Access During Crisis: Applying Accessibility Metrics to Public Transport Systems During the COVID-19 Pandemic from an Equity Perspective

Abstract: Accessibility—the ease of reaching desired destinations—has enjoyed increasing recognition as a valuable metric of land-use and transport-system interactions. Accessibility's unifying focus and the accompanying shift from a mobility-centric agenda have led to its adoption as a key performance measure for long-range planning and scenario development. The proliferation of publicly available data and easy-to-use free and open-source software tools mean that practitioners and policymakers can now generate accessibility measures more quickly and conveniently, allowing for these metrics to be applied to a broader range of situations. In this study, we show how accessibility could be used as a rapid diagnostic tool to assess the potential impacts of public-transport service adjustments during a public-health crisis. We examine accessibility changes to a range of job and activity types resulting from the service alterations the greater Montreal region's public-transport operators made in response to COVID-19. Using publicly available data and free software, we find that accessibility to many jobs and opportunities classified as essential declined more severely than jobs and opportunities that were deemed nonessential. We also find that the public-transport service changes that took place between May 2019 and May 2020 in Montreal significantly reduced the number of health-sector workers who could reach some area hospitals within 45 minutes by transit at key shift-change times. Findings based on accessibility generally cannot determine the extent to which any particular traveler or destination might be specifically affected, but they are useful to quickly pinpoint potential problems that may require additional study. Although this paper focuses on using accessibility to analyze public-transport operators' responses to a unique health crisis, it may also be of interest to practitioners wishing to incorporate equity analysis into their planning processes more generally as it suggests a quick and straightforward method to assess accessibility by public transport for defined groups.

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1 Introduction
Accessibility, the ease of reaching desired destinations, is a comprehensive performance measure that is increasingly valued by planners and practitioners for its ability to bridge the gap between mobility and land use (Geurs & van Wee, 2004). At its simplest, accessibility measures how many "opportunities," such as jobs or services, a person can reach at a given cost, usually expressed in time, money or both (Hansen 1959). Accessibility can be improved either by placing opportunities in closer proximity to people (land use) or by making it faster, cheaper, or otherwise easier for people to travel to these opportunities (Owen & Murphy, 2019). This unified focus renders accessibility better suited than more traditional planning approaches to address seemingly intractable urban challenges, including the equitable allocation of transport services and the reduction of transport-related environmental impacts (Farrington 2007). To date, most of the growing number of real-world applications of access have emerged as part of long-range planning processes or in connection with scenario analysis for infrastructure investment. In this chapter, we show how accessibility could be used in the real-time assessment of public-transport service adjustments during emergencies, taking the impact of Montreal, Canada, transit agencies' response to the COVID-19 pandemic as an example.

The COVID-19 pandemic posed unprecedented challenges for public transport agencies forced to balance their response to precipitous declines in ridership with their central role as an essential public service for frontline workers and others. As the pandemic spiked in April 2020, for example, public bus ridership on Montreal's primary operator fell by 82 percent; Metro ridership was down 92 percent during the same time (Olson, 2020). Even as public transport agencies curtailed or canceled services, however, many low-wage workers had no choice but to travel, raising important questions of equity (Bartik, Cullen, Glaeser, Luca, & Stanton, 2020).

In this chapter, we explore how access to so-called essential and nonessential jobs and services evolved during the spring of 2020 due to service changes in Montreal. We also assess how health facilities' access to healthcare workers changed during this period. Using readily available census data and open-source software, we demonstrate a methodology that public transport agencies—even those with limited resources—could adopt to evaluate quickly and cheaply potential service adjustments in response to future crises, including public-health emergencies or natural disasters. Although this chapter focuses on using accessibility to analyze Montreal public transport operators' responses to a unique health crisis, it may be of interest to practitioners wishing to incorporate equity analysis into their planning processes more generally as it suggests a quick and straightforward method to assess accessibility by public transport for defined groups.

1.1 Research Questions

The animating goal of this chapter is to show how accessibility might be calculated and used by policymakers and practitioners to quickly identify and communicate the projected impacts of public-transport service adjustments during an emergency. The methods described here are not intended to definitively assess the appropriateness of particular service adjustments. Nor could they be relied on to dictate possible alternatives. Instead, they represent a means to conduct a quick diagnostic assessment of potential impacts as a predicate to more detailed analyses relying on fewer simplifying assumption and more specialized data if necessary.

To that end, this chapter explores three research questions:

1. How did public-transport service adjustments in response to COVID-19 affect accessibility to jobs and services in the greater Montreal region and how were these changes in accessibility distributed spatially, temporally, and socio-demographically?
2. How well did these service adjustments in response to COVID-19 preserve accessibility to those jobs and services deemed essential during the pandemic?
3. How specifically did the service adjustments affect access to health-related opportunities for the general public and the potential availability of health-sector workers for hospitals?

2 Methods and Data

With a population of more than 4 million in 2016, Montreal is the largest city in Quebec and one of the largest in Canada. The region possesses an extensive, well-used, and mature multi-operator public transport-network including metro, bus, and commuter-rail service. We elected to conduct a year-over-year comparison of accessibility to help control for seasonal service adjustments. By May 2020, Montreal had experienced its deepest COVID-related public-transport service cuts. For this comparison, we therefore selected May 8, 2019, and May 13, 2020, which represent typical, nonholiday weekdays.

Accessibility can be measured in numerous ways with varying degrees of complexity and sophistication. Here, we use the simplest measure: cumulative accessibility (Handy & Niemeier, 1997). Cumulative accessibility sums the number of destinations a person can reach from a given origin within a defined time or distance. Though this metric does not account for the relative attractiveness of destinations that are closer, it has the distinct advantage of being easily communicated and understood, making it an obvious choice for quick calculations to help shape policy decisions. For our analysis, we selected a 45-minute travel-time cut-off to align with the average commute in Montreal.

Widely available standardized transit data in the form of General Transit Feed Specification (GTFS) schedules and the proliferation of user-friendly and intuitive open-source software tools has rendered the calculation of accessibility more "accessible".

The first step in the calculation of accessibility is to obtain information about the transport network and the people, locations, and opportunities it links. For our origins and destinations, we use the geographical center, or "centroids", of census tracts. To identify the opportunities or activities available at each destination, we relied primarily on home-to-work travel flows from Canada's 2016 census. These data include the number of people from each census tract traveling for work to every other census tract and are broken down by job categories as defined by the North American Industry Classification System (NAICS). To calculate available opportunities at any given destination, we simply summed the number of work trips for each job category terminating in each census tract throughout the region. These work destinations perform double duty: They are employment locations for the workers traveling to them and also serve as a convenient proxy for the various types of services that may be available to the public at a given location.

To obtain these home-to-work flows, broken down by job category, the researchers had to pay Canada's statistics agency, Statistics Canada, for a special extraction. In other jurisdictions, however, similar types of data may be available for free, although not necessarily with the level of specificity required to analyze changes by detailed job category. For example, the U.S. Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) data contain home-to-work flows broken down by worker age, broad salary ranges, and general job category. The LEHD data are available for free from the Bureau's Web site and through other free and open-source software packages. Other options to obtain "opportunities" data include information from OpenStreetMap, a freely available, volunteer-edited mapping service that can be accessed using a variety of tools. Here, we used OpenStreetMap data to identify the locations of hospitals.

For information about the transport system, including the road and pedestrian network and transit service schedules, we relied on free, broadly available sources. Our road network came from OpenStreetMap downloaded from the GEOFABRIK regional extracts survey. Our transit schedules for both study periods May 2019 and

May 2020 were downloaded from OpenMobilityData, formerly known as Transit Feeds (OpenMobilityData). OpenMobilityData offers an archive of historic transit schedules in the almost-universally-adopted General Transit Feed Specification (GTFS). The GTFS can be browsed and downloaded manually or, as we did here, a simple software script can be created to identify and download the relevant schedules programmatically.

Calculating accessibility also requires tools to estimate the ease of reaching given destinations. In the past, it was already relatively easy to calculate travel times or distance for single-mode trips by car, bicycle or on foot, between various points using GIS software such as QGIS. Multi-modal travel, especially with public transport, was far more difficult to route over a network and often required expensive and/or complicated private software. Major advancements in powerful, open-source tools have largely erased this challenge.

For this analysis, we rely on R, an open-source programming language that benefits from a worldwide network of contributors who produce freely available add-on software packages with an enormous range of functionalities. Many of these packages assist with transport analysis. Two, in particular, are relevant to transit-based multi-modal trip routing: opentripplanner and the more recently developed r5r. Here, we used r5r, which allows users to "drive" Conveyal's java-based R5 routing engine from within R, making it substantially easier for nonprogrammers to deploy this powerful and fast tool to calculate matrices of travel times between all origins and destinations over a public-transport network (Pereira, Saraiva, Herszenhut, Braga, & Conway, 2021). Using r5r, we calculated travel time-matrices for various times of the day based on typical peak and off-peak travel. For our more detailed look at health workers' access to hospitals, we also calculated travel times coinciding with typical shift changes for facilities in the Montreal region. Finally, to understand one aspect of the potential equity impacts of public transport service adjustments, we downloaded and mapped census tract median household income data from Canada's 2016 census using the cancensus R package (von Bergmann, 2021). Cancensus offers users an easy and intuitive way to directly census data and geographic boundaries—already linked—directly into R for immediate use. Similar packages are available for U.S. Census data and other jurisdictions. Table 1 provides a brief overview of the main packages and data sources on which we relied.

Table 1 R packages and data sources used in this analysis.

R Packages	
cancensus	Search for and download ready-to-use Canadian census data and geographies
osmdata	Download points-of-interest, such as retail stores or hospitals, from OpenStreetMap
r5r	Quickly calculate travel-matrices for all origins and destinations over a public-

	transport network using Conveyal's java-based R5 routing engine. r5r requires GTFS public-transport schedules and .pbf-format street networks from OpenStreetMap.
Data Sources	
Statistics Canada – 2016 Home-to-Work Travel Flows by Job Category	Home-to-work flows, which show the number of people traveling between different origins and destinations, allow researchers to identify the number of "opportunities," such as jobs or services provided by workers that exist at any given destination. (Available for purchase from Statistics Canada)
GEOFABRIK OpenStreetMap Data Extracts	The free server offers downloadable extracts of complete OpenStreetMap data for different areas, ranging from whole continents to national sub-regions. The data can be downloaded in the .pbf format required by r5r. Command-line software is available to trim the sub-regional OpenStreetMap data to the study area to reduce computation time.
OpenMobilityData (formerly Transit Feeds)	Online repository of historical GTFS-format public transport schedules from operators around the world.

3 Findings

3.1 Accessibility Across the Montreal Region

Accessibility to jobs and other destinations of interest declined most significantly during the early-morning hours, illustrating that transit agencies made deeper cuts during these peak times (See Figure 1). As the maps illustrate, more census tracts experienced year-over-year declines in overall accessibility to jobs/opportunities during the 7 a.m. peak than during later hours of the day. The most severe declines in accessibility took place across suburban regions, such as Laval and Longueuil, off the Island of Montreal.

Without detailed knowledge of transit operators' scheduling and response, it is difficult to completely isolate COVID-related adjustments and their impact. We elected to measure changes in accessibility from May to May to control for potential

regular seasonal schedule changes that might have occurred between the onset of the pandemic's widespread impacts in March 2020 and spring 2020, when transit agencies began to enact some of the most significant changes in their schedules. As expected, many census tracts actually experienced year-over-year increases in accessibility, shown in light green in the maps in Figure 1. These increases likely stem from service adjustments unrelated to the transit agencies' response to COVID-19. It is conceivable—even likely—that these areas of year-over-year accessibility improvements actually witnessed declines relative to the beginning of the pandemic. Decision makers could further explore this possibility by conducting the same analysis on a month-to-month basis. For our analysis, however, we determined that declines in access year-over-year, reflecting greater difficulty in traveling by transit, would be of greater relevance to policymakers and operators.

The juxtaposition of areal socio-demographic information and changes in transit-system performance offer policymakers and transport operators an opportunity to explore and highlight the impacts of service adjustments on equity. Here, we see that morning reductions in accessibility largely occurred outside the region's poorest census tracts, as measured by median household income. This is particularly important because lower-income groups are frequently more reliant on public transport. The black outlines in the maps in Figure 1 show the census tracts from the lowest household-income decile. Across most of the Island of Montreal, census tracts in this income decile experienced relatively minor reductions in average transit-based accessibility year over year, with the vast majority ranging from 0% to 5%. Some lower-income census tracts on the Island of Montreal and in Longueuil recorded year-over-year improvements in accessibility. The maps also allow us to easily pinpoint areas that may deserve additional scrutiny. In south eastern areas of Laval and northern and eastern areas of the Island of Montreal, there are a handful of lower-income census tracts that saw greater-than-40% decreases in accessibility during the morning travel hours.

Median household income offers just one of a vast range of possible metrics to assess the equity impacts of service adjustments. The selection of the most appropriate measures will depend on a mix of considerations unique to different populations, policymakers and operators. But easily obtainable census information, such as age, gender, income, education levels, and immigration status—alone or in combination—offer numerous potential options. Many ready-made, publicly available indicators of social deprivation also exist. These areal summary measures elide important differences among individuals within populations and can thus mask very real discrepancies in transport systems' usefulness and usability for different people. They cannot therefore serve as a substitute for more granular knowledge about transport systems' user populations. But they can be extremely useful in quickly exploring and communicating potentially problematic outcomes from proposed service adjustments.

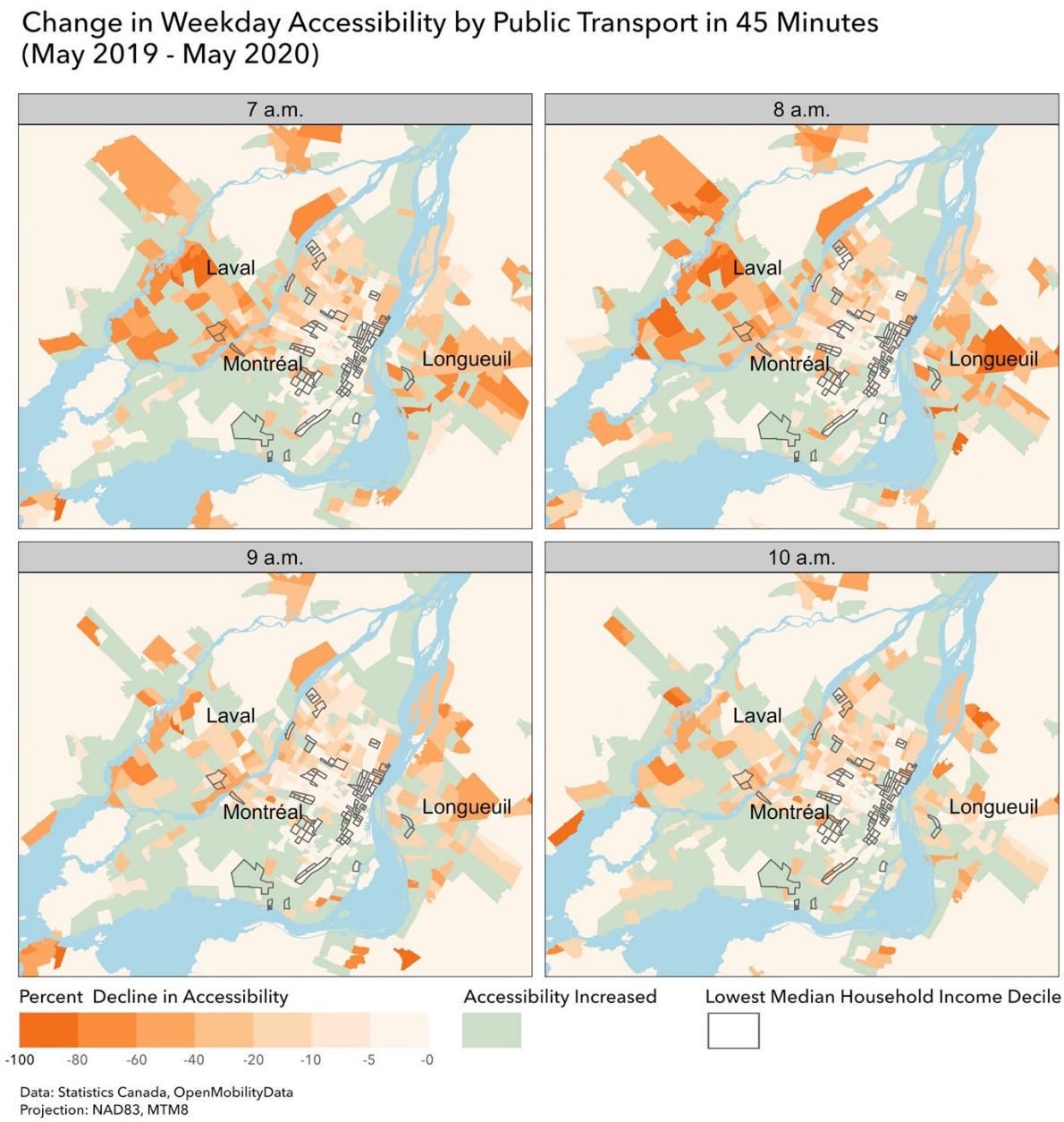

Figure 1 Change in Accessibility in 45-Minutes by Public Transport to All Jobs/Opportunities

3.2 Accessibility Impacts Across Job/Destination Categories

As part of the region's pandemic response, businesses and services were broadly classified into those that were essential and those that were nonessential. In most cases, essential business and services were allowed to remain open and required in-person operation. Essential businesses included certain retail locations, such as grocery stores; many healthcare facilities; some wholesale operations; and at various times, construction. Nonessential businesses were largely shuttered or were able to operate with employees working remotely, eliminating the need to travel. These included, financial services offices, for example. One potential measure of a public-transport systems' efficiency during the pandemic, then, is to examine the

extent to which necessary service adjustments preserved access to essential businesses and services for both workers and the general public. The work-to-home census data we used to generate our "opportunities" data set defines jobs by commonly used categories, allowing us to consider the relative changes in average access to essential and non-essential destinations.

We find that in the Montreal region, service adjustments—particularly during the early-morning hours—travel to essential jobs and services may have actually been more negatively affected than travel to nonessential locations. For workers departing at around 7 a.m., average accessibility to jobs in their sectors declined by about 5% to 13%. See Figure 2. The categories where declines were most severe included construction, health, manufacturing, and wholesale operations. During the later-morning period, the range of declines for all job categories compresses and clusters around an approximate 5% drop in average accessibility.

Figure 2 Percent changes in average accessibility across job categories. The upper panel shows changes in average accessibility weighted by the number of workers in each category. The lower panel shows changes in average accessibility weighted by the total population experiencing those changes.

A similar pattern exists for population-weighted access to opportunities across categories, as shown in the lower panel of Figure 2. Although the gap between access to essential and nonessential services is smaller, declines in access to essential categories of businesses are consistently greater at 7 a.m. Construction, health, manufacturing, retail and wholesale categories all experienced declines in average accessibility of more than 10%. No systematic difference between those destinations that were considered significantly different for different types of opportunities. Over the morning, the range becomes more tightly compressed.

This quick diagnostic review of system performance suggests that service adjustments were not necessarily calibrated to preserve access to essential rather than nonessential functions. If they were, declines would be expected to be less severe for categories deemed essential.

In some cases, it may not be possible to make precisely target different categories of accessibility. For example, some categories of jobs or destinations, such as retail, may be more spatially dispersed than management or manufacturing jobs. In other cases, certain types of destinations may routinely co-locate with others. Access to one would necessarily mean access to the other. To determine whether this may have occurred here, we examined the correlation between different categories of employment within census tracts. Figure 3 shows the results.

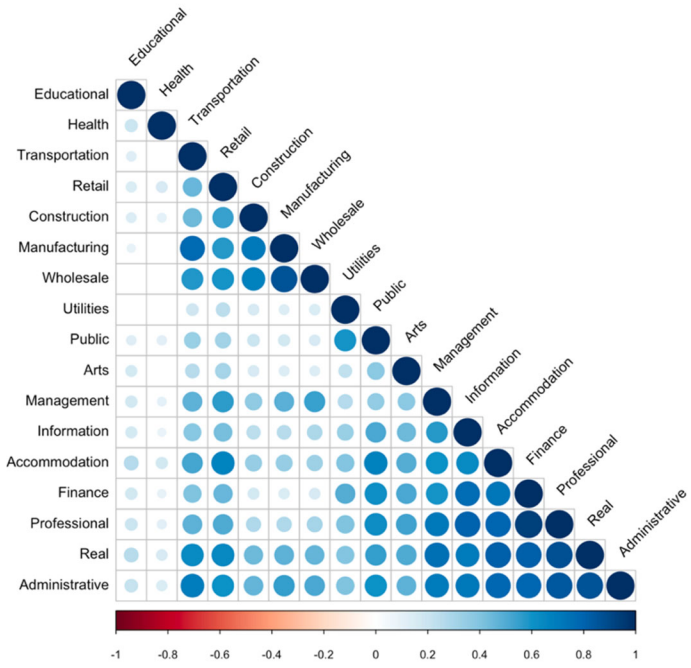

Figure 3 Correlation between the number of jobs of different within census tracts.

While many categories show strong correlation with one another, some of the designated essential businesses do so to a lesser extent. Health, in particular, demonstrates very little correlation with other opportunity categories. This suggests that it could be at least theoretically possible to more precisely target service adjustments to preserve access to health-related facilities for both workers and the general population. (The actual ability to do so, however, depends not just on the dispersion of the facilities themselves but also on the residential or origin locations of the people who desire to reach them.)

3.3 Accessibility to Health Facilities

Changes in accessibility to health-related opportunities specifically reflect a similar temporal, spatial and sociodemographic pattern to changes in accessibility to all types of opportunities. The largest reductions in access take place during the early-morning hours in suburban, off-island areas and largely avoid the lowest-income census tracts (See Figure 4). By later in the morning, reductions in accessibility to health-related opportunities are much less acute posing fewer potential challenges to members of the general public seeking care who may be considered less likely than healthcare workers to travel in the early-morning hours.

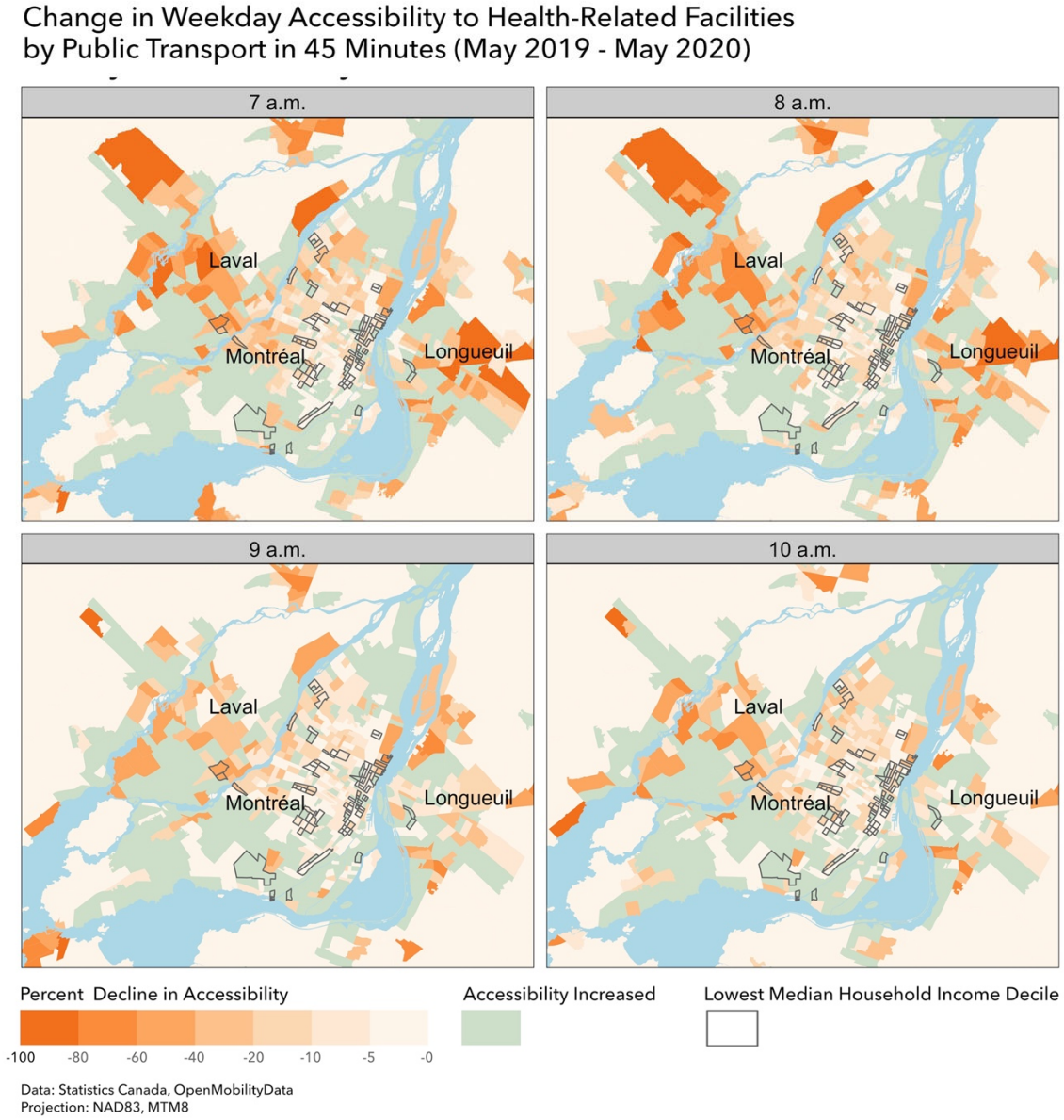

Figure 4 Change in Access to Health-Related Facilities Within 45-Minutes by Public Transport

Visualized differently, the same travel and accessibility data demonstrate the potential challenge from the perspective of hospitals which rely on public transport

to consistently ferry healthcare workers to and from the facilities. The maps in Figure 5 show the change from May 2019 to May 2020 in the number of health-sector workers able to reach hospitals and other major health facilities within 45 minutes using public transport. Travel times were calculated for departures around 7 a.m., 3 p.m., and 11 p.m. to align with typical shift changes in Montreal-area hospitals, which generally occur at 7:30 a.m., 3:30 p.m. and 11:30 p.m. For the first shift, two hospitals saw the number of health-sector workers able to reach them within 45 minutes by transit decline by more than 55% year over year. Another eight hospitals experienced declines in accessibility by workers of between 15% and 25% at 7 a.m. In many cases, the hospitals experiencing the greatest declines in worker accessibility varied over the course of the day.

This approach to measuring accessibility differs from our earlier analysis, which focuses on the number of opportunities individuals could reach, and instead identifies the number of workers potentially available to specific facilities. This general measure of worker accessibility does not necessarily mean employees of a particular hospital will definitely experience difficulty arriving at work since it does not account for actual mode choice or specific hospital-location/employee-residence pairs. It may, however, serve to help transit operators and even hospital officials quickly identify highlight potential challenges. In the case of hospital administrators, reviewing these sorts of potential impacts from public transport service adjustments could encourage them investigate further by directly polling workers and, when necessary, deploy alternative travel arrangements.

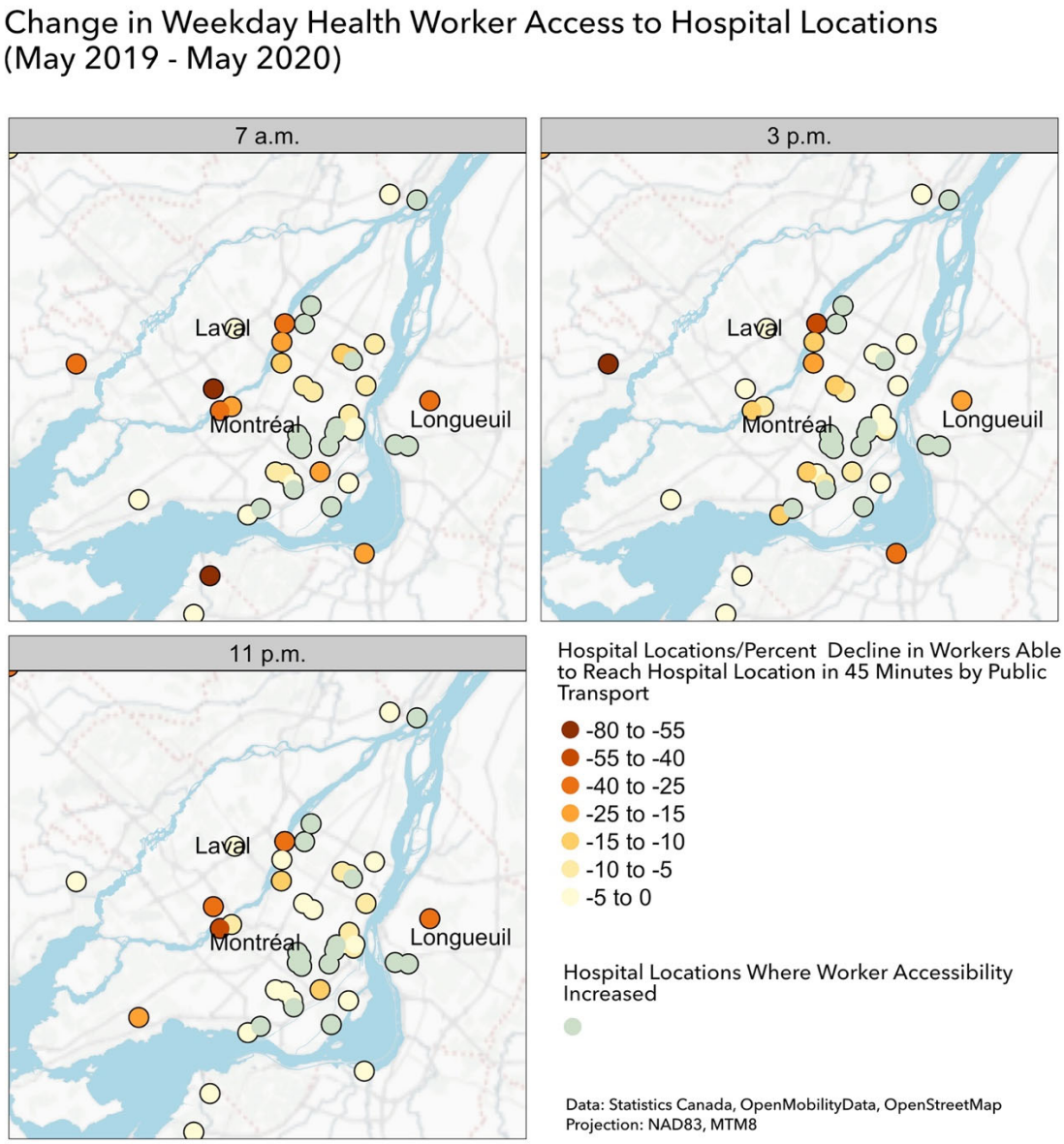

Figure 5 Percent change in the number of health-sector workers able to reach hospital locations in 45 minutes by public transport.

4 Conclusion

The objective of this type of accessibility "quick check" is to offer a quick and relatively easy methodology to help policymakers determine whether more in-depth analyses should be conducted of proposed or implemented service adjustments. It necessarily relies on a number of simplifying assumptions. For example, the work-to-home travel information we rely on to identify job/business destinations for this analysis does not include actual time-of-departure information. For purposes of this analysis, we assumed that the total number of jobs or other destinations available at a particular location throughout the day is correlated to

some extent with jobs/destinations that might be available at particular times. It is, therefore, impossible to know for certain how severely workers or others might have been affected by the service adjustments at any given hour.

For these reasons, this diagnostic cannot tell policymakers and transit officials precisely how to navigate the multitude of financial, economic, humanitarian, and political considerations that shape emergency responses. Nevertheless, it may help them more readily identify and communicate the need for more detailed analyses that ultimately suggest more nuanced approaches to service adjustments in response to public health or other emergencies.

Here, the results suggest the possibility that access to essential locations might have been more severely compromised by COVID-related service adjustments than access to less important destinations. Access to this type of information could allow policymakers and transit operators to explore alternative adjustments or to proactively communicate with groups or organizations that might be affected, allowing them to consider their own alternatives. The easy generation and communication of these types of accessibility calculations also render it easier for potentially affected groups or organizations to conduct their own analyses and advocate on their own behalf. Enhancements in publicly available data and dramatic improvements in the functionality of freely available and relatively easy-to-use technology mean that accessibility measures can be more broadly deployed by a wider range of people. The increasing acknowledgement of accessibility as a meaningful, easily calculated, and communicated measure will see its adoption in new situations, including as a way to quickly pinpoint potential impacts of transport operators' responses to public health or other emergencies.

5 Acknowledgments

[Acknowlegements]

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