Comparing Transit Service Equity and Transit Captivity of Toronto Traffic Analysis Zones Using Connectivity Measures

A Research Report by Benjamin Mumford, Gordon Huang, and Harry Zhao

Introduction & Executive Summary

As public transit agencies across North American urban centers begin to consider the socioeconomic implications of transportation planning, one important aspect of transportation equity lies in being cautious about how transit service planning can affect the mobility of transit-dependent neighbourhoods, especially those that are historically socio-spatially vulnerable. The City of Toronto and the TTC, its public transit agency, readily cites equity as a goal in its planning documents (Social Policy Analysis and Research, City of Toronto, 2014; Toronto Transit Commission, 2019). However, while low-income households rely more on public transit for their daily travel needs, such as commutes to and from employment sites, socially vulnerable communities in Toronto evidently have poorer transit connectivity to their employment locations than their counterparts in other major Canadian cities (Deboosere & El-Geneidy, 2018, p. 62). The current COVID-19 pandemic has further underlined the importance of equitable transit service planning. As public transit agencies like the TTC scramble to react to the contingent shock in transit ridership, it is imperative that decisions in transit service reallocations are made through a socioeconomically equitable lens (Toronto Transit Commission, 2020).

The purpose of this research report revolves around assessing equity in transit service planning by the TTC, in terms of both equitable planning processes and equitable outcomes in service distribution. This paper will explore the relationship between transit planning equity and the idea of transit captivity, which is a concept used to categorize transit riders long before the current adoption of socioeconomic equity frameworks. Transit research and analysis regularly delineates two types of riders: captive riders and choice riders (Krizek & El-Geneidy, 2007, p. 72). While the exact socio-spatial factors used for this determination vary across different agencies and research initiatives, this research aims to understand captivity as a label for regions within cities that are socioeconomically disadvantaged, and that have poor transit accessibility and connectivity. Using Transportation Tomorrow Survey data from 2016 and General Transit Feed Specification data from 2020, this research presents a pandemic snapshot of transit service qualities across neighbourhoods that are identified as transit captive based on socioeconomic and accessibility measures. The concepts of accessibility and connectivity have been proven in previous transportation research as appropriate measures of transit service quality (Kaplan et al., 2014; Welch & Mishra, 2013). Through comparing the GTFS data before and during the pandemic, this report will also present how the pandemic has affected the transit connectivity for transit captive neighbourhoods. The research process also features an interview with transit service planners from a major transit agency located in the Greater Toronto Area. The direct input from experienced transit planners will inform this report's analysis of how equity is incorporated in real life service planning decisions, as well as how transit planning's equity scope relates to their understanding of transit captivity.

This research report argues that while service reductions across the TTC's bus networks seem to have been made using equity considerations, poor transit connectivity and accessibility of captive neighbourhoods in Toronto reflect potential flaws in how the TTC defines equity and equitable measures. A brief review of recent relevant literature provides insights into how equity should be defined in transportation studies and plans. The review will also identify socioeconomic variables that have had success in predicting transit captivity. The report will then feature a 3 stage method and analysis section, followed by a conclusion and brief discussion about avenues for industry. This report is structured into 3 stages because much of the methodology is intertwined with results and discussion, which then informs the methodology used for further analysis. Stage 1 will utilize statistical methods to test the validity of extracted socioeconomic variables to be used for a socio-spatial analytic framework to determine neighbourhood captivity. Stage 1 will also apply transit accessibility measures to traffic analysis zones in Toronto. Stage 2 uses a sample of TAZs determined by their socioeconomic variables to perform connectivity analyses. Stage 2 will then feature a brief case study of a model captive neighbourhood in Toronto that is dependent on transit for peak AM commutes, despite being poorly served by public transit. Stage 3 will be focused on comparing TTC's equity measures to research results.

Ultimately, this study found that socio-economic variables including income and car ownership are useful for identifying transit captive regions. However, these metrics can be greatly improved through the addition of geographic, transit accessibility variables, and connectivity variables. The TTC's current equity framework, which relies upon socio-economic data and the City of Toronto's neighbourhood improvement areas, misses some captive TAZs and results in these TAZs having inadequate transit connectivity to jobs and other trip destinations.

Literature Review

Past research on the topic of transportation equity frequently cites Litman (2002) for definition of transportation equity (El-Geneidy et al., 2016; Fan et al., 2012; Welch & Mishra, 2013). Litman (2002) proposes that transportation equity is the umbrella term for two vastly different ideologies: vertical and horizontal equity. While horizontal equity is concerned with providing equal access for riders of similar socioeconomic conditions, vertical equity refers to ensuring that access to transit is prioritized for those who are socioeconomically disadvantaged (p.4). More recent transit planning studies have expanded on Litman (2002)'s definition for transportation equity. Karner & Marcantonio (2018), for example, pushes for a more bottom-up definition of transit equity that focuses on community representation. They proposed that while equitable distribution of transit services is a matter of outcome, equitable transit service planning cannot be fully achieved without substantive community involvement in the planning process, especially in neighbourhoods that are historically underrepresented in public policies (p.106).

Foth et al. (2013) argued that in planning practice, and even in actual research initiatives, transportation equity is a concept that lacks conventional definition, and most studies have varied benchmarks for what is considered equitable. Foth et al. (2013) further suggested that transit scholars need to focus on how different public transit agencies define transportation equity, for in most cases, their definitions are vague, and lack tangible measures and plans for achieving equitable service planning (p.2).

While the practice of understanding transit ridership bases through a socioeconomic equity lens is still considered novel for many transit agencies, the conventional understanding of transit ridership bases around the idea of transit captivity has been a decades long practice (van Lierop & El-Geneidy, 2017, p. 21). Scholars recount that long before adopting an equity lens, the conventional method of understanding different kinds of transit riders is through the categorization of transit captive riders and choice riders (Jacques et al., 2013, p. 626). Riders who are transit captive are assumed to have no other viable transportation choices, and thus will take transit for their trips no matter the comfortability and service quality (Beimborn et al., 2003, p. 1). Choice riders are assumed to have different mode options but choose to take transit due to comfortability or convenience. Previous research has deemed that the majority of transit users in the North American cities are choice users, and this group of users are thus more valued by transit agencies (Krizek & El-Geneidy, 2007, p. 72). Conversely, scholars argue that transit agencies deprioritize services to captive riders, whose captivity leave them no choice but to remain loyal to public transit services (Beimborn et al., 2003). This framework for market segmentation is utilized by the TTC in transit service decision making as well. Public documents published as recently as 2003 feature market segmentation studies that group users based on the captive – choice dichotomy (Toronto Transit Commission, 2003, Appendix B).

While conventional measures of captivity revolved around car ownership rates, recent transit service planning studies trend toward a more nuanced measure and definition of transit captivity (van Lierop & El-Geneidy, 2017). Transit scholars who are critical of the captive – choice dichotomy have tried to advance the framework in two different ways. Beimborn et al. (2003) and Krizek & El-Geneidy (2007) are examples of studies that tried to supplement more nuance to the idea of captivity within the dichotomous framework. More recent works by van Lierop & El-Geneidy (2017) and Jacques et al. (2012) aimed at adding more dimensions and categories that go beyond captive and choice, which they deemed to be unfit for describing ridership behaviours. The overall direction that these studies took was to precisely define what a captive rider is. Jacques et al. (2012) emphasized that captivity does not directly correlate to negative trip experiences, and that captive riders can very much be well-served by transit services. Van Lierop & El-Geneidy (2017) further explored the idea of a well-served captive rider and suggested that a third category of captive-by-choice riders be adopted. This new category relies on household income as a variable to delineate those who do have many transportation choices but chooses to take transit because they are very well served by public transit. This delineation has implications for transit service planning and equity, as it encourages planners to prioritize those who are truly captive to public transit, rather than those who are ostensibly captive (van Lierop & El-Geneidy, 2017, p. 37).

This synthesis provides an overarching framework for the following research and analysis, as well as an appropriate starting point for the definition of captivity used herein. This report aims to adopt an understanding of captivity that is socio-spatially multivariate, but given the limited scope of this research, the report will not attempt to theoretically reinvent market segmentation frameworks. Rather, this study investigates true transit captivity for its potential as a label for areas that are socio-spatially vulnerable, reflected by the area's poor transit accessibility and connectivity. The delineation between different categories of riders who are not truly captive is not included within the scope of this study.

Stage 1: Defining Captivity and Selecting Study Traffic Analysis Zones

Methodology

The first stage of this report focuses on defining transit captivity and then using this definition to identify Traffic Analysis Zones (TAZs) for further study. The definition of transit captivity used to select TAZs is derived from previous researchers' definitions of transit captivity and verified using statistical analysis. This socio-economic definition of captivity was then combined with geographic data relating to TAZs' access to transit to further narrow this report's definition of captivity.

Looking first at socio-economic variables, this report's definition of transit captivity focused largely on car ownership rates and household income. Previous researchers highlighted both sets of variables as key determinants of captivity (Beimborn et al., 2003; Delbox & Curie, 2011; Jacques et al., 2013; van Lierop & El-Geneidy, 2017). Based on the work of these researchers, this report assumes that transit riders who own cars or who have greater household incomes have greater choice in their decision to use public transit. Contrasting this, riders who do not own an automobile or who have low household incomes have less choice in their use of transit, and can be considered captive.

This report considers these two socio-economic variables at the scale of the Traffic Analysis Zone (TAZ). The TAZ is used to aggregate household and trip data from the Transportation Tomorrow Survey (TTS) and is the smallest geographic area at which data is publicly available. For statistical analysis and to confirm variable selection, this study extracted several variables from the TTS. Selected socio-economic variables included household car ownership and household income, as well as demographic information about constituent households. Alongside this data, this study extracted trip data relating to all journeys made during the weekday morning peak hour (8:00 – 9:00 AM).

This report also incorporated geographic variables relating to each TAZ's access to rapid transit. Point data taken from Toronto Open Data and Metrolinx Open Data was used to plot all TTC Subway, GO Rail, and UP Rail stations within the City of Toronto. TAZs within 800-metres of these stations were considered to be within the rapid transit network. This report also considered TAZs in downtown Toronto, represented by Planning District 1, to be within the rapid transit network due to their ease of access to streetcar services. The selection of an 800-metre buffer was based off existing research and the definition of walkability used in the Metrolinx 2041 Plan.

To confirm the selection of socio-economic and geographic variables, this study relied upon statistical methods. T-distribution models were used to construct and confirm hypotheses about the relationship of transit ridership to socio-economic (car ownership rates, household incomes above $100,000 and household incomes below $40,000) and geographic variables (within or outside of RTN Region). This research used the two-tailed t-test to see if the mean is significantly greater or less than the mean. The P-value indicates the accuracy of the null hypothesis, the three hypotheses being: high income causes low transit ridership, high income surges the car ownership rate, and that low car ownership encourages high usage of transit. All three hypotheses were proven. P values >0.05 indicates that alignment with the null hypothesis (table 1) showing that households without car ownership see higher usage of transit even when located beyond the rapid transit network.

Ultimately variables including the proportion of the population aged under 24-years old, the proportion of the population aged over 65-years old, and the proportion of people with valid drivers' licenses showed poor relationships. Thus, they were not used to delineate captive TAZs, despite having been used to describe captivity by previous researchers (Delbosc & Currie, 2011; Jacques et al., 2013, p.634).

Correlations	Relationship between High Income cause low transit ridership	Relationship between High income and surge of vehicle ownership	Relationship between no vehicle ownership and increase of transit ridership
Within RTN Region	P - Value = 0.1912	P -Value = 0.5423	P - Value = 0.095511
Outside of RTN Region	P -Value = 0.007108	P - Value = 0.006346	P - Value = 0.0004761

Table 1: P-values to confirm correlation between socioeconomic variables and transit usage rate

<u>Results</u>

Based on the variables described above, this study selected twenty-one TAZs for further analysis (see Figure 1). These twenty-one TAZs had the lowest rates of car ownership in the City of Toronto, making up the top decile of low car ownership and each having over 30% of households not possessing an automobile. From these twenty-one TAZs, twelve could be characterized as "captive" due to their overall low car ownership and low household incomes. Ten, however, could be characterized as "choice". Despite their low car ownership, these TAZs had generally high household incomes.

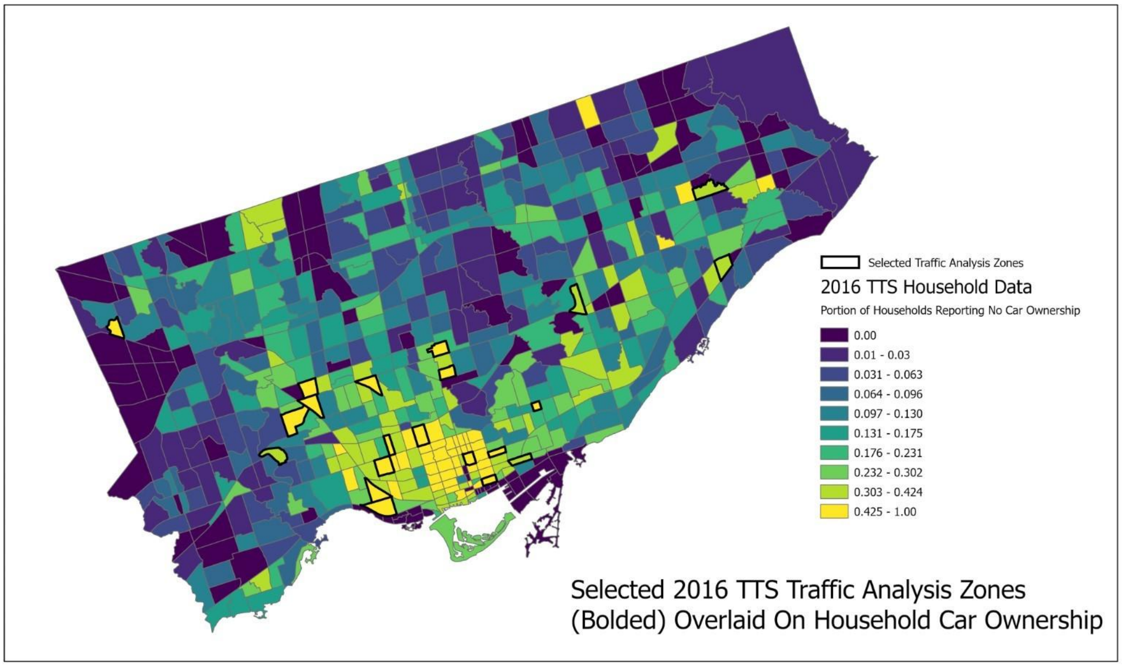


Figure 1: Selected Traffic Analysis Zones

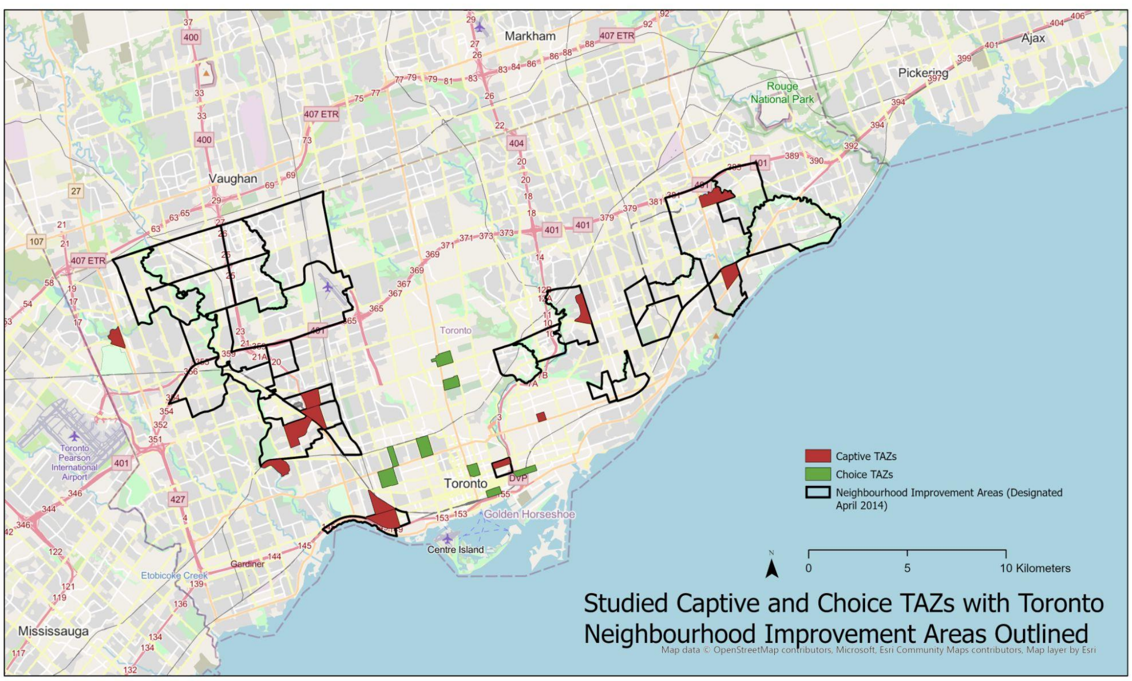


Figure 2: Selected Traffic Analysis Zones coded into captive and choice and overlaid on Toronto's neighbourhood improvement areas

Considering the geographic variable and access to transit, there was a clear division between captive and choice TAZs' access to the rapid transit network. Only three of the twelve captive TAZs were in proximity to the rapid transit network and only one of the twelve fell within Planning District One. This is sharply contrasted with the selected choice TAZs, of which nine of ten were within the rapid transit network.

Stage 2: Determining Connectivity and Assessing Change During Pandemic

While the accessibility of transit services for any TAZ is an important indicator of how well-served a neighbourhood is by transit, connectivity is a rather dynamic variable that is sensitive to changes in transit service planning. Welch & Mishra (2013) argued that connectivity is an important measure of the adequacy of transit service. It can be used to infer how well a potential rider can move about the city using real-time data on transit service supplies (p.31). Such a measure of connectivity can thus be used to visualize and quantify the changes in transit service supplies and how it affects individual TAZs. This section aims to compare transit connectivity across TAZs of varying socio-spatial statuses, as well as quantifying how transit connectivity has been affected by service reductions during the COVID-19 Pandemic (Toronto Transit Commission, 2020).

<u>Methods</u>

Transit-sheds derived from archived GTFS data were used to examine transit service levels as well as changes in transit service levels during the COVID-19 pandemic. Archived GTFS data from February 2020 was used to show transit service pre-COVID-19 while GTFS data from April 2020 was used to model transit service levels following the initial round of pandemic service reductions.

Transit-sheds were constructed for 60-minute combined walk and transit trips departing all twenty-one of the study TAZs. These were modelled solely for journeys departing during the weekday morning peak hour (8:00 - 9:00 AM). This time period allows the connectivity calculations to broadly match up with both existing scholarship and key metrics in the Metrolinx 2041 Plan. Once constructed, the transit-sheds were connected to TAZ-scale employment and trip data extracted from the 2016 TTS. This allowed examination of the numbers of jobs accessible within each transit-shed, as well as the percentage of trip destinations present within the transit-shed. The jobs figure was derived from TAZ employment figures found in the 2016 TTS while the destination figure was derived from origin-destination matrices.

Origin-destination matrices constructed from the 2016 TTS data were a valuable tool for understanding the transit needs of TAZs. By mapping all trip destinations from each study TAZ, this research was able to determine what percentage of trips fell within the 60-minute transit-shed, and could be considered reasonable transit commutes. It was particularly of note what percentage of transit trips were made outside of the 60-minute transit-shed as these can be assumed to be made by extremely captive riders. This study further used this origin-destination data to hypothesize that TAZs with a high percentage of transit-based trips beyond the 60-minute transit-shed are inadequately served by transit.

Having considered the pre-COVID transit connectivity of the study TAZs, this study then sought to examine how the pandemic affected transit connectivity for different communities. To do so, archived GTFS data from April 2020 were used to construct a second set of transit-sheds. These were representative of the initial set of service reductions made due to the COVID-19 pandemic. The main hypothesis here was that some neighbourhoods received a disproportionate amount of service reductions. To determine if the hypothesis was correct, the study then looked at the differences in the February 2020 and April 2020 transit-sheds and specifically considered the number of employment centres within each transit-shed, recording the decreases seen by each TAZ.

Results

Results from comparing pre-pandemic GTFS maps show that while the average number of employment positions in TAZs identified as predominantly choice neighbourhoods is around 1,080,000, that of captive neighbourhoods is around 783,000 (See Appendix A). This indicates that prior to the pandemic, captive neighbourhoods saw unequal outcomes - having adequate transit connections to only about 72.5% of employment opportunities relative to choice neighbourhoods. The Origin-Destination matrices also reveal that while 20% of all transit trips from captive neighbourhoods are for destinations outside of the 60-minute transit shed, only 13% of transit trips from choice neighbourhoods are bound for destinations outside of their 60-minute transit sheds. These two sets of data illustrate vastly different transit connectivities, which further reinforces the research's hypothesis that captive neighbourhoods are commonly poorly served by transit services, resulting in disproportionately low connectivity for socio-spatially vulnerable communities. Also observable from the connectivity analysis is the importance of spatial variables for predicting transit service quality. All high connectivity TAZs, regardless of their captivity, have adequate accessibility to rapid transit networks or proximity to Planning District 1. (See Appendix B for further information)

The April 2020 GTFS transit shed shows that while connectivity has decreased across all TAZs due to service readjustments during COVID-19, the decrease was more substantial for TAZs that are already considered transit captive and poorly served. As transit sheds for all TAZs shrunk in sizes, TAZs located within the rapid transit network or within Planning District 1 had retained on average 97.8% of the employment opportunities that were accessible in 60 minutes of total commute time as they had pre-COVID due to slightly lowered service frequencies.

Meanwhile TAZs representing neighbourhoods with lower transit accessibility only retained on average 92% of their pre-COVID employment opportunities. Therefore, for communities that were already socio-spatially disadvantaged by relatively poor connectivity prior to the pandemic, the pandemic has also disproportionately exacerbated poor transit connectivity for them.

TAZ 369 (Shown in Figure 4) is a clear example of a poorly served transit captive neighbourhood. This north Etobicoke TAZ has a very high proportion of low-income households (44%), with about half of total households also not owning automobiles. This TAZ experiences poor transit accessibility as it is located outside of the rapid transit network and Planning District 1. This TAZ also has poor connectivity, with only 281,000 jobs connected by 60-minute transit commutes, which is abysmal even when compared to the average for all captive TAZs, which shows connection to around 783,000 jobs. The region's captivity to transit is further highlighted as despite poor transit accessibility and connectivity, many commuters (50% of commuting trips) are destined for employment sites outside of the 60-minute transit-shed. TAZ 369 has also seen the largest decrease in connectivity during COVID-19. While the average decrease in total number of employment opportunities connected by transit for TAZs outside of the accessibility buffer is 8%, TAZ 369 has seen a 21% decrease in that measure. Visual comparison of its pandemic service decrease implies cutbacks in its range eastbound along the York Mills Road corridor; decreases in connectivity to Downtown Toronto can also be observed. TAZ 369 is perhaps an extreme case of a socio-spatially vulnerable neighbourhood that is transit captive but poorly served. Equitable transit service planning has to ensure that in times of crises, neighbourhoods such as TAZ 369 have adequate transit connectivity to reliably connect its socioeconomically vulnerable residents to and from employment sites.

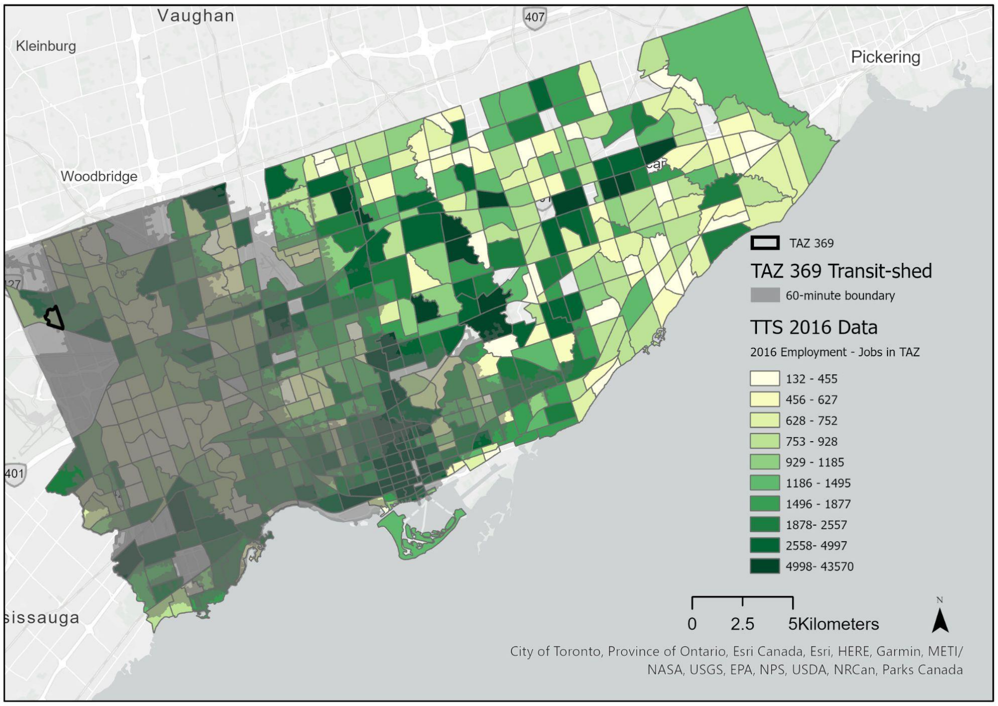


Figure 3: TAZ 369 Transit-shed and Employment Locations Map

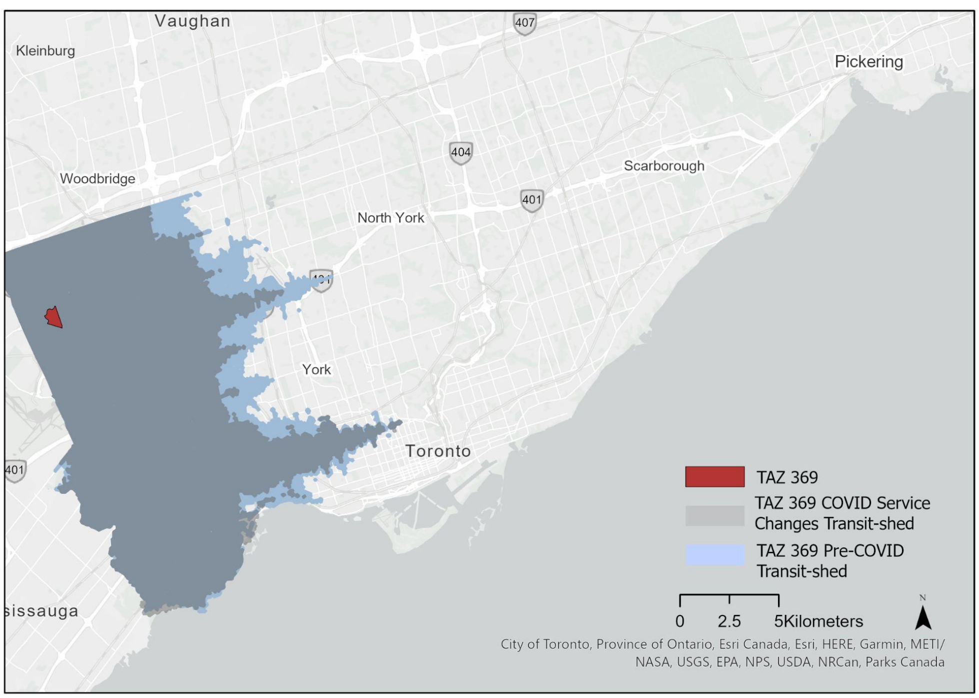


Figure 4: TAZ 369 Comparison of Pre- and Pandemic Transit-shed

Stage 3: Applying Captivity and Connectivity to Official Planning Documents, Supplemented by Interview with Industry Professionals.

Methods

This stage of analysis will assess how measures of equity as they are stated in TTC's 5 Year Service Plan (2019) compares to research results from stages 1 and 2. A key indication of how well the current equity framework works in identifying socio-spatially vulnerable communities can be tested by comparing TAZs that the study has identified as transit captive to the census tracts deemed as Neighbourhood Improvement Areas by the City of Toronto. Aside from GIS-based spatial analyses and reviewing planning documents for measures of transit service equity, this study also features a structured interview with transit service planners at the York Regional Transit agency (YRT), which is a transit agency that serves a major municipality in the Greater Toronto and Hamilton Region. Although the spatial scope of this research is on the City of Toronto and its transit agency, Toronto Transportation Commission, the input from industry professionals in adjacent municipalities can be just as helpful in constructing an understanding of the role that captivity plays in equitable transit service planning.

Due to time constraints, the interview had to be conducted in a strictly structured manner through email. The interviewee at York Regional Transit was asked about the agency's use of the concept of captivity in transit ridership segmentation. The interview then pivoted toward understanding how such a major transit agency in the GTHA employs socioeconomic factors to make transit service planning decisions, especially to react to sudden decreases in transit ridership inflicted by events like the COVID-19 pandemic. The last section of the interview calls back to recent transportation scholarly works on the importance of community engagement in transit service planning (Karner & Marcantonio, 2018). Questions were asked about how YRT approaches community engagement in service planning, as well as whether service reduction planning during the COVID-19 pandemic sought after community input.

Results

TTC's 5 Year Service Planning Document (2019) reveals that the TTC currently utilizes an equity framework for transit service planning (Toronto Transit Commission, 2019, p. 43). While the document does not explicitly state how the TTC defines equitable transit outcomes and what measures will be used to assess progress in promoting equitable transit outcomes, the document does refer to two new policies for advancing equity. The first and most recently adopted policy aims at promoting a new customer feedback program with an emphasis on consultation with communities identified as Neighbourhood Improvement Areas by the City of Toronto. A published timeline also illustrates the transit service planning team's initiative to prioritize Neighborhood Improvement Areas in service supply allocations starting in 2022 (p.76). Neighbourhood Improvement Areas consist of 31 census tracts in Toronto identified by social planners to be socioeconomically vulnerable (Social Policy Analysis and Research, City of Toronto, 2014). While the TTC does not have their own definitions of equity to assist with identifying socio-spatially disadvantaged areas, they do adopt socio-economic definitions for transportation equity from other agencies in the city. Neighbourhood Improvement Areas are also referred to in more contingent plans, such as TTC's COVID-19 Transition Plan (Toronto Transit Commission, 2020). Overcrowding in bus services due to decrease in transit service supplies was analyzed with equity considerations by prioritizing service supplies in corridors along Neighbourhood Improvement Areas. While the TTC is actively implementing equity measures based on Neighbourhood Improvement Areas as a definition of where socioeconomic inequities are spatially present, this section will argue later that this specific approach may not be adequate or accurate for illustrating transit-based equity needs across the city.

The interview with service planners working for the YRT revealed that while YRT does not employ a dichotomous practice of segmenting transit riders into captive and choice riders, many socioeconomic factors, such as unemployment rates, income, receipt of social assistance, secondary school graduation rates, ethnic marginalization, walkability, access to healthy food, and access to green space, inform the agency's operations and long-term official plans. The interviewee's avoidance of the term "equity" in discussions around socioeconomic considerations in transit service planning is in line with the region's 2016 transportation master plan, which also made no mention of the use of equity frameworks for transit planning (York Region, 2016). However, the interviewee suggested that the transit agencies that do not strive for an explicitly defined notion of equity may still be working toward equitable results through extensive stakeholder outreach and partnership building with community organizations and other government agencies. They also stated that community consultations have always been a part of the year-long analytic processes in determining service supply reallocations. Regarding service reductions made during the COVID-19 pandemic, they reiterated that community inputs are constantly collected to assess the potential for improvements in transit services. While the interviewed planner does not specify the exact weighting that socioeconomic data has compared to direct input from community members, it is also not clear whose input is sought after. This is because the interviewee often points toward community organizations, intergovernmental agencies, youth shelters, food banks, indigenous partners, and even large private employers as the stakeholders that agencies proactively seek to build partnerships with, while it is unclear if any outreach aims toward transit riders directly.

This approach toward equitable transit service planning is similar in nature to the approach TTC takes in that neither transit agencies explicitly articulate their definitions and measures of equity in planning, and that neither uses existing transit-specific data to pinpoint neighbourhoods in their service areas that are historically socio-spatially underrepresented and under-served. While TTC’s 5 Year Service Plan (2019) vows to apply an equity lens to transit service planning through extensive community engagement and prioritizing service supplies for Neighbourhood Improvement Areas, it must recognize that this designation was made with socioeconomic vulnerability and public health-based vulnerabilities in mind. Meanwhile, out of the 15 indicators used to determine the 31 census tracts (Figure 2) that make up Neighbourhood Improvement Areas, none of them are interested in the ability for a person to move around the city via public transportation (Social Policy Analysis and Research, City of Toronto, 2014). As the case study from Stage 2 has shown, certain TAZ 369 is a neighbourhood that is poorly served despite being transit captive. Yet such a socio-spatially vulnerable area is not spatially included as a Neighbourhood Improvement Area by TTC’s definition of equity. This is partly because their definition of equity does not revolve around the neighbourhood’s accessibility and connectivity to transit.

Conclusion and Avenues for Industry

This research report aimed to apply a socio-spatial framework in understanding transit service planning. The framework, built around variables such as income, car ownership, and accessibility to rapid transit nodes, successfully identified extremely transit captive TAZs. Recent GTFS data were then used to visualize and quantify changes in connectivity for each TAZ, all of which helped construct a snapshot of the adequacy of transit services during the pandemic to some of Toronto’s most socio-spatially disadvantaged neighbourhoods. The report then questions the viability of TTC’s equity framework featured in its 5 Year Service Plan, this analysis was further informed by an interview with transit service planners at the York Regional Transit agency.

Research findings indicate clear correlations between socioeconomic vulnerability and public transit uptake. However, TAZs that were more socioeconomically disadvantaged were observed to have less transit accessibility. This research's use of straight-line distance as the only indicator of accessibility leaves room for future explorations in this topic to expand on the definition of accessibility to create a more accurate framework. This report established that while some neighbourhoods' poor accessibility to rapid transit is tied to their socioeconomic makeup, connectivity, which is dictated by the allocation of transit service supplies, can nonetheless increase the quality of public transit services for socio-spatially disadvantaged TAZs.

The report found that while TTC's service planning team has taken efforts to increase service connectivity for certain disadvantaged neighbourhoods recognized as Neighbourhood Improvement Areas, the metric used to identify these areas should involve more transit-based indicators. This report's use of the concept of transit captivity has shown that there are indeed certain areas in the city that have not been identified as socio-spatially vulnerable by the TTC. In terms of making quick, spontaneous decisions about service adjustments in response to sudden shocks in transit ridership, the interview with transit service planners from YRT revealed the importance of stakeholder consultation as a service planning practice. It serves as a reminder that direct output from stakeholders is just as important and useful as socio-spatial analytics when it comes to long term strategic planning and solving real-time problems. However, and this can be valuable for future research initiatives, this report also questions whether transit riders are given enough representations in stakeholder consultations.

Ultimately, this report concludes that the TTC's equity initiatives in transit service planning can be improved. Its first initiative of public consultation should be mindful in centering on transit riders as the subject of consultation. The report also found that while TTC's use of Neighbourhood Improvement Areas as the spatial framework for its equity lens is an appropriate initiative for equity in service planning, actual transit-related indicators of socio-spatial vulnerabilities, such as transit accessibility or connectivity, should also be considered. This is highlighted by the exclusion of TAZ 369, which is justifiably one of the most poorly-served transit-captive TAZ, from Neighbourhood Improvement Areas, and therefore will not be considered for equitable distribution of transit service resources by the TTC.

This research report offers many insights into the way equity can be defined for the purpose of transit service planning by public transit agencies. This report recommends that transit agencies be cautious when adopting equity measures based solely on socioeconomic factors. This report instead recommends that transit agencies use a combination of transit service related data and extensive community consultation to map out regions in service areas that are socio-spatially vulnerable. This report also recommends that agencies consider connectivity alongside accessibility to the rapid transit network.

References

Beimborn, E. A., Greenwald, M. J., & Jin, X. (2003). Accessibility, Connectivity, and Captivity: Impacts on Transit Choice. *Transportation Research Record*, *1835*(1), 1–9. https://doi.org/10.3141/1835-01

Carleton, P. R., & Porter, J. D. (2018). A comparative analysis of the challenges in measuring transit equity: Definitions, interpretations, and limitations. *Journal of Transport Geography*, *72*, 64–75. https://doi.org/10.1016/j.jtrangeo.2018.08.012

Deboosere, R., & El-Geneidy, A. (2018). Evaluating equity and accessibility to jobs by public transport across Canada. *Journal of Transport Geography*, *73*(Complete), 54–63. https://doi.org/10.1016/j.jtrangeo.2018.10.006

Deboosere, R., El-Geneidy, A. M., & Levinson, D. (2018). Accessibility-oriented development. *Journal of Transport Geography*, *70*, 11–20. https://doi.org/10.1016/j.jtrangeo.2018.05.015

Delbosc, A., & Currie, G. (2011). Using Lorenz curves to assess public transport equity. *Journal of Transport Geography*, *19*(6), 1252–1259. https://doi.org/10.1016/j.jtrangeo.2011.02.008

El-Geneidy, A., Buliung, R., Diab, E., van Lierop, D., Langlois, M., & Legrain, A. (2016). Non-stop equity: Assessing daily intersections between transit accessibility and social disparity across the Greater Toronto and Hamilton Area (GTHA). *Environment and Planning B: Planning and Design*, *43*(3), 540–560. https://doi.org/10.1177/0265813515617659

Fan, Y., Guthrie, A., & Levinson, D. (2012). Impact of light-rail implementation on labor market accessibility: A transportation equity perspective. *Journal of Transport and Land Use*, *5*(3), 28–39.

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: Examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of Transport Geography*, *29*, 1–10. https://doi.org/10.1016/j.jtrangeo.2012.12.008

Grise, E., & El-Geneidy, A. (2017). Where is the Happy Transit Rider? Evaluating Satisfaction with Regional Rail Service Using a Spatial Segmentation Approach. *Transportation Research Part A: Policy and Practice*, *el g*, 24.

Jacques, C., Manaugh, K., & El-Geneidy, A. M. (2013). Rescuing the captive [mode] user: An alternative approach to transport market segmentation. *Transportation*, *40*(3), 625–645. https://doi.org/10.1007/s11116-012-9437-2

Kaplan, S., Popoks, D., Prato, C. G., & Ceder, A. (Avi). (2014). Using connectivity for measuring equity in transit provision. *Journal of Transport Geography*, *37*, 82–92. https://doi.org/10.1016/j.jtrangeo.2014.04.016

Karner, A., & Marcantonio, R. A. (2018). Achieving Transportation Equity: Meaningful Public Involvement to Meet the Needs of Underserved Communities. *Public Works Management & Policy*, *23*(2), 105–126. https://doi.org/10.1177/1087724X17738792

Krizek, K. J., & El-Geneidy, A. (2007). Segmenting Preferences and Habits of Transit Users and Non-Users. *University of South Florida, Center for Urban Transportation Research*.

Litman, T. (2002). Evaluating Transportation Equity. *World Transport Policy & Practice*, *8*(2), 66.

Metrolinx. (2018). *2041 Regional Transportation Plan*.

Social Policy Analysis and Research, City of Toronto. (2014). *Toronto Strong Neighbourhoods Strategy 2020 Neighbourhood Equity Index Methodological Documentation*.

Toronto Transit Commission. (2019). *5 Year Service Plan & 10 Year Outlook* (p. 105).

Toronto Transit Commission. (2020a). *2021 Annual Service Plan*.

Toronto Transit Commission. (2020b). *Chief Executive Officer's Report—December 2020 Update*.

Toronto Transit Commission. (2020c). *COVID-19 Transitioning from Response to Restart and Recovery* (p. 39).

van Lierop, D., & El-Geneidy, A. (2017). A New Market Segmentation Approach: Evidence from Two Canadian Cities. *Journal of Public Transportation*, *20*(1), 20–43.

Welch, T., & Mishra, S. (2013). A measure of equity for public transit connectivity. *Journal of Transport Geography*, *33*, 29–41. https://doi.org/10.1016/j.jtrangeo.2013.09.007

York Region. (2016). *The Regional Municipality of York Transportation Master Plan*.

Data Sources

2016 Transportation Tomorrow Survey. *Data Management Group*, 2021. Extracted from: dmg.utoronto.ca

Metrolinx GTFS Files. *Metrolinx*, February 2020. Extracted from: https://www.transit.land/operators

Metrolinx GTFS Files. *Metrolinx,* April 2020. Extracted from: https://www.transit.land/operators

Neighbourhood Improvement Areas Shapefile. *City of Toronto,* 2014. Extracted from: https://open.toronto.ca/dataset/neighbourhood-improvement-areas/

TTC GTFS Files. *Toronto Transit Commission*, February 2020. Extracted from: https://www.transit.land/operators

TTC GTFS FIles. *Toronto Transit Commission*, April 2020. Extracted from: https://www.transit.land/operators

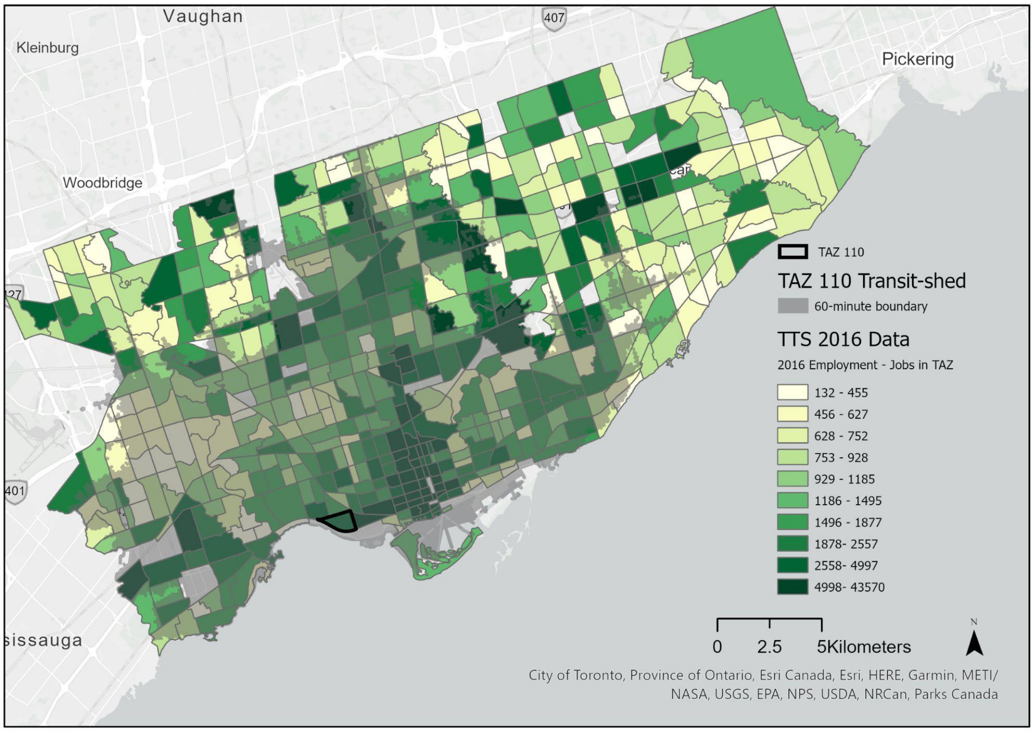
Appendix A: Key Statistics on Selected TAZs

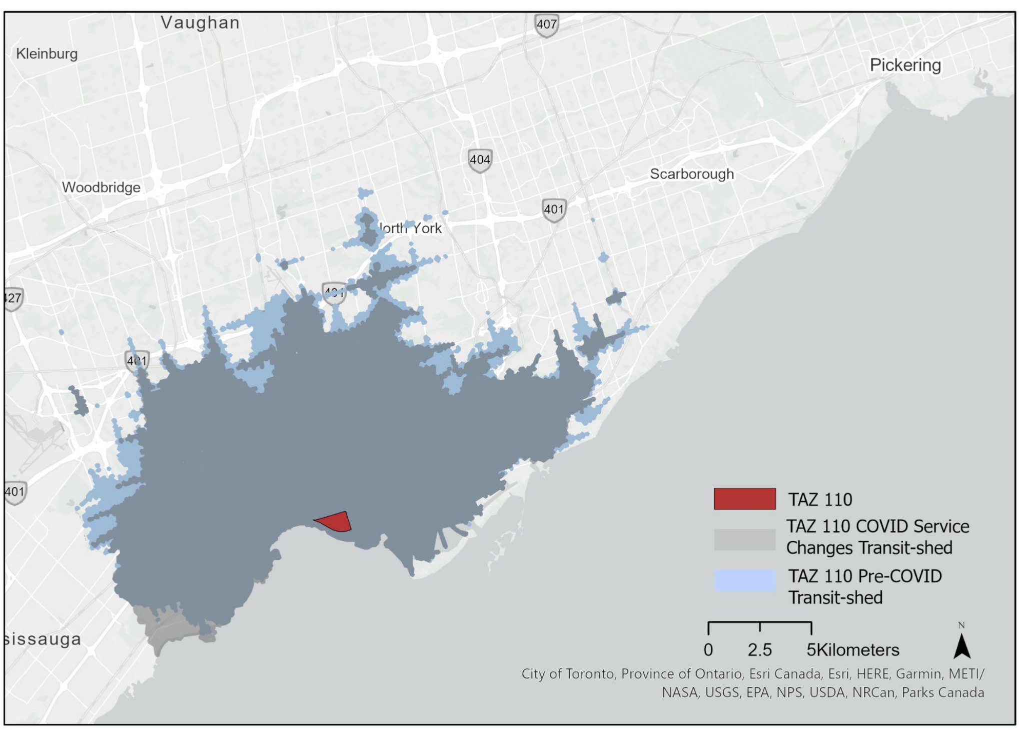
Traffic Analysis Zone of Household	HBW and HBS Transit	Portion of Households without Automobile	Portion of Households who are High Income (> $100,000 Annual Income)	Portion of Households who are Low Income (< $39,999 Annual Income)	In Current Rapid Transit Network
369	0.485	0.490	0.060	0.436	N
151	0.582	0.544	0.087	0.387	N
149	0.430	0.582	0.004	0.418	N
143	0.512	0.427	0.063	0.389	N
552	0.646	0.318	0.013	0.395	N
494	0.344	0.313	0.048	0.361	N
245	0.546	0.305	0.091	0.307	N
268	0.445	0.345	0.427	0.161	N
128	0.449	0.316	0.202	0.359	N
109	0.382	0.528	0.164	0.359	N
110	0.520	0.512	0.088	0.423	Y
26	0.449	0.475	0.252	0.270	Y
18	0.446	0.463	0.117	0.353	Y
72	0.362	0.441	0.329	0.151	Y
103	0.540	0.556	0.262	0.188	Y
101	0.576	0.469	0.125	0.298	Y
209	0.649	0.454	0.209	0.151	Y
275	0.365	0.529	0.103	0.482	Y
211	0.564	0.438	0.208	0.225	Y
38	0.387	0.562	0.198	0.260	Y

Traffic Analysis Zone of Household	Pre-COVID (FEB20) Jobs Access)	COVID (APR20) Jobs Access	Jobs Connectivity Change (APR 2020 Connectivity as % of FEB 2020 Connectivity)	Captive or Choice
369	217265	173769	0.800	Captive
151	793950	722353	0.910	Captive
149	832409	820470	0.986	Captive
143	834752	772792	0.926	Captive
552	416624	380295	0.913	Captive
494	312849	300522	0.961	Captive
245	929587	902961	0.971	Captive
268	986634	820335	0.831	Choice
128	867474	864949	0.997	Captive
109	845005	807842	0.956	Captive
110	846361	800891	0.946	Captive
26	974358	946353	0.971	Choice
18	1041444	1000628	0.961	Captive
72	1131335	1150268	1.017	Choice
103	1087029	1088622	1.001	Choice
101	1096660	1056625	0.963	Choice
209	1088181	1065022	0.979	Choice
275	1139650	1115060	0.978	Captive
211	1059858	1040363	0.982	Choice
38	1099711	1082644	0.984	Choice

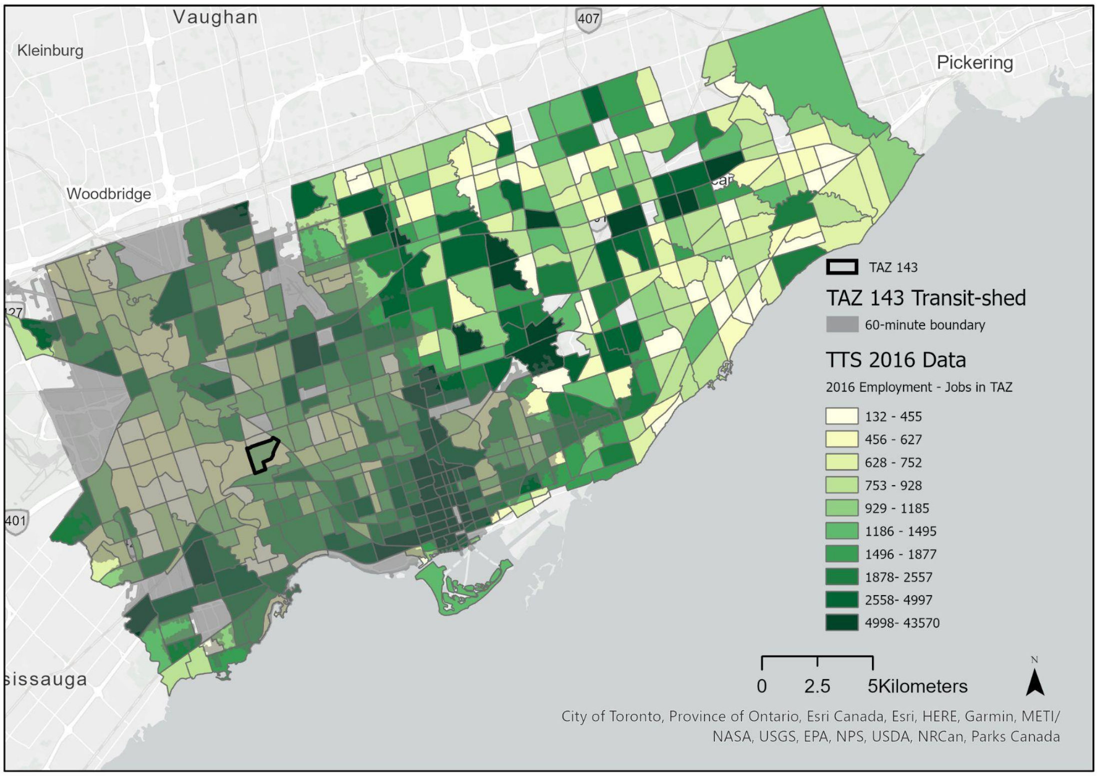
Appendix B: Additional Mapping and Analysis of Studied TAZs

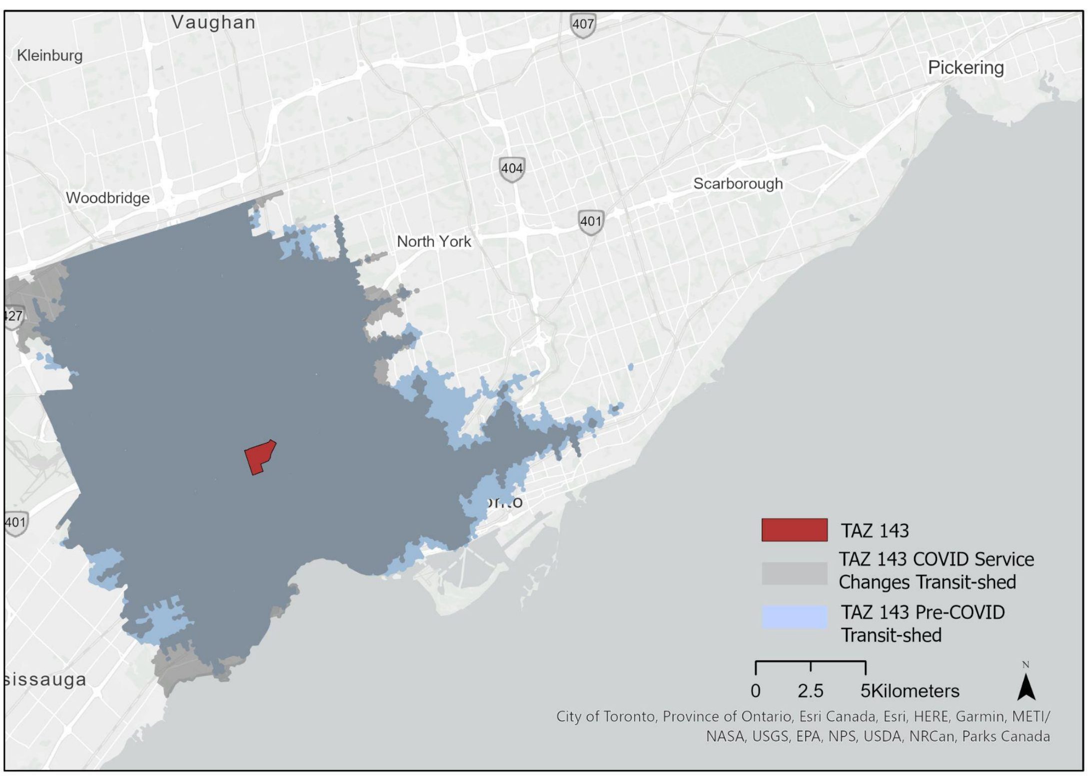
TAZ 110 Mapping



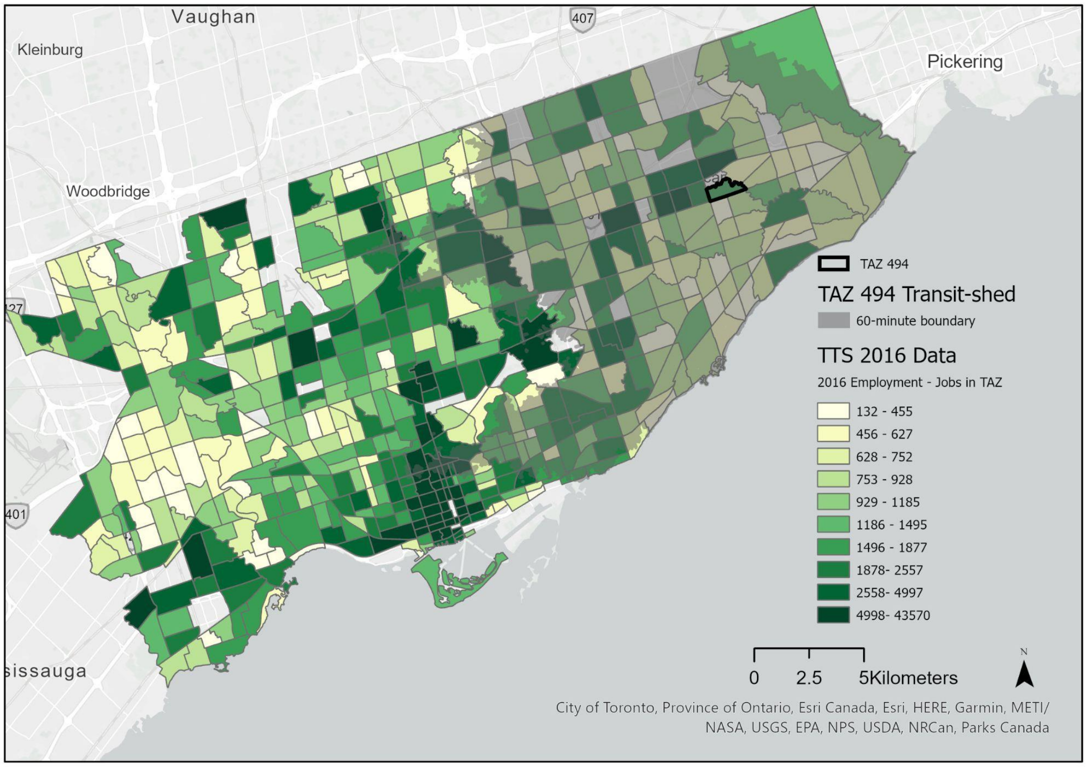


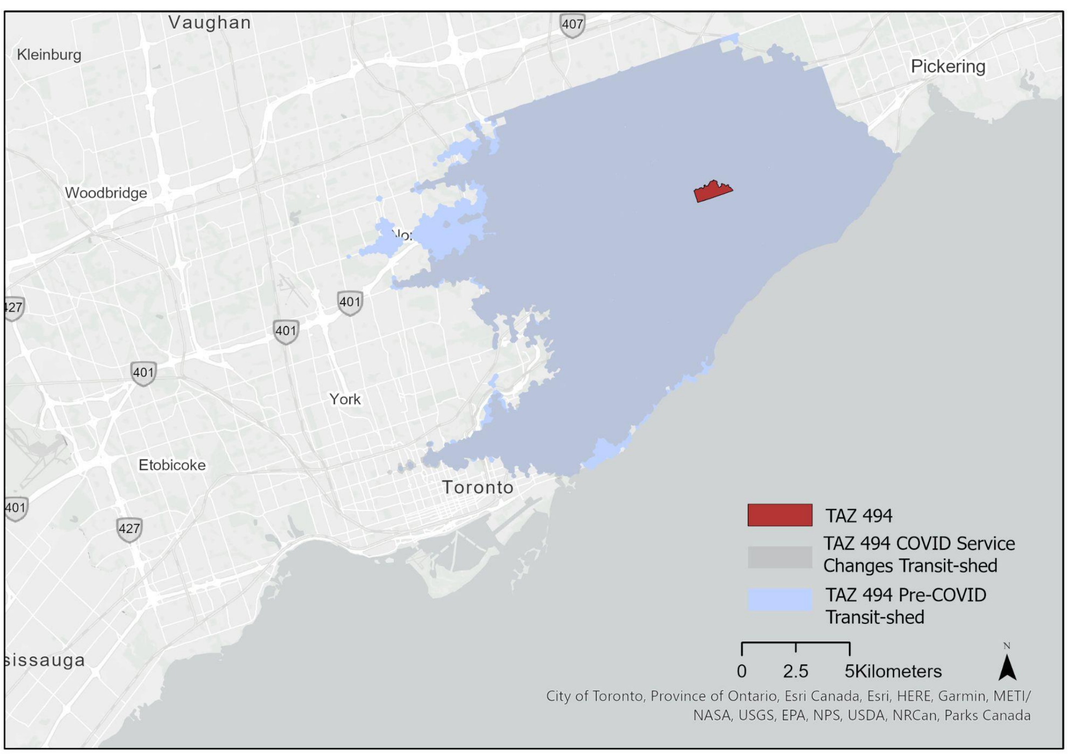
TAZ 143 Mapping





TAZ 494 Mapping





Appendix C: Statistical Methods:

Relationship between High Income cause low transit ridership

```
# perform two sample t-test for high-income and low-income groups
t.test(high_inc_transit, low_inc_transit)
```

```
##
##  Welch Two Sample t-test
##
## data:  high_inc_transit and low_inc_transit
## t = 1.318, df = 81.999, p-value = 0.1912
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.005546693  0.027327477
## sample estimates:
##  mean of x  mean of y
## 0.09654511 0.08565472
```

The P-value prove that there is no significant difference between low income and high income households # in how often they use transit with a p-value of 0.1912.

Relationship between High income and surge of vehicle ownership

```
t.test(high_inc_vehicle, low_inc_vehicle)
```

```
##
##  Welch Two Sample t-test
##
## data:  high_inc_vehicle and low_inc_vehicle
## t = 0.61255, df = 66.861, p-value = 0.5423
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.01500463  0.02829106
```

1

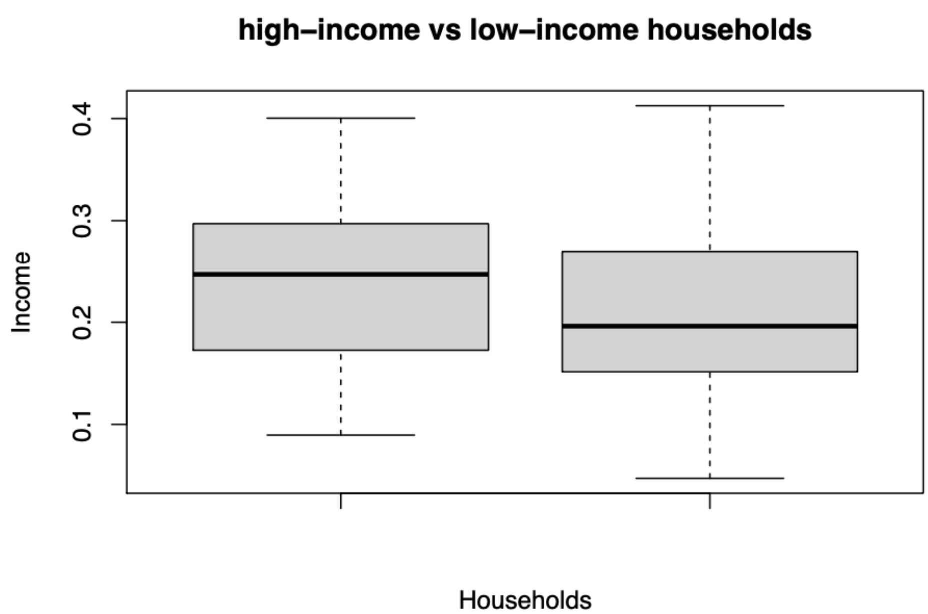
Low car ownership encourages high usage of transit ridership

```
t.test(no_vehicle , transit)
```

```
##
##  Welch Two Sample t-test
##
## data:  no_vehicle and transit
## t = 4.2742, df = 17.629, p-value = 0.0004761
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  0.1087839 0.3197345
## sample estimates:
## mean of x mean of y
## 0.5364374 0.3221782
```

```r
## Visualize the data ##

boxplot(high_inc, low_inc, data = dataset,
main = "high-income vs low-income households",
xlab="Households", ylab="Income")
```




```r
summary(cars)
```

```
##      speed           dist
##  Min.   : 4.0   Min.   :  2.00
##  1st Qu.:12.0   1st Qu.: 26.00
##  Median :15.0   Median : 36.00
##  Mean   :15.4   Mean   : 42.98
##  3rd Qu.:19.0   3rd Qu.: 56.00
##  Max.   :25.0   Max.   :120.00
```

Proportion of high income and low income that takes place in the first two hypotheses.