept in land use and transportation planning, refers to the ease with which potential opportunities can be reached using a travel mode (Handy and Niemeier, 1997). In contrast, *mobility* refers to the ability to move along (Morris, Dumble and Wigan, 1979). Among different accessibility measures, such as opportunity-based, gravity-based, utility-based, and space-time measures (Geurs & Van Wee, 2004), most studies tend to use the cumulative-opportunity measure, also called isochronic measure, as it is easier to interpret, communicate, and can be applied to different modes of travel (). It evaluates accessibility by counting the opportunities that can be accessed from a specific location within a determined threshold (Boisjoly and El-Geneidy, 2017). Numerous researchers have been studying accessibility within urban areas due to its profound impacts on land values (El-Geneidy and Levinson, 2006), employment rates (Tyndall, 2017), transit use (Owen and Levinson, 2015), and social equity (Allen and Farber, 2020). Recently, a variety of studies have been carried out to assess accessibility in different contexts during the COVID-19 pandemic (Kang et al., 2020; Allen and Farber, 2021; ; Paez and Higgins, 2021; Pereira et al., 2021). For instance, a study conducted in Illinois evaluated the spatial accessibility of COVID-19 healthcare resources to identify areas with a low level of spatial accessibility that requires additional health resources (Kang et al., 2020). Another study evaluated the accessibility to vaccination sites and their variation across the population to promote the equity of access (Paez and Higgins, 2021).

Despite several studies on changes in human mobility and accessibility during the pandemic (de Haas et al., 2020; Wilbur et al., 2020; Anwari et al., 2021; Kim and Kwan, 2021; Matson et al., 2021), little attention has been paid to assessing the accessibility benefits of new public transit infrastructures offered during the pandemic, particularly while focusing on accessibility to different essential services. Additionally, it is hard to find studies that focused on assessing the local benefits experienced by different segments of the corridor over the span of the day. To fill these gaps, this study considers the City of Winnipeg as a case analysis to better understand how a new public transit service can benefit individuals' accessibility to specific essential services during the COVID-19 pandemic.

## 3. New public transit service in Winnipeg: BLUE BRT and Southwest Transitway

Winnipeg Transit has proposed the concept of Transitway since the 1970s to connect downtown with Southwest Winnipeg (Winnipeg Transit, 2021b). In April 2012, the Southwest Transitway Stage 1 was commissioned to complete the dedicated roadway. However, there were two main drawbacks to this service, which led to significant changes in travel time. Firstly, due to the population growth and increased ridership, passengers often experienced pass-ups, which refers to when the arrived bus is full and passengers must wait for the next bus (Kavanagh, 2019).

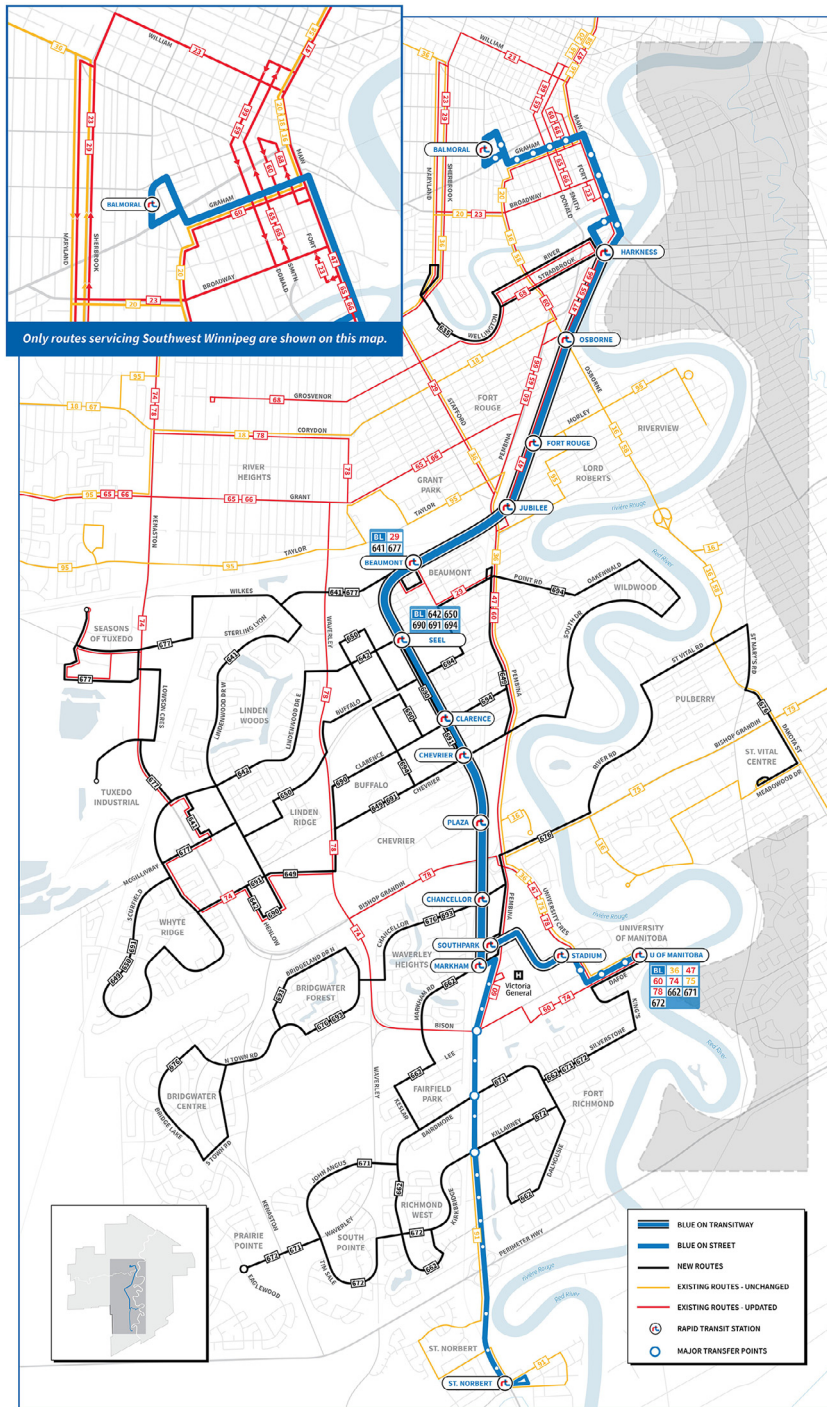


Fig. 1. The map of the new spine route (BLUE BRT) + feeder routes (black routes) network and Southwest Transitway (a bold blue line) (Winnipeg Transit, 2021a).

Secondly, it suffered from poor on-time performance as it could not meet coordinated schedules because of the traffic congestion.

To meet challenges associated with the bus routes in Southwest Winnipeg, Winnipeg Transit adopted a new plan for the Southwest Transitway Stage 2 in March 2016 and proposed a new spine and feeder service model to the public in April 2019 (see Fig. 1). The neighbourhood feeder routes in this network were planned to connect passengers from local neighbourhoods to the Southwest Transitway stations where they can transfer to the spine route, named BLUE rapid transit line.

Finally, the new Southwest Transitway including the BLUE BRT was launched in April 2020 during the COVID-19 pandemic. It started to operate under a full schedule despite the closure of the University of Manitoba and other non-essential businesses, and a 70 percent reduction in the number of passengers (Kavanagh, 2020). Consequently, the

untimely release and the financial burden of this new service have led to controversial remarks among Winnipeggers (Winnipeg Transit, 2021a).

This new Southwest Transitway, including the BLUE rapid transit line, is a high-speed dedicated roadway for buses traveling between Downtown, the University of Manitoba, and St. Norbert, but without a transit signal priority system (see Fig. 1) (Winnipeg Transit, 2021b). It addresses the shortcomings of the previous transit service and enhances the overall performance of the transportation network by offering an efficient, fast, and frequent transit service. By construction of this network, some new transit routes have begun service, while some corridors have been replaced or have ceased operation. In addition to these changes to the transit routes, enhancing on-time performance, maintaining headway spacing, increasing staff establishment, operation frequency, and the number of articulated buses and stations could have contributed to

**Table 1**  
Selected essential services.

Health	Grocery	Finance	Accommodation
Health and Personal Care Stores (Eye Care, Drug Stores, pharmacies, etc.)	Grocery Stores (Supermarkets, Markets, Convenience Stores, etc.)	Depository Credit Intermediation (BMO, TD, Scotia Bank, RBC, etc.)	Hotel and Motels
Offices of other Health Practitioners (Chiropractor, Physiotherapy, Massage, etc.)	General Merchandise Stores, including Warehouse Clubs and Supercenters (Dollarama, Walmart, Costco, etc.)	Accounting, Tax Preparation, Bookkeeping, and Payroll Services (H&R Block, Liberty Tax Service, etc.)	
Other Ambulatory Health Care Services (Hearing, Therapy, etc.)	Grocery and Related Product Merchant Wholesalers (Tea Stores)	Non-Depository Credit Intermediation (Money Mart, Pawnshops, Cash Money Services, etc.)	
General Medical and Surgical Hospitals (Hospitals)	Specialty Food Stores (Meat Shops, Frozen Foods, Delis, etc.)	Agencies, Brokerages, and other Insurance Related Activities (Allstate, Co-operators, etc.)	
Offices of Dentists (Dentists, Orthodontists, etc.)			
Offices of Physicians (Medical Clinics, and Health Services)			
Specialty (except Psychiatric and Substance Abuse) Hospitals (Gynecology, Lab Services, etc.)			

the accessibility improvements (Winnipeg Transit, 2021b). Accordingly, to evaluate these radical changes in the Southwest Transitway network and take into account the concerns in the local community, it is vital to assess the impact of the new BRT service on residents' accessibility during the pandemic and over the span of the day.

## 4. Method

### 4.1. Data

#### 4.1.1. Transportation

To create a multimodal transport network dataset, we integrate the walking (e.g., sidewalk) network with the public transit network. We obtain street network data from OpenStreetMap (OSM), a collaborative street map database around the globe, to build the walking network (OpenStreetMap 2021). As per the public transit network, we utilize General Transit Feed Specification (GTFS) data which is typically used for estimating the travel time by transit from one point to many other points (Farber et al., 2014). The GTFS is a common data format for public transit data that contains information about public transit schedules, fares, routes, stops, and associated geographic information (e.g., locations of stops and shapes of routes) ((Google 2021b). We collect Winnipeg Transit GTFS feeds for before and after the new BRT periods directly from an open-source GTFS collection website: OpenMobility-Data (OpenMobilityData 2021). To investigate the accessibility changes and conduct a fair evaluation on accessibility benefits of the new BRT, we select April 20, 2020, as a date after the BLUE BRT implementation when it was operating on a full schedule without any service reduction (CTV News Winnipeg, 2020b). Correspondingly, we choose April 22, 2019, as a date before the BLUE BRT implementation.

#### 4.1.2. Essential services

Essential services refer to critical infrastructure services that must stay open during a disaster or an emergency as they ensure human health, welfare, and economic wellbeing (Government of Canada 2021a). For instance, grocery and convenience stores are among the essential services since food availability has a substantial effect on community health (Kar et al., 2021). To specify essential services which can be open during the lockdown, the Winnipeg government listed essential businesses, including accommodations, transportation, retail and wholesale, research, and finance (Gerbrandt, 2020). Accordingly, in this study, we consider four types of essential services: 1) financial, 2) health-care, 3) grocery, and 4) accommodation and obtain their location data from the SafeGraph (SafeGraph, 2021), which is a dataset containing 6 million points of interest across the US and Canada (Ossola, 2020). A detailed description of the selected essential services is presented in Table 1 Fig. 2. presents the geographic distributions of these essential services in Winnipeg.

### 4.2. Creating multimodal transit network and generating isochrones

This study aims to gauge the accessibility by deploying the space-time constrained cumulative measure within the travel time isochrones. To this end, we employ OpenTripPlanner (OTP) and *otpr* R package (Young, 2020) for generating isochrone polygons which indicate locations that can be accessed from a specific origin (e.g., home, centroids of dissemination blocks) within a predetermined travel time (e.g., 30 minutes, 1 hour) or less and measuring accessibility (O'Sullivan et al., 2000a). OTP is a free open-source trip planner that analyzes the transportation network and helps passengers to plan a trip with multiple modes of transportation (OpenTripPlanner 2021). Using the *otpr* R package, we can send queries to the relevant OTP API resource and retrieve useful R objects (RDocumentation, 2019).

Based on the collected multimodal transportation network data highlighted in the previous section, we create and query our own multimodal journey planner using a local OTP server. The first step to generate an isochrone area is building an OTP network graph for streets and transit services and launching the OTP instance on a local machine (Young, 2021). Once an OTP instance has been started, we use the OTP server to delineate an isochrone polygon representing the geographic areas that can be reached from an origin via walking and public transit networks given a specified time budget. Travel times account for first-mile walking time from a trip start point to the public transit station, waiting (initial/transfer) and in-vehicle travel time, and last-mile walking from the stop to the final destination (e.g., essential service location) (Stępnik et al., 2019).

In the public transit industry, a 400-meter buffer around the transit line serves as a common identifier for the service area, which is the area from which most residents can walk to reach the transit. However, generated service areas in several Canadian cities showed that most passengers' walking distance to bus transit services is around 500 meters. For instance, the service area for the city of Saskatoon is 532 meters which represents the 85<sup>th</sup> percentile of walking distance to public transit stops in the city (Bree, Fuller and Diab, 2020). Accordingly, we use the centroids of dissemination blocks located with a 500-meter catchment area of the new BLUE rapid transit corridor for our trip starting points (Government of Canada 2021b). To investigate the impacts of transit lane reservation (i.e., dedicated (separated) lane) on accessibility, we split our trip origins (centroids of the dissemination blocks) into two categories based on their proximity to the dedicated or non-dedicated lane sections of the BLUE BRT corridor and use for the analysis.

Due to the lack of observed travel behaviour data and an ideal cut-off time (Xi, Miller and Saxe, 2018), we consider four different travel time budgets to create isochrone polygons. According to Canada's 2016 Census, the average commuting duration in Winnipeg is 24 minutes (Statistics Canada, 2019). We, therefore, choose 30 minutes as a standard travel time cut-off for measuring local accessibility. We also choose a 60-minute cutoff time since it is a standard time budget for measuring regional-level accessibility (Lee and Miller, 2018). As a part of the sen-

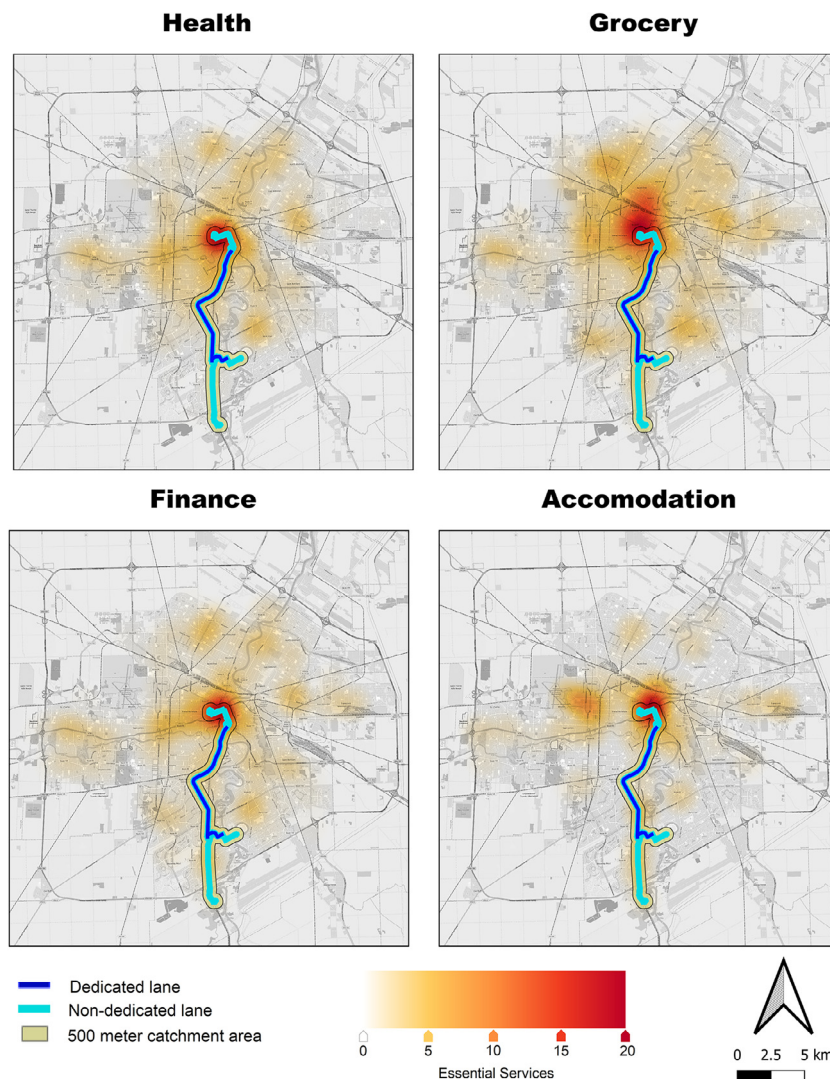


Fig. 2. Geographic distributions of essential services in the city of Winnipeg.

sitivity analysis and to take into account those able or eager to travel to more distant destinations, we select two additional time limits, 45 and 75 minutes.

As our travel time windows, we select morning peak (7 - 9 AM), mid-day off-peak (11 AM - 1 PM), early evening peak (3:30 - 5:30 PM), and late evening off-peak duration (7 - 9 PM) based on Winnipeg Transit's schedules to take into account the variability in the public transit schedules and frequency which can have a profound impact on the total travel time due to the factors such as missed connections and prolonged transfer times (Cooke and Halsey, 1966; Farber et al., 2014; Kim and Lee, 2019; Winnipeg Transit, 2021a). Lastly, to address possible variances in accessibility depending on the trip starting times within a time window, we choose the 15-minute temporal resolution for generating isochrones within a specific time window as it offers a lower computational time with reasonable precision when measuring transit-based accessibility (Stepniak et al., 2019). For example, during the morning peak time (7 - 9 AM), we create a total of nine isochrones based upon different departure times with 15-min intervals, including 7:00, 7:15, 7:30, 7:45, 8:00, 8:15, 8:30, 8:45, 9:00 AM.

#### 4.3. Calculate the cumulative accessibility measure

This study deploys the cumulative accessibility approach (O'Sullivan et al., 2000a; El-Geneidy and Levinson, 2006; Lee and Miller, 2018, 2019; Kim and Lee, 2019) to count the total number of potential opportunities that are accessible from an origin within

a specific time limit. For each trip origin (i.e., dissemination block centroid) and time budget (i.e., 30, 45, 60, 75 minutes), we generate nine isochrones for a given time window (e.g., 7 - 9 AM). We then compute the cumulative accessibility index for each isochrone using the `otp_evaluate_surface()` function in the `otp_r` R package. `otp_r` sums the number of essential services located within an isochrone, producing the cumulative accessibility index for each type of essential service: financial, health, grocery, and accommodation (Young, 2020). The average of the cumulative accessibility across all nine isochrones within a time window is calculated and used as a benchmark when measuring accessibility benefits before and after the BRT introduction.

## 5. Results

### 5.1. Space-time accessibility maps

In this section, we visualize space-time accessibility maps before and after the construction of the BLUE rapid transit line. Due to the space limitation, we select 8 AM and 12 PM as representative peak and non-peak hours respectively. To illustrate the impacts of lane designation (with vs. without dedicated lane) on accessibility, we select two sample starting points within the 500-meter catchment area of the dedicated and non-dedicated lanes Fig. 3. illustrates the space-time accessible areas within different time budgets at 8 AM pre and post the new BRT introduction. As can be seen, although the area of accessible regions became larger for the origin located within the dedicated lane section, the

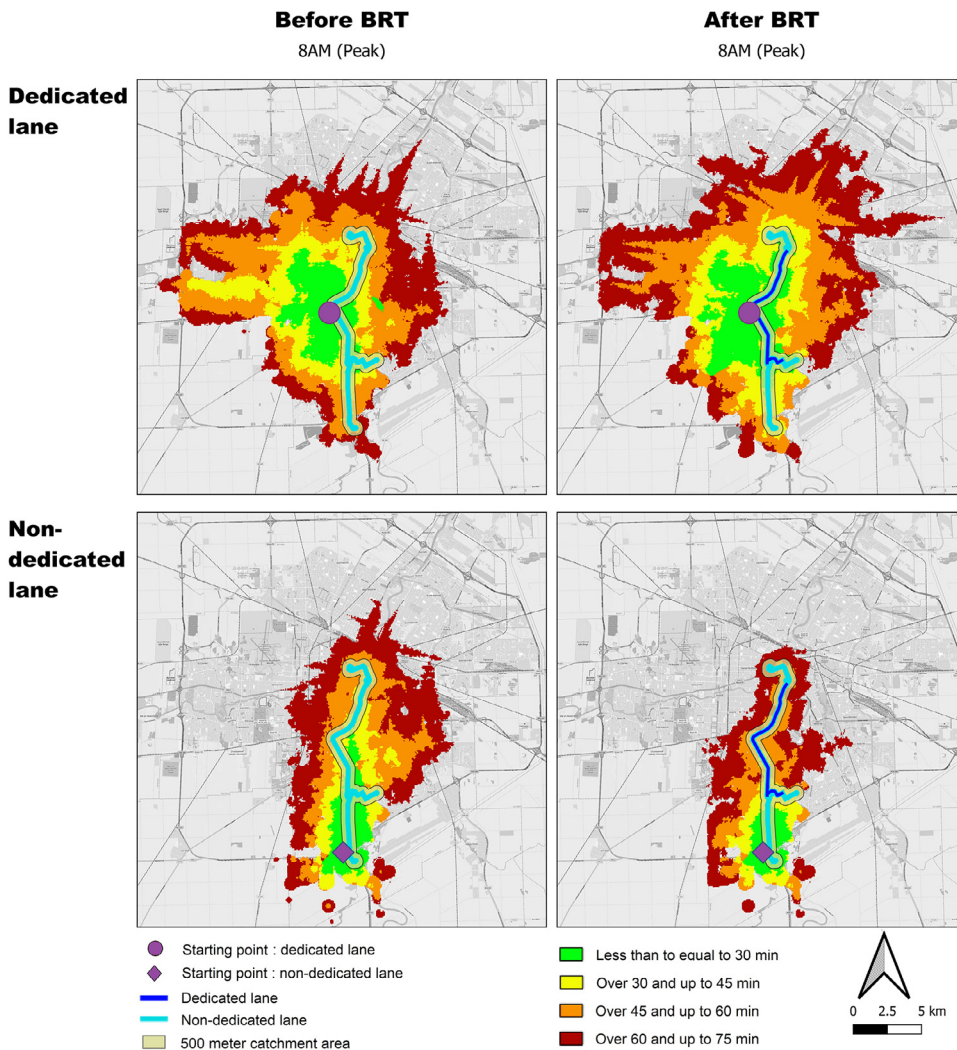


Fig. 3. Space-time accessibility maps at 8 AM (peak time).

counterpart in the non-dedicated lane part presents a smaller accessible area after the BRT construction, especially in Northern Winnipeg. Substantial changes in the transit network, such as the addition, elimination, and relocation of several transit routes and stops, as well as changes in bus schedules, could have contributed to the decline in the area of accessible regions near the non-dedicated lane section.

Fig. 4 shows the isochrone maps at noon, reflecting a similar pattern as the previous Fig. 3. Based on Figures 3 and 4, it is evident that the accessible regions from the starting point located near the dedicated lane section are larger than those in non-dedicated lanes, regardless of both new BRT construction and the time window. The dedicated lane (Southwest Transitway) in the new BRT service provides the greatest enhancement in accessible areas during off-peak hours (12 PM). Meanwhile, the largest accessible area is from the dedicated lane section after the BRT during the morning peak. It can be explained by the higher transit frequency and shorter headways during this peak period as it is a popular time for commuting to work.

### 5.2. Space-time constrained cumulative accessibility to essential services

In this section, we present cumulative accessibility results using bar graphs showing accessibility levels across different parts of the BLUE corridor: 1) entire corridor, 2) dedicated lane section, and 3) non-dedicated lane part Fig. 5. presents the results for the entire corridor, focusing on the 30-minute and 60-minute time budgets. The details on the accessibility percentage changes for all of the essential services within

each time window and every time budget (30, 45, 60, 75 minutes) are provided in Table 2.

As can be seen in Fig. 5, the accessibility to most destinations is higher during morning rush hours (7 - 9 AM), which is in line with the previous section. Additionally, regardless of BRT implementation and time budget, the most accessible destinations are health services especially in morning rush hours, whereas the least accessible services are accommodations, especially during early evening rush hours. Such difference could be due to the greater number of health services near the transit line as well as the higher frequency of service during morning rush hours.

A notable finding in Fig. 5 is that in almost all bar charts, we can see a rise in accessibility after the BRT implementation implying the positive impacts of the new BLUE BRT on residents' accessibility. Specifically, the highest increases in accessibility can be seen within the late evening time duration (7 - 9 PM) which can considerably benefit night shift essential workers. In addition, as illustrated in Fig. 5, within 30 minutes time budget, accommodation services see the greatest rise in accessibility, whereas within 60 minutes time budget, grocery services face the most increase.

Despite the overall increase in accessibility after the BRT construction, there have been a marginal drop in local (i.e., 30-minute) access to health and finance services during early evening rush hours (around 0.6%), as well as regional (i.e., 60-minute) accessibility to health services during morning rush hour (about 0.1%). A possible explanation for these minor reductions could be the changes in transit schedules and stop locations combined with the elimination of some feeder routes.

**Table 2**

The accessibility percentage changes for all of the essential services within each time window and all time budgets (30, 45, 60, 75 minutes).

	Time budget	Departure time	Dedicated lane	Non-dedicated lane	Entire corridor
<b>Health</b>	30 mins	7AM - 9AM	4.70%	-1.30%	0.91%
		11AM - 1PM	8.27%	-1.18%	2.44%
		3:30PM - 5:30PM	2.07%	-2.29%	-0.64%
	45 mins	7PM - 9PM	8.60%	-0.92%	2.68%
		7AM - 9AM	4.88%	-1.95%	0.93%
		11AM - 1PM	7.97%	0.55%	3.68%
	60 mins	3:30PM - 5:30PM	3.68%	-0.99%	0.99%
		7PM - 9PM	10.22%	1.90%	5.41%
		7AM - 9AM	3.94%	-3.60%	-0.11%
	75 mins	11AM - 1PM	5.73%	-1.82%	1.65%
		3:30PM - 5:30PM	3.41%	-2.70%	0.17%
		7PM - 9PM	8.65%	4.06%	6.21%
<b>Grocery</b>	30 mins	7AM - 9AM	1.43%	-3.23%	-1.02%
		11AM - 1PM	3.56%	-0.90%	1.22%
		3:30PM - 5:30PM	1.46%	-2.14%	-0.41%
	45 mins	7PM - 9PM	4.12%	5.29%	4.72%
		7AM - 9AM	6.71%	-1.15%	1.27%
		11AM - 1PM	24.64%	-1.60%	2.44%
	60 mins	3:30PM - 5:30PM	4.98%	-1.11%	0.80%
		7PM - 9PM	16.84%	-1.63%	4.04%
		7AM - 9AM	7.15%	-2.37%	1.28%
	75 mins	11AM - 1PM	15.88%	-0.68%	3.67%
		3:30PM - 5:30PM	4.36%	-2.25%	0.31%
		7PM - 9PM	15.48%	1.04%	6.62%
<b>Finance</b>	30 mins	7AM - 9AM	7.29%	-2.88%	1.69%
		11AM - 1PM	8.47%	-0.56%	4.04%
		3:30PM - 5:30PM	5.34%	-2.03%	1.33%
	45 mins	7PM - 9PM	13.41%	4.16%	8.33%
		7AM - 9AM	3.62%	-3.10%	0.08%
		11AM - 1PM	2.70%	0.08%	3.14%
	60 mins	3:30PM - 5:30PM	2.57%	-2.43%	0.29%
		7PM - 9PM	6.94%	5.47%	6.18%
		7AM - 9AM	4.92%	-1.80%	0.65%
	75 mins	11AM - 1PM	18.16%	-4.76%	2.74%
		3:30PM - 5:30PM	2.25%	-2.40%	-0.67%
		7PM - 9PM	13.17%	-0.92%	4.23%
<b>Accommodation</b>	30 mins	7AM - 9AM	5.24%	-2.98%	0.45%
		11AM - 1PM	10.36%	-0.52%	3.49%
		3:30PM - 5:30PM	2.77%	-1.96%	0.03%
	45 mins	7PM - 9PM	13.39%	1.44%	6.40%
		7AM - 9AM	5.95%	-3.33%	0.91%
		11AM - 1PM	5.40%	-1.65%	2.49%
	60 mins	3:30PM - 5:30PM	4.01%	-3.16%	0.17%
		7PM - 9PM	10.82%	5.00%	7.70%
		7AM - 9AM	2.46%	-2.83%	-0.32%
	75 mins	11AM - 1PM	1.69%	-0.64%	1.79%
		3:30PM - 5:30PM	2.04%	-2.09%	-0.11%
		7PM - 9PM	5.31%	5.78%	5.55%
<b>Accommodation</b>	30 mins	7AM - 9AM	8.86%	-2.18%	1.76%
		11AM - 1PM	13.97%	-1.98%	3.87%
		3:30PM - 5:30PM	10.22%	-1.01%	3.06%
	45 mins	7PM - 9PM	17.07%	-1.05%	5.48%
		7AM - 9AM	8.23%	-2.53%	1.88%
		11AM - 1PM	9.92%	-0.24%	3.94%
	60 mins	3:30PM - 5:30PM	7.10%	-0.49%	2.68%
		7PM - 9PM	13.53%	2.14%	6.82%
		7AM - 9AM	6.46%	-2.91%	1.60%
	75 mins	11AM - 1PM	7.06%	-1.58%	2.45%
		3:30PM - 5:30PM	4.76%	-2.12%	1.48%
		7PM - 9PM	10.92%	4.34%	7.40%
75 mins	7AM - 9AM	3.10%	-9.15%	-1.32%	
	11AM - 1PM	5.50%	-1.56%	3.12%	
	3:30PM - 5:30PM	3.32%	-5.38%	0.48%	
		7PM - 9PM	4.58%	-5.96%	1.90%



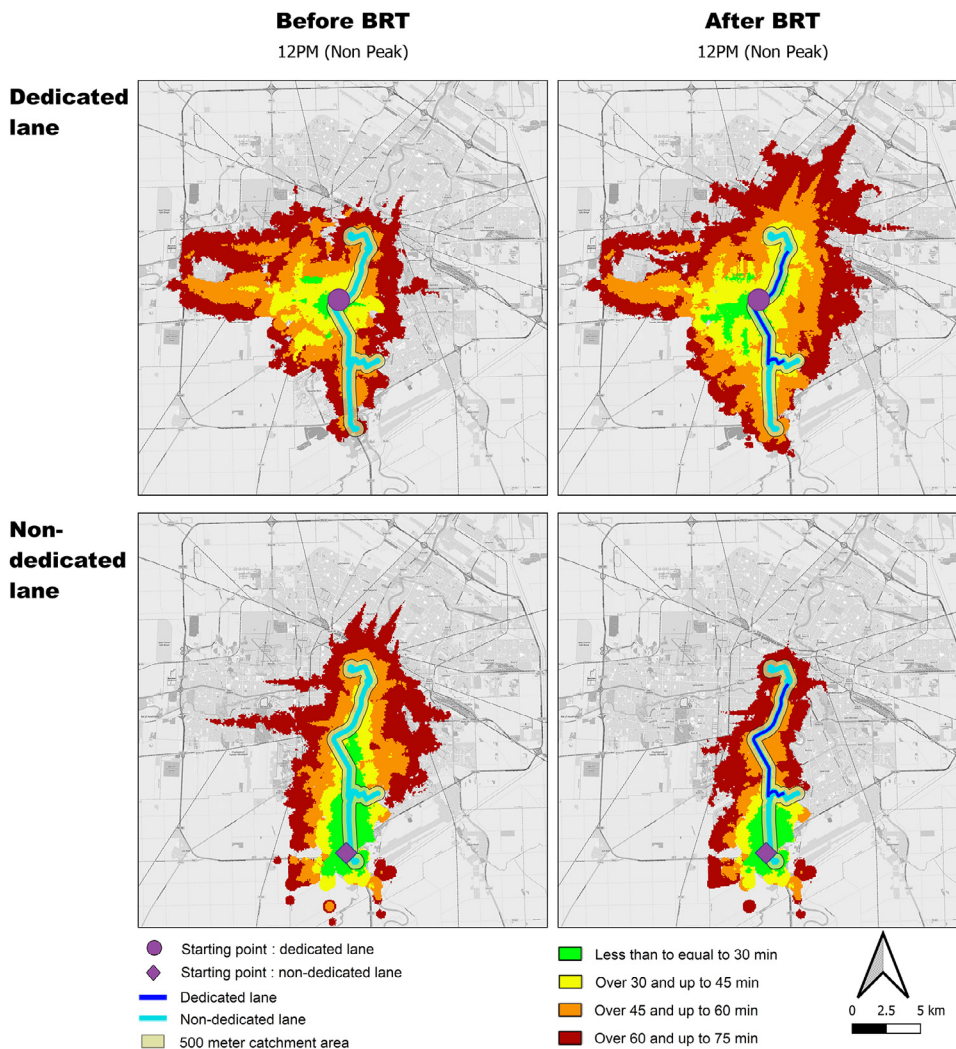


Fig. 4. Space-time accessibility maps at 12 PM (off-peak time).

Figures 6 and 7 visualize the accessibility analysis results for dedicated vs. non-dedicated lane sections with the 30-minute and 60-minute time budgets, respectively. In line with the previous section (Figures 3 and 4), the graphs of both time limits reveal a general increase in accessibility in the dedicated lane part but a drop in the non-dedicated lane sections, except for the 60 minutes time budget during the late evening hours, when there is a climb in accessibility in both dedicated and non-dedicated lane parts. These decreases can be related to adjusting the service schedules by decreasing some of the feeder routes frequency during the COVID-19 pandemic. However, the percentages of the rises in accessibility in the dedicated lane section are higher than the associated absolute percentages of decreases in the non-dedicated lane section.

While there is a rise in accessibility in the area near the dedicated lane during all time windows and across both time budgets, the highest increase is observed for accommodation services. In addition, the average percentage increase is higher within the 30-minute time budget (9.8%) than in 60 minutes (7.6%). Further, the results indicate that in both time budgets, the percentage increase in accessibility in the area near the dedicated lane is larger during mid-day and late evening off-peak hours, especially where it hits the highest percentage increase of approximately 25% for grocery and 18% for finance services within 30 minutes time budget during mid-day hours.

One thing to note is that the accessibility level of block centroids located near the non-dedicated lane is generally higher than those near the dedicated lane, regardless of the BRT implementation, departure time, and travel time budget. Further, the accessibility to health services is the highest while that of accommodations is the lowest. One possible

explanation is the uneven spatial distribution of the essential services and their disproportionate concentrations near the non-dedicated lane section as shown in Fig. 2.

Overall, the findings are consistent with those reported in the previous section (Figures 3 and 4). The results of this study indicate that the implementation of the BLUE BRT along Southwest Transitway and other changes made to the transit network have considerably benefitted accessibility, particularly for trip origins within the 500-meter catchment area of the dedicated lane during the mid-day and late evening non-peak hours (11 AM - 1 PM and 7 - 9 PM).

### 5.3. Geographic patterns of accessibility benefits

Figures 8 and 9 visually demonstrate the average accessibility benefits across all time budgets for each dissemination block in the morning peak (7 - 9 AM) and mid-day off-peak (11 AM - 1 PM) period, respectively. Green points represent the centroids of the dissemination blocks where the average accessibility has increased while the red points demonstrate those centroids witnessing a decline in accessibility. Both Figures 8 and 9 reveal trends similar to those presented in the previous sections; the BLUE BRT construction and other changes made to the previous transit network, have substantially improved the accessibility of dissemination blocks within a 500-meter catchment area of the dedicated lane section. In contrast, the accessibility of block centroids in the vicinity of the non-dedicated lane parts, which are located in the north and south parts of the BRT corridor, has generally declined. Specifically, the number of red points along the non-dedicated lane sections is smaller during the 11 AM - 1 PM time window (Fig. 9) compared to the

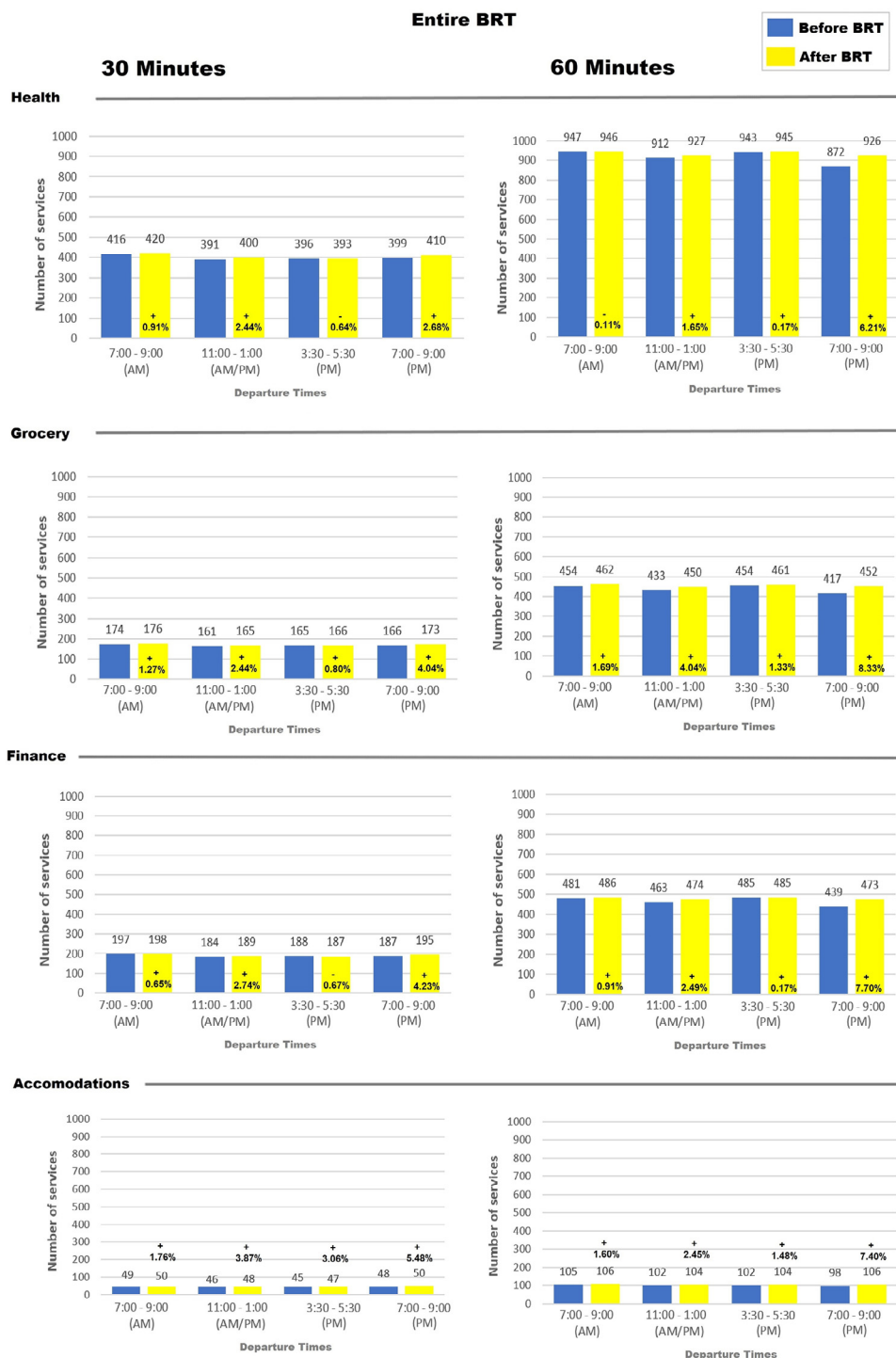


Fig. 5. Cumulative accessibility analysis for the entire corridor.

corresponding number during the morning rush hours (Fig. 8). This indicates that the majority of dissemination blocks near the non-dedicated lanes have seen a reduction in accessibility during morning peak hours. In the case of dissemination blocks near the dedicated lane, the number of darker green points is larger during the mid-day time window, indicating that the higher accessibility benefits are observed during this period.

## 6. Conclusion and discussion

In this study, we dealt with Winnipeggers' controversial remarks about the untimely release of the new BRT service by evaluating its impacts on accessibility during the COVID-19 pandemic. To this end,

we investigated the accessibility benefits of Winnipeg's new BLUE BRT service and Southwest Transitway on four essential services, namely 1) health, 2) accommodation, 3) finance, and 4) grocery. To account for changes in public transit schedule and frequency, we considered four different time windows (morning peak, mid-day off-peak, early evening peak, and late evening off-peak hours) of a day as our departure times. Using Winnipeg's GTFS data, we calculated the multimodal space-time constrained cumulative access measures from the centroids of dissemination blocks located within a 500-meter catchment area of the BLUE BRT corridor before and after its implementation. This helped us to focus on presenting a fine-grained analysis of accessibility at the local level of the BRT corridor. Additionally, we explored the impacts of lane reservation on accessibility improvements by comparing changes in ac-

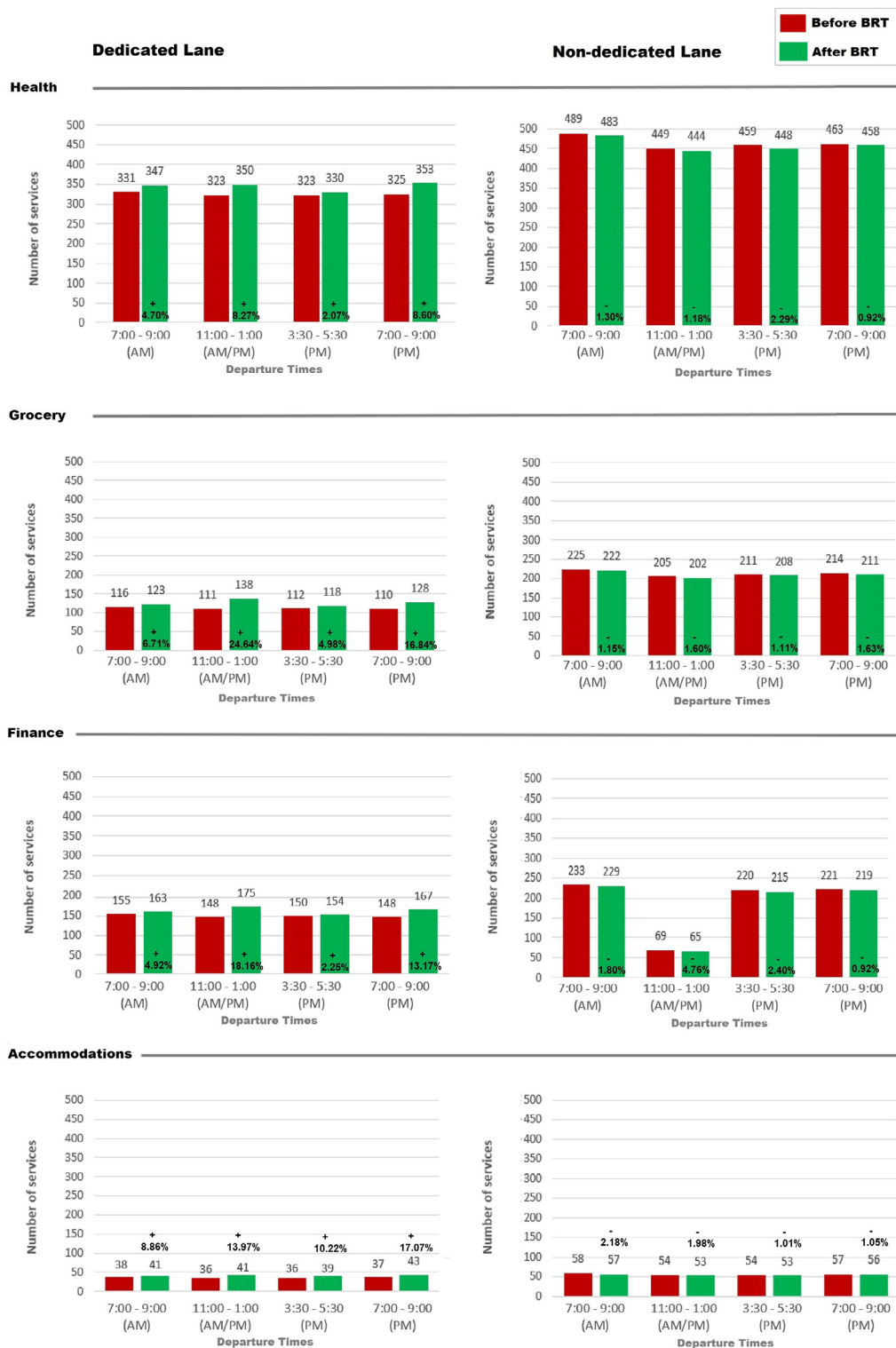


Fig. 6. Cumulative accessibility analysis for the dedicated vs. non-dedicated lane sections (30-minute time budget).

cessibility across different types of segments along the BLUE corridor: sections with- vs. without dedicated lanes.

The results of the accessibility assessment after the new BRT introduction revealed that while there was a growth in the area of accessible regions near the dedicated lane section, the counterpart near the non-dedicated lane part saw a decline. Similarly, the origin located within the dedicated lane section saw a rise in accessibility, whereas there was a marginal decrease for the origin near the non-dedicated lane section,

indicating the significant impact of lane reservation on accessibility improvement. However, findings confirm that the BLUE BRT line resulted in an overall positive impact on accessibility to essential services, especially for trip origins near the dedicated lane during the mid-day and late evening off-peak hours (11 AM - 1 PM, 7 - 9 PM) within the 30-minute time budget. This accessibility improvement during late evening hours is imperative for low-income essential workers who have to do night shift work.

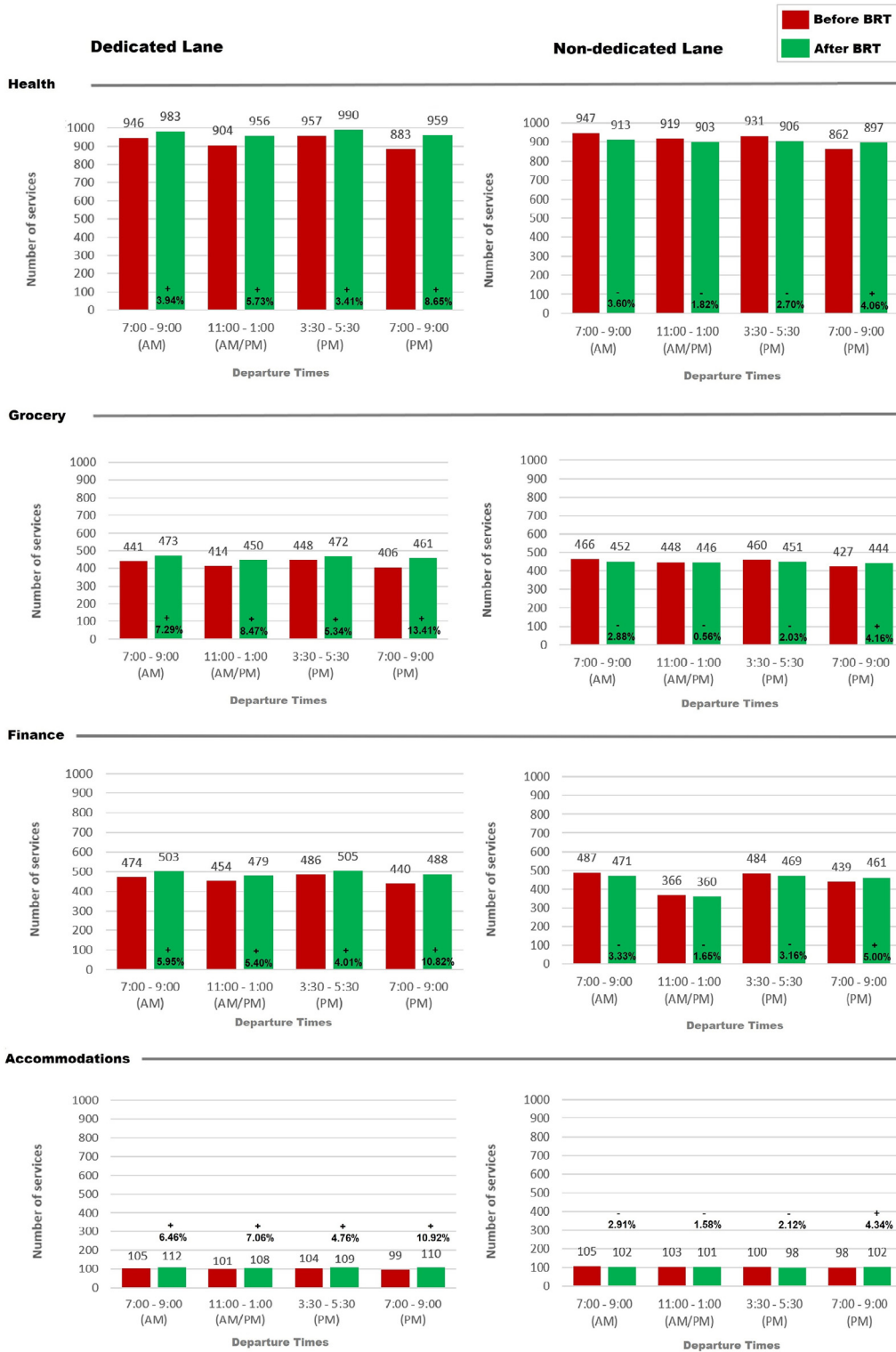


Fig. 7. Cumulative accessibility analysis for the dedicated vs. non-dedicated lane sections (60-minute time budget).

This research offers implications to transport planners and policy-makers for enhancing accessibility to essential services. To our knowledge, this is the first study examining the accessibility benefits of the new BRT service that was introduced during the pandemic. Considering the unintended outcome of the BLUE implementation on the accessibility of origins near the non-dedicated lane sections, our research further demonstrates an opportunity for improving service quality at these areas by extending the dedicated lane in the new BRT transitway. This will

help the residents of these areas to have better accessibility to a bigger number of essential services near the northern end of the corridor. In addition, the results of this research suggest that transport planners consider taking alternative steps such as increasing service frequency or constructing new feeder routes near the non-dedicated lane section to increase accessibility for origins within this section.

This study has some limitations that should be addressed in future research. First, we only examined the accessibility to four essential ser-

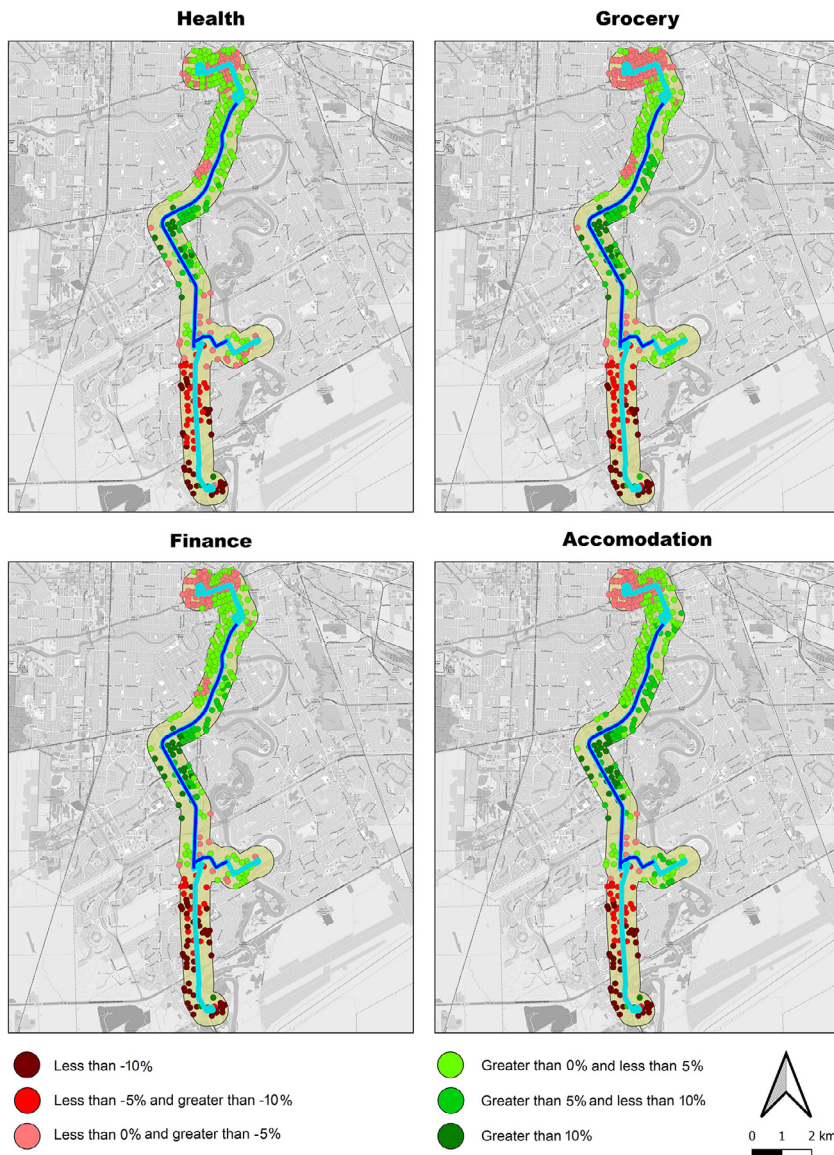
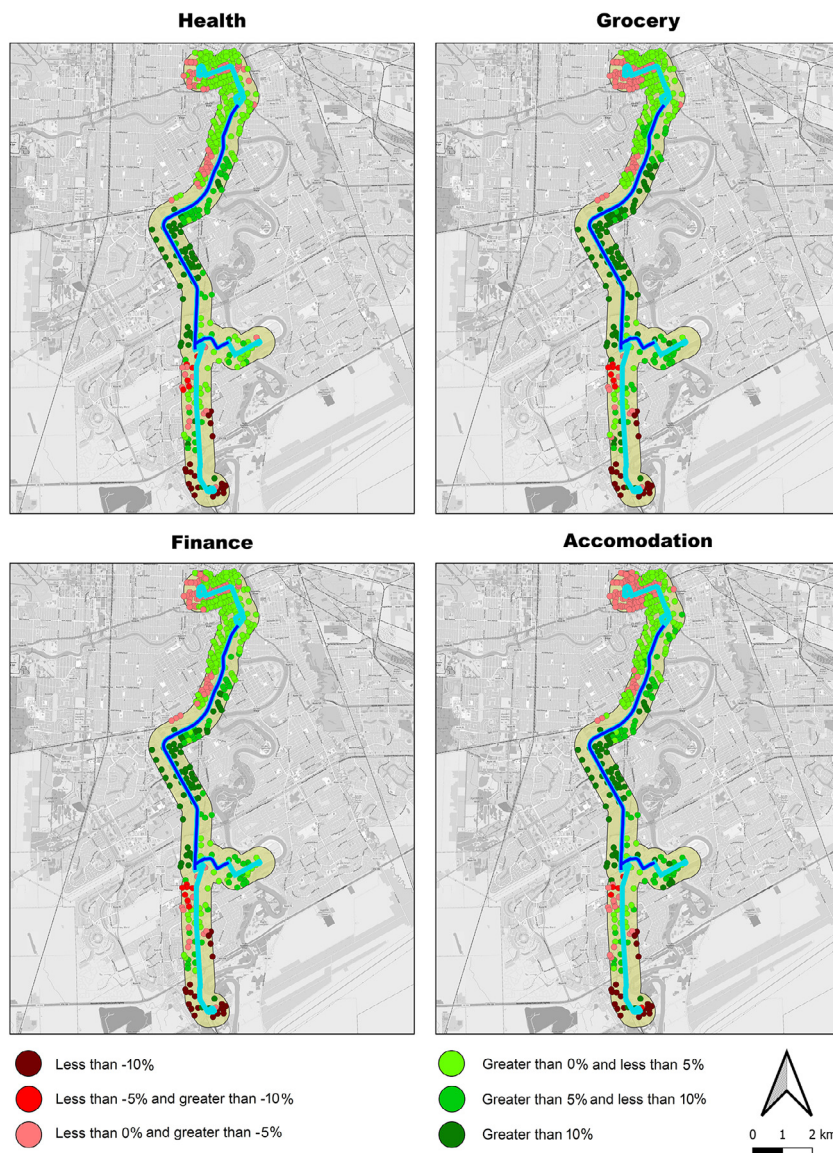


Fig. 8. Geospatial representation of changes in accessibility to each essential service during the morning peak (7 – 9 AM).

vices from origins within a 500-meter catchment area of the BLUE corridor. Future studies can include a wider list of essential services and experiment with different catchment area settings. A possible option is gradually increasing the size of the catchment area to capture the distance decay effects on the new BRT's accessibility benefits. Also, to conduct a more comprehensive assessment and to demonstrate accessibility variations across different days of week and times of a day, future studies should consider measuring accessibility on weekends or late night times. Uncertainties in travel times should be taken into account in future research as well (Chen et al., 2013, 2019). The current study used static GTFS data and assumed all public transit services operate perfectly on time, which is not the case in the real world. In the face of travel time uncertainty, people can also take heterogenous risk-management strategies such as choosing routes not only based on travel time but also considering reliability (Lee and Miller, 2020). Using real-time GTFS data or Automatic Vehicle Location (AVL) data reflecting delays and addressing travelers' behaviours under travel time uncertainty would facilitate a more robust evaluation of the impacts of new public transit services on people's accessibility in space and time (Zhang et al., 2018; Liu and Miller, 2020). Regarding the methodology, we used simple isochrones (can be interpreted as potential path areas (PPAs) in time geography (Miller, 2005) to represent people's potential mobility areas via public

transit and walking within a limited time budget and evaluate the new BRT's accessibility benefits. Future studies can employ advanced time geographic measures such as potential multimodal network areas defined within a multimodal network (including a wide range of first/last-mile options) rather than a planar space or a network corresponding to a single transport mode (e.g., automobile) for a more realistic assessment of the new BRT's accessibility impacts. Lastly, due to the lack of the exact residential location information, we considered the centroids of dissemination blocks as a proxy, which could lead to an overestimation or underestimation of accessibility measures.

A viable next step of this research is to assess the impacts of transit service-cut on accessibility to essential services and ridership during the pandemic. In addition, unlike this study that examined the potential mobility (i.e., accessibility) benefits of the new BRT, future studies could attempt to explore the impacts of the BRT on realized mobility patterns (e.g., travel behaviours, transit ridership) within urban areas. In terms of accessibility equity, which is the primary concern among transport planners, future research can examine the difference between community-level vs. individual-level accessibility within a dissemination block or neighbourhood before and after the system change. This can be calculated using an average space-time prism that summarizes individuals' accessibility experiences within the selected area (Lee and



**Fig. 9.** Geospatial representation of changes in accessibility to each essential service during the mid-day off-peak (11 AM – 1 PM).

Miller, 2019). Furthermore, using socio-economic data and the Palma ratio, which is a measure of inequity in transit-based accessibility, future studies can assess the impact of new BRT service on the equity in access to essential services across space, income, race, and occupation (Liu, Kwan and Kan, 2021). Lastly, future studies can employ ridership and on-time performance data to evaluate the effectiveness of the new BRT service after the pandemic.

#### Declaration of Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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