Research Report

Vehicle for Hire Bylaw Review

Report 5: The Relationship Between PTC and Public Transit: Descriptive Analysis

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UTTRI TECHNICAL SUPPORT FOR THE CITY OF TORONTO VEHICLE FOR HIRE BYLAW REVIEW

Report No: 5

The Relationship Between PTC and Public Transit: Descriptive Analysis

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1 Introduction

This report is a technical support document for the City of Toronto's *Vehicle for Hire Bylaw Review*, prepared by the University of Toronto Transportation Research Institute (UTTRI). It aims to investigate the relationship between Private Transportation Companies (PTC) and public transit in the City of Toronto. The analysis includes a comparison of the travel patterns of PTC and public transit users for different trip markets over time of day, impacts of subway service disruption on PTC usage and comparison of the travel attributes (e.g. travel time and a number of transfers) of PTC and public transit for equivalent trips.

The investigation was based on multiple datasets including 17,837,489 records of PTC trips made in the City of Toronto from Sept 2016 to Apr 2017, 2016 Transportation Tomorrow Survey (TTS) data on weekday public transit ridership in Toronto, TTC subway disruption log data from Sept 2016 to Apr 2017, and the estimated transit travel attributes of the fastest transit alternative of the PTC trips using the OpenTripPlanner API.

The rest of the report is organized as follows. Section 2 presents the literature review of previous studies on the topic of PTC and public transit. Sections 3 to 5 illustrate the investigation of the relationship between PTC and public transit. Specifically, Section 3 presents the comparison of travel patterns of the riders of the two modes for different trip markets across a typical 24-hour weekday. Section 4 investigates the impacts of subway disruptions on the demand for PTC usage. Section 5 explores the differences in transportation service of PTC and public transit in terms of total travel time, in-vehicle travel time, out-of-vehicle travel time and walking distance. Moreover, the section incorporates temporal and spatial analyses which investigate the temporal and spatial variance in the travel attributes difference. Section 6 provides a summary of the key findings of the descriptive analysis completed for this report.

2 Literature Review

PTC services, such as Uber and Lyft, have experienced rapid growth in the past few years. Due to their fast, convenient, reliable and door-to-door services, the PTC ridership rose from 1.9 to 4.2 billion from 2016 to 2018 in the United States (Schaller, 2018). However, many North American transit agencies have reported stagnation and even decline in public transit ridership in recent years. For efficient city transportation planning, it is important for transit agencies and transportation planners to understand how this emerging transportation service is affecting the current public transit system.

Due to the sparse availability of PTC data, limited research has been done thus far on the effect of ride-hailing services on public transit. However, the few existing studies completed on this topic have helped establish a baseline understanding of this question. Generally, these studies have concluded three different relationships: ride-hailing complements public transit by solving the first and last mile problem and by helping fill the temporal and spatial gaps in transit service (Cohen & Shaheen, 2018; Hoffmann, 2016; Murphy, 2016); ride-hailing diverts passengers away from public transit by providing a better service (Graehler, Mucci, & Erhardt, 2019; Rayle, Dai, Chan, Cervero, & Shaheen, 2016; Schaller, 2018); ride-hailing both complements and substitutes public transit with the impacts varying according to the operating conditions (Clewlow & Mishra, 2017; Hall, Price, & Palsson, 2017; Mucci, 2017; Nelson & Sadowsky, 2017).

A study by the American Public Transportation Association (APTA) (Murphy, 2016) examined the relationship between public transit and shared modes including PTC. A survey was implemented on shared mobility users across seven cities in the U.S.: Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle and Washington, DC. The findings of this study suggest that public transit and PTC have different targeted markets. A majority of the PTC trips are generated during the evening and late-night hours, most likely due to poor transit service available at this time. Furthermore, if PTC service had not been available, 34% of the users would have chosen private driving, 24% would use carsharing and only 14% of the respondents claimed to use public transit instead. As a result, the study suggests that PTC is complementing public transit and is improving urban mobility.

Comparatively, another study (Schaller, 2018) performed a descriptive analysis of PTC and public transit based on recently published research and data from a national travel survey in the U.S. The survey results showed that 60% of PTC users would have used public transit if the PTC service had not been available, and 40% would have taken a private vehicle or a taxicab. The author concluded that due to PTC service being faster, more reliable, and convenient than non-auto modes, ride-hailing is attracting passengers mainly from public transit, cycling and walking rather than driving. The paper also explained that private auto owners mainly use ride-hailing when parking is an issue or to avoid drinking and driving.

Similarly, Rayle et al. (Rayle et al., 2016) carried out a survey on 380 PTC users at three "hot spots" for PTC services in San Francisco. The survey results showed that 33% of the respondents would have taken public transit if PTC had not been available. Furthermore, based on the pickup and drop-off locations of the surveyed trips provided by the respondents, Rayle et al. found that 28% of the trips started and ended within walking distance from a rail station, and 81% of the trips had both the origin and destination located within a bus stop accessible area. The authors also estimated the transit travel time of the surveyed PTC trips using Google Directions API. They found that 66% of the trips would have been at least twice as long if taken by public transit. However, there are some limitations with regards to the sample size, survey time and locations, which might cause additional errors in the results.

Sadowsky and Nelson (Nelson & Sadowsky, 2017) completed a descriptive analysis study that stood apart from previous research because they adopted regression methods to compare transit ridership before and after Uber and Lyft started their operation in major U.S. urban areas. By using a discontinuous regression model, the authors found that the initial entry of Uber helps increase transit ridership by providing access to and from transit stops. However, after the subsequent entry of Lyft, transit ridership started falling into a decline. The authors hypothesized that this result occurred due to competitive pricing between the two companies. Lower prices made ride-hailing trips more cost-effective and people transitioned to using ride-hailing services for entire trips rather than combing it with public transit.

Unique from other studies, Mucci (Mucci, 2017) utilized both transit and PTC ridership data to evaluate the impacts of PTC on bus and rail usage. The author developed rail-stop and bus-stop direct ridership models. These models included the average daily number of PTC pickups and drop-offs within walking distance to a stop as one of the independent variables. The coefficient and significance of the PTC ridership variable suggest that PTC is associated with a 7% increase in rail ridership but a 10% decrease in bus ridership.

Unfortunately, the majority of the previous studies on PTC suffered from a lack of detailed trip level PTC data necessary for rigours analysis. Therefore, most of those are based on survey results at aggregate scales, such as a city scale or a transit agency scale. In addition, previous research did not take the time-variant and space-variant effects into account when investigating the relationship between PTC and public transit.

In this study which supports the VfH Bylaw Review project, it is very beneficial to have detailed PTC trip information (e.g. coordinates, date, travel time and trip distance) over time (from Sept 2016 to Apr 2017) for our investigation. However, due to time constraints, comparable detailed transit route and stop ridership has not been acquired from the Toronto Transit Commission (TTC) yet. Given this situation, the TTS ridership for an average weekday in the fall of 2016 is used in Section 3 in the comparison between demand for PTC and transit for multiple trip markets by the time of day. In Section 5, we estimated for each PTC trip in Toronto the transit service attributes (e.g. travel time and the number of transfers) of the best transit option to travel between the same origin and destination pairs and at the same time of day. The analysis of the difference between PTC and transit service shows if there is a substantial travel time-saving in favour of PTC versus public transit and how competitive public transit services can be with PTC.

3 Comparison between Travel Patterns of PTC and Public Transit Users

Transit is an efficient and relatively inexpensive transportation alternative for people to move around within the City of Toronto. The Toronto Transit Commission (TTC) provides all-day, every-day transit service in the city. Based on the TTC service standards (TTC, 2017), the transit network is designed so that 90% of the population and employment is within a 400 metre (5 minutes) walk to transit services seven days a week. Daily transit ridership has strong commuter patterns. As the TTS data shows, 42% of commuters ride public transit to work every day. In comparison, only 0.5% of commuters use PTC to get to/from work. Different from transit demand, PTC is known as a prevailing mode to get to/back from social activities during evenings (Young & Farber, 2019; Schaller, 2018). Therefore, it is expected that transit and PTC will have distinct differences in their respective travel patterns across the day.

To better understand the spatial variation in travel patterns, four categories are defined: trips within Planning District 1 (i.e., the downtown area), trips with only the destination in PD 1, trips with only the origin in PD 1 and trips outside of PD 1. These four types of trips represent different trip markets in Toronto with distinct transit service characteristics (see Figure 1 to Figure 4).

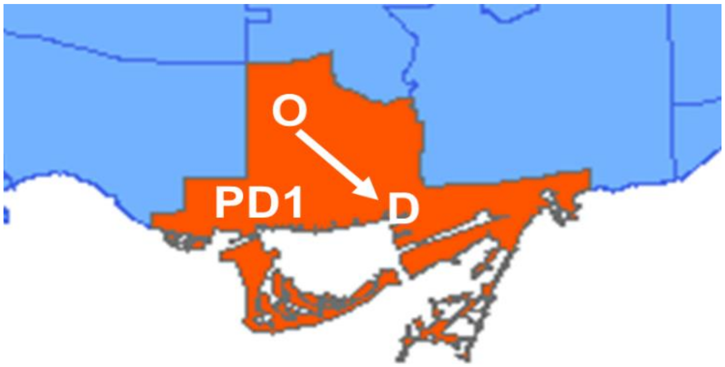

Figure 1 Trip market 1: trips within PD 1

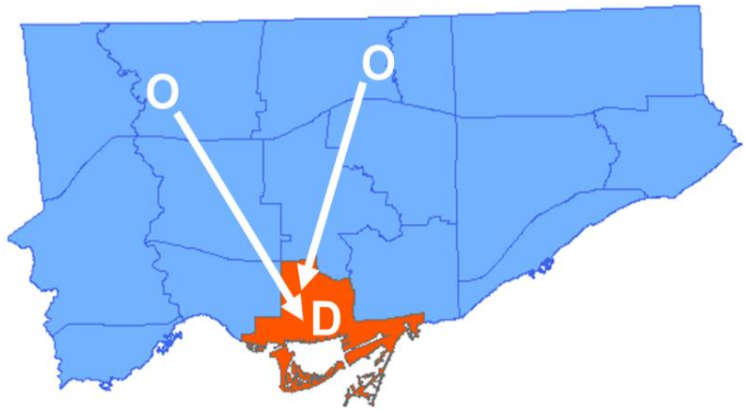

Figure 2 Trip market 2: trips with only destination in PD 1

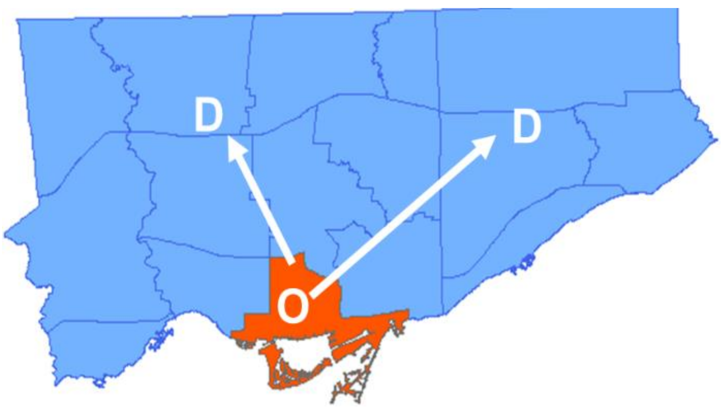

Figure 3 Trip market 3: trips with only origin in PD 1

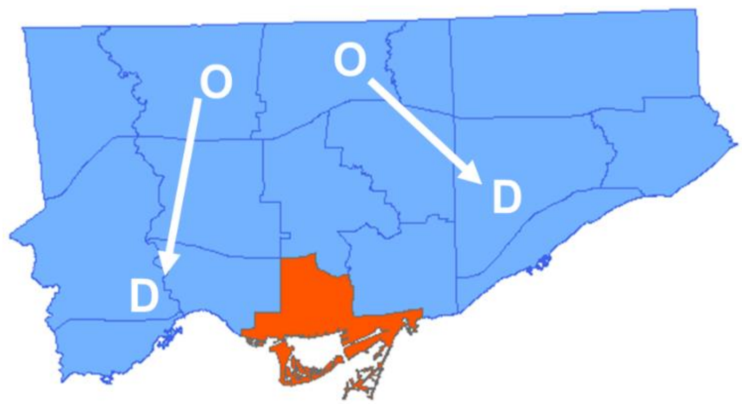

Figure 4 Trip market 4: trips outside of PD 1

3.1 Comparison of Weekday Ridership

In this section, 2016 TTS data and PTC data provided by the City of Toronto are used to compare the weekday ridership of public transit and PTC. Based on the 2016 TTS, public transit ridership on a regular weekday in the fall of 2016 was 1,335,441 person trips, while the average weekday ridership of PTC in the fall of 2016 (based on the PTC data) was 60,733 person trips, amounting to 5% only of the transit ridership.

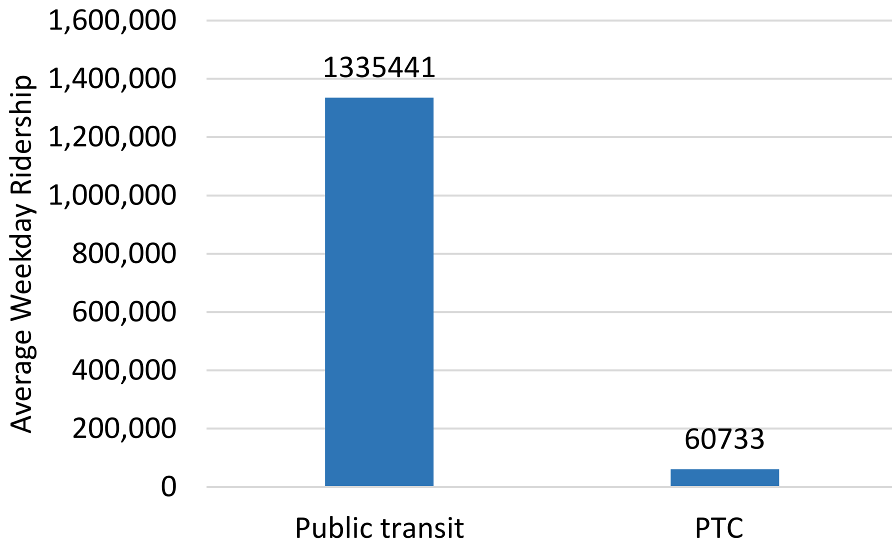

Figure 5 Average weekday ridership of public transit and PTC

The breakdown of PTC and public transit trips by the trip market are displayed in the following charts (see Figure 6).

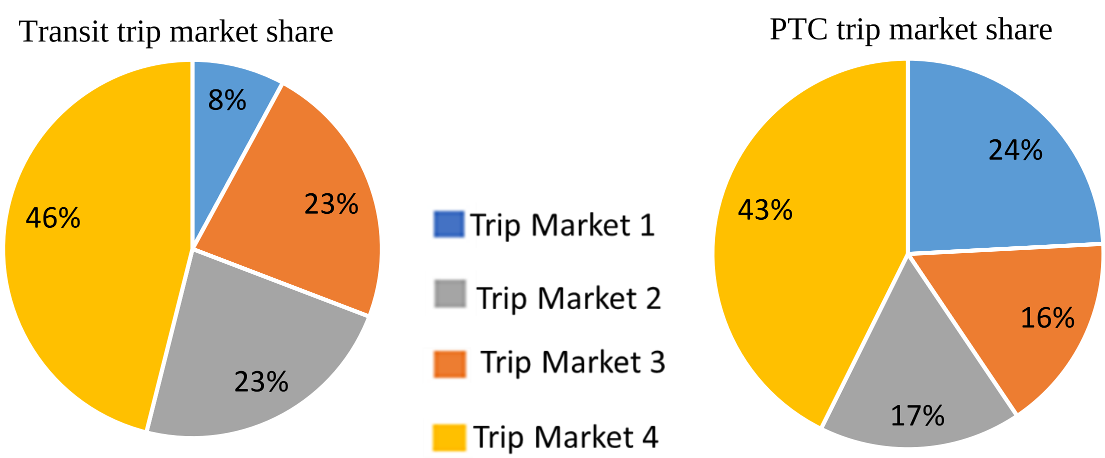

Figure 6 Trip market share of transit and PTC (2016)

The charts show that transit and PTC have similar percentages of their trips travelling outside of PD 1 (trip market 4). It can also be seen that transit has a larger portion of its trips with only one end in PD 1 (trip market 2 and 3) than PTC. However, the major difference occurs in trip market 1. Almost one in four weekday PTC trips have both ends in PD1, while the corresponding trip market accounts for 8% of daily transit trips. It is noteworthy that PD1 attracts a relatively high percentage of PTC trips despite having a dense multimodal transit network with the subway at its core, suggesting a competitive relationship between transit and PTC in the downtown area. Relative to transit, PTC provides faster services but is more expensive. For example, an UberXL trip charges a $5 base fare, $1.55 per km and $0.35 per minute (http://uberestimate.com/prices/Toronto). In contrast, transit only costs $3.25 per trip (cheaper if using Presto or monthly pass). Since trips within the downtown area are usually short in distance, PTC becomes cost-effective and it seems many people choose PTC over transit due to better services and competitive pricing.

3.2 Comparison of Hourly Ridership for Different Trip Markets Across Time of Day

In this section, hourly ridership of PTC and public transit for a regular weekday is plotted over time and then compared across the four different trip markets (see Figure *7* to Figure *10*).

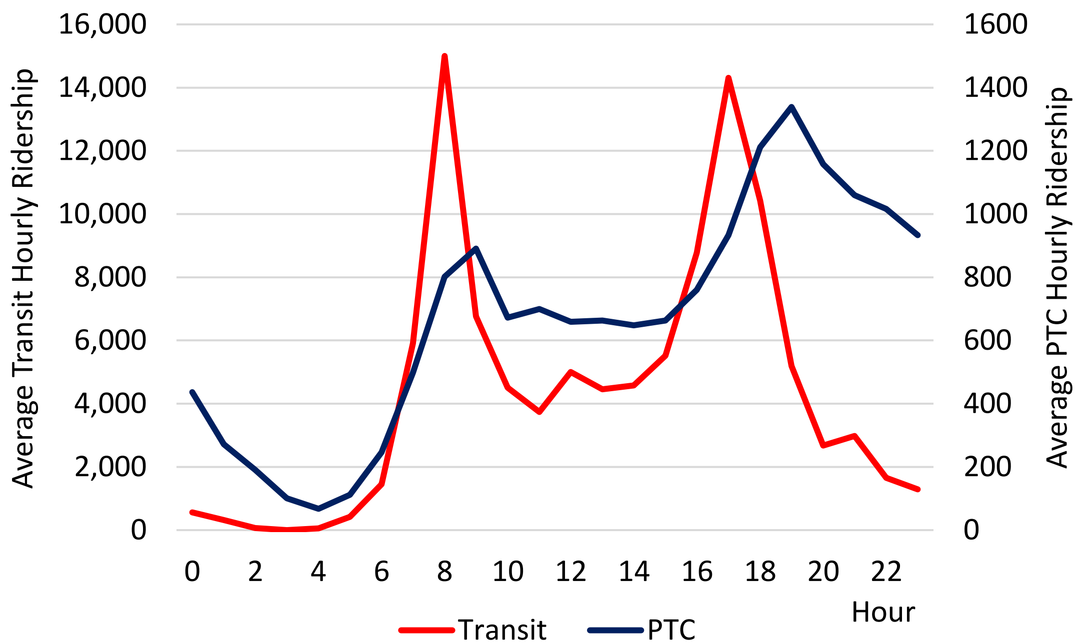

Figure 7 Hourly ridership for trip market 1 (Trips within PD 1)

The travel pattern for trip market 1 shows that transit and PTC both have clear commuter patterns with two distinct peaks, one in the morning and one in the afternoon/evening. However, PTC peaks are shifted later relative to the transit peaks. For instance, the transit afternoon peak happens around 5 pm, but the PTC' evening peak occurs at 7 pm. This could be explained by the different travel purposes. The transit afternoon peak occurs around 5 pm, around the time of leaving work and using public transit to go home. However, the PTC peak occurs around 7 pm, possibly serving trips to/from social activities such as dinner or watching a sports game. In terms of the maximum hourly ridership, it occurs at different peak periods for the two modes. PTC has a higher peak in the evening than in the morning, while transit has a higher peak in the morning than in the afternoon, which might also be explained by different travel purposes.

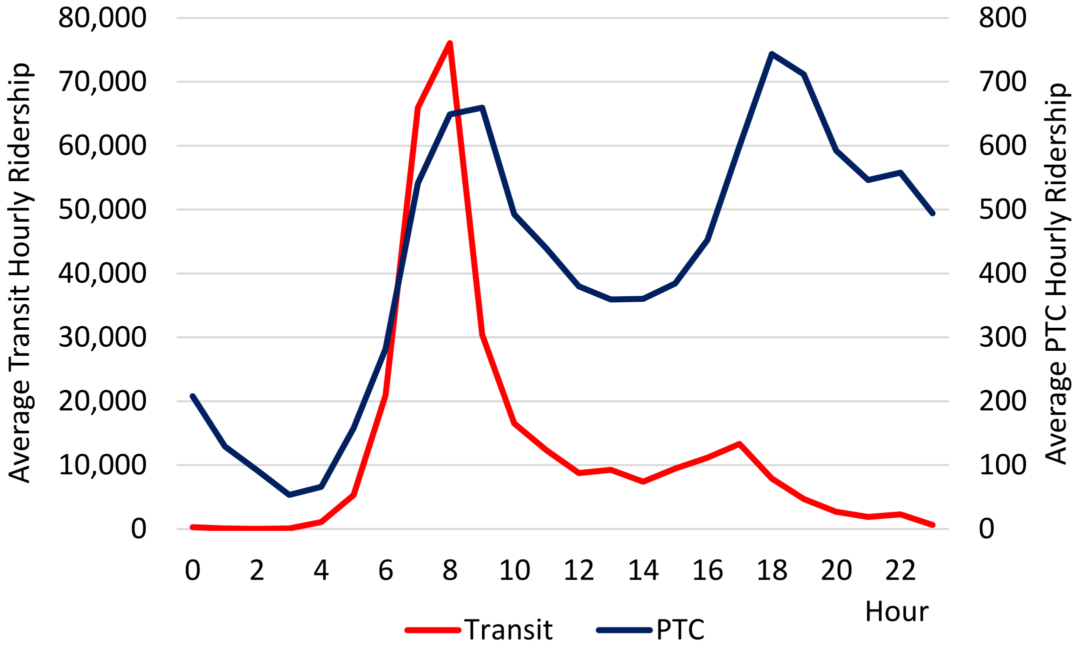

Figure 8 Hourly ridership for trip market 2 (Trips with the only destination in PD 1)

For trip market 2, which represents trips coming to downtown from other planning districts, transit has a significantly high morning peak but a low afternoon peak. This result conforms with prior expectations since Toronto's downtown area is the city's main employment centre and public transit services into downtown are abundant and of high quality. As such, many commuters use transit in the morning to travel from home to work in PD 1. On the other hand, PTC to downtown has two comparable peaks, in the morning and in the evening. This indicates that there are a number of people using PTC to commute in the morning and also plenty of people are using them to travel to the downtown area in the evening.

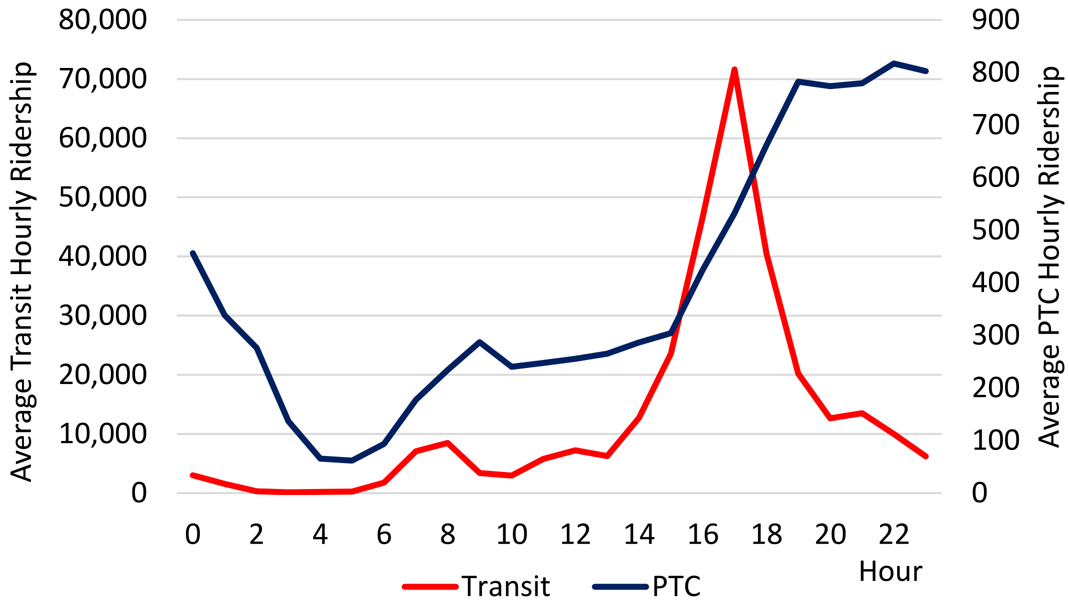

Figure 9 Hourly ridership for trip market 3 (Trips with the only origin in PD 1)

In terms of the trip market 3 (trips going from downtown to elsewhere in Toronto), Figure *9* shows that transit and PTC both have low morning peaks but significantly high afternoon/evening peaks. Transit achieves its maximum ridership at 5 pm representing the pattern of people going from work to home. Meanwhile, PTC hourly ridership keeps increasing from 3 pm and reaches its highest value at 11 pm. This suggests that even though ridership will increase around 5 pm due to regular commuter patterns, there are even more PTC trips departing from downtown to outside of PD 1 after regular work hours in the evening.

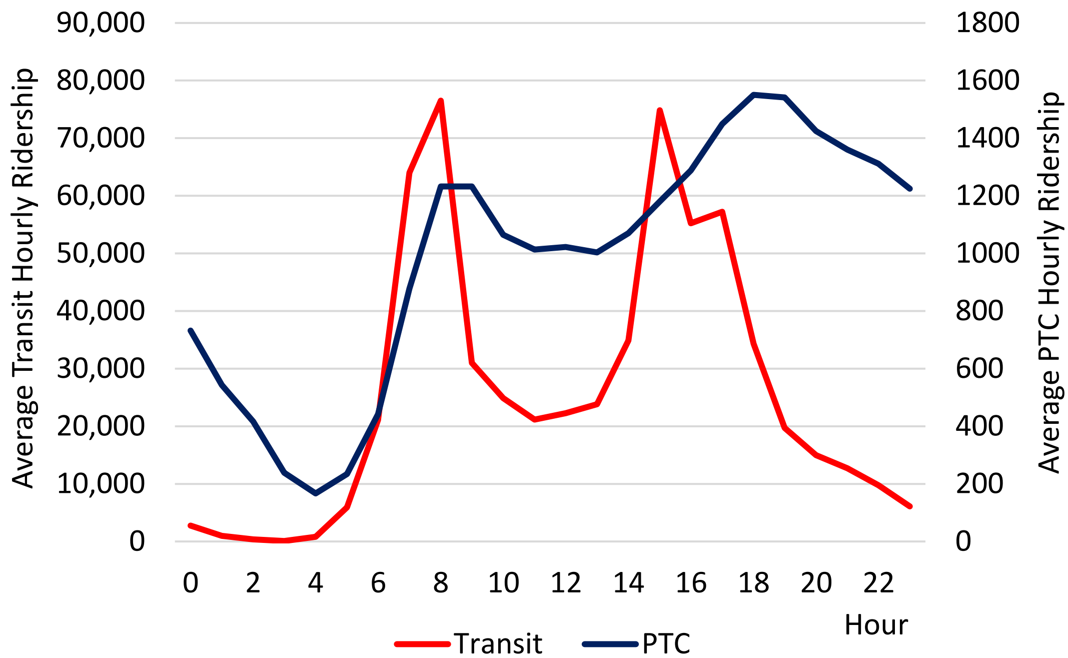

Figure 10 Hourly ridership for trip market 4 (Trips outside of PD 1)

Based on Figure *10*, trips outside of PD 1 have similar patterns to trips within PD 1. Transit and PTC have well-defined commuter patterns with PTC peaks shifted later relative to transit (with the evening peak shifted more). As previously mentioned, this could be occurring due to differences in trip purposes.

3.3 Key Findings

- PTC ridership on a regular weekday in the fall of 2016 is 5% of public transit ridership.
- PTC trips are concentrated in the downtown area where transit service is most developed.
- PTC is competitive with public transit for trips within the downtown area likely due to the short distances and comparable cost.
- PTC and public transit both have well-defined commuter patterns across the four trip markets, with PTC peaks shifted later relative to transit (the evening peak shifted more than the morning peak).

4 The Impacts of Subway Disruption on PTC Usage

Subway disruptions are events that negatively affect subway services, and these disruptions can happen at a subway station or along a subway route. They may have serious impacts on a riders' journey depending on the nature of the disruption. For instance, jammed doors or doors blocked by debris can lead to delays of 10 minutes on average, while signal and operational issues can cause delays of longer duration, affecting many riders, particularly during the peak periods. When severe delays occur are anticipated (30 minutes or longer), the TTC usually dispatches shuttle buses to serve stranded subway passengers. However, shuttle buses cannot carry the same passenger volume as a subway. Therefore, some riders would likely shift to other alternatives, such as walking, taxis or PTC. Under such circumstances, PTC acts as a complementary mode by filling gaps in the rail transit services.

In this section, the PTC data (provided by the City of Toronto) and TTC subway disruption data (available on the city's open data website: https://www.toronto.ca/city-government/data-research-maps/open-data/open-data-catalogue/#917dd033-1fe5-4ba8-04ca-f683eec89761) are used to explore the impacts of subway disruption on PTC usage around a subway station area. The study period is from September 2016 to April 2017. During this period, detailed information on each subway incident was documented by the TTC. This includes disruption date and time, name of the affected subway station, affected subway line ID, disruption code (reason), minutes of delay and minutes of gap (minutes of delay plus the time until the next train comes). Most of the time, one disruption record corresponds to one affected subway station. However, if a disruption event involved multiple stations, additional rows are manually added for each affected subway station. Moreover, records with zero delays are removed from the original dataset, due to the assumption that a subway passenger's travel behaviour would not change if they experienced zero delays.

In this analysis, we compare the PTC usage within 250 metres (buffer zone) of a subway station before and during a subway disruption. This comparison is an attempt to mimic the experimental design method, which is a part of the scientific method. Specifically, the "treatment" group is the PTC pickup counts within 250m of a subway station during the one hour of the subway disruption. In contrast, the "control" group is used as a baseline measure, which is the corresponding PTC ridership within the same buffer area during the same hour period but a week prior (without a subway disruption). The difference between the "control" and "treatment" group indicates the change of PTC ridership due to subway disruptions.

To ensure the subway disruption is the only "treatment", subway disruption records are removed from the dataset if a subway disruption occurred in both the "control" and "treatment" situations. In terms of the size of a station buffer, a distance of 250m is chosen to capture the full length of a subway station, including all exits, but not so large a radius as to capture multiple stations. When a disruption happens, passengers on a train/in a subway station and looking for alternative travel options will likely exit to the surface street. It is assumed that these passengers will stay within one block (approximately 200m, according to https://en.wikipedia.org/wiki/City_block) of the subway station they exited to access an alternative travel mode (e.g. PTC). In addition, an extra 50 metres is added to the buffer zone to help capture the effect that some people might walk a bit farther from the disrupted subway station to find an alternative mode. The extra buffer distance also helps compensate for the aggregation error caused by approximating the PTC trip pick-up location to the nearest intersection. It is noteworthy that the methodology here captures only the "localized" effects of subway service disruption and not the system-wide effects (for example, transit riders at other parts of the system but affected by the subway disruption and riders learning about the disruption before starting their trips and adjusting their travel plans accordingly).

4.1 Statistics of Subway Disruption from Sept 2016 to Apr 2017

The first step involves compiling all of the TTC subway disruption data from September 2016 to April 2017 in order to create a baseline understanding of the frequency at which subway disruptions affect Toronto's rapid rail transit system. Figure *11* below illustrates the frequency distribution of subway disruption length, which resembles an exponential distribution. A total of 3084 disruption events occurred in the City of Toronto from September 2016 to April 2017, which amounts to a daily average of 13 disruptions. It should also be noted that a majority of the delays are brief. Specifically, about 68% of the disruption events cause delays that last fewer than 5 minutes and only 3% of the disruption events last over 20 minutes.

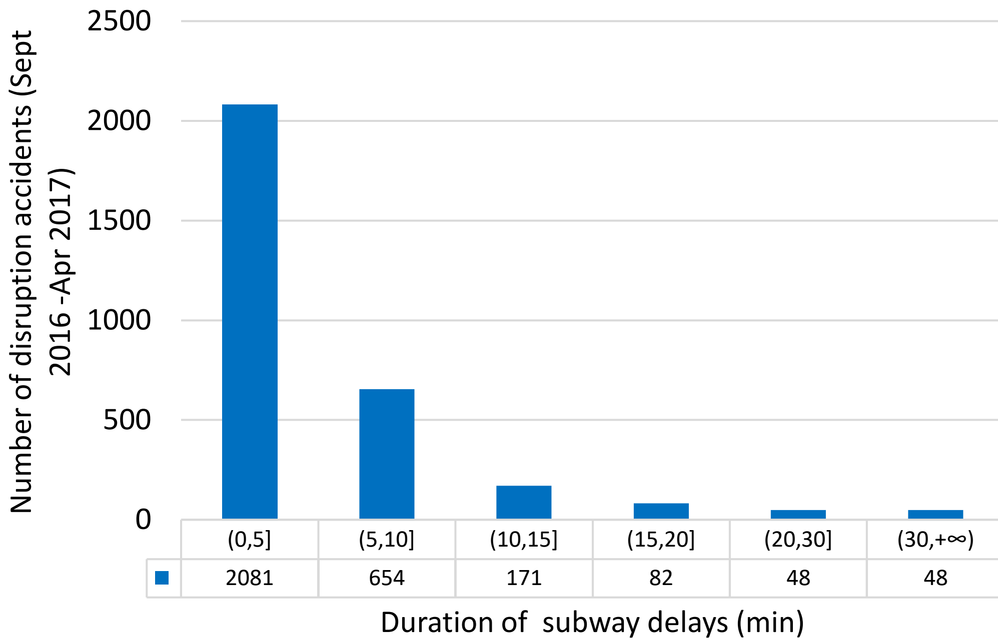

Figure 11 Distribution of subway disruption delays

4.2 Comparison between the "Control" and "Treatment" Groups

Figure *12* presents the average PTC ridership for both the "control" and "treatment" groups. Specifically, the average PTC ridership of the "treatment" group is the average number of PTC pickup counts between September 2016 and April 2017 from locations within 250m of a subway station within one hour of subway disruption. The average PTC ridership of the "control" group collects the same PTC usage information corresponding to the same location and daytime a week prior provided that no subway disruption was experienced.

Within the scenarios previously stated, the data shows that there are slightly more PTC trips generated during the hour of subway disruption than the prior week with no delays (8.24 trips vs 7.55 trips). This implies that the delays of subway trains have marginally positive impacts (a 9%

increase) on PTC pickup counds around a subway station. However, this is just an aggregate result without considering the duration of the subway delays. It is expected that longer subway delays would lead to a higher increase in PTC usage. Also, as noted previously, this is just the immediate "localized" effect, which does not capture other network-level effects.

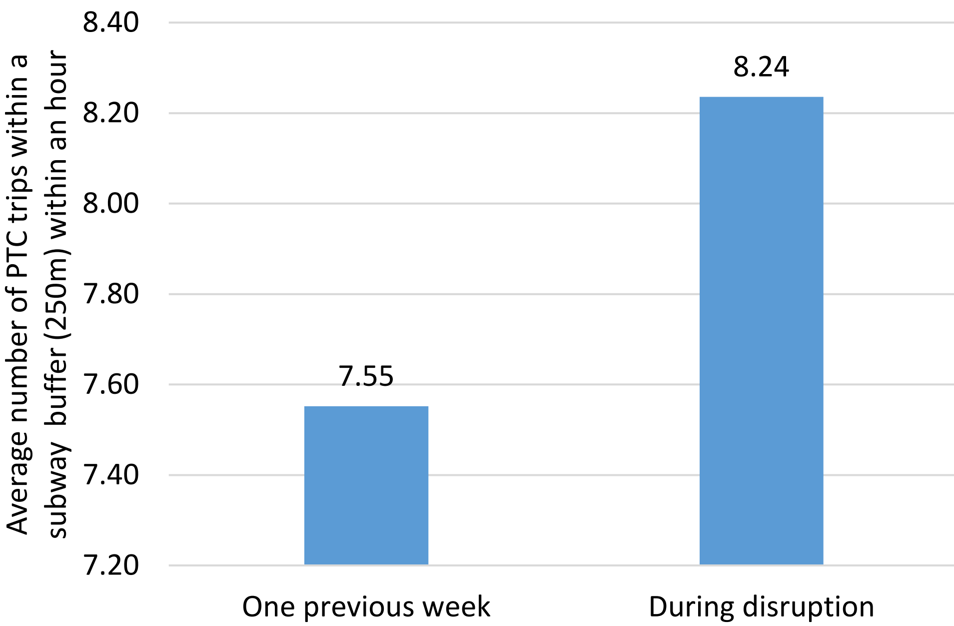

Figure 12 PTC usage before and during subway disruption

As shown in Figure *13*, when subway delays increase in time, the percentage of PTC usage drastically increases. For instance, there is only a 0.2 % increase in PTC pickup counts when a short disruption occurs (0 to 5 minutes delays). Meanwhile, disruptions resulting in more than 30 minutes of delays lead to a 110% increase in PTC usage. These findings appear logical since subway passengers are likely to wait for the next train if their commute time is only extended by several minutes. However, if the passenger's commute time is greatly extended while waiting for the next train to arrive, subway riders are likely to switch to other travel modes, such as PTC.

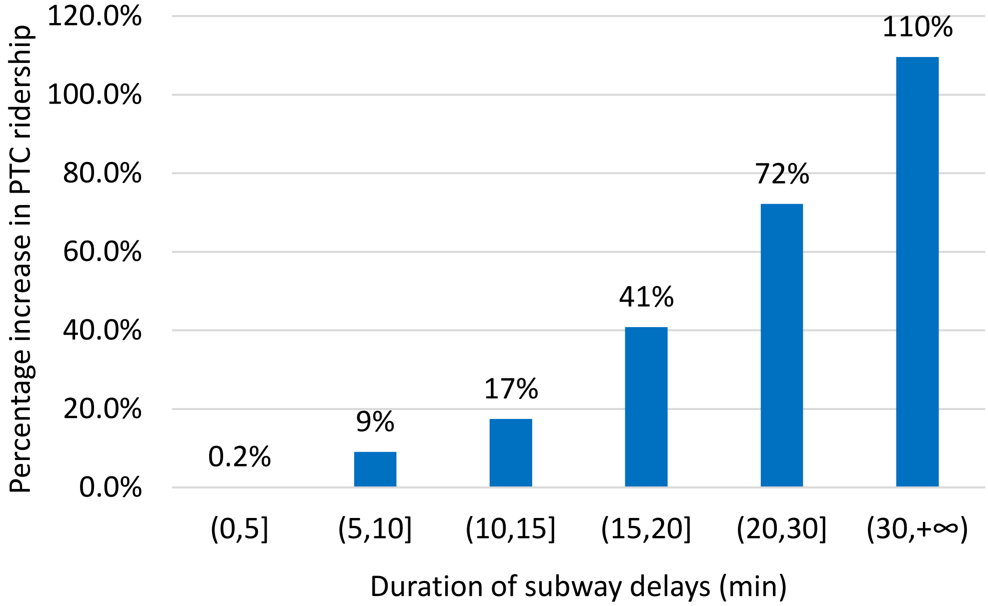

Figure 13 Percentage increase in PTC ridership over the duration of subway delays

Table 1 Average number of PTC trips before and during a subway disruption event for various ranges of delays

Range of delays	One previous week	During subway disruption	Difference	% increase
(0,5]	7.92	7.94	0.01	0.2%
(5,10]	7.18	7.83	0.65	9%
(10,15]	7.78	9.14	1.36	17%
(15,20]	9.23	13.00	3.77	41%
(20,30]	5.17	8.90	3.73	72%
(30,+∞)	6.94	14.54	7.60	110%

4.3 Key Findings

- Majority of subway disruptions are minor. 68% of disruptions caused delays within 5 minutes, and only 3% led to over 20 minutes delays.
- Overall, subway disruptions cause an approximately 9% increase in PTC usage by people immediately affected by the disruption. The effects of subway disruptions on PTC usage at the network level is unknown.
- PTC demand drastically increases with an increase in subway disruption delays.

5 Comparison of Travel Attributes of PTC and Public Transit

Due to PTC competitive and convenient services, it is reasonable to hypothesize that PTC is diverting ridership away from public transit. Unfortunately, due to insufficient detailed transit ridership data, it is impossible in this report to draw a conclusion on the impacts of PTC services on public transit ridership at the route or station level. Nonetheless, the transit travel attributes can be compared with PTC travel attributes for identical times and trip pick-up and drop off locations to help answer this question. The results of this comparison will also help determine how competitive public transit is relative to PTC services.

The tool utilized to estimate the transit travel attributes (e.g. total travel time and a number of transfers) for all PTC trips is called OpenTripPlanner (OTP). OTP is a family of open source software projects that provide passenger information and transportation network analysis services. It is written in Java and distributed as a single executable JAR file. With a built transit and road network, travel attributes of different kinds of modes (e.g. drive, transit and bicycle) can be estimated through an API call in a Python script.

5.1 OTP Instance Construction

In order to obtain transit information for specified trips, the first step is to build a transit network for a local OTP instance. It requires the General Transit Feed Specification (GTFS) data and OpenStreetMap (OSM) data of the study area.

Transport agencies around the world provide GTFS data to the public, including transit routes, stops and trips information. Seven TTC GTFS zip files with different effective time periods were downloaded from the GTFS feed website (https://transit.land/feed-registry/). Trips generated outside of the effective time period of the GTFS data could not be estimated by the OTP since the transit network is expired.

Table 2 GTFS zip files and corresponding effective periods

GTFS zip files	Effective Periods
1	Sept 4th, 2016 to Oct 8th, 2016
2	Oct 9th, 2016 to Nov 19th, 2016
3	Nov 20th, 2016 to Dec 27th, 2016
4	Dec 18th, 2016 to Jan 7th, 2017
5	Jan 8th, 2017 to Feb 18th, 2017
6	Feb 12th, 2017 to Mar 25th, 2017
7	Mar 26th, 2017 to May 6th, 2017

In terms of the street network data for the City of Toronto, OpenStreetMap data was downloaded from OSM Extracts by Interline (https://www.interline.io/osm/extracts/). OSM Extracts by Interline mirrors the entire OpenStreetMap planet and creates a city and region-sized extracts.

With GTFS.zip files, OSM.pbf files and OTP.jar files stored under the same folder, the resulting representation of the transit network can be saved and passed to an OTP server in memory simply by using the following command.

```
$ java -Xmx2G -jar otp.jar --build /home/username/otp --inMemory --anlayst
```

Once the network build operation is finished, an OTP instance will run locally and can be opened in a web browser, which represents a web client that interacts with the local OTP instance (As shown in *Figure 14*).

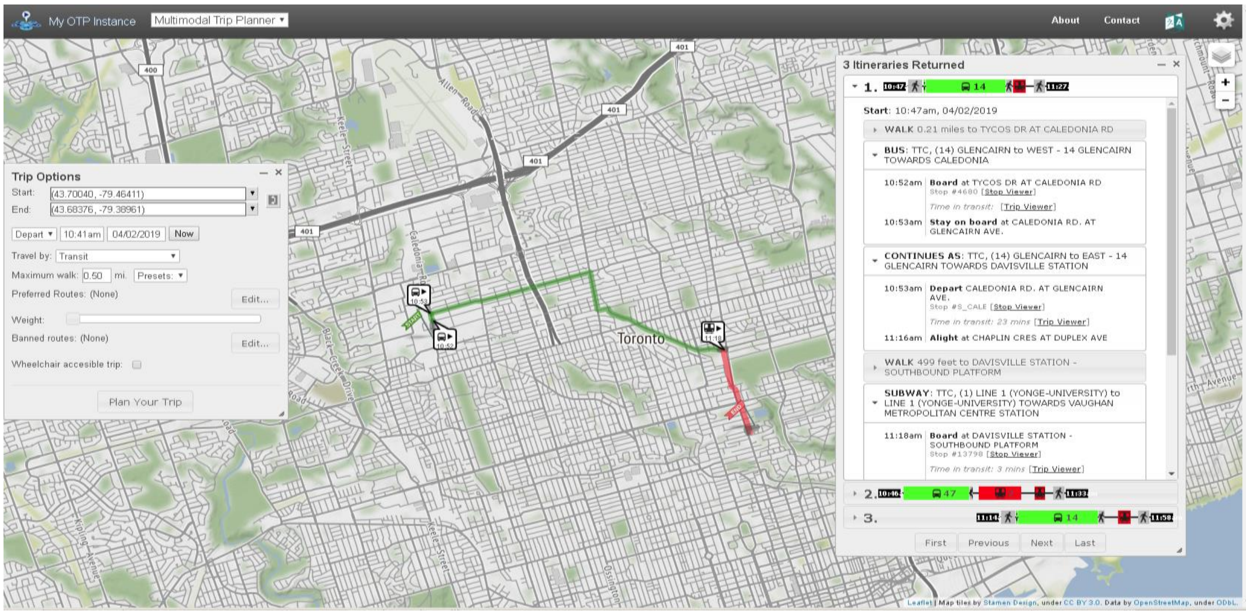

Figure 14 An OTP instance opened in a web browser

As inputs in an OTP instance, fields that can be defined are coordinates of start and end points, departure DateTime, travel mode, maximum walking distance, and other parameters (see the left window in Figure *14*). Once the inputs have been correctly entered, OTP will present detailed trip information for the top 3 fastest itineraries (see the right window in Figure *14*). For transit trips, OTP summarizes each itinerary in terms of total travel time, walk time, transit in-vehicle travel time, waiting time, walking distance and number of transfers.

5.2 Estimating Transit Travel Attributes

The goal of this analysis is to examine the difference in travel service between public transit and PTC by estimating the transit travel attributes for PTC trips. The study period is from Sept 2016 to Mar 2017. PTC trips generated after Mar 2017 are excluded in this analysis because all timestamps except for drop-off DateTime are truncated to the next hour. As a result, it is not clear when a PTC trip was actually requested, which is one of the inputs of the OTP program. Due to time constraints and a very large dataset, only a 5% random sample (703,018 trips) of the total PTC trip population (14,060,349 trips) from Sept 2016 to Mar 2017 was selected and estimated in OTP.

A Python script is written to make a request to OpenTripPlanner, and as a result, the transit service information is obtained. The following parameters must be known so they can be used as inputs to extract the transit travel information: 1) coordinates of start and end points: the same coordinates as pickup and drop-off locations of each PTC trip in the sample; 2) departure date and time: the same date and time as when PTC trips are requested; 3) travel mode: transit and walking; 4) maximum walking distance: no limit. As the output, OTP returns detailed transit service information (see Table *4*) for three itineraries of the analyzed trip. However, only the first itinerary information (the fastest trip) is extracted and saved into a CSV file. This data extraction method was developed based on the assumption that people are rational and will choose the fastest transit itinerary.

Table 3 Parameters of OpenTripPlanner (inputs)

Parameters	Values
Coordinates of start and end points	Consistent with coordinates of pickup and drop-off locations of PTC trips
Departure date and time	Consistent with request date and time of PTC trips
Travel mode	Transit and walking
Maximum walk distance	No limit

Table 4 Extracted transit service attributes (outputs)

Transit service attributes	Description
Total travel time (min)	Total travel time of finishing a PTC trip by transit and walking
Walk time (min)	Access walking time plus egress walking time
In vehicle travel time (min)	Total travel time on board transit vehicles
Waiting time (min)	Total waiting time for transit vehicles
Walk distance (m)	Access, transfer and egress walking distance
Number of transfers	Number of transfers in a transit trip
Number of times using rapid transit service	Number of times using different subway lines

5.3 Comparison of Travel Attributes Between PTC and Public Transit

In this section, a comparison of the travel attributes between PTC and public transit is conducted on the number of transfers, types of transit mode usage, travel time and walking distance. To make the travel time comparison between the two modes, it is decomposed into in-vehicle travel time and out-of-vehicle travel time. For a PTC trip, in-vehicle travel time is basically the ride duration, while out-of-vehicle travel time is the waiting time from when a person requests a ride until he/she is actually picked up by a PTC vehicle. Comparatively, for transit in-vehicle travel time, it is the total travel time a passenger spends in a transit vehicle and transit out-of-vehicle travel time consists of the transit walking and waiting time.

Table 5 Definition of aggregate travel times

Travel Time	PTC	Public Transit
In-vehicle travel time	In-vehicle travel time	In-vehicle travel time
Out-of-vehicle travel time	Waiting time	Walking time + waiting time
Total travel time	In-vehicle travel time + out-of-vehicle travel time	In-vehicle travel time + out-of-vehicle travel time

Departure information (coordinates and request date and time) from a total of 703,018 PTC trips are input into OTP instances to obtain corresponding transit alternatives to the PTC trips. Based on the output from OTP, 92.4% of the PTC trips could be completed by transit and walking, while 7% of the PTC trips would not involve any transit routes and could be completed by just walking. However, 0.6% of the PTC trips could not be completed either by transit or walk. Some of those trips were coded as having the same start and end points and some trips had unrecognizable start/end points (e.g. points on the water).

Since the focus of this section is to compare PTC and transit services, the PTC trips (92.4%) that can be replicated by using some form of public transit are studied in the next section (Section 5.3.1). As for the walking trips and infeasible transit trips, they are briefly discussed in Section 5.3.4 and Section 5.3.5.

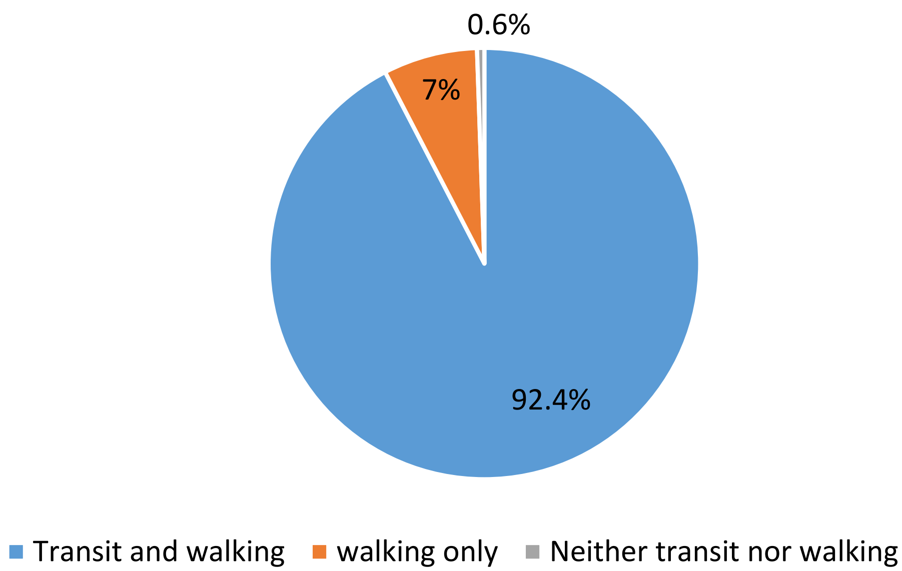

Figure 15 Transit availability of the PTC trips

5.3.1 Transit Trips

5.3.1.1 Number of Transfers

Figure *16* illustrates the number of transfers that are required for a passenger to make if the PTC trips were taken by public transit. The data shows that 47% of the trips would not require any transfer, 39% of the trips would require one transfer and 14% of the trips would require at least two transfers. These results suggest that 53% of the PTC trips could be replaced by multi-stage transit trips and 47% could be replaced by single-stage transit trips.

In contrast, Figure *17* displays the number of transfers of 2016 TTS transit trips within Toronto. The chart shows that compared to the transit alternatives for the PTC trips, the TTS transit trips have a higher percentage of trips transferring at least twice but a lower percentage for no transfers. It is quite surprising that PTC trips would involve fewer transfers if taken by public transit. However, this could be possible when considering other factors, such as total travel time, walking distance and weather conditions.

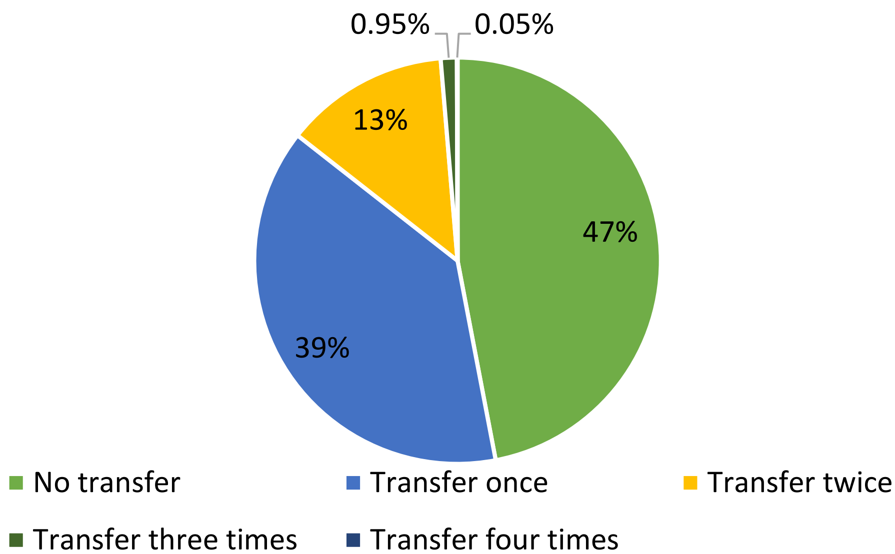

Figure 16 Number of transfers of PTC trips if using public transit

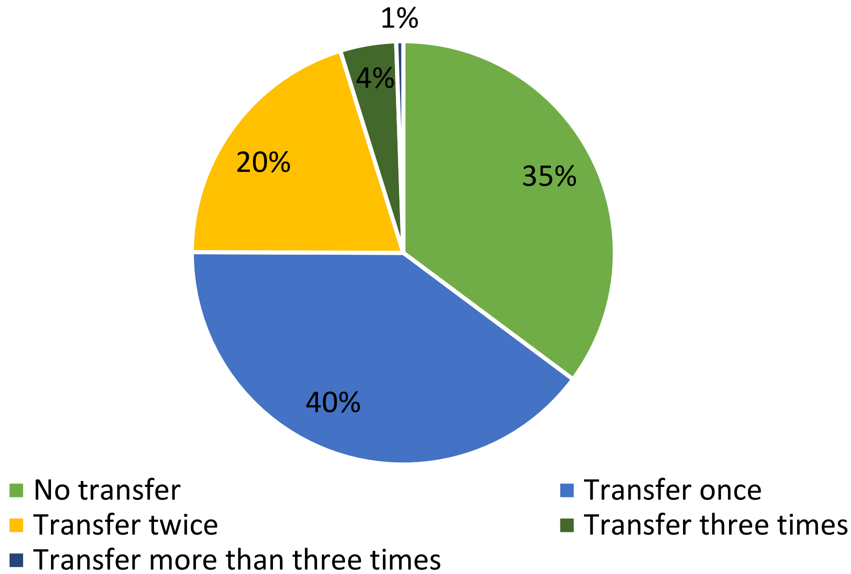

Figure 17 Number of transfers of 2016 TTS transit trips within Toronto

5.3.1.2 Transit Mode Usage

A transit trip might involve multiple transit modes, such as a bus, streetcar, and subway. Figure *18* presents the percentage of the trips with the following transit modes being used: subway only, surface transit only, and a combination of subway and surface transit. As shown in the figure, a majority of the PTC trips (65%) would involve surface transit only, while 27% of the trips would require the use of both subway and surface transit, and 8% would rely solely on the subway. On the other hand, Figure *19* displays the transit mode share of the 2016 TTS transit trips within Toronto. It shows that the percentage of the three transit modes is more evenly distributed (26%, 36%, and 39%) relative to that of the transit alternatives to the PTC trips. This indicates that the PTC trips are more likely to involve surface transit usage than subway usage if the trips were completed by public transit. In other words, PTC trips are more likely to replace ones that could be undertaken by surface transit than those with good subway options.

The results also suggest that PTC is more comparable to surface transit (bus and streetcar) than rail transit services (subway). It might be explained by the service provided by PTC and above-ground public transit. Surface transit and PTC both run on the surface and experience the same surrounding environment (e.g. intersection traffic lights and traffic congestion). However, surface transit is cheaper but involves access and egress walking distance, transfers and dwelling time at each stop. Thus, there are some trade-offs between taking surface transit and PTC. On the other hand, the subway is running underground without being influenced by traffic congestion, and the subway is also cheaper, so it is expected that a few PTC trips would involve only subway usage. In other words, for trips with both origins and destinations in close proximity to the subway system, PTC represents a less attractive alternative to transit compared to trips with origins/destinations close to surface transit.

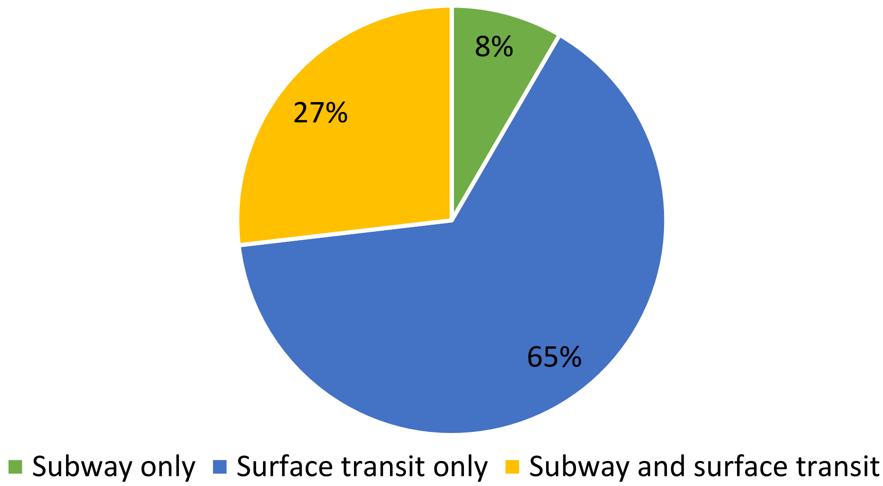

Figure 18 Transit mode share of PTC trips if using public transit

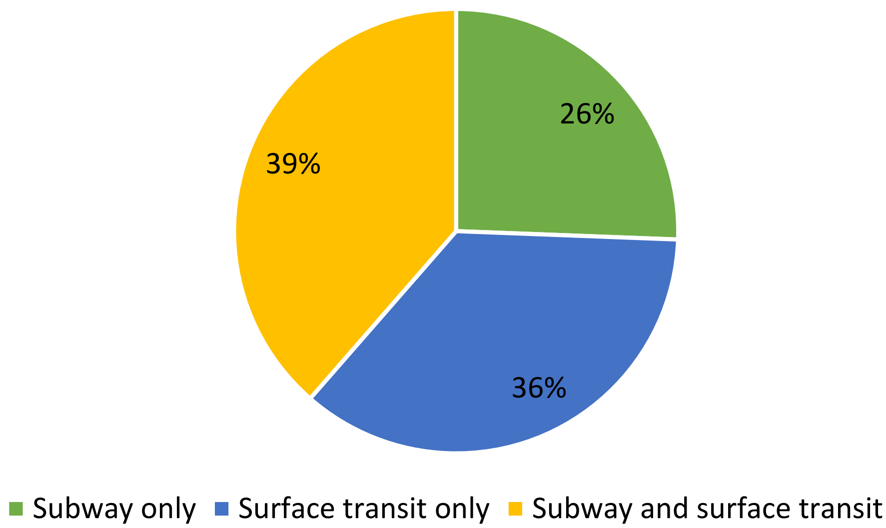

Figure 19 Transit mode share of 2016 TTS transit trips within Toronto

5.3.1.3 Total Travel Time

Figure *20* shows the frequency distribution of total travel time of PTC and public transit. Table *6* presents the statistics of the total travel time for both modes. In comparison with PTC, the transit total travel time has a larger spread. The average PTC total travel time is 20.89 minutes, while the average value by transit is 31.06 minutes. Therefore, on average, PTC could save passengers around 10 minutes of total travel time compared to public transit.

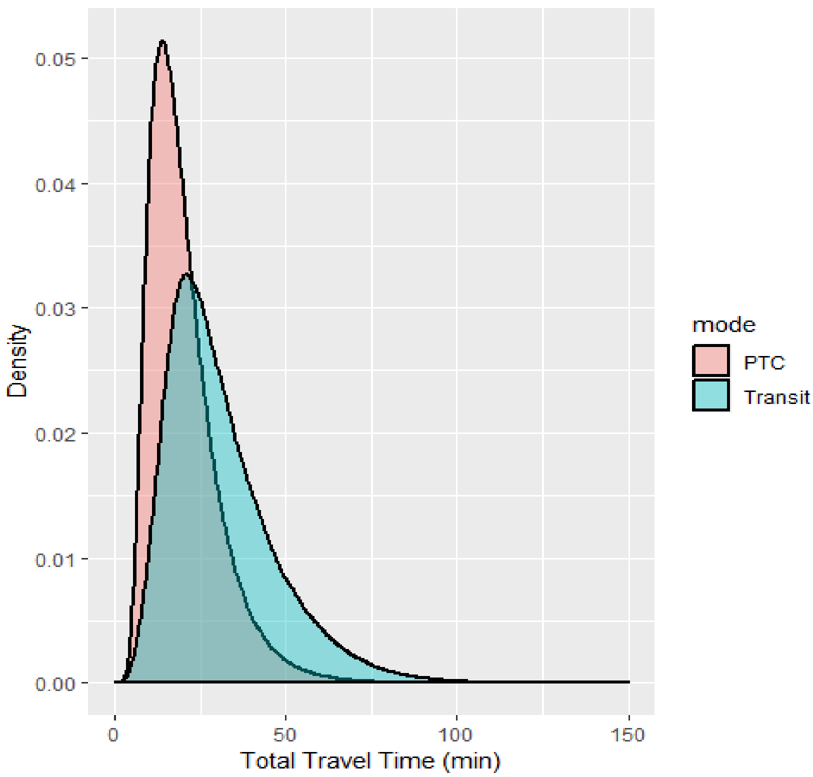

Figure 20 Frequency distribution of total travel time

Table 6 Statistics of total travel time (min)

Mode	Min	1^{st} quartile	Median	Mean	3^{rd} quartile	Max
PTC	0.97	13.63	18.63	20.89	25.67	177.98
Transit	1.22	19.70	27.68	31.06	39.12	322.00

In terms of the difference in total travel time by mode, *Table 7* lists the statistical difference in total travel time between transit and PTC over the same trips. The average difference is 10 minutes. In addition, *Figure 21* displays the frequency distribution of the PTC trips over various ranges of difference in total travel time. It can be seen that majority of the trips (59%) would save 0 to 15 minutes of travel time by riding PTC rather than transit.

Table 7 Statistial difference in total travel time between transit and PTC (min)

Min	1st quartile	Median	Mean	3rd quartile	Max
-172.93	3.1	8.6	10.18	15.52	307.8

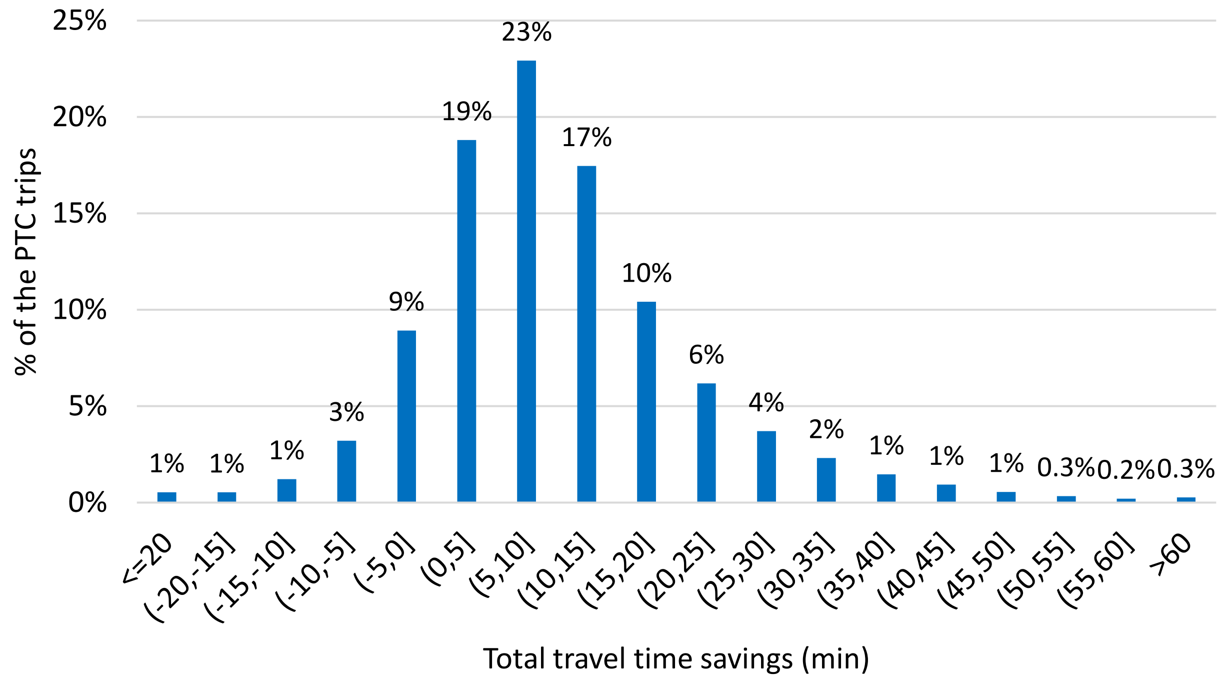

Figure 21 Frequency distribution of the PTC trips over total travel time savings

Table 8 Percentage of PTC trips for various ranges of total travel time savings

Range of total travel time savings (min)	%
<=20	1%
(-20, -15]	1%
(-15, -10]	1%
(-10, -5]	3%
(-5, 0]	9%
(0, 5]	19%
(5, 10]	23%
(10, 15]	17%
(15, 20]	10%
(20, 25]	6%
(25, 30]	4%
(30, 35]	2%
(35, 40]	1%
(40, 45]	1%
(45, 50]	1%
(50, 55]	0.3%
(55, 60]	0.2%
>60	0.3%

It is expected that the difference in total travel time of PTC and transit would vary by trip distance. Figure *22* is a scatter plot of the trip distance versus total travel time by PTC and transit. Blue circles represent transit and red rectangles represent PTC. The plot shows a trend that both PTC and public transit total travel time increase when the trip distance increases, but transit total travel time has a higher range. Moreover, Figure *23* suggests that the difference between the total travel time of the two modes slightly increases as the trip distance becomes larger. This correlation likely occurs because there are few direct transit routes for long distance trips expect for trips along transit routes. Therefore, detours, transfers and out-of-vehicle time would lead to longer total travel time for transit, while PTC does not experience these issues.

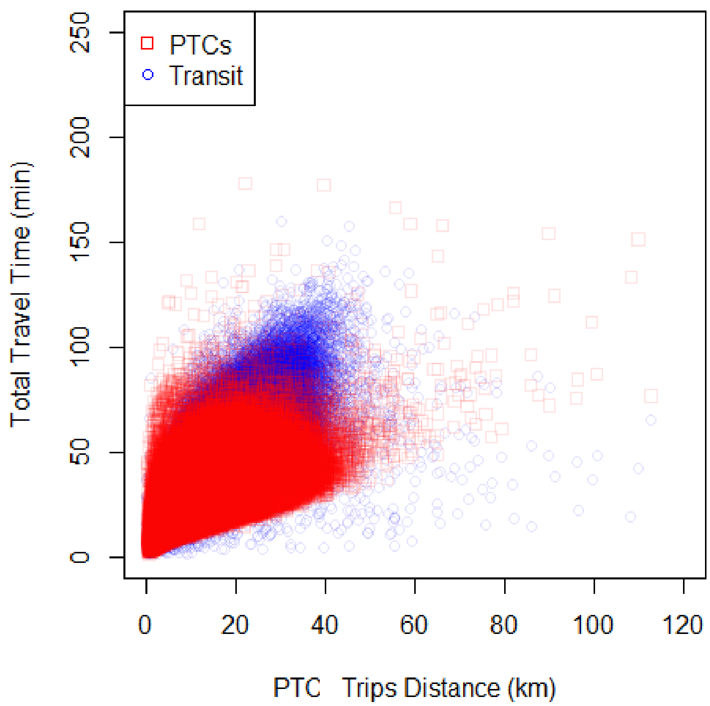

Figure 22 PTC trip distance vs total travel time

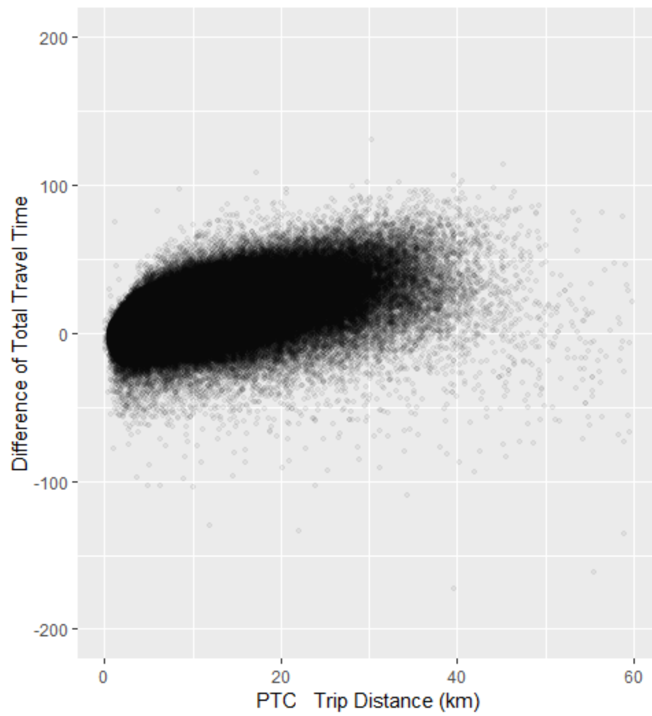

Figure 23 PTC trip distance vs difference of total travel time

Figure *24* illustrates the frequency distribution of the ratio of the total travel time by transit to the total travel time by PTC. The average ratio is 1.57, which means on average, transit would take 1.57 times longer than PTC to complete a trip. Based on the cumulative probability distribution, 14% of the PTC trips would have a faster transit alternative than PTC (ratio <1), while 86% of the PTC trips would have taken longer if they were completed by public transit (ratio > 1) and 20% of the PTC trips would have taken at least twice as long if they were completed by public transit (ratio > 2).

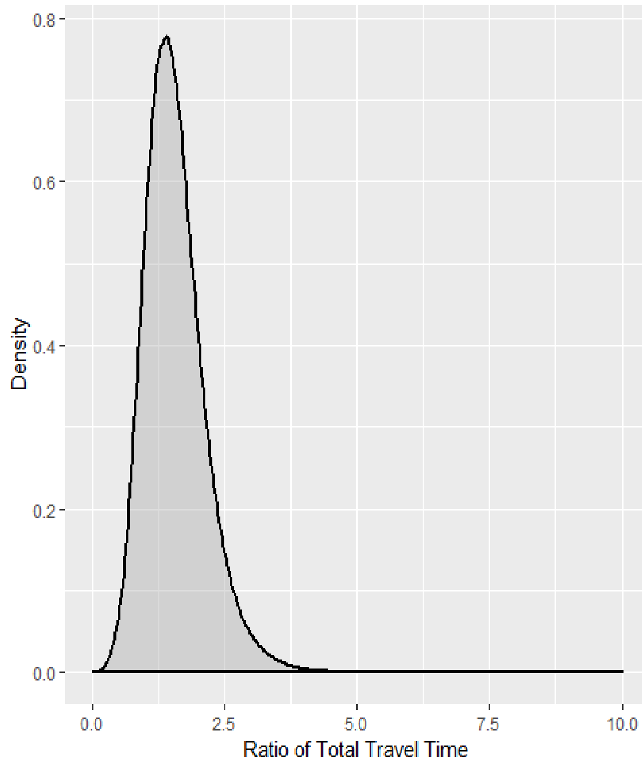

Figure 24 Frequency distribution of the ratio of transit to PTC total travel time

With regards to the 14% of the PTC trips where PTC is slower than transit, *Figure 25* illustrates the generation of these trips through the time of day and day of the week. It can be seen that there are two peaks for weekdays, one in the morning and one in the afternoon, which indicates public transit is faster than PTC services mainly during these time periods. As for weekends, most of the PTC trips happened during Saturday evening/night and Sunday afternoon.

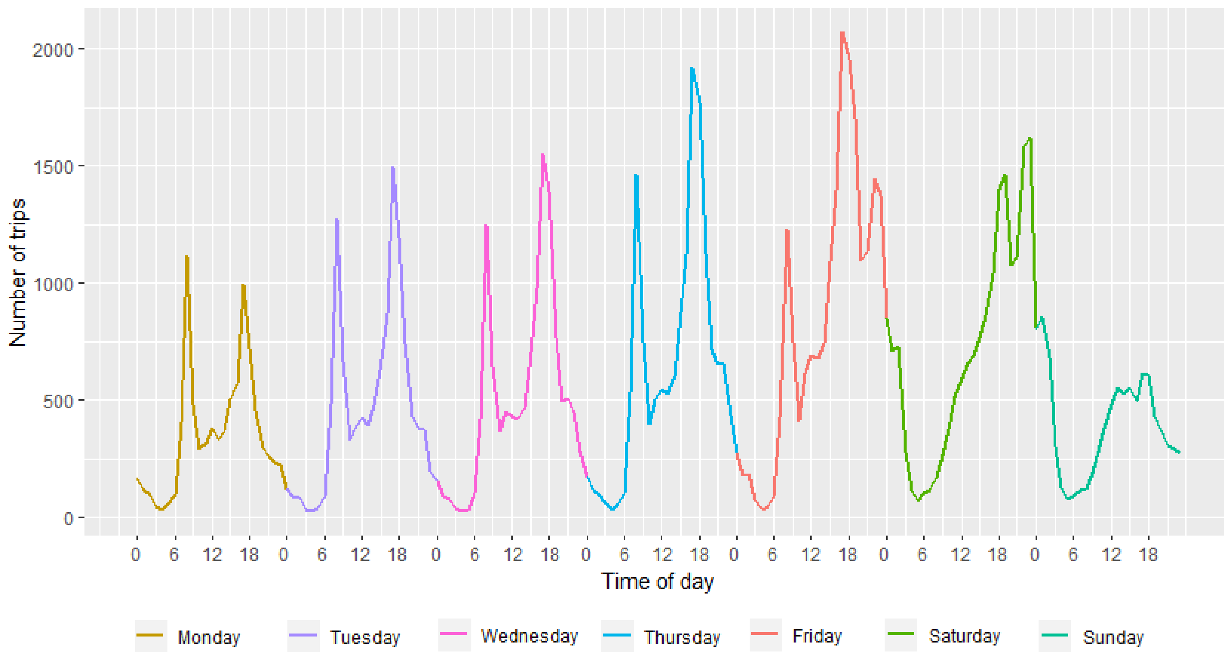

Figure 25 Number of the PTC trips where PTC is slower than transit, by the time of day and day of the week

Table 9 displays the statistics of speed for the PTC trips. The average PTC speed for trips where PTC is slower than transit is 19 km/h, while the average speed is 29 km/h for trips where PTC is faster than transit. Furthermore, *Figure 26* illustrates PTC speed for both types of trips over the course of the week. It can be seen that the average PTC speed for trips where PTC is faster than transit is higher than that of trips where PTC is slower than transit across the time of day and day of the week. However, both types of trips demonstrate a similar pattern of speed. The speed is the highest overnight across the week and the lowest at morning and at afternoon peaks for weekdays. This is likely due to the fact that traffic congestion is the heaviest during commuter hours, while the roads are much less congested overnight. Therefore, due to limited traffic capacity and high travel demand during morning and afternoon peak hours, PTC speed is minimal for those two periods. Comparatively, there is less fluctuation in speed during weekend daytime, which is likely due to relatively constant travel demand during the daytime of weekends.

Table 9 Statistics of speed for the PTC trips (km/h)

PTC trips	Min	1st quartile	Median	Mean	3rd quartile	Max
PTC is slower than transit	0.15	13.53	17.56	19.04	22.97	92.02
PTC is faster than transit	0.47	20	26.13	29.14	34.9	102.55

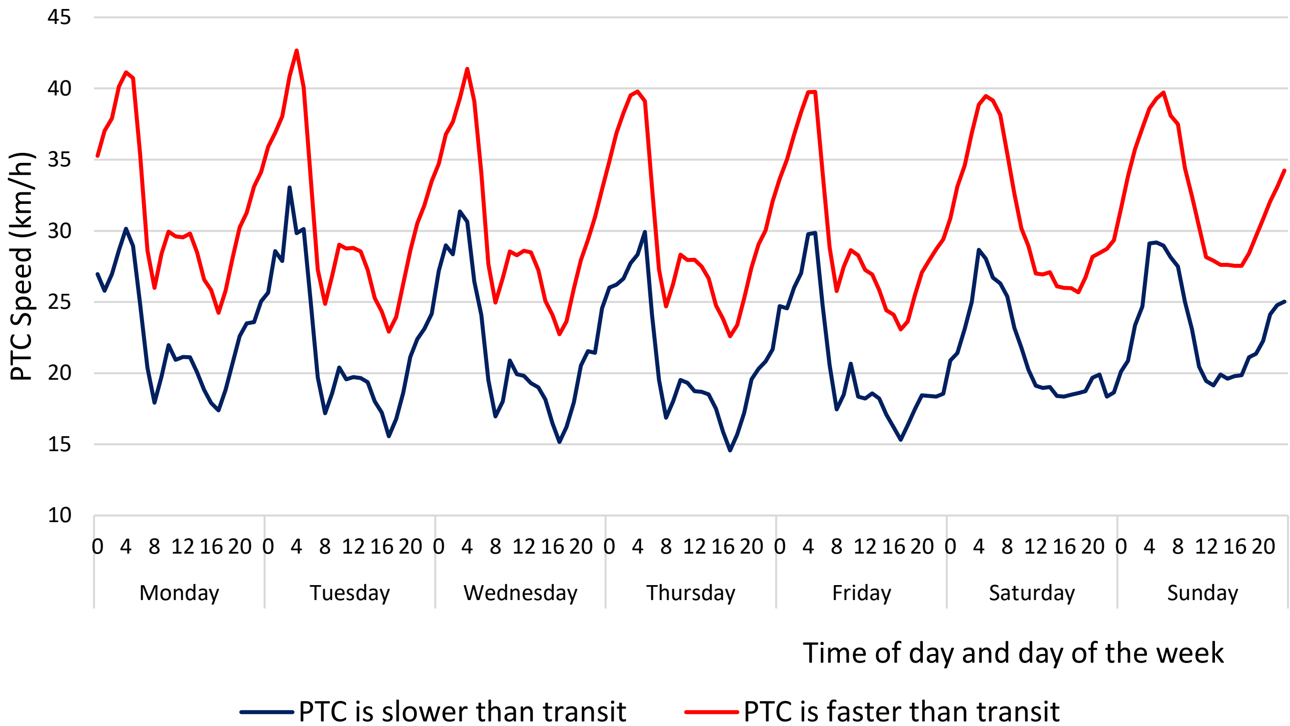

Figure 26 Speed of the PTC trips where PTC is slower than transit, by the time of day and day of the week

As discussed above, majority of the PTC trips, for which transit outperforms PTC in terms of total travel time, occurred when roads are most likely congested (e.g. the morning peak and afternoon peak). This provides empirical evidence that traffic congestions might cause PTC services to be slower than public transit. However, another possible explanation could be that some of the PTC trips might be shared rides, such as UberPool and LyftLine. This means a PTC driver is allowed to pick up and drop off multiple passengers along the way, and this will increase passengers travel time due to the added stops. The Figure seen below (*Figure 27*) shows the percentage of different types of PTC services for the PTC trips where PTC is slower than public transit. As the data shows, 26% of the trips were shared rides, while the rest of the rides (74%) were exclusive services.

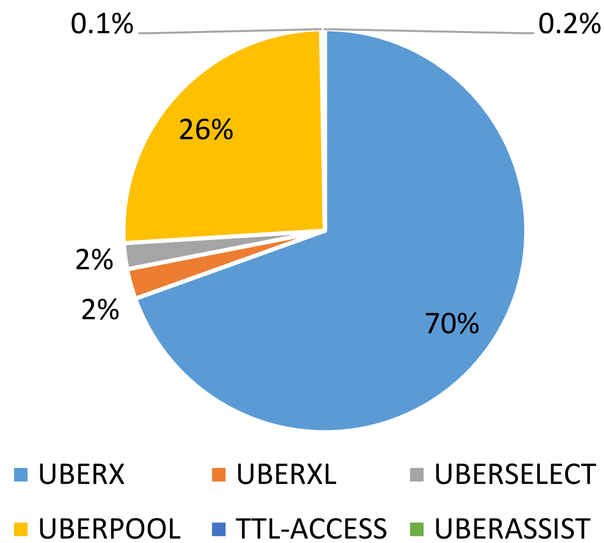

Figure 27 Percentage of different PTC services for PTC trips where PTC is slower than transit

5.3.1.4 In-vehicle Travel Time

The frequency distribution for in-vehicle travel time of PTC and public transit displays similar patterns to the total travel time (see *Figure 28*). The average PTC in-vehicle travel time is 15.11 minutes, while the average transit in-vehicle travel time is 18.76 minutes. The average difference in the in-vehicle travel time between the two modes is only 3.65 minutes.

Figure 29 shows the frequency distribution of the ratio of transit in-vehicle travel time to PTC in-vehicle travel time. The average ratio is 1.25, which means that transit in-vehicle travel time would be 1.25 times as long as PTC in-vehicle travel time. Furthermore, about 64% of the PTC trips would have longer in-vehicle travel time if completed by public transit (ratio > 1) and 10% would have taken at least twice as long if taken by public transit (ratio > 2).

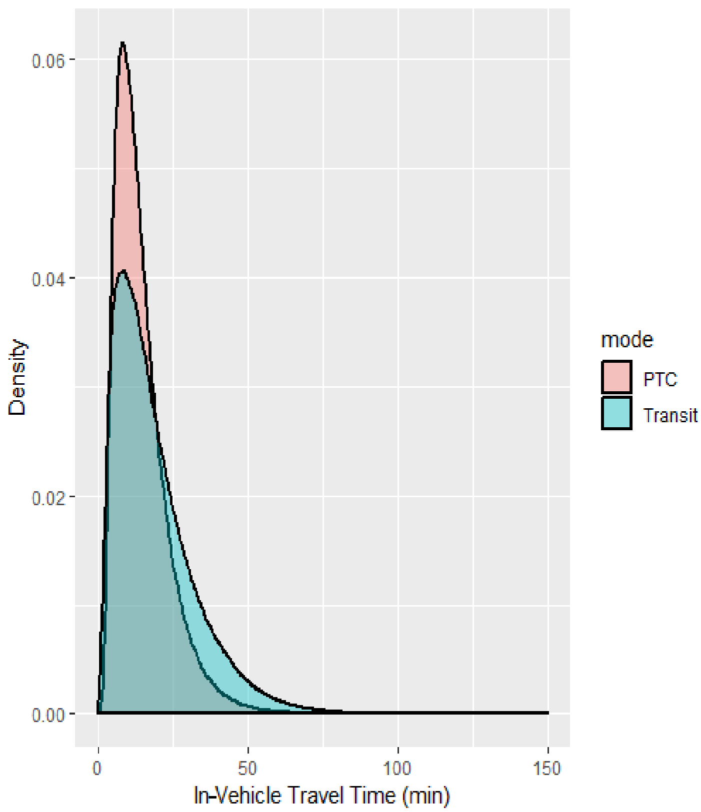

Figure 28 Frequency distribution of in-vehicle travel time

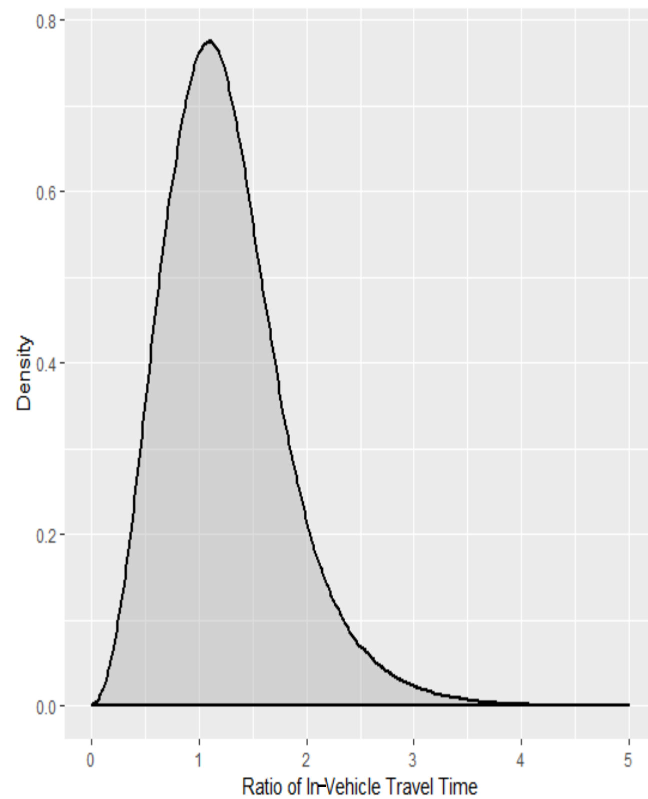

Figure 29 Frequency distribution of the ratio of transit to PTC in-vehicle travel time

Table 10 Statistics of in-vehicle travel time (min)

Mode	Min	1st quartile	Median	Mean	3rd quartile	Max
PTC	0.80	8.73	12.97	15.11	19.13	170.13
Transit	0.20	8.83	15.48	18.76	25.32	122.12

5.3.1.5 Out-of-vehicle Travel Time

As defined in Section 5.3, the PTC out-of-vehicle travel time is measured as the passenger waiting time, which is the duration between the recorded request time and the pick-up time. The transit out-of-vehicle travel time consists of walking time (total of access, transfer, and egress walking times) and waiting time.

As Figure *30* illustrates, the transit out-of-vehicle travel time has a larger spread than the corresponding PTC time. The average PTC out-of-vehicle travel time is 5.78 minutes, while the average transit out-of-vehicle travel time is 12.30 minutes. Furthermore, Figure *31* shows the frequency distribution of the ratio of transit to PTC out-of-vehicle travel time. The average ratio of transit to PTC is 3.36, which means that the transit out-of-vehicle travel time would be 3.36 times longer than the PTC out-of-vehicle travel time. In addition, 85% of the PTC trips would experience longer out-of-vehicle travel time if taken by public transit (ratio >1) and 57% would take at least twice as long if using public transit to finish a trip (ratio >2).

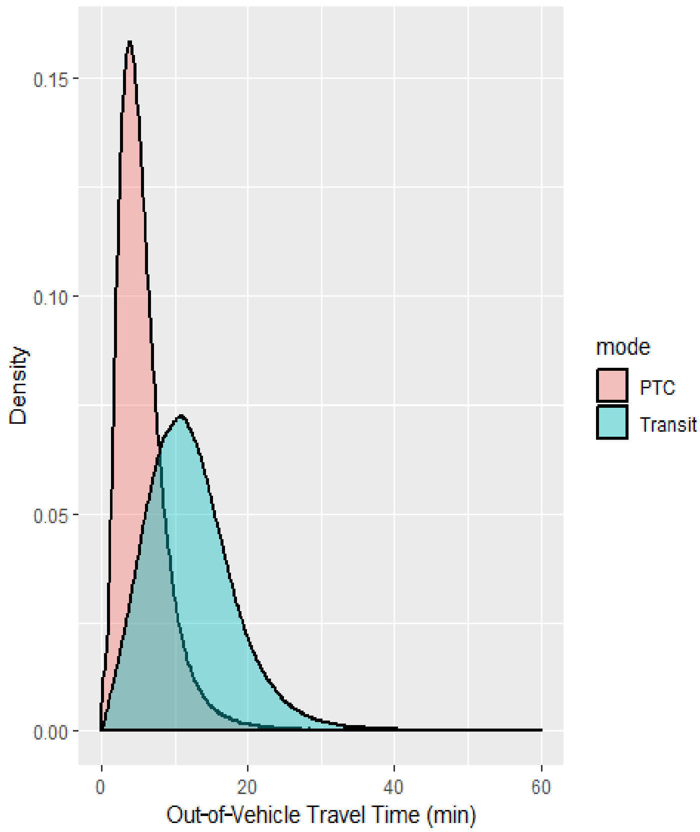

Figure 30 Frequency distribution of out-of-vehicle travel time

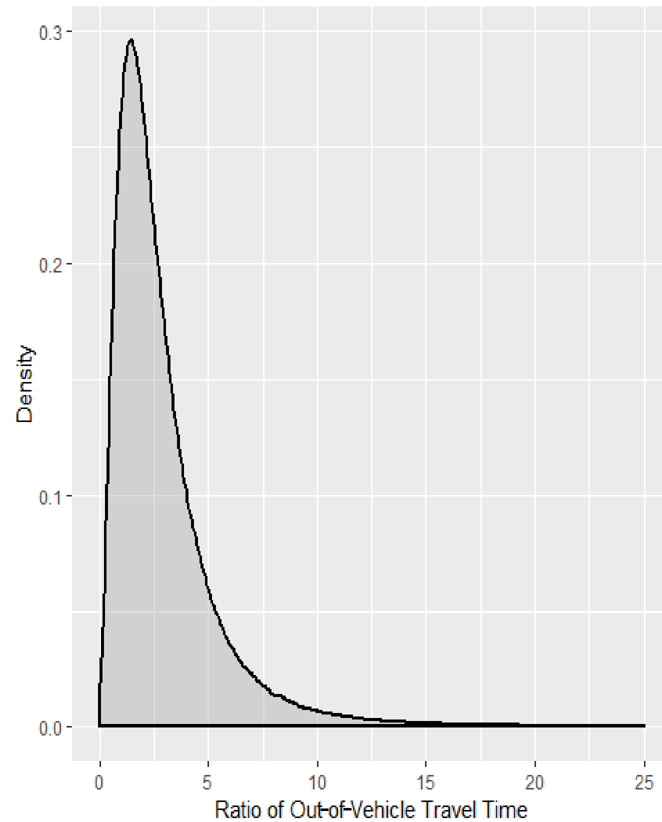

Figure 31 Frequency distribution of the ratio of transit to PTC out-of-vehicle travel time

Table 11 Statistics of out-of-vehicle travel time (min)

Mode	Min	1st quartile	Median	Mean	3rd quartile	Max
PTC	0.03	3.35	4.98	5.78	7.18	80.03
Transit	0.22	8.02	11.58	12.30	15.62	309.00

To better understand the relationship between the out-of-vehicle travel time of public transit and PTC, the two travel times for each individual trip are plotted in *Figure 32*. It displays a scatter plot of the two travel times and their marginal distributions. It is hypothesized that transit out-of-vehicle travel time would increase as PTC out-of-vehicle travel time increases. However, it appears that there is a nonlinear relationship between transit and PTC out-of-vehicle travel times. Furthermore, based on the marginal distributions of the two values and the scatter plot, it can be seen that the out-of-vehicle travel time for the majority of the PTC trips falls within a small range of values (0 to 7 minutes), while that of the corresponding transit trips displays a wider range of values (0 to 80 minutes). This implies that PTC has a more consistent out-of-vehicle travel time (waiting time) than that of transit.

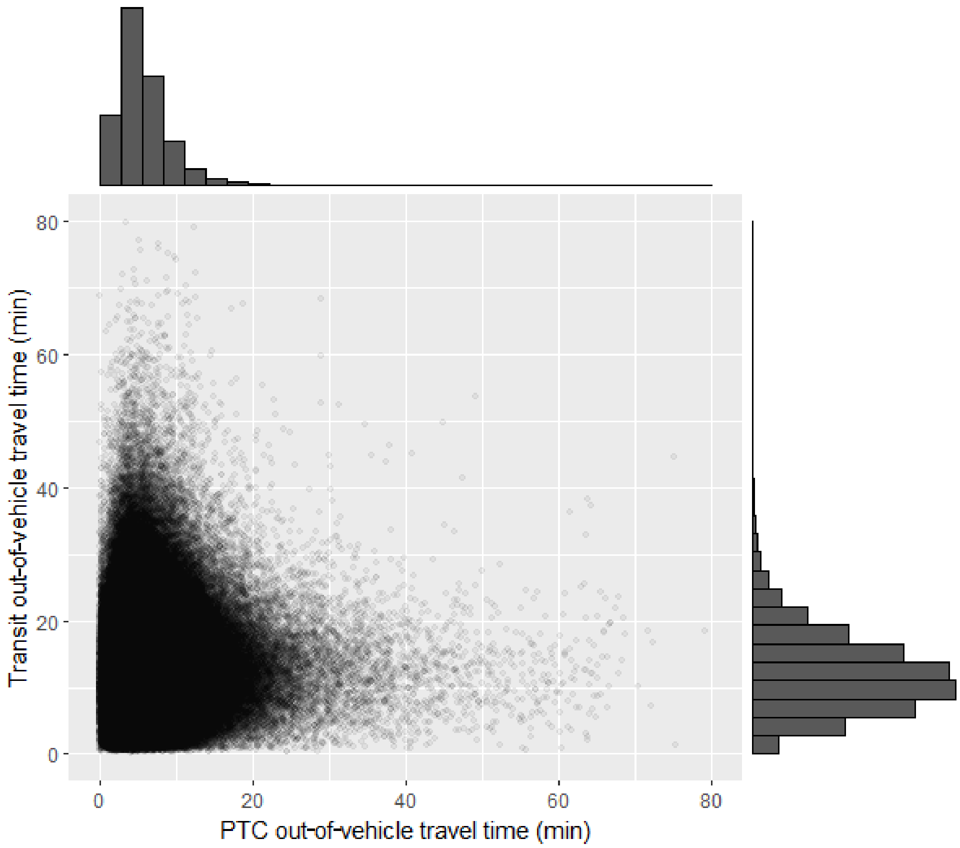

Figure 32 Transit out-of-vehicle travel time vs PTC out-of-vehicle travel time

Table 12 Summary of the comparison of travel time between public transit and PTC

Travel time	Average ratio	% (ratio >1)	% (ratio>2)	Average difference	% account for the difference in total travel time
Total travel time	1.57	86%	20%	10.17 min	-
In-vehicle travel time	1.25	64%	10%	3.65 min	36%
Out-of-vehicle travel time	3.36	85%	57%	6.52 min	64%

Combined with the findings from Section 5.3.1.3 to 5.3.1.5, *Table 12* summarises the results of the comparison between PTC and public transit travel time. It shows that out-of-vehicle travel time has the largest ratio and in-vehicle travel time has the smallest ratio. This implies that there is a substantial out-of-vehicle travel time improvement (proportionally) by using PTC services over transit services. However, there is little time to be saved from in-vehicle travel time by taking PTC (the average difference is just 4 minutes). According to *Table 12*, the in-vehicle travel time accounts for 36% of the difference in transit and PTC total travel time. In contrast, the out-of-vehicle travel time is responsible for 64% of the difference in total travel time between the two modes. This implies that the main difference between PTC and transit services is accounted for by the out-of-vehicle travel time, not the in-vehicle travel time. Note that the above analysis does not assign higher weights to out-of-vehicle time relative to in-vehicle time, as is well supported by empirical evidence in the general travel behavioural literature. If proper weights are applied, the out-of-vehicle time would account for a higher percentage of the difference in travel times between transit and PTC, implying that the observed PTC trips would require much higher out-of-vehicle time if the travellers were to use public transit instead.

5.3.1.6 Transit Walking Distance

The transit walking distance information that was exported from the OpenTripPlanner, includes all types of walking in a transit trip: access distance from the trip origin to a transit stop, transfer distance between transit vehicles (if required), and egress distance from a transit stop to the trip destination. *Figure 33* plots the frequency distribution of walking distance for the transit alternatives of the PTC trips. The average transit walking distance is 743.1 m. Based on the cumulative probability, only 5% of the trips would require a walking distance of 200m or less. A high majority of the trips (80%) require a walking distance of at least 400m to complete the overall trip.

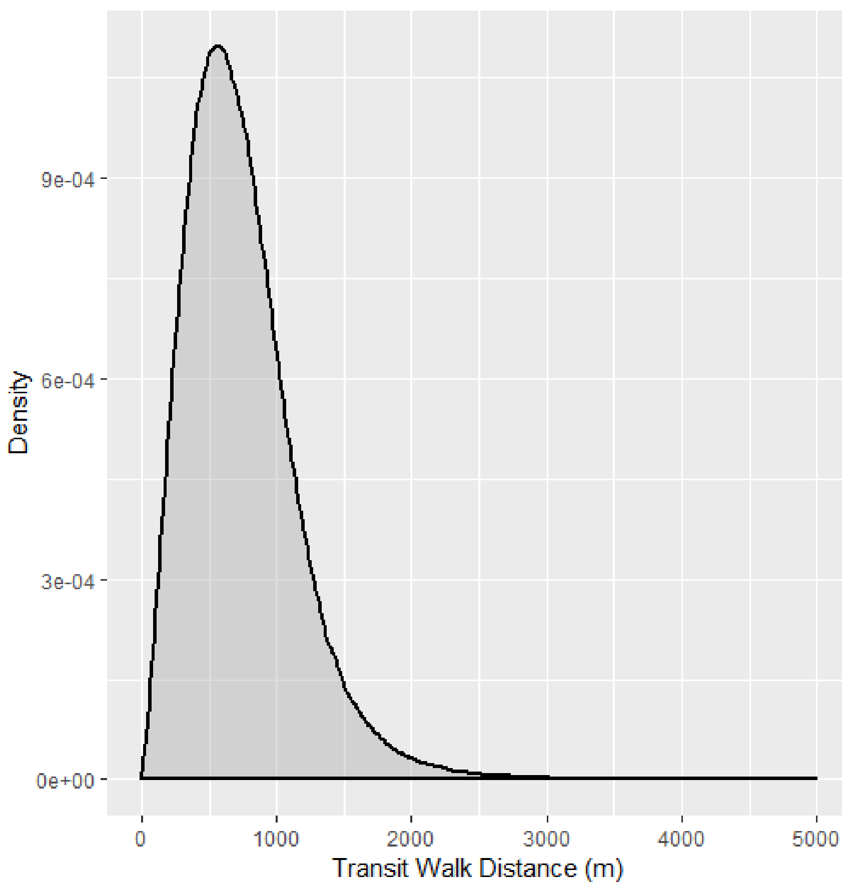

Figure 33 Frequency distribution of transit walking distance

Table 13 Statistics of walking distance (m)

Min	1st quartile	Median	Mean	3rd quartile	Max
14.6	447.4	678.8	743.1	957.4	6784.6

5.3.1.7 Weighed Total Travel Time

Any transit trip is composed of four main components: walking to/from a transit stop, waiting for a transit vehicle to arrive, riding in the vehicle and transferring from one vehicle to another if required. Transit users may perceive each component differently. For instance, in-vehicle travel time is usually considered as progress towards the destination, while walking time and waiting time are usually perceived to be "delays" to actual travel. Some passengers may be willing to add an extra ten minutes of in-vehicle travel time in exchange for removing 3 minutes of walking time. In other words, passengers are placing different weights on the various components of travel time to reflect inconveniences. This false sense of time is the psychological travel time that a passenger feels, which is typically perceived to be longer than the actual travel time. The psychological travel time plays an important role in a person's trip decision-making process and must be considered when comparing transit to PTC. Therefore, different weighting factors should be applied to the different stages of a trip to properly reflect the perceived travel time of a trip.

Based on the TTC service standard (TTC, 2017), weighting factors for different trip components are shown below in *Table 14*. As suggested, 1 minute of waiting time is equivalent to 1.5 minutes of in-vehicle travel time, 1 minute of walking time is equivalent to 2 minutes of in-vehicle travel time and 1 transfer is equivalent to 10 minutes of in-vehicle travel time.

Table 14 Use of weight in travel time (based on TTC service standard)

Trip Component	Weight
Each minute of in-vehicle travelling time	1.0
Each minute of waiting time	1.5
Each minute of walking time	2.0
Each transfer	10.0

With these weighting factors being considered, the weighted total travel time of PTC and public transit is expressed as follows.

weighted total travel time of PTC = 1.5 × waiting time + 1 × in vehicle travel time

weighted total travel time of Transit = 2 × walking time +1.5 × waiting time + 1 × in vehicle travel time + 10 × number of transfers

Figure 34 shows the frequency distribution of the weighted total travel time of PTC and public transit. *Table 15* presents the statistics of the weighted total travel time. In comparison with public transit, PTC weighted total travel time has a smaller spread. The average value of PTC is 23.78

minutes and the average value of transit is 49.08 minutes. Therefore, an average PTC trip could save a passenger 25.30 minutes of perceived travel time.

In terms of the difference in weighted total travel time for each trip, *Figure 35* illustrates the frequency distribution of the ratio of transit weighted total travel time to PTC weighted total travel time. The average ratio is 2.21, which means on average, transit would take 2.21 times longer than PTC to complete a trip. According to the calculated cumulative probability, 94% of the PTC trips would take longer if public transit was used and 54% of the PTC trips would have been at least twice as long if taken by public transit (ratio > 2).

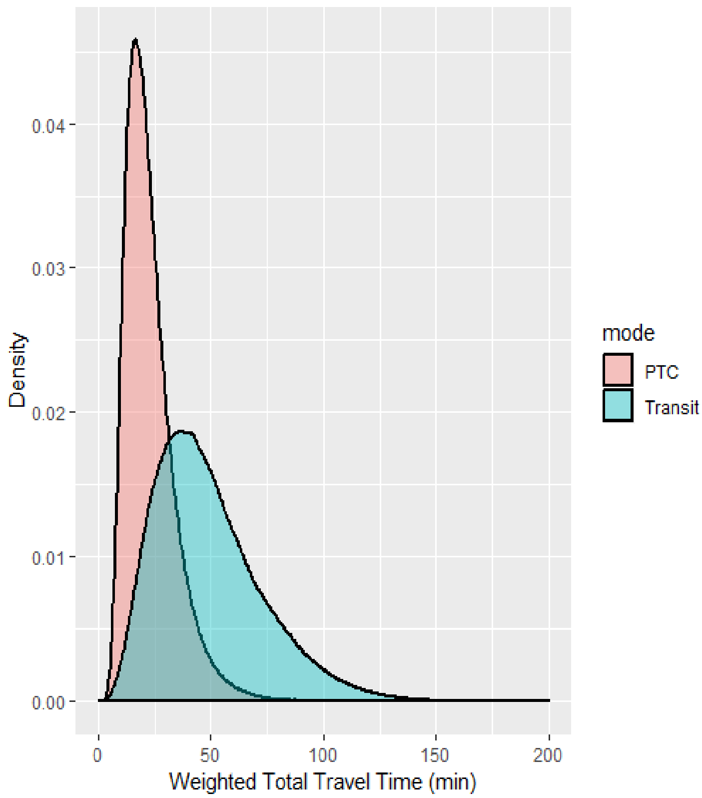

Figure 34 Frequency distribution of weighted total travel time

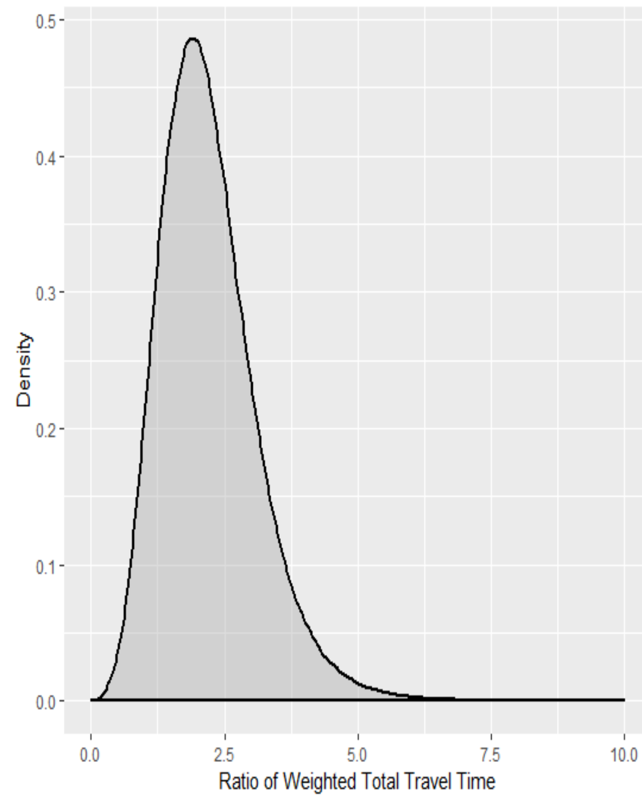

Figure 35 Frequency distribution of the ratio of transit to PTC weighted total travel time

Table 15 Statistics of weighed total travel time (min)

Mode	Min	1st quartile	Median	Mean	3rd quartile	Max
PTC	1.03	15.81	21.38	23.78	29.06	186.25
Transit	1.62	31.42	44.98	49.08	62.44	492.10

5.3.2 Temporal Analysis

Transit schedule changes by time of day and day of the week based on travel demand. For instance, there are more transit routes running frequently during the morning peak on a weekday than overnight on a weekend. Hence, the differences between the level of service of transit and PTC also vary across the time of day and day of the week.

In this section, transit attributes and differences between PTC and transit services are plotted by time of day and day of the week to investigate the time variant effect. First of all, the percentage of transit mode share is displayed in *Figure 36*. Then, the average ratios of transit to PTC travel time (total travel time, in-vehicle travel time and out-of-vehicle travel time) are calculated for every hour of weekdays and weekends. These ratios are plotted by time of day and day of the week, as can be seen from *Figure 37* to *Figure 39*. A ratio larger than 1 implies that public transit would have a longer travel time than PTC for the same trip. Moreover, the average walking distance involved in a transit trip is displayed over time of day and day of the week as well (see *Figure 40*).

5.3.2.1 Transit Mode Usage

The level of transit services varies across different transit modes, for example, rail transit (e.g. subway) provides a faster travel time than surface transit due to higher speed and less interaction with other modes. It is demonstrated in Section 5.3.1.2 that PTC trips are more comparable to bus and streetcar services than subway services. It is further expected that this relationship will hold true across the time of day and day of the week.

Figure 36 shows the usage percentage of different transit modes that can be taken in order to complete the PTC trips by the time of day and day of the week. Several observations can be drawn from this figure. The usage of surface transit possesses the highest mode share over the course of the week, while the subway is associated with the lowest transit mode share, which is consistent with the results found in Section 5.3.1.2. Furthermore, there is not much difference in weekday and weekend patterns for each transit mode. Surface transit achieves its maximum mode share (100%) overnight. Meanwhile, subway only and the combination of subway and surface transit hit their minimum values (0%) overnight as well. It is happening due to the fact that TTC subway services are not available from 1:30 am to 6:00 am on weekdays and Saturdays, and from 1:30 am to 8:00 am on Sundays. Therefore, any PTC trips starting during these time periods will not involve any subway usage. It can be seen that the surface transit mode share for weekdays has two peaks during a day, the first during the morning peak period and the second during the afternoon peak period. This implies PTC trips generated during the commute peak periods would involve more surface transit usage than any other time during the day if completed by public transit. On the contrary, subway mode share seems to have two drops during the same time periods, which indicates there would be less subway usage in the morning and afternoon peaks. However, there is not much variation in weekend daytime across the three transit modes, which can be explained by the lack of commuter patterns for weekends.

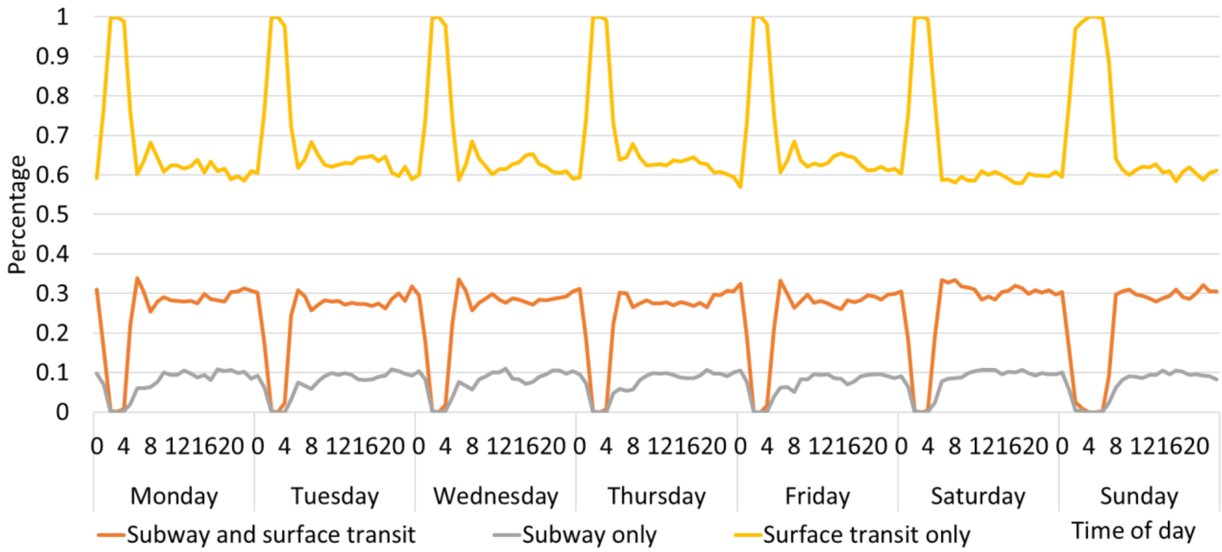

Figure 36 Transit mode share by the time of day and day of week

5.3.2.2 Total Travel Time

Figure *37* presents the ratio of transit to PTC total travel time for the four trip markets over the course of the week. With regards to weekday trips, market 1 (trips within PD 1) has the smallest ratio across the time of day. This means the proportional difference in total travel time (for weekday trips) between public transit and PTC is the smallest for market 1 out of the 4 trip scenarios. This can be explained by the better transit services that are provided in Toronto's downtown, compared to the transit service provided elsewhere. It should also be pointed out that the temporal variation in the ratio for the four trip markets has similar patterns. All curves have their maximum values around 4 am and hit their minimum points at 8 am in the morning and 5 pm in the afternoon. This implies that the proportional difference in total travel time between transit and PTC is the largest overnight but the smallest during morning and afternoon rush hours. This can be explained by the fact that overnight transit services are very poor since a few major bus routes are still operating from 1:30 am to 5 am. TTC achieves its best services in terms of service coverage and frequency during the morning and afternoon rush hours when people go to/leave from work. Therefore, for a trip to Toronto on a weekday, transit services are more comparable to PTC services during the morning and evening peaks than other times of the day. It is interesting to see the ratio of transit to PTC travel time come closest to 1 for trips within Toronto's downtown during the morning and afternoon rush hours (8 am and 5 pm, respectively), which indicates the competitiveness of transit services (particularly rapid transit) with auto in spatial and temporal contexts of high congestion levels. This point is further illustrated for trips to downtown (trip market 2) at 8 am and trips from downtown (trip market 3) at 5 pm.

As for the weekends, trip market 1 (trips within PD 1) has the smallest ratio across throughout the day. In contrast, either trip market 3 (trips with only the origin in PD 1) or trip market 4 (trips outside of PD 1) has the largest ratio depending on the time of day. The weekend average ratios do not follow a distinct pattern like the weekday ratios. The weekend average ratios of the total travel time for the four trip markets do not have sharp drops, which is likely because transit services do not vary substantially among the various time periods of a weekend day. However, similar to weekday patterns, the ratios of the four trip markets both hit the maximum values around 4 am in the morning.

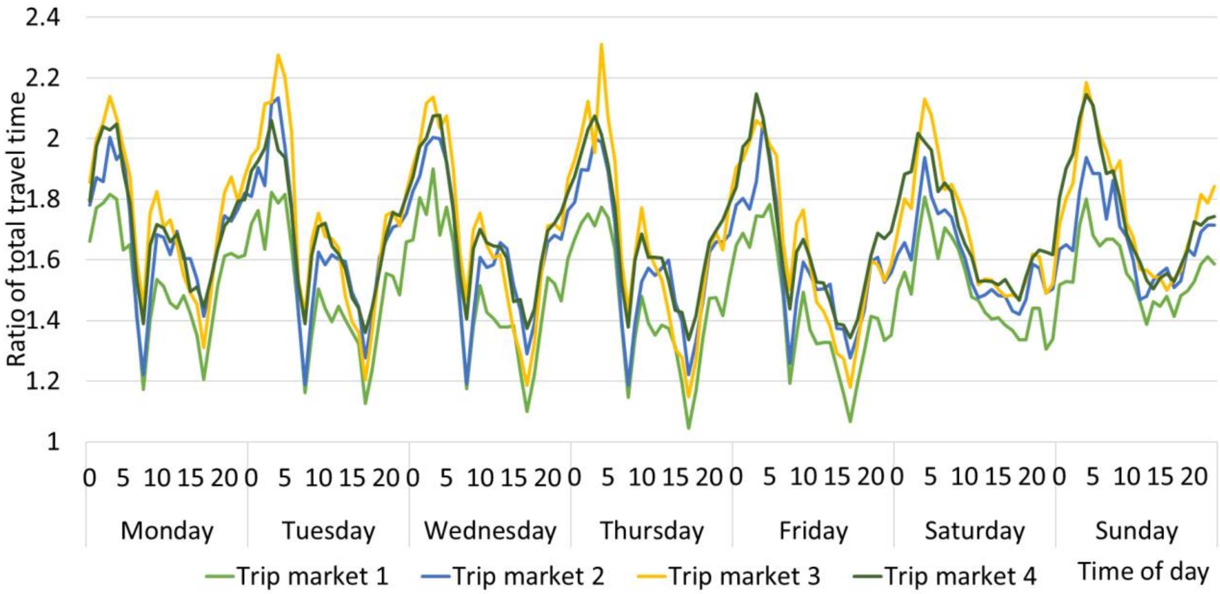

Figure 37 Average ratio of transit to PTC total travel time for the four trip markets by the time of day and day of week

5.3.2.3 In-vehicle Travel Time

Figure 38 plots the average ratio of transit to PTC in-vehicle travel time for the four trip markets across the time of day and day of the week. It can be easily seen that trip market 1 (trips within PD 1) has the lowest ratio throughout a week. For weekday trips, during morning and afternoon rush hours, the average ratio of trip market 1 even drops below 1, which implies that transit would have shorter in-vehicle travel time than PTC would when completing the same trip. The other three trip markets have larger values than trip market 1 and there is no distinct difference among them. All of the trip markets have the minimum values at 8 am and 5 pm but achieve the maximum values around 5 am.

In terms of the ratio of in-vehicle travel time for weekends, it has some similar findings as weekdays. For example, trip market 1 (trips within PD 1) has the lowest ratio throughout the day. There is also no recognizable difference between trip market 2, 3 and 4. The major difference between weekdays and weekends is that the weekend's ratios during the time of day do not fluctuate very much. As mentioned earlier, this discrepancy between weekday and weekend might be due to different transit schedules. The weekend transit schedule does not vary much across the day.

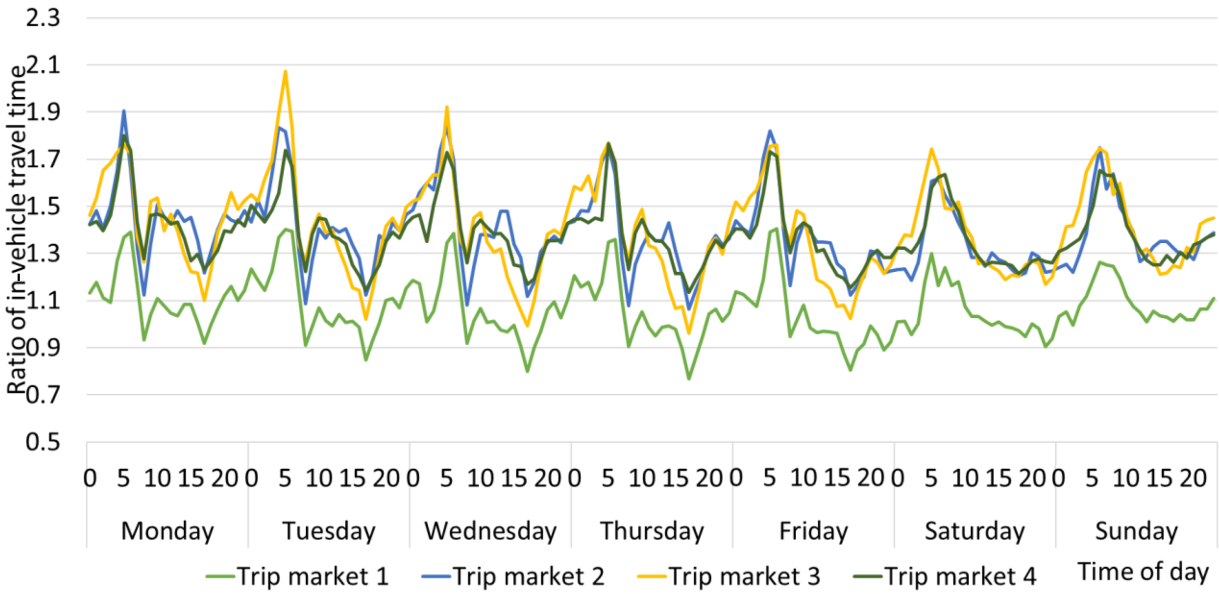

Figure 38 Average ratio of transit to PTC in-vehicle travel time for the four trip markets across the time of day and day of week

5.3.2.4 Out-of-vehicle Travel Time

Figure *39* displays the average ratio of transit to PTC out-of-vehicle travel time for the four trip markets over the course of the week. As shown, trip market 1 (trips within PD 1) and trip market 3 (trips with only the origin in PD 1) have larger ratios than trip markets 2 and 4. A possible explanation for these results is that trips starting in PD 1 have smaller PTC out-of-vehicle travel time than trips starting elsewhere because there is more PTC supply in the downtown area than in other areas. Therefore, PTC trips with origins in PD 1 would experience relatively small wait time (out-of-vehicle travel time), so the ratio of transit to PTC is relatively large. With regards to the temporal variation of ratios of transit to PTC for the four trip markets for weekdays, the trend shows that the smallest ratios happen at the morning peak and the afternoon peak. The largest ratios of the four trip markets are achieved overnight. However, the ratio of transit to PTC out-of-vehicle travel time for weekends do not have clear-defined minimum points, which can be explained by unvaried transit services throughout the day on weekends. During the daytime, trip market 1 and trip market 3 have larger ratios than that of trip market 2 and 4. As mentioned earlier, it is probably due to smaller PTC out-of-vehicle travel time in the downtown area.

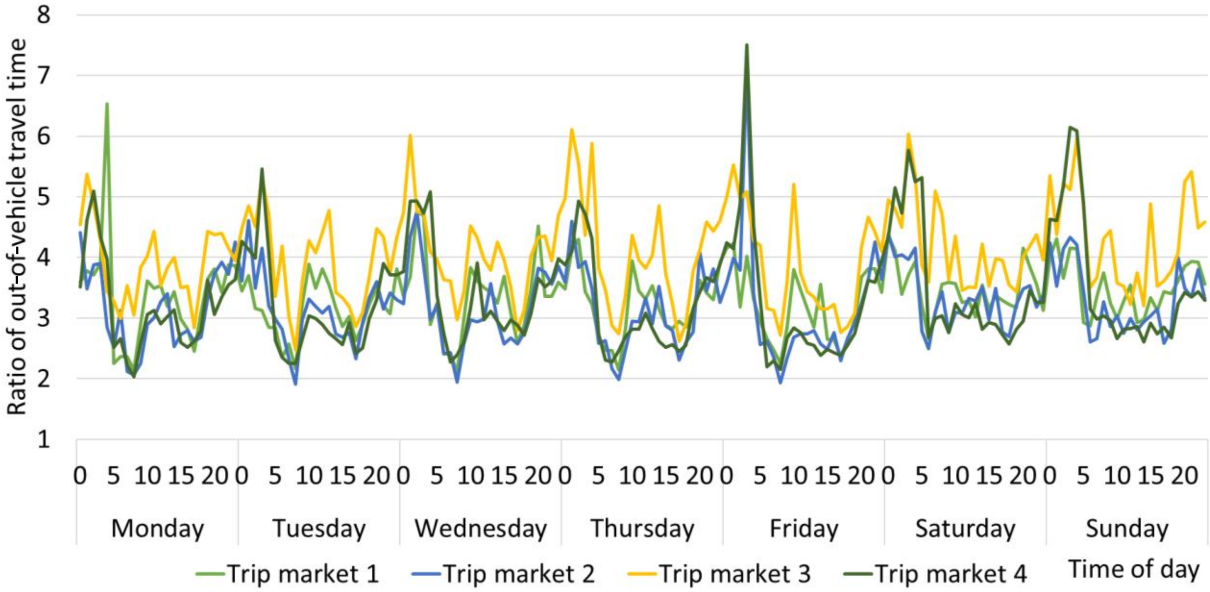

Figure 39 Average ratio of transit to PTC out-of-vehicle travel time for the four trip markets across the time of day and day of week

5.3.2.5 Walking Distance

Figure 40 displays the variation of the average walking distance involved in a transit trip for the four trip markets by the time of day and day of the week. As expected, trip market 1 (trips within PD 1) has the shortest walking distance while trip market 4 (trips outside of Toronto) has the longest walking distance across a week. The result is logical because transit stops are more densely distributed in the downtown area than elsewhere in Toronto. Hence, trips travelled within downtown are expected to have smaller access and egress walking distance than trips travelled outside of the downtown. Furthermore, it is calculated that the average walking distance for weekdays is smaller than that of weekends (662.41m vs 788.10m).The walking distance across the four trip markets for weekdays and weekends have the same patterns over time. The four trip markets achieve the maximum values overnight (around 3 am) and almost stay constant during the daytime. This is most likely because TTC provides only 31 late-night bus route services from 1:30 am to 5 am (the Blue Night Network). If a person who lives far away from any major transit corridors wants to take transit overnight, they will have a long distance to reach the nearest transit stop. On the other hand, TTC daytime services do not vary significantly in terms of routes in operation. Therefore, there is not much fluctuation in average walk distance during the day.

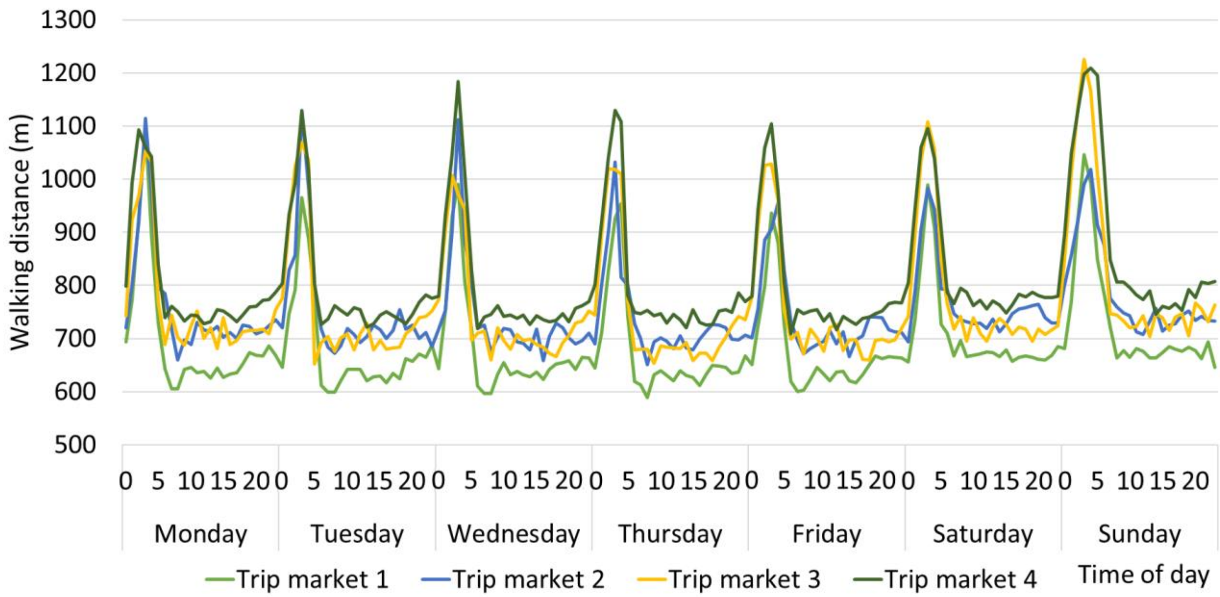

Figure 40 Average walking distance for the four trip markets across the time of day and day of week

5.3.2.5 Requested Time Intervals

As requested by the Big Data Innovation Team of the City of Toronto, there are several specific time periods that the City has shown interest in, based on findings from other studies. For example, it is shown that Friday evenings are different from the rest of the weekday evenings because PTC ridership for Friday evenings (from 19 pm to 22 pm) is much higher than that of other weekdays. The Big Data Innovation Team proposed several time periods that require further investigation. Specifically, these time periods are: weekday overnight (3am to 7am, Monday-Friday), weekday morning peak (7am to 10am, Monday-Friday), weekday afternoon peak (16pm to 19pm, Monday-Friday), weekday evening (19pm to 22pm, Monday-Thursday), Friday/Saturday evening (19pm to 22pm), Friday/Saturday early night (22pm to 24pm) and Friday/Saturday late night (0am to 3am).

In this section, the average differences in total travel time, in-vehicle travel time and out-of-vehicle travel time for each time period are calculated and presented in *Table 16*. The transit mode share and walking distance involved in a transit trip are displayed in this section as well.

Table 16 Attributes for interested time periods

	Weekday overnight	Weekday morning peak	Weekday afternoon peak	Weekday evening	Friday/Saturday evening	Friday/Saturday early night	Friday/Saturday late night
Difference in total travel time (min)	16	8	6	10	9	9	13
Difference in in-vehicle travel time (min)	9	4	1	4	3	2	4
Difference in out-of-vehicle travel time (min)	7	5	5	7	7	7	9
Walking distance (m)	826	693	697	711	725	725	899
% using subway only	4%	7%	9%	10%	10%	9%	6%
% using surface transit only	76%	66%	64%	61%	61%	61%	77%
% using subway and surface transit	20%	28%	28%	29%	30%	30%	18%

The results presented in *Table 16* are consistent with the findings from Section 5.3.2. The results were similar for the difference in travel times and walking distance; trips which started during the weekday morning and afternoon peaks would involve the shortest walking distance and the smallest difference in travel times (total travel time and out-of-vehicle travel time) between public transit and PTC. In contrast, weekday overnight and Friday/Saturday late night correspond to the largest values. In terms of transit mode share, PTC trips, if completed by public transit, would involve more subway usage if generated in evenings than other periods. Meanwhile, PTC trips would associate with more surface transit usage for a weekday overnight and Friday/Saturday late night than other time periods, if taken by transit.

5.3.3 Spatial Analysis

Besides exploring the proportional difference in service attributes between transit and PTC over time, spatial analysis is also necessary to have an overall understanding of the relationship between public transit and PTC. The main question this section attempts to address is how the difference between PTC and transit travel services change over space in the City of Toronto.

In this section, 625 traffic analysis zones (TAZ) of Toronto are colour-coded based on different average values for all trips generated within each TAZ zone. A map evaluating all of the TAZs is generated for each of the following average values: number of transfers, difference in total travel time and ratios for transit to PTC (including total travel time, in-vehicle travel time and out-of-vehicle travel time) for each TAZ. The map is overlaid on the TTC route map for reference. Darker areas in the map represent higher ratios while lighter areas represent smaller ratios. It is expected to see that areas with good transit services will have a lighter colour, while areas with poor transit services will have a darker colour.

5.3.3.1 Number of Transfers

Figure 41 presents a map for the average number of transfers of the transit alternative to PTC trips for each TAZ in the City of Toronto. The map shows that the old Toronto area (downtown) has a lighter colour than other areas, which indicates that PTC trips generated in the downtown would involve fewer transfers, if undertaken by trainsit, than trips generated in other zones (e.g. Etobicoke and East York). This finding appears logical because transit services are the most developed in the downtown area due to the higher population and employment densities.

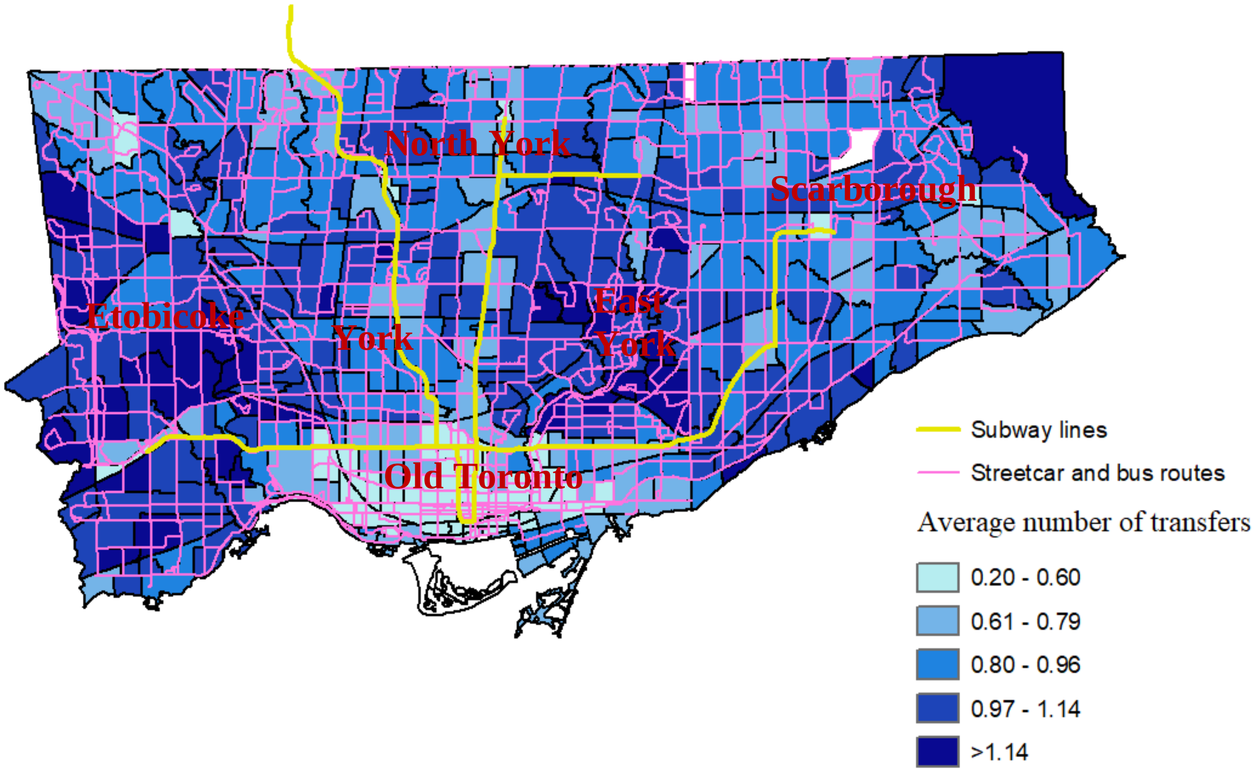

Figure 41 Number of transfers per TAZ

5.3.3.2 Total Travel Time

Figure 42 displays a map of the average ratio of transit to PTC total travel time for each TAZ in the City of Toronto. The map shows that the downtown area, the York and North York areas have the lowest ratio (the lightest colours) of transit to PTC total travel time. This implies that the transit total travel time is more comparable to the PTC total travel time for trips generated in these areas. The map also shows that the outer areas have a higher ratio (such as west of Etobicoke and East York), which represents a higher proportional discrepancy in total travel time between public transit and PTC for trips starting in those areas.

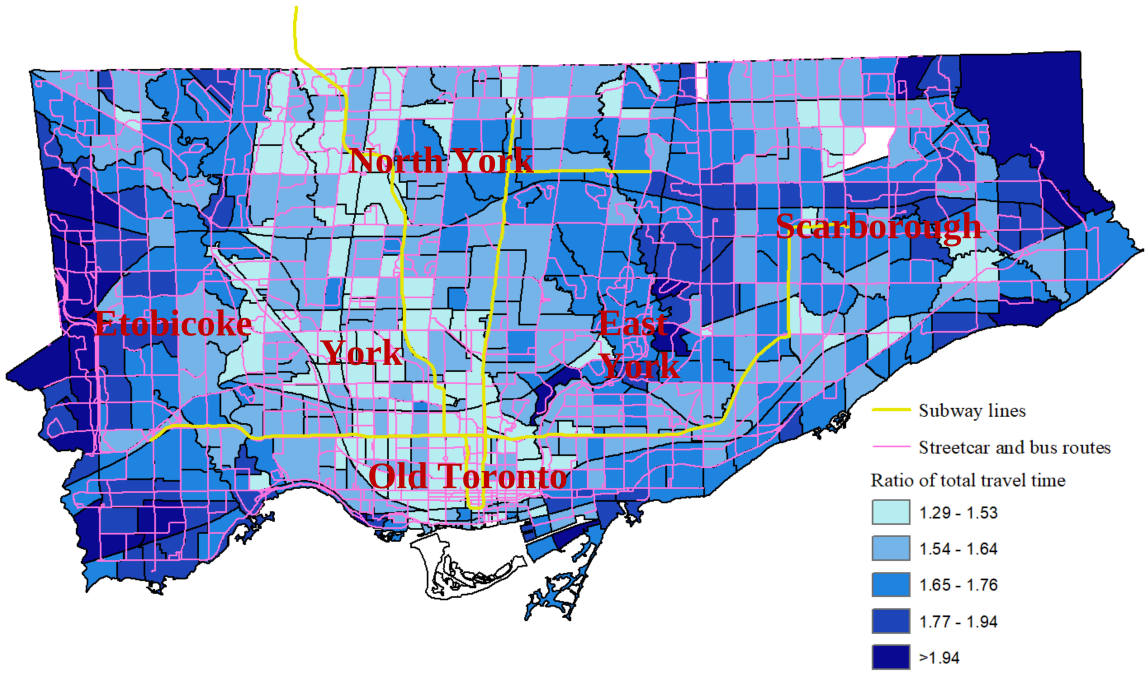

Figure 42 Average ratio of transit to PTC total travel time per TAZ

5.3.3.3 In-vehicle Travel Time

Figure 43 illustrates the average ratio of transit to PTC in-vehicle travel time across all TAZs in the City of Toronto. The figure shows zones around TTC subway lines having a lighter colour than other areas. This indicates that trips starting near a subway line have a smaller proportional difference for in-vehicle travel time when comparing transit and PTC. Transit trips starting near a subway line are more likely to involve subway usage, which is a faster mode of travel than PTC vehicles. Therefore, trips that are generated around subway lines have an increased probability of having a lower ratio for in-vehicle travel time between transit and PTC, than trips generated elsewhere.

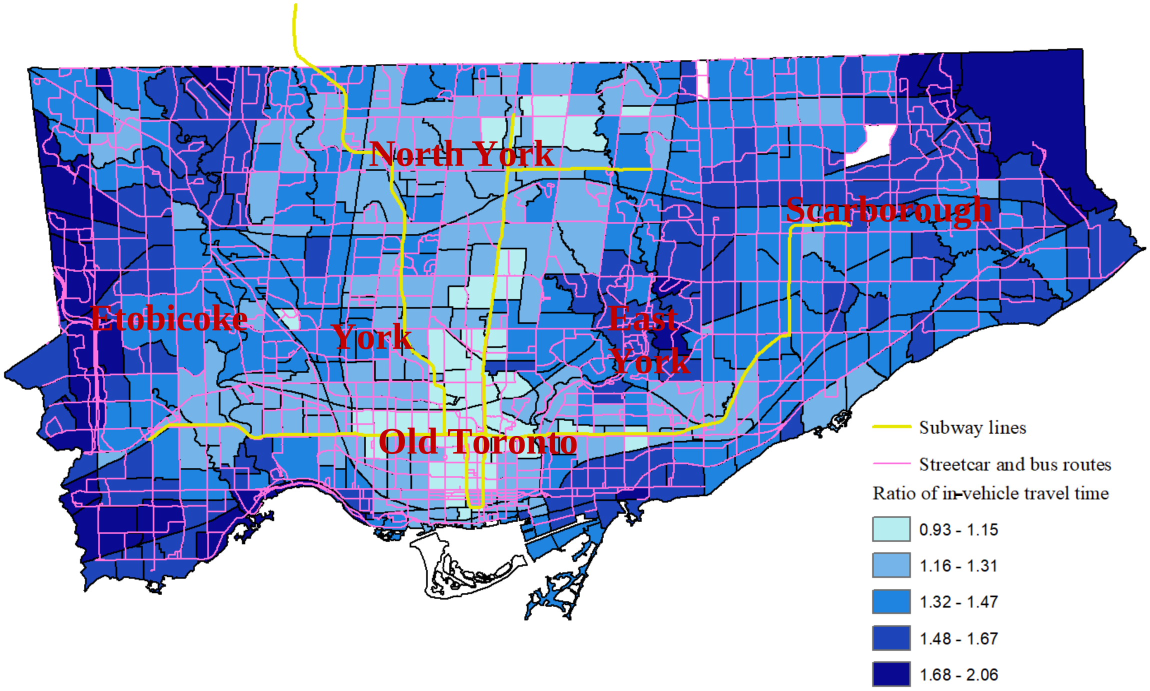

Figure 43 Average ratio of transit to PTC in-vehicle travel time per TAZ

5.3.3.4 Out-of-vehicle Travel Time

In Figure *44*, the average ratio of transit to PTC out-of-vehicle travel time for each TAZ zone shows results that are different from the previous two maps. The downtown and subway areas have a darker colour than the suburban areas (e.g. Etobicoke and Scarborough). This result implies that there is a less proportional difference in out-of-vehicle travel time between the two travel modes in suburban areas than in downtown and strong transit service areas. A possible explanation for these results is that PTC have more supply in the downtown and subway areas due to higher demand, and the supply of PTC decreases the further away from those areas. This means a passenger will be picked up more quickly by a PTC driver in "busier areas" than in inactive areas. This probably leads to shorter PTC waiting times (PTC out-of-vehicle travel time), which then is likely to cause a higher ratio between transit and PTC for out-of-vehicle travel times.

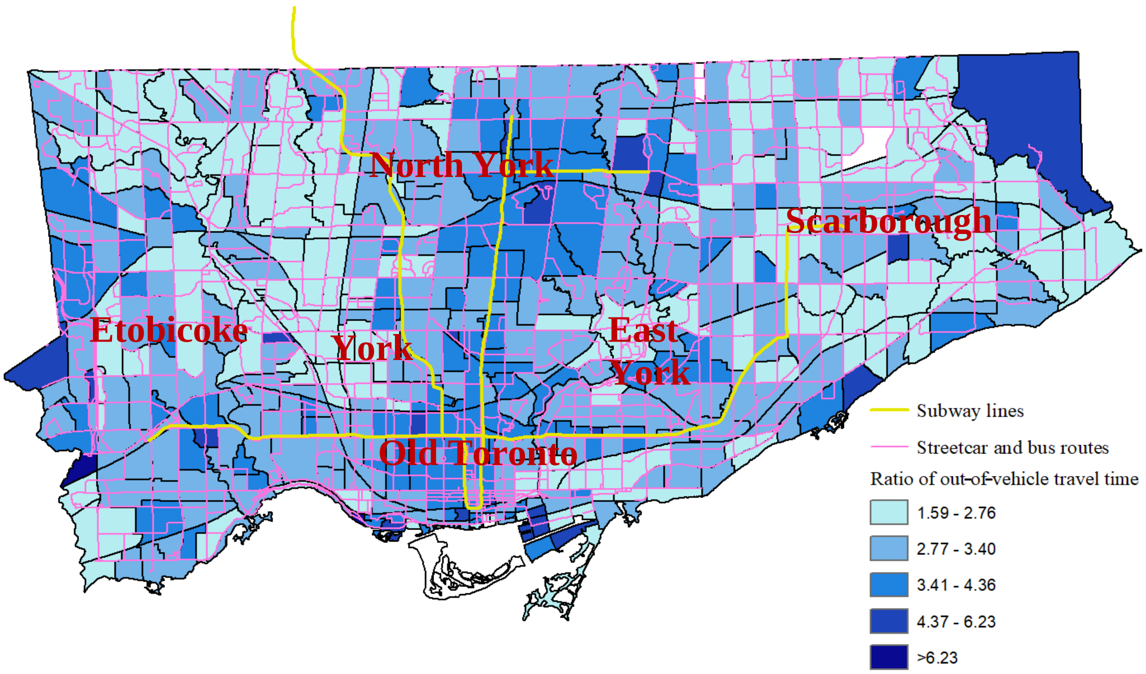

Figure 44 Average ratio of transit to PTC out-of-vehicle travel time per TAZ

5.3.4 Walking Trips

As mentioned in Section 5.3, 7% of the PTC trips have walking as a better option than transit. It is suspected that these 7% of PTC trips were probably too short to realistically be served by transit, while some might have taken place in "transit deserts" which had no access to public transit or at times when no transit services were available. For the latter scenario, PTC is complementing public transit by filling a gap of transit services. In this section, a brief analysis of the walking trips is conducted to investigate the characteristics of these trips.

Figure *45* displays the frequency distribution of the distance of the walking trips, and Table *17* presents the corresponding statistics. It is shown that the average walking distance is just 1.3 km and the majority of the trips (75%) are under 1.5 km. These findings confirm the hypothesis that the majority of the walking trips are too short to be served by public transit. However, there are some walking trips that involve a very long walking distance (e.g. the maximum walking distance is over 10 kilometers). Such extremely long "walking" trips are outliers that are unrealistic to be conducted. The fact that OTP suggests walking over transit for these trips indicates that the transit service for these trips is very poor.

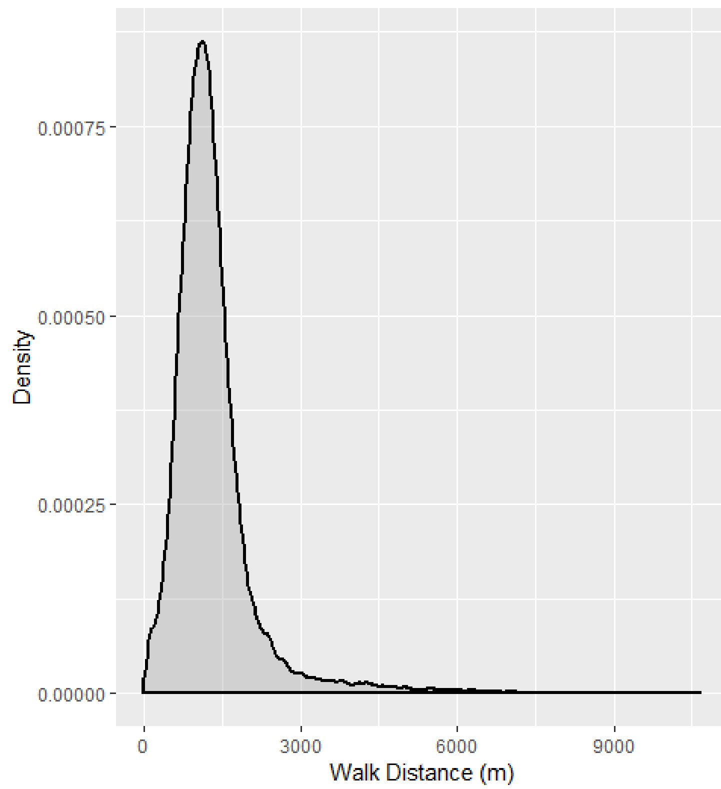

Figure 45 Frequency distribution of walking distance of the walking trips

Table 17 Statistics of walking distance (m)

Min	1st quartile	Median	Mean	3rd quartile	Max
4.4	870.3	1169.3	1317.1	1517.6	10655.9

In terms of when and where the walking trips would generate, *Figure 46* and *Figure 47* illustrate the trip frequency across time and space. As *Figure 46* shows, a large number of walking trips occur during Saturday night (12 am to 4 am), followed by Sunday morning (9 am to 12 pm) and Friday night (12 am to 4 am). Furthermore, *Figure 47* displays a map of the number of walking trips generated in each TAZ, the darker colours represent a higher number of walking trips. The map suggests that the downtown area induces more walking trips than other districts. As a result of the temporal and spatial plots, it can be implied that walking trips are more likely to happen in the old Toronto area on weekends, especially weekend nights when transit services are minimal.

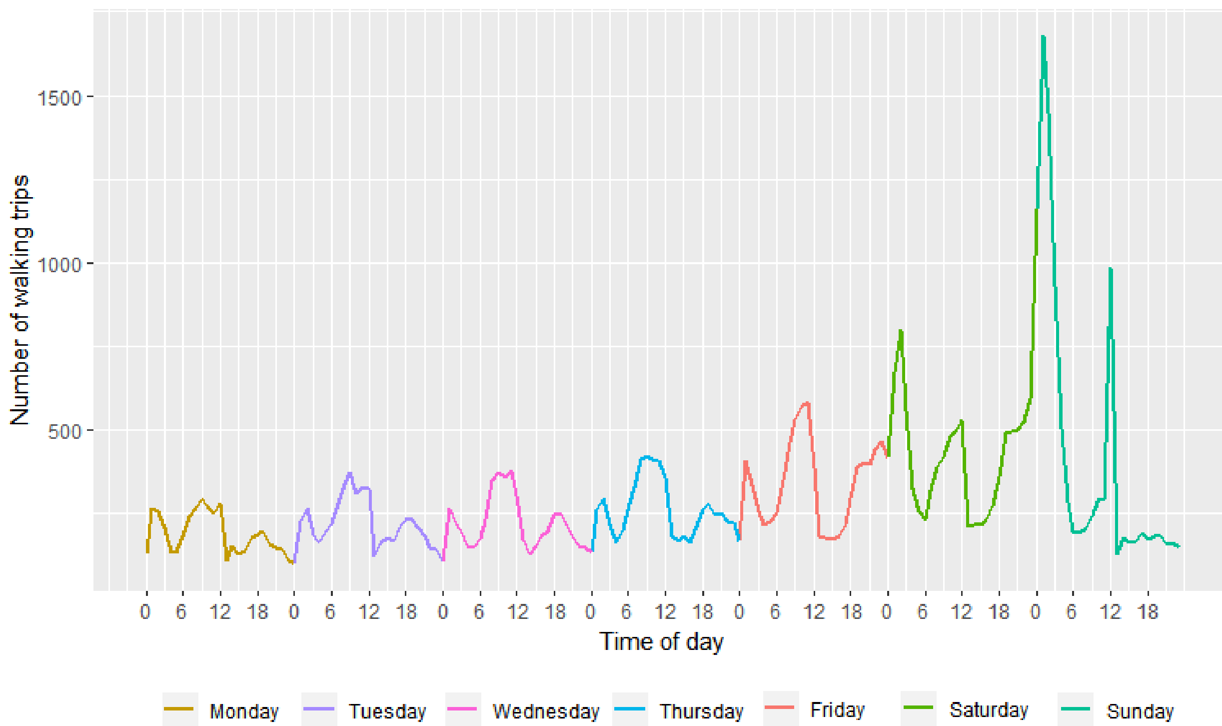

Figure 46 Number of the walking trips by the time of day and day of week

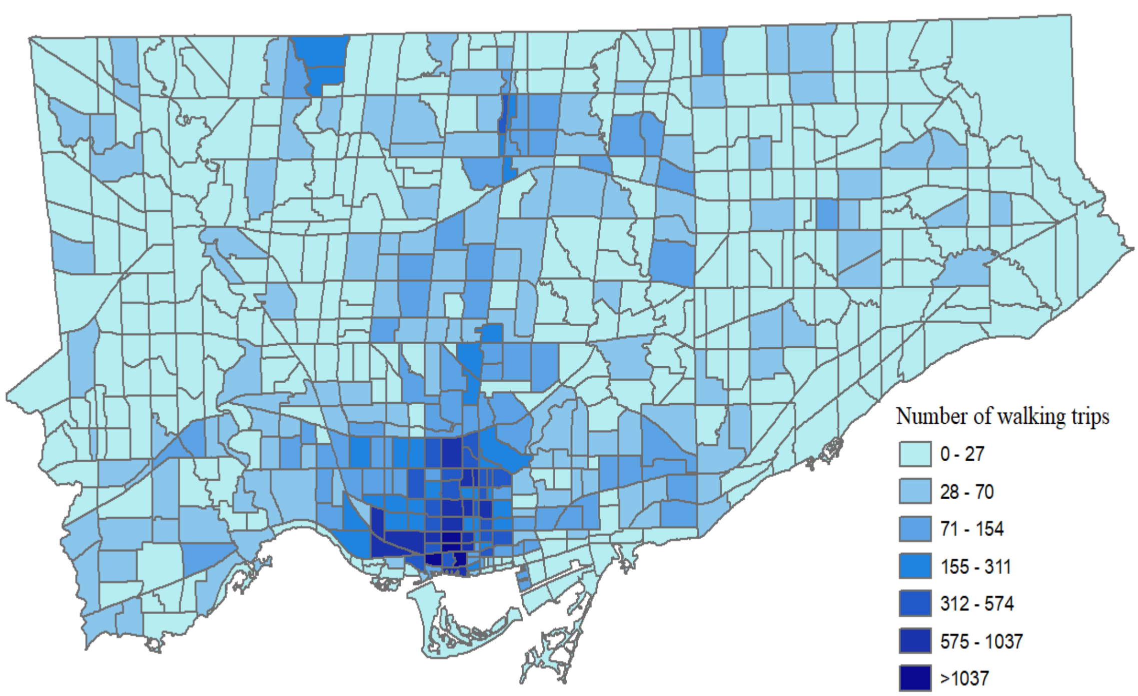

Figure 47 Number of the walking trips per TAZ

5.3.5 PTC Trips with Infeasible Transit Alternatives

Not all PTC trips would have feasible transit alternatives. As stated in Section 5.3, 0.6% of the analyzed PTC trips could not be completed by either transit or walk, due to the same start and end points or unrecognizable start/end locations (e.g. the origin was approximated to a point over water). Even though 92.4% of the PTC trips do have corresponding transit alternatives, some of them might be unrealistic to be considered by passengers. For instance, transit trips with extremely long total travel time or walking distance. Hence, it is possible that people choose PTC over transit because of infeasible transit solutions. For those trips with unrealistic transit alternatives, PTC is acting as a complement to public transit services.

The definition of infeasible transit trips in this report is defined as follows: 1). Trips without a transit or walking option 2). Trips whose corresponding transit alternatives would take longer than 150 minutes or involve walking distances over 2 kilometers. According to this definition, a total of 2% of the PTC trips would have an infeasible transit substitute.

In this section, a temporal and spatial analysis of the PTC trips with infeasible transit options is conducted to understand when and where these trips occur. Figure *48* shows that the majority of these PTC trips happen overnight, especially during Friday and Saturday nights. This is probably occurring due to fewer transit routes operating overnight. As a result, it is more likely to induce an infeasible transit trip overnight than any other time period. Furthermore, Figure 49 displays a map of the PTC trips without a transit alternative for each TAZ. The result implies that downtown Toronto has more infeasible transit trips than other districts in Toronto. This could possibly be explained by the high demand for PTC trips in Toronto's downtown. As stated in Section 4, almost one-quarter of the PTC trips occurred within just the downtown area. Moreover, the downtown is the home of the entertainment district and major sports venues which generate many evening and late night trips. Consequently, it is understandable there are more PTC trips without a feasible transit option in downtown than other areas.

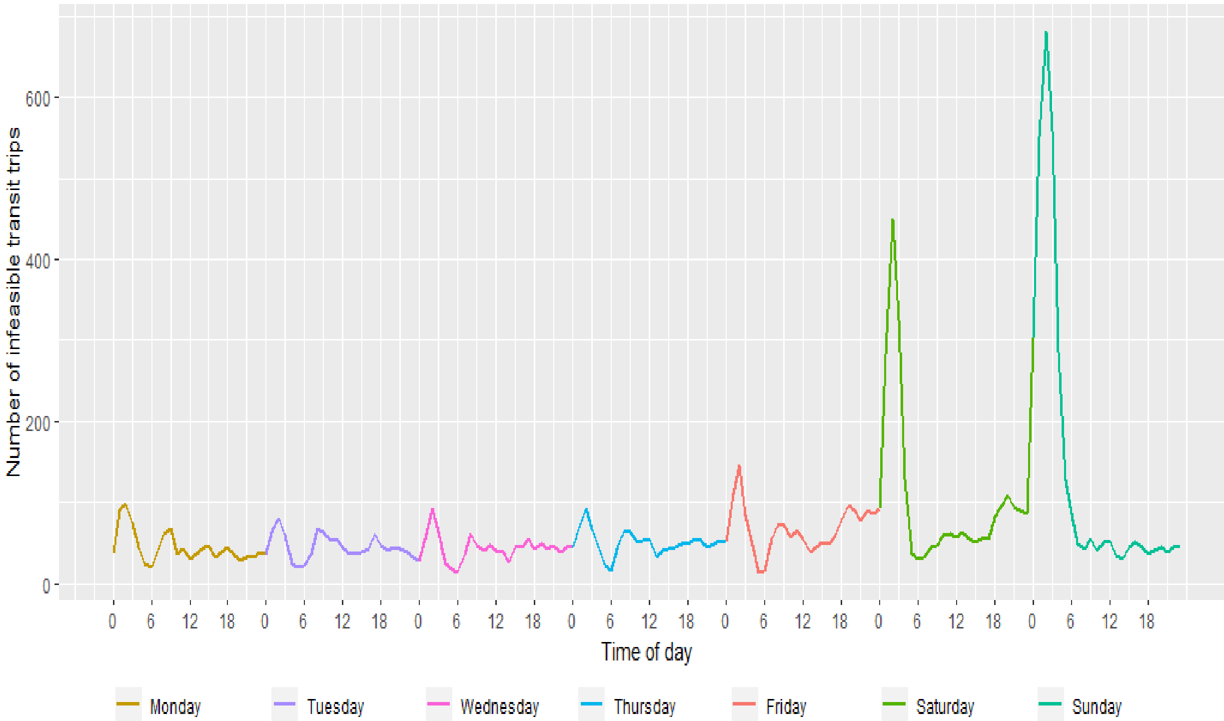

Figure 48 Number of the infeasible transit trips by the time of day and day of week

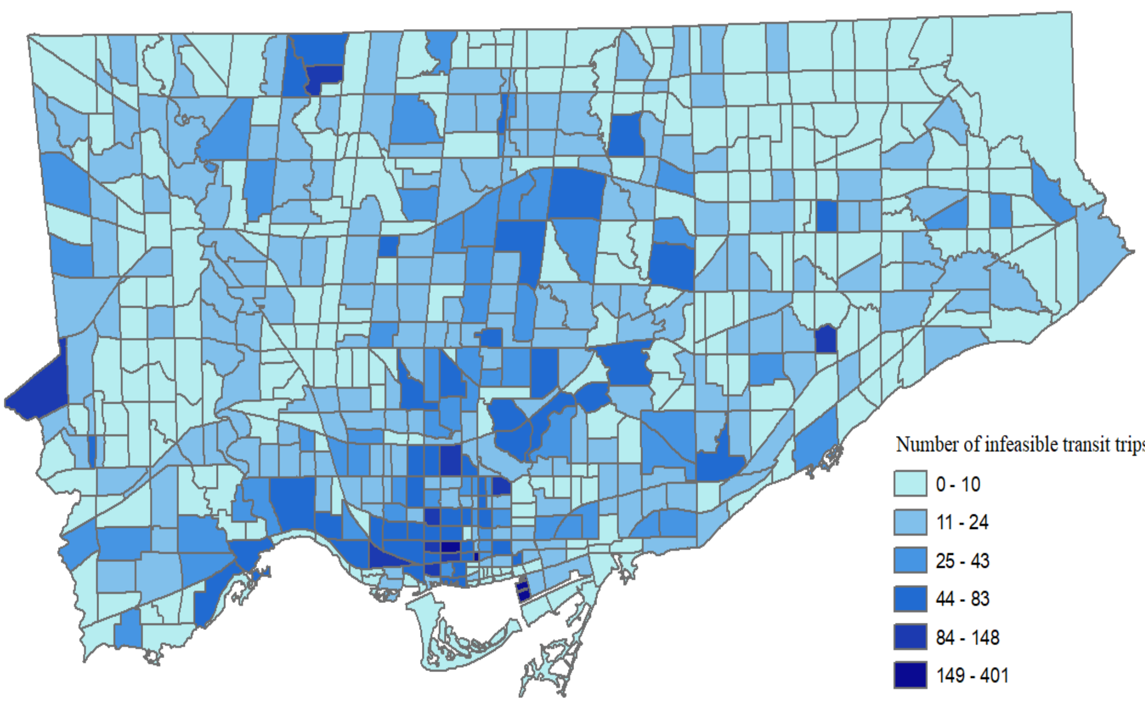

Figure 49 Number of infeasible transit trips per TAZ

5.4 Key Findings

- 47% of the PTC trips would involve no transfers if made by transit, while 53% would require at least one transfer.
- 65% of the PTC trips would only involve the usage of surface transit if they were taken by public transit, but 8% only would use subway services.
- On average, transit would take 1.57 times longer in actual travel time than PTC over an identical PTC trip.
- On average, the difference in total travel time between public transit and PTC is about 10 minutes. Moreover, the difference in total travel time increases as the trip distance becomes larger.
- For 86% of the PTC trips, taking transit would end up with a longer total travel time than taking PTC.
- On average, the transit weighted total travel time is 2.21 times longer than the PTC weighted total travel time.
- The average ratio of transit to PTC in-vehicle travel time is 1.25.
- The average ratio of transit to PTC out-of-vehicle travel time is 3.36.
- The difference in out-of-vehicle travel time between transit and PTC is the main reason for why a transit trip takes longer than a PTC trip.
- A large majority of the PTC trips (80%) would result in passengers having to walk at least 400 metres if transit were taken instead.
- Transit would offer comparable service travel times to PTC services on weekdays during the morning peak and the afternoon peak than other times of the day.
- The proportional difference between transit and PTC travel time does not vary much throughout the day on weekends, but the proportional difference increases overnight due to reduced transit services.
- If made by transit, PTC trips within the downtown would have the smallest total walking distance (average value: 662m) compared to other trip markets, while PTC trips outside of the downtown would have the longest walk distance (average value: 788m).
- Transit total travel time is more comparable to PTC total travel time for trips originating within the downtown, York and North York areas than trips originating in other areas in Toronto.
- Transit in-vehicle travel time is more comparable to PTC in-vehicle travel time for trips originating in areas near subway services than in other areas in Toronto.
- Transit out-of-vehicle travel time is more comparable to PTC out-of-vehicle travel time for trips starting in suburban areas than in high populated areas (e.g. areas around subway lines), which might be due to less PTC supply in the suburbs than in busy areas. This means PTC trips have a relatively longer waiting time (PTC out-of-vehicle travel time) in suburban areas, causing a lower ratio for out-of-vehicle travel times.
- 7% of the PTC trips would be completed by just walking. 75% of the walking trips are under 1.5 kilometres and the majority of them occur on weekends and in the downtown area.
- 2% of the PTC trips had infeasible transit alternatives and most of these trips were generated on weekend overnights and in Toronto's downtown.

6 Summary

This report attempts to investigate the relationship between public transit and PTC, utilizing the detailed trip-level PTC data (from Sept 2016 to Apr 2017) provided by the City of Toronto and available transit ridership and subway disruption data for the same time period. Three descriptive analyses were conducted to answer this research question, specifically, a comparison of travel patterns for four trip markets by the time of day, an investigation of the impacts of subway disruption on PTC usage, and a comparison of transit and PTC service characteristics for the observed PTC trips.

In Section 3, hourly ridership of public transit and PTC for an average weekday in the fall of 2016 were compared across the four trip markets (trips within PD 1, trips with only the destination in PD 1, trips with only the origin in PD 1 and trips outside of PD 1). The results show that PTC ridership for an average weekday is 5% of the transit weekday ridership. Moreover, almost 25% of the weekday PTC trips occurred within Toronto's downtown area where public transit is the most abundant. In terms of travel patterns during a weekday, PTC and public transit both have well-defined commuter patterns, which are represented by a morning peak and an afternoon/evening peak for trips within PD 1 and outside of PD 1. Also, the commuter patterns are described by a clear morning peak for trips entering into PD 1 and a clear afternoon/evening peak for trips departing from PD 1. However, PTC evening peaks are wider than the morning peaks, while transit morning peaks are higher than the evening peaks. This discrepancy could be explained by different trip purposes.

With regards to the complementary relationship between PTC and public transit, the impacts of subway disruptions on PTC usage within subway station buffers are analyzed in Section 4. The total number of PTC rides within a 250m radius of subway stations during an hour of subway disruption were compared with the total number of PTC rides (also within a 250m buffer of the same subway stations) that occurred a week prior without a subway disruption. The difference in PTC usage of the two scenarios shows that subway disruptions caused approximately 9% increase in PTC ridership around subway station areas. Furthermore, the results indicate that longer subway delays could induce a higher percentage increase in PTC usage by people immediately affected by the disruption. However, the effects of subway disruptions on PTC usage at the network level is unknown.

Finally, in order to investigate if there is a substantial service improvement by using PTC over public transit, the transit travel attributes (total travel time, in-vehicle travel time, out-of-vehicle travel time and walking distance) were compared with corresponding PTC travel attributes for a sample of the PTC trips. In order to estimate the transit travel attributes, trip information of 703,018 PTC trips (within the City of Toronto) was uploaded into an OpenTripPlanner instance, which then ran all of the PTC trips to determine the transit travel attributes for the best transit trip plan.

The travel attributes for public and PTC were then analyzed, and the results show that the majority of the PTC trips (91%) have feasible transit alternatives. In general, PTC provides faster services than public transit in most cases (86%). On average, transit total travel time would be 1.57 times longer than PTC total travel time. Furthermore, when considering the psychological effect of the out-of-vehicle travel time, the weighted transit total travel time would be 2.21 times longer than the weighted PTC total travel time.

When separating the total travel time into in-vehicle and out-of-vehicle travel times, it is shown that transit and PTC in-vehicle travel time do not have a big gap (average difference of 4 minutes). In contrast, the difference in out-of-vehicle travel time is responsible for a large percent (64%) of the difference in total travel time between PTC and transit alternatives. When looking into the difference in transit and PTC services across time and space, the results indicate that there is a smaller proportional difference between transit and PTC services for weekdays than weekends. This is especially true during the morning and afternoon peak hours when transit provides the maximum services. From a spatial perspective, trips originating in areas with good transit services have a smaller proportional difference in total travel time and in-vehicle travel time between transit and PTC, relative to trips starting elsewhere in Toronto. However, the result is the opposite for out-of-vehicle travel time, trips generated in well-served transit areas usually have a larger proportional difference in out-of-vehicle travel time. As explained, it might be due to a shorter PTC out-of-vehicle travel time in busier areas than in suburban areas.

In spite of the above results, this study has some limitations. For example, due to time constraints, only a random 5% sample of the total PTC trips were used as input into the OpenTripPlanner program, which might cause induce sampling error affecting the results. Moreover, constrained by limited TTC transit route ridership data, this report did not have the opportunity to quantify the impacts of PTC usage on public transit ridership for multiple transit modes across the time of day and day of the week. Nevertheless, this report laid the foundation for future analysis. The more specific temporal and spatial analysis will be conducted in the next step to help draw a clearer relationship between the traditional transit services and the emerging PTC services.

Acknowledgments and Disclaimer

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Appendix

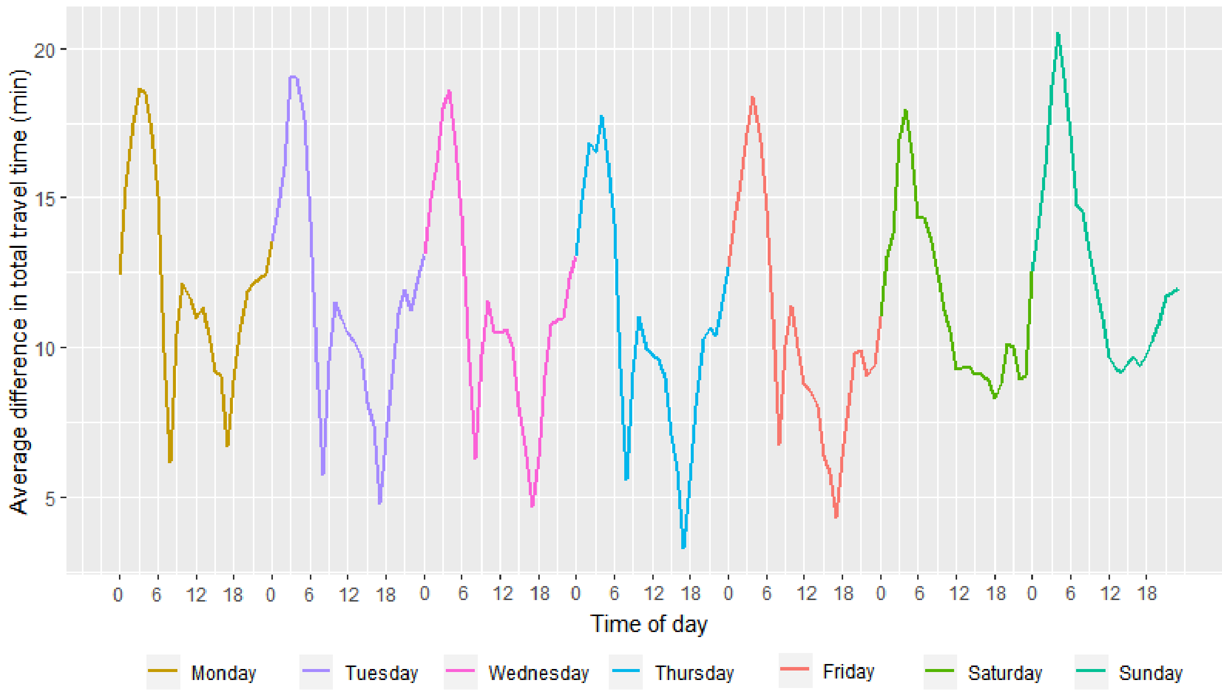

Figure A- 1 Average difference in total travel time over time of day and day of week

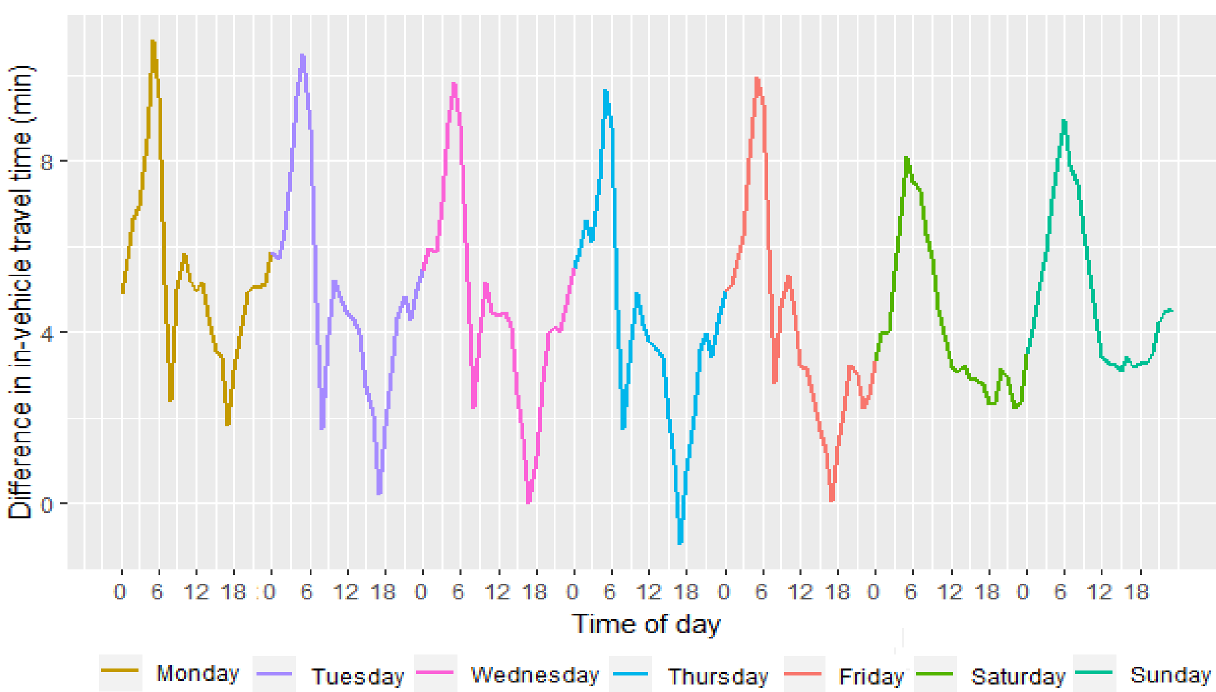

Figure A- 2 Average difference in in-vehicle travel time over time of day and day of week

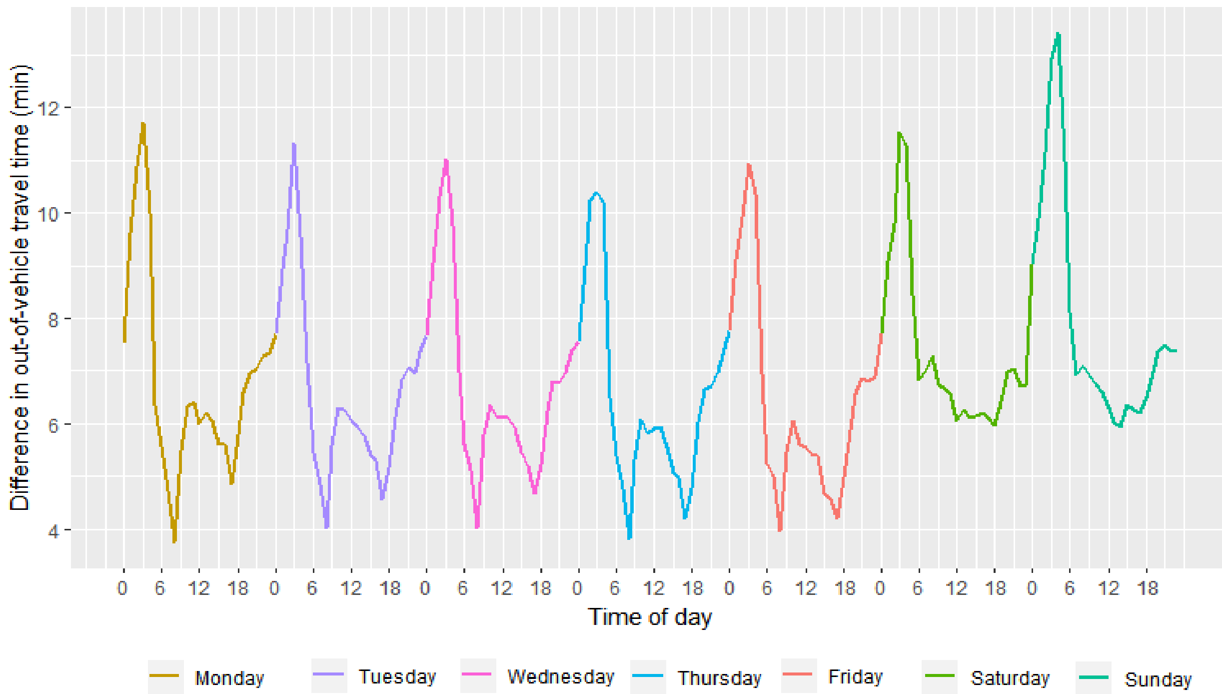

Figure A- 3 Average difference in out-of-vehicle travel time over time of day and day of week

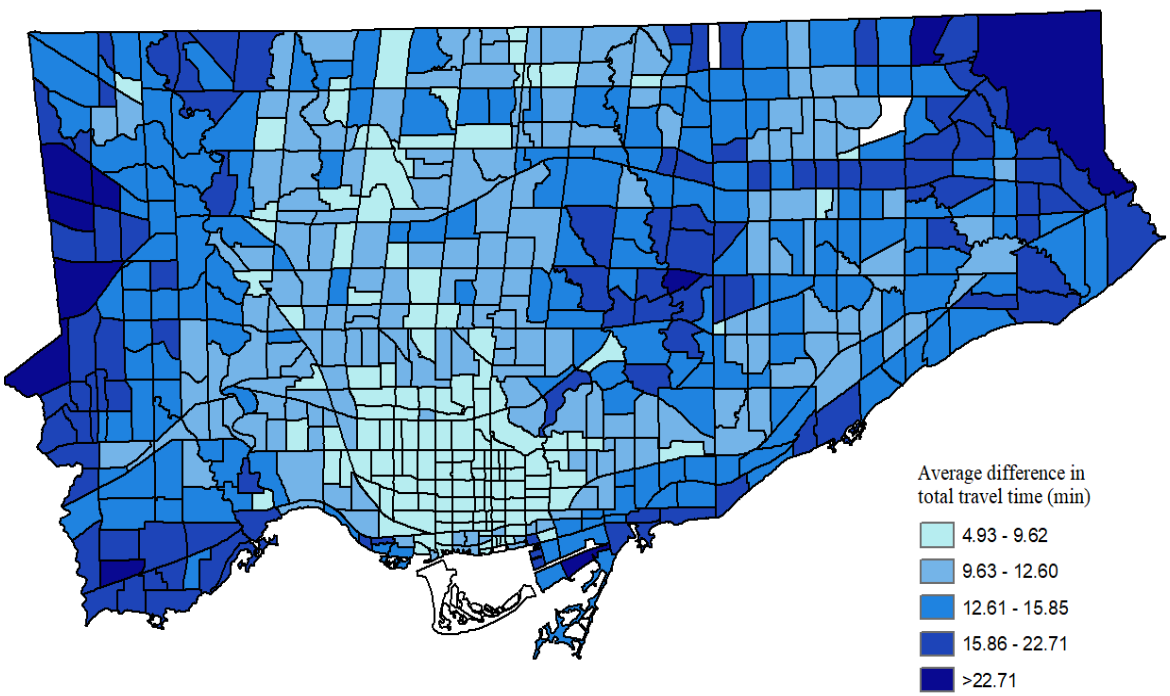

Figure A- 4 Average difference in total travel time per TAZ

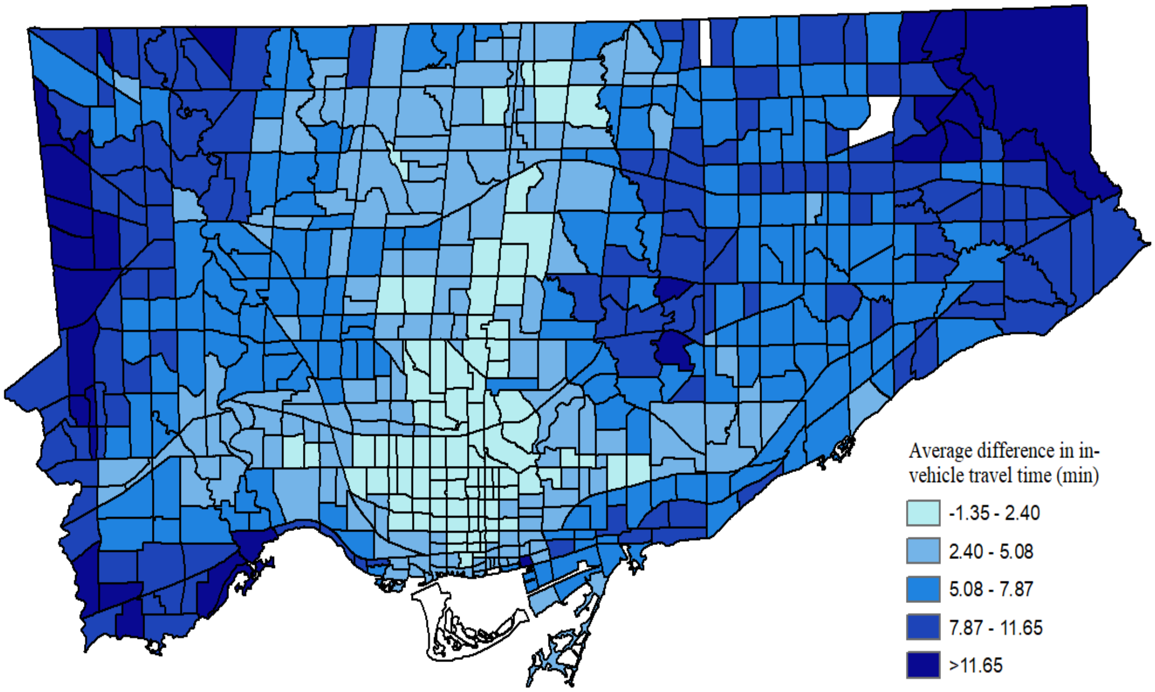

Figure A- 5 Average difference in in-vehicle travel time per TAZ

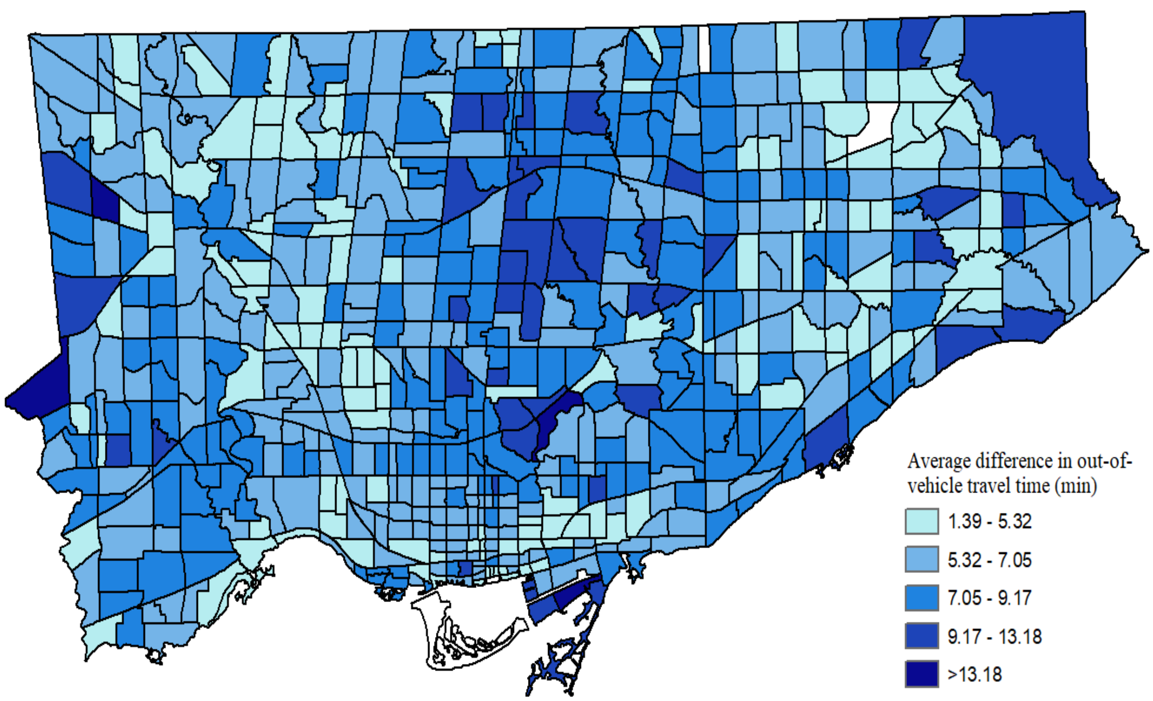

Figure A- 6 Average difference in out-of-vehicle travel time per TAZ