Ministry of Transportation Ontario

ALTERNATIVE METHODOLOGIES FOR TRAVEL TIME STUDIES

FINAL REPORT

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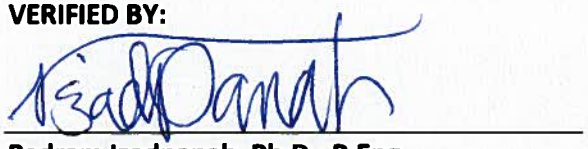

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1 Introduction

Travel time is the most widely used measure of traffic performance. Most road authorities have programs to conduct travel time studies to quantify effects of their capital investments in terms of travel time improvements and to identify traffic bottlenecks which require road improvements in the future.

The Ministry of Transportation Ontario (MTO), Central Region has undertaken biennial Travel Time Studies (TTS) of major provincial roads in the Greater Toronto-Hamilton Area (GTHA) since 1996. In the past a few years, some of the municipalities in the GTHA including the City of Toronto, York Region, and Durham have also joined these studies. The results of these studies aid the ministry staff to assess the future directions and strategic improvement requirements of specific segments of provincial highways. Results also help staff to justify, prioritize, and program new operational and capital work projects and monitor the results after completion. Traditionally MTO use labour intensive methodologies such as using GPS equipped probe vehicles to collect travel time information.

Recent developments within the wireless communication field and widespread use of mobile devices and in-vehicle navigation systems provided the opportunity to obtain traffic information over a wide spatial area at relatively low cost. MTO is interested in exploring new technologies and methodologies for automated traffic data collection. Automation of the biennial travel time studies has multiple benefits including (1) minimizing the costs associated with data collection; (2) the possibility of extending the data collection to additional roads in the provincial network; (3) increasing the data collection time coverage to include year-round information and capture monthly or seasonal variations of travel time; and (4) obtaining more information about the travel patterns in the study areas such as origin-destination information and mode share. There is also potential for these new methodologies to provide better quality travel time data.

A number of technologies have emerged into the market since approximately 2007 which are able to provide travel time information including:

- Mobile phone based technologies,
- In-vehicle navigation system based technologies, and
- Automatic Vehicle Identification (AVI) systems.

In the mobile phone based technologies, positions of mobile phones are obtained from tracking the position of cell phones using triangulation methods of cellular towers or GPS receivers embedded in the phones (Izadpanah and Hellinga, 2007). In the in-vehicle navigation systems, positions of the vehicle are obtained from the GPS receiver of the in-vehicle navigation device. The positions are either transmitted to a server using the cellular network or are transmitted to the server once the owner of the device connects it to the Internet for updating purposes. The AVI systems cover a wide range of technologies such as automatic licence plate recognition, Radio Frequency

Identification (RFID), Bluetooth, WIFI, ZigBee, etc. In all of these technologies a vehicle is identified at a location (e.g. locations A) in the network and the timestamp of this event is recorded. The vehicle also is identified at another location (e.g. locations B) downstream of the first location and the timestamp associated with the second event is recorded. The difference between the timestamp of location A and B is the travel time of the vehicle between location A and B.

One of the challenges with the aforementioned technologies is that they have different levels of accuracy and the different market penetration of the underlying technologies or devices. Very few large-scale independent assessment and comparative analyses of these technologies side-by-side have been conducted. As a result, the main objectives of this study were to (1) Assess various technologies in terms of travel time accuracy, reliability, and sample size requirements compared to the traditional GPS equipped probe vehicles technology; (2) identify advantages and disadvantages associated with different technologies for various roadway types including freeways, arterials, and ramps; and (3) identify additional information which can be obtained from these technologies such as origin- destination and mode choice information.

To achieve the objectives of the study, travel time data from two vendors namely INRIX and TomTom were purchased for the Province of Ontario for freeways, arterials, and ramps within the study area. Also, travel time obtained from Bluetooth receivers were obtained from the Ministry for selected arterial road sections and ramps. . These data sources were assessed against travel times obtained from MTO TTS GPS data which were considered as the benchmark. A statistical methodology was developed to compare each data source to the benchmark. This report summarizes the results of this project in terms of suitability of each data source for different roadway types and lessons learned dealing with large amount of data obtained from vendors including mapping systems, aggregation of traffic metrics to obtain route traffic metrics, and additional information which can be obtained from these technologies such as trip origin-destination information and mode choice information. This project can assist MTO to choose the most appropriate data sources to obtain historical wide area travel time information for their network.

2 Study Area

MTO selected approximately a quarter of the roadways that were surveyed in the 2008 and 2010 TTS as the evaluation study area. The study area included 725 directional km of freeway, 407 directional km of arterials, and 8 ramps within the Greater Toronto Area (GTA) in the Province of Ontario. The study area is shown with darker dotted lines in **Figure 1**. The highways, arterial roads, and ramps that comprise the evaluation study area for vendors (i.e. INRIX and TomTom) are presented in **Appendix A.**

For evaluation, three different levels of segmentation (macro, meso, and micro) for highway and arterial roads are considered. The definition of the three levels of segment, along with ramp segments, is presented in **Table 1**.

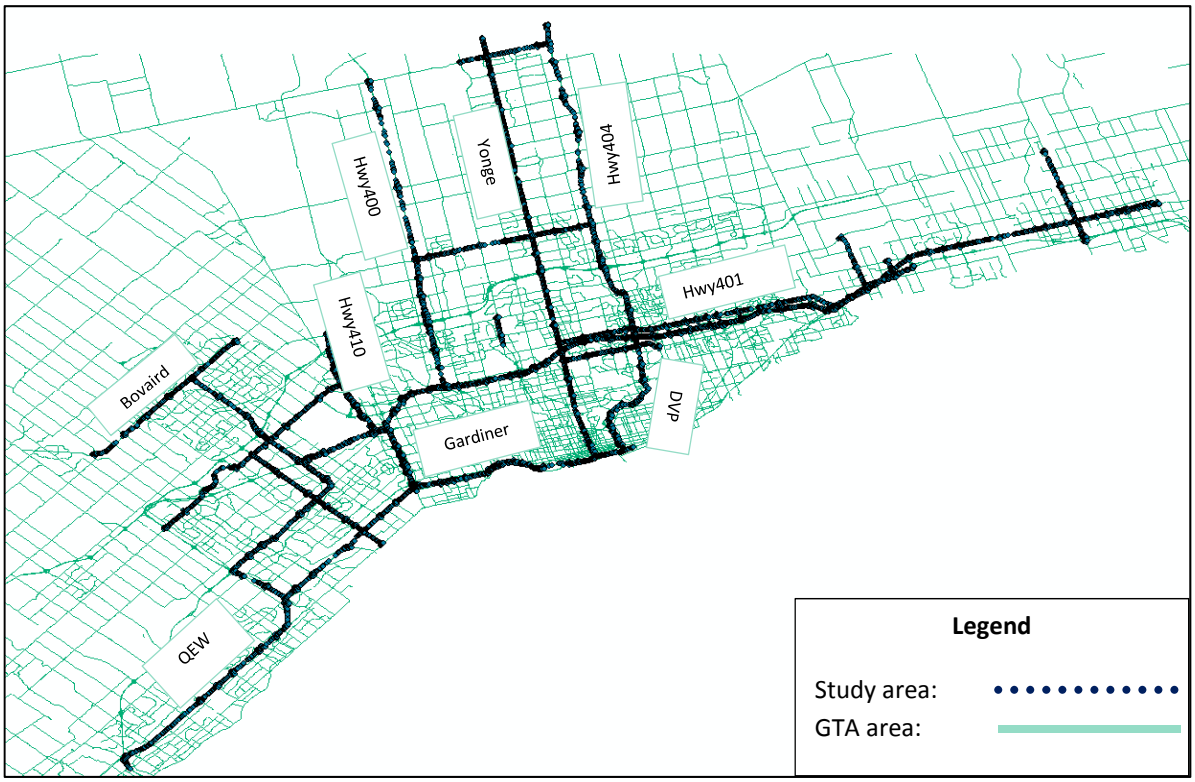


Figure 1: Study Area

Table 1: Definition of Segmentation Types

Segment Types	Description
Micro-Segments	Micro segments are road sections between two consecutive interchanges in the highway context or road sections between consecutive intersections in the arterial context.
Meso-Segments	Meso segments are the combination of several micro sections (Average length of macro sections is 4.4 km)
Macro-Segments	Macro segments are combination of several meso sections (Averge length of macro sections is 24.6 km)
Ramps	For Ramp-segments, the start boundary is one interchange before the ramp and the end boundary is one interchange after the ramp

As for Bluetooth Technology, MTO installed the Bluetooth receivers in pre-specified locations, as a sub-section of the aforementioned study area (see **Table 2).**

Table 2 Bluetooth Locations

Road Type	Roadway	Segment Length (km)	Begins At	Ends At
Ramp	400 SB to 401 EB	9.16	Hwy 400 / Finch Ave.	Hwy 401 / Weston Rd.
	404 SB to 401 WB (GPL)	5.59	Hwy 404/ Finch Ave.	Hwy 401 / Leslie Ave.
	404 SB to 401 WB (HOV)	5.63		
	401 EB to 404 NB (Exp/Coll)	6.04	Hwy 401 / Leslie Rd.	Hwy 404 / Sheppard Ave.
Arterial	Yonge St.	5.4	Moore Park Ave.	High Tech Rd.
	York Mills Rd.	7.7	Wilson Ave.	Parkwoods Village Dr.
	Derry Rd.	7.88	Humberwood Blvd.	West of Derry Rd.
	Kingston Rd.	9.66	Rotherglen Rd.	Atona Rd.

3 Study Period

One of the objectives of this study is to compare the data obtained from different data sources to the MTO benchmark data. The benchmark data were collected by MTO in 2008 and 2010 during the months of September, October, and November. These three months are referred to as the study period thereafter in this report.

TomTom provided the data associated with the same time periods in 2008 and 2010. However INRIX was only able to provide the historical traffic data associated with the 2010 TTS. As for the Bluetooth technology, historical traffic information was not available. Therefore MTO deployed Bluetooth receivers and provided CIMIA+ with the 24 hours data for the Fall of 2011, for selected ramp and arterial roadways. In order to have a benchmark to evaluate the performance of the Bluetooth data against, CIMA+ collected GPS data using GPS equipped probe vehicles (identical to the approach MTO method used in the previous TTS) on the same segments where Bluetooth data were collected.

4 Study Data

In this study the following three data sources were used:

- Bluetooth,
- INRIX, and
- TomTom.

As stated before, these data sources were evaluated against GPS-based benchmark. The benchmark consists of travel time obtained from GPS equipped probe vehicles. These data were obtained from the 2010 TTS for INRIX, the 2010 and 2008 TTS for TomTom, and 2011 CIMA+ GPS equipped probe runs for Bluetooth.

In the rest of this section, the benchmark data as well as the data obtained from the other data sources will be described.

4.1 Benchmark

MTO has used GPS equipped probe vehicles to collect travel time information for freeways and selected arterials within the Greater Toronto Area (GTHA) since 2000. The data collection was conducted on weekdays to capture travel times experienced by commuters, on weekends to obtain information for future lane closures related to construction and maintenance activities, and on the Canada Day and the Labour Day weekends to capture the travel time experienced by motorists travelling for recreational purposes. In this project, the data collected in the fall of 2008 and 2010 was used as benchmark against which data from other providers are assessed. The following

subsections describe the data collection period and methodology (MTO Travel Time Study, 2008). It is noteworthy that the data collection methodology and the data evaluation methodology for the data collected by CIMA+ are identical to those of the 2008 and 2010 TTS. As a result, it is not separately described.

4.1.1 Survey Periods

All data were collected within the periods identified in **Table 3**. The AM peak times differ slightly between ramp and highway versus arterial segments.

Table 3 Data Collection Periods

Roadway	Period	
	AM	PM
Ramp and highways	6:30 to 9:30	15:30 to 18:30
Arterials	6:00 to 9:30	

4.1.2 Survey Techniques[1]

Average Car Techniques

Surveyors were instructed to operate their vehicle in a safe manner and comply with the average car technique. The average car technique required the surveyor to operate their vehicle in any available general travel lane at a speed that is, in the opinion of the driver, the average speed of the traffic stream.

Overtaking or yielding to a vehicle or vehicle platoon that is travelling at a speed that is substantially different from the general traffic stream was permitted. In the event that no other vehicles were present, drivers were instructed to use their judgement in selecting a comfortable and safe travel speed for existing conditions, with consideration to the posted speed limit.

GPS Receiver

Surveyor placed the GPS receiver in an appropriate location, typically mounted on the vehicle dashboard, with exposure to the sky through the windshield. The GPS was then initialized to establish an adequate signal and a positional register. The GPS receivers were configured to record data to the NAD-83 standard. The accuracy of the GPS receivers was 10 m. During the surveys, the GPS receivers generally recorded data at a polling interval of 3 seconds. The GPS output file was

[1] IBI Group. (2009). 2008 Travel Time Study, Ministry of Transportation Ontario, Final Report

then mapped with the study area in MapInfo® to identify possible GPS signal loss locations and anywhere where the surveyors might have gone off course.

Capturing Route Begin and End Points

All acceleration and deceleration of the survey vehicle related to starting and ending a route occurred outside the limits of the specified survey boundaries. All surveyors began their survey routes upstream of the specified start locations and ended their surveys downstream of the specified end locations. This technique ensured that surveyors completed an entire route at the true operating speed and that accurate and representative travel times and speeds were captured between the two locations.

Temporal Distribution of Surveys

A minimum of 9 runs in the AM peak period and 9 runs in PM peak period were conducted on each road segment in each direction. Even distribution of these initial targets was required throughout the survey period (e.g. three surveys per hour for 3 hours peak period). The traffic data were collected on three different weekdays (e.g. Tuesday, Wednesday and Thursday) throughout the survey period. The final performance measures were calculated from data over each entire peak period.

Run and Incident Logging

Each driver completed a daily run log with the date, driver's name, and GPS device serial number. The run log required a running number of runs, and each particular run's name, direction, start and end times and a yes/no response to any incidents on the run. In the event that the driver experienced an incident, he or she was to complete an incident log. The incident log asked the driver to explain the type of incident (construction, collision, etc.), the start/end time or start/end location, as well as any general comments. All drivers were instructed to be as explicit as possible when describing an incident, although it was understood that some details may have been lost given that drivers were to complete their run before completing a log sheet.

4.2 Bluetooth Technology

4.2.1 Bluetooth Data Collection

Bluetooth is a telecommunications industry specification that defines the protocol by which mobile phones, computers, personal digital assistants, car radios, and other digital devices can be interconnected using short-range wireless communications. Every Bluetooth device has a unique 48-bit address referred to as ID. Bluetooth transceivers that are powered on and are set in the "discover" mode continuously transmit their ID for the purpose of identifying a device to communicate with; and to establish a link with the "responding devices". This process is continuous, and will transmit inquiries even if, for example, someone is talking on the mobile phone using a headset. If receiver units are deployed on the side of roadways, they can register the ID associated with the Bluetooth enabled devices in vehicles that pass by as well as the time stamp

associated with the detection instances. Therefore, travel time and average speed of individual vehicles on the road section between two consecutive Bluetooth receivers can be obtained.

As previously described, MTO installed the Bluetooth receivers in a sub-section of the study area and provided us with the raw data for all 7 weeks of study period. **Table 4** presents the Bluetooth unit locations and data collection schedule for both ramp and arterial roadways. **Table 5** presents a sample of data received from MTO for a Bluetooth receiver installed on an intersection (Yonge Street and Steeles Avenue). Also the details of the Bluetooth locations for arterial segments for both traffic directions are provided in **Appendix B**.

Table 4 Bluetooth Locations and Data Collection Schedule

Road Type	Week #	Roadway	Segment Length (km)	Begins At	Ends At	Data Collection Dates (2011)
Ramp	1	400 SB to 401 EB	9.16	Hwy 400 / Finch Ave.	Hwy 401 / Weston Rd.	Aug. 16th - Aug. 18th
	2	404 SB to 401 WB (GPL)	5.59	Hwy 404/ Finch Ave.	Hwy 401 / Leslie Ave.	Aug. 23rd - Aug. 25th
		404 SB to 401 WB (HOV)	5.63			
	3	401 EB to 404 NB (Exp/Coll)	6.04	Hwy 401 / Leslie Rd.	Hwy 404 / Sheppard Ave.	Aug. 30th - Sep. 1st
Arterial	4	Yonge St.	5.4	Moore Park Ave.	High Tech Rd.	Sep. 13th, 15th, 16th
	5	York Mills Rd.	7.7	Wilson Ave.	Parkwoods Village Dr.	Sep. 20th - Sep. 22nd
	6	Derry Rd.	7.88	Humberwood Blvd.	West of Derry Rd.	Sep. 27th, 29th, 30th
	7	Kingston Rd.	9.66	Rotherglen Rd.	Atona Rd.	Oct. 4th - Oct. 6th

Table 5 A Sample of Raw Bluetooth Data Received on 22nd of September, 2011 from Yonge St.- Steeles Ave. Intersection during week 4, Northbound

MACID	MACIDNUM	YEAR	MONTH	DAY	HOUR	MIN	SEC
'001EE21C84FF'	1.32643E+11	2011	9	12	14	3	2
'00054F8A5CE9'	22809304297	2011	9	12	14	3	2
'68EBAE5BF3BE'	1.15361E+14	2011	9	12	14	3	7

4.2.2 Equipped Probe Vehicle for Bluetooth Evaluation

In order to have a benchmark to evaluate the performance of the Bluetooth units, CIMA+ undertook GPS data collection on the ramp and arterial segments defined in this project in conjunction with the Bluetooth data collection periods along each road segment. As stated before, our team conducted the data collection according to the methodology described in the MTO 2010 TTS. A team of trained personnel performed all GPS data collection activities. CIMA+ was responsible for the coordination of drivers, supply of GPS equipment, collection of data, and delivery of data. As an example, a survey run log sheet and incident report log is provided in **Appendix C**.

4.3 TomTom Custom Travel Times

The data from in-vehicle navigation systems were purchased from TomTom. TomTom has over 45 million navigation devices in use around the world with a comprehensive historical database of traffic information. Since 2007, over 2.5 trillion consumer driven data points have been collected from TomTom users around the world. TomTom has developed a service which provides historical traffic information (e.g. travel time, speed, standard deviation of travel time, standard deviation of speed, etc.) about transportation networks to potential customers in various geographical areas in the world.

The data obtained from this vendor included two components: (1) network data (see **Figure 2**) and (2) traffic data. The network data were obtained in the form of a GIS map in which each link had a unique link ID. The traffic data was received in text files including link ID, date, time, average travel time, standard deviation of travel time, average speed, standard deviation of speed, number of observations, and percentiles of speed from 5% to 95% (i.e. 5th percentile speed, 10th percentile speed, etc.).

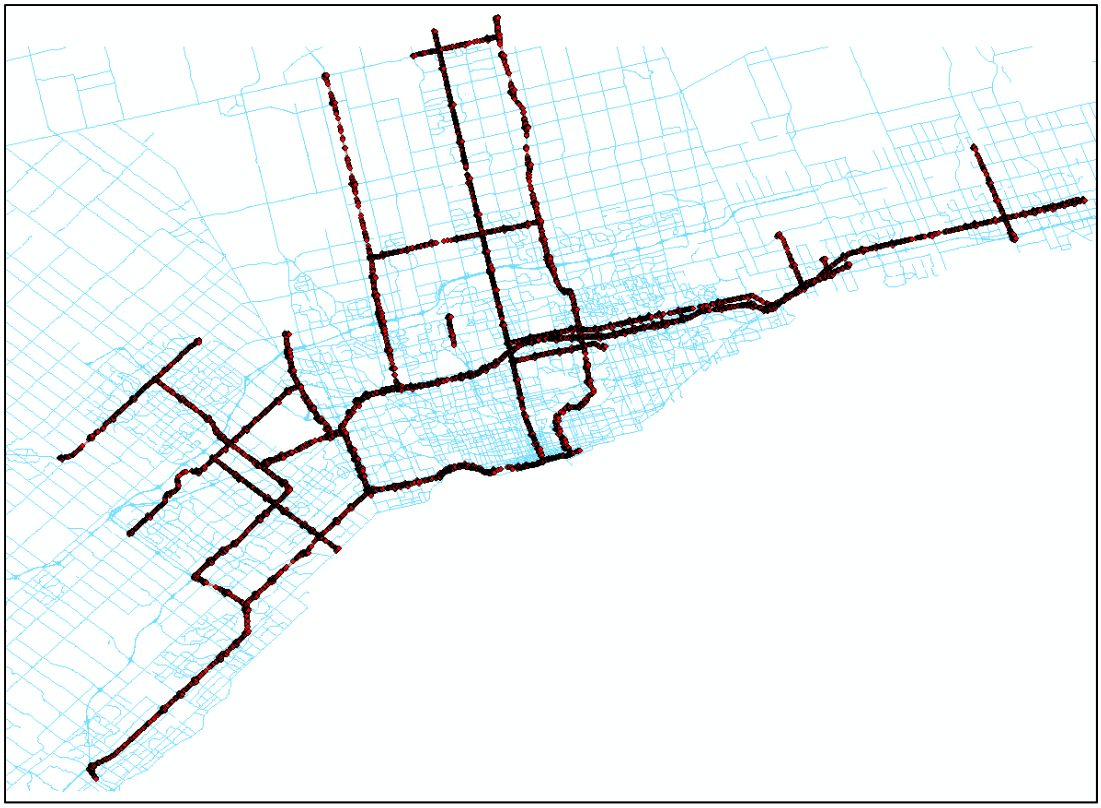


Figure 2 TomTom Network Data Coverage

The TomTom Custom Travel Time system is able to provide aggregated travel time for each day of week during the study period. For each day of week, the TomTom system is capable of providing the traffic data for 7 bins. The start and end of each bin are pre-defined by the user. The minimum length of each bin can be one hour. In this study the following bins were used:.

- 6AM-8AM,
- 8AM-9AM,
- 9AM-10AM,
- 3PM-4PM,
- 4PM-5PM,
- 5PM-6PM, and
- 6PM-7PM.

The above bins were selected to be the closest match with the MTO definition of peak periods as shown in Table 3. Therefore, if for a road segment traffic data is provided for Monday for Bin 1, it means that the observed data for all Mondays within the study period have been aggregated from 6:00 AM to 8:00 AM. As a result, the data provider provides neither travel times of individual vehicles which travelled each link during the study period nor travel time for each individual day (e.g. October 3rd, 2010 from 8AM to 9AM). The primary source of traffic information is passenger cars and the technology is similar in nature to the traditional travel time studies conducted by MTO (the benchmark).

4.4 INRIX

INRIX uses a proprietary data fusion engine which has been developed using a Bayesian modelling and proprietary error correction technology to process over 400 sources of data aggregated by the INRIX Smart Driver Network and generate traffic information. The data sources include mobile phones, GPS navigation systems, and other sources of data. INRIX covers 5,419 centreline km and 21,963 centreline km in the Greater Toronto Area and Ontario respectively. The coverage area includes freeways, urban arterials, rural arterials, and side streets.

The format of the data was very similar to the previous data provider in that it included the two components of the network data and traffic data. The network component was received as part of a GIS map. **Figure 3** presents the INRIX network data associated with the study area.

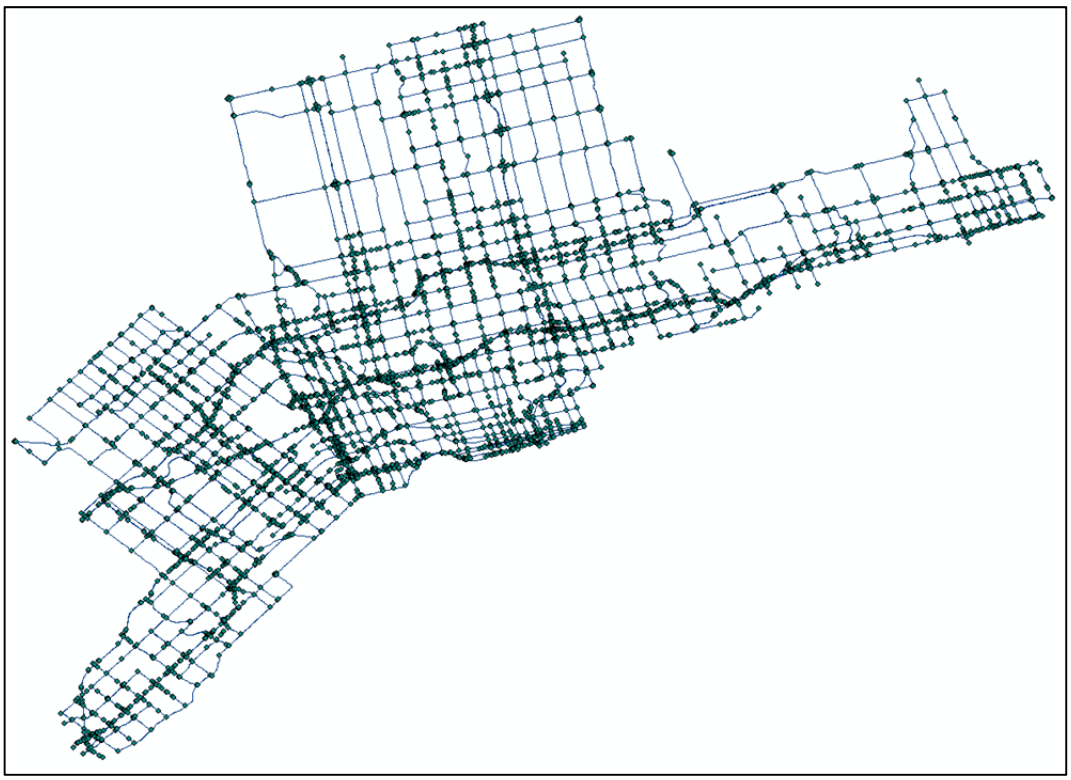


Figure 3 INRIX Network Data Coverage

The traffic data was also similar to the previous data provider. However, INRIX was able to provide 15 minute aggregated data for each day of weeks in the study period (e.g. aggregated data for 7:00 AM to 7:15 AM for all Mondays).

Traffic data supplied by INRIX, similar to TomTom, consists of link ID, date, time, average speed, standard deviation of speed, number of observations, and percentiles of speed from 5% to 95% (i.e. 5th percentile speed, 10th percentile speed, etc.). In the INRIX data, average travel time and standard deviation of travel time were not explicitly provided. It should be noted that average travel time and standard deviation of travel time (or variance of travel time) can be estimated from average speed and variance of speed (Hayya et al., 1975).

5 Data Processing

5.1 Bluetooth Data

The Ministry deployed Bluetooth receivers at pre-defined locations on selected arterials and ramps as shown in **Table 4**. Once Bluetooth enabled devices are in range of one of the receivers, the MACID of the Bluetooth device and the timestamp associated with this event are recorded. MTO provided us with the raw data, including MACIDs and timestamps associated with all detections. We developed a code in VBA (Microsoft Visual basics for Applications), that is able to match the same MACID between two consecutive Bluetooth receivers and calculate the travel time of individual vehicles in an excel spreadsheet. A sample output of travel time calculation is presented in **Table 6**.

Table 6 Travel Time from Two Consecutive Bluetooth Units

Week #	Direction	Bluetooth Location	Vehicle ID	Year	Month	Day	Hour	Minute	Second	Travel Time (sec)
4	Northbound	Moore Park Ave.	CC55AD2A4205	2011	09	13	0	2	48	39
		Steeles Ave.					0	3	27	

In order to evaluate the Bluetooth technology in normal traffic conditions, we removed the collected data during severe events (e.g. collisions). During data collection for Bluetooth technology, a collision occurred on August 17th, and the corresponding travel times between 4:20 PM and 5:25 PM were excluded from the analysis, as shown in **Figure 4**.

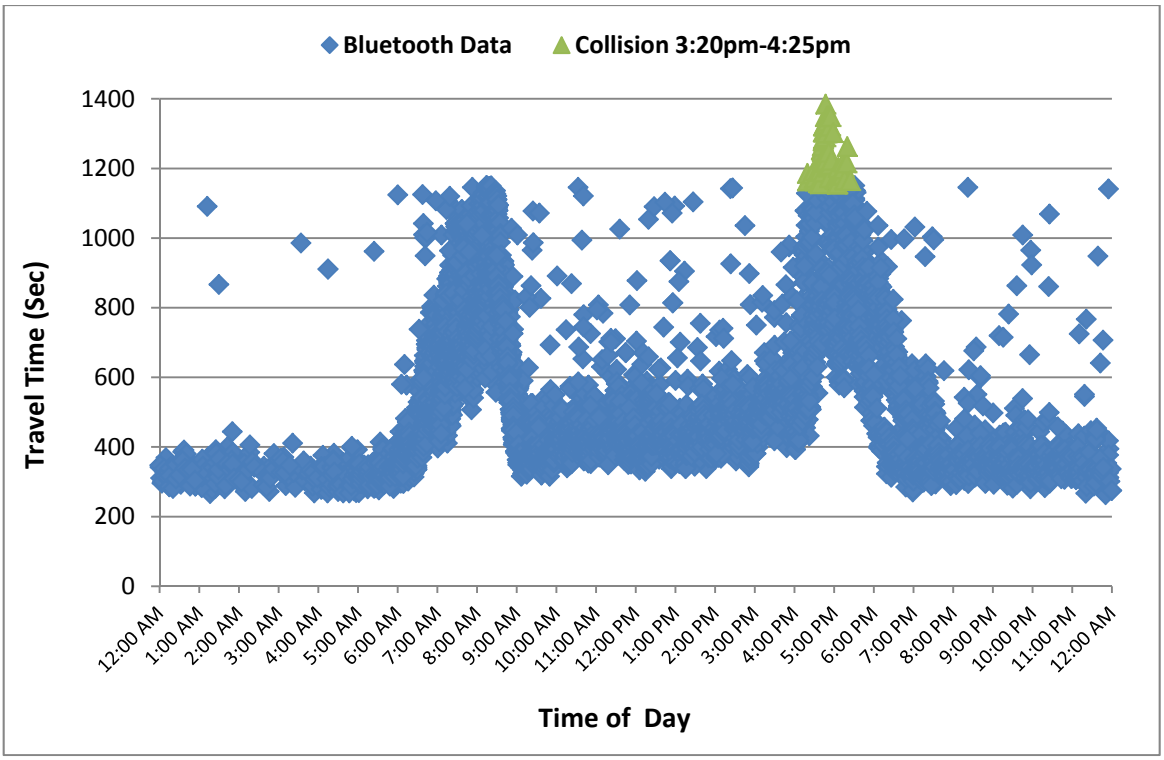


Figure 4 An Example of Severe Event during Data Collection

5.1.1 Quality Control of the Bluetooth Database

The data that are gathered by Bluetooth technology require quality control in order to remove outlier observations. Examples of outlier data would be vehicles making a stop or taking a detour between two stations. Since these vehicles would experience a travel time that is atypical, these observations should therefore be removed from the data set of valid observations to avoid producing erroneous travel time estimates. In this study, a two-phase filtering approach is presented to accurately capture travel time outliers collected form Bluetooth receivers. The proposed approach is described in the following subsections.

Filtering Phase-1

In order to filter the database for uninterrupted traffic facilities (e.g. ramps), we eliminated the entire matched ID with a travel time higher than 3.5 times of the Free Flow Travel Time (FFTT). The upper limit value of 3.5 of FFTT was selected because the rate at which the number of observations increases with the increase of the upper limit of the acceptable travel time changes significantly at 3.5*FFTT. Further increase in the upper limit has very low marginal increase in the number of observations. This is graphically shown in **Figure 5**. An example of FFTT calculation is also provided in

Table 7, based on the posted speed.

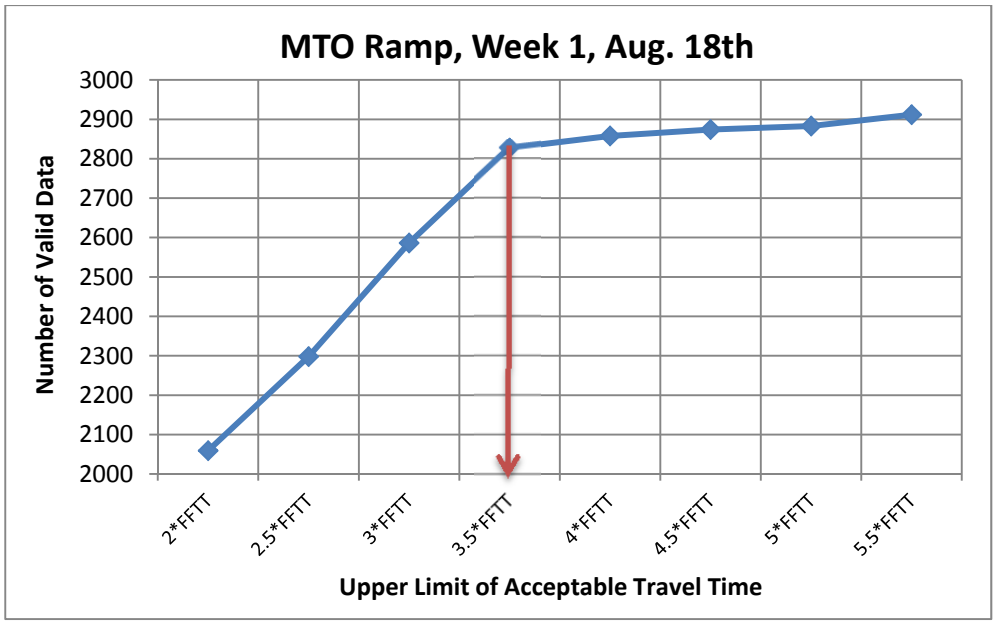


Figure 5 Methodology to identify the upper Limit of Acceptable Travel Time

Table 7 Example of FFTT Calculation for a Ramp Section

Week #	Roadway	Posted Speed (kph)	Segment Length (km)	FFTT (sec)
1	400 SB to 401 EB	100	9.16	329
2	404 SB to 401 WB (GPL)	100	5.59	201
	404 SB to 401 WB (HOV)	100	5.63	203
3	401 EB to 404 NB (Exp/Coll)	100	6.04	217

Figure 6 and **Figure 7** illustrate the results of applying the first-phase filtering on a ramp segment. **Figure 6** provides the raw travel time data for the ramp segment between Highway 400 Southbound and Highway 401 Eastbound. The data is gathered on 16th of August, 2011. Also **Figure 7** presents the processed travel time data after filtering.

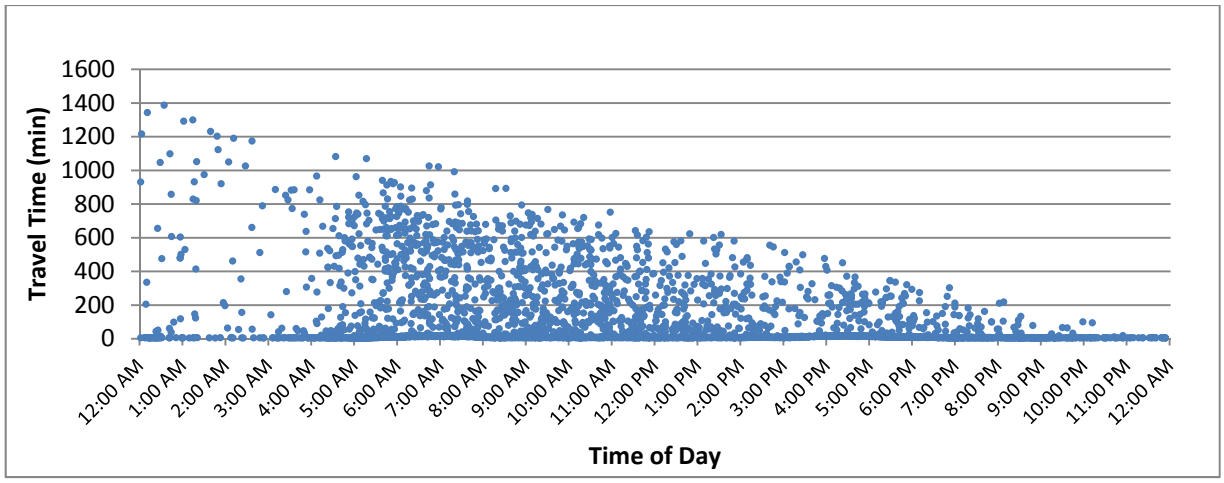


Figure 6 Raw Travel Time Data before Filtering for a Ramp section

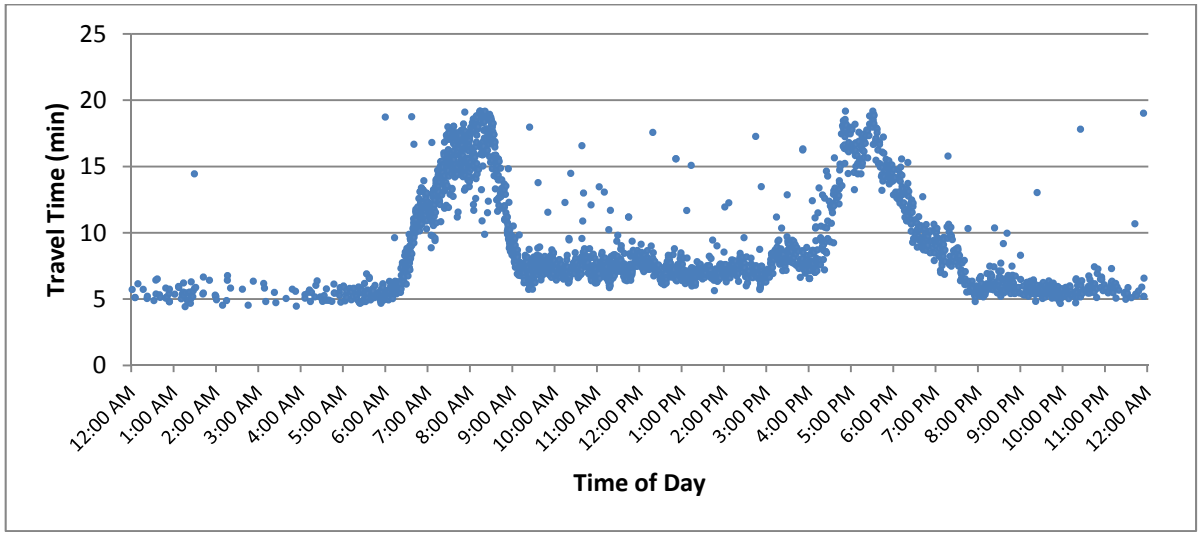


Figure 7 Processed Travel Time Data after Filtering for a Ramp section

On the other hand, the intrinsic traffic behaviour difference associated with freeway and arterial segments requires a slightly different methodology for suppressing high frequency noise signals, and filtering data for interrupted flow facilities. For this section, an approximate travel time range is defined for each segment based on FFTT, predicted average travel time during peak hours, and traffic signal characteristics. The approximate ranges are then mapped with each data plot to validate and examine cut-off thresholds. An example application of the methodology is presented in **Table 8**.

In this table, the Lower Limit describes the situation where the traffic is moving with the free flow speed (i.e. posted speed), while facing green phase on both intermediate traffic signals between two consecutive Bluetooth receivers. In this case, the traffic stream is similar to uninterrupted flow facilities. On the other hand, the "Upper Limit" refers to a congested traffic, where the vehicle speed is lower than the lowest vehicle speed encountered in free flow condition. In this scenario, the average travel time is the summation of in-vehicle travel time under moving and stopping

condition. The stopping time is assumed to be for a full traffic cycle length for both signalized intersections at the two end s of a link. For arterial segments, we hypothetically assumed that the average waiting time per signalized intersection would be 50 seconds.

Table 8 Example of Approximate Travel Time Range in an Arterial Segment

Week #	Date	Roadway	Start Point	End Point	Segment Length (km)	Posted Speed (kph)	Travel Time Limits	Average Traveling Speed (kph)	Average Moving Travel Time (sec)	Waiting Time (sec)	Total Travel Time (sec)
4	Sep. 15th	Yonge St.	Steeles Ave. (B2)	Clark Ave. (B3)	1.03	60	Lower Limit	60	61.8	0	61.8
							Upper Limit	20	185.4	100	284.5

The purpose of determining a lower limit and an upper limit for travel time is to define an expected window for travel time variations of an arterial link. In this analysis, two inevitable sources of errors are the approximation in average traveling speed, and waiting time. **Figure 8** and **Figure 9** illustrate the application of the primary filtering applied to the same dataset of **Table 8**.

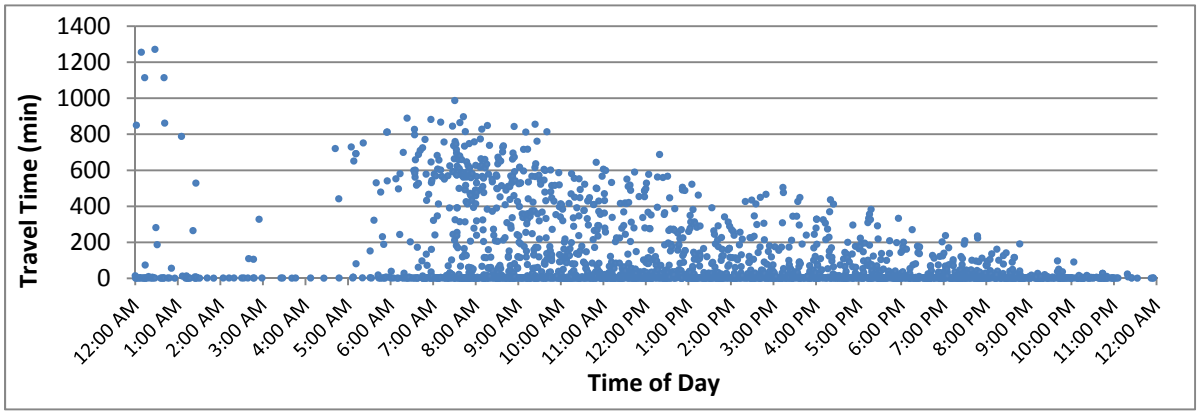


Figure 8 Raw Travel Time Data before Filtering for Yonge St. between Steeles Ave. and Clark Ave.

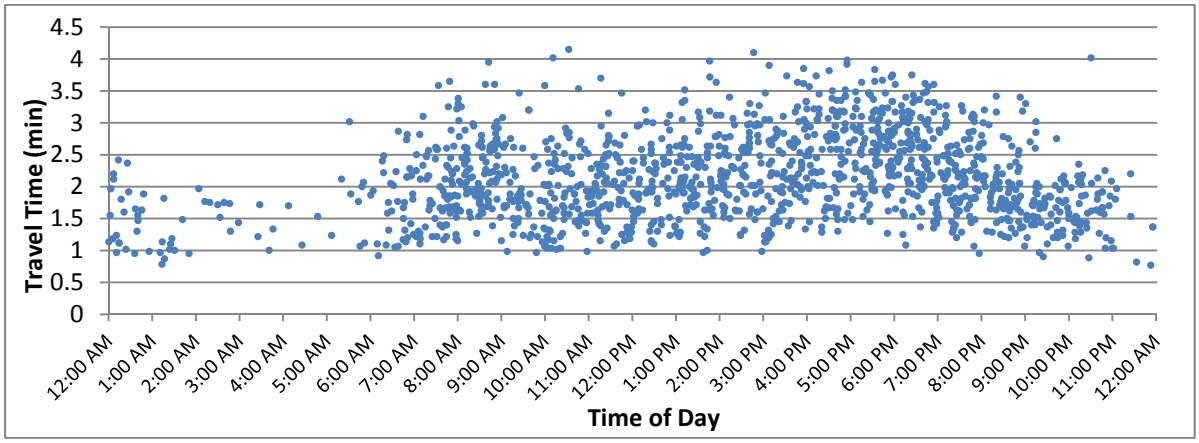


Figure 9 Processed Travel Time Data after Filtering Phase-1 for Yonge St. between Steeles Ave. and Clark Ave.

Filtering Phase-2

In the previous descriptive filtering approach, we primary focused on determination of a lower and an upper limit for travel time. However, an accurate and robust data filtering procedure is needed to identify valid data within each sampling interval (e.g. 2 minutes), and a dynamically varying validity window, based on average and variance of travel time (minimum and maximum acceptable travel time). In this study, an innovative statistical methodology proposed by Dion and Rakha (2006) was used to detect Bluetooth travel time outliers. Applications of the algorithm to freeway and arterial links demonstrated the ability of the proposed algorithm to efficiently track typical variations in average link travel times. This algorithm determines average travel times between successive Bluetooth receivers by first ignoring all duplicate records that might be generated by the communication equipment, and then by applying a series of filters to the collected travel times to remove invalid observations. The algorithm considers as invalid any observed travel time that falls outside a validity range that is determined based upon the following four factors:

- Expected average trip time and trip time variability in future time interval.
- Number of consecutive intervals without any readings since the last recorded trip time.
- Number of consecutive data points either above or below the validity range and
- Variability in travel times within an analysis interval.

The detailed description of the filtering algorithm methodology is presented in **Appendix D**. As can be observed in **Figure 10** and **Figure 11**, the data observations fall in-between the minimum and maximum bounds from the application of the filtering algorithm. The algorithm is able to correctly follow the underlying travel time increases during peak periods, and remove travel time outliers. These figures illustrate the variations in the interval average travel time, as well as lower and upper limits of the validity window, consistent with the dataset of **Figure 8** (ramp segment between Hwy 400 SB and Hwy 401 EB). Also the application of the filtering algorithm for a sample arterial segment is presented in **Figure 12** and **Figure 13** (Yonge St. between Steeles Ave. and Clark Ave).

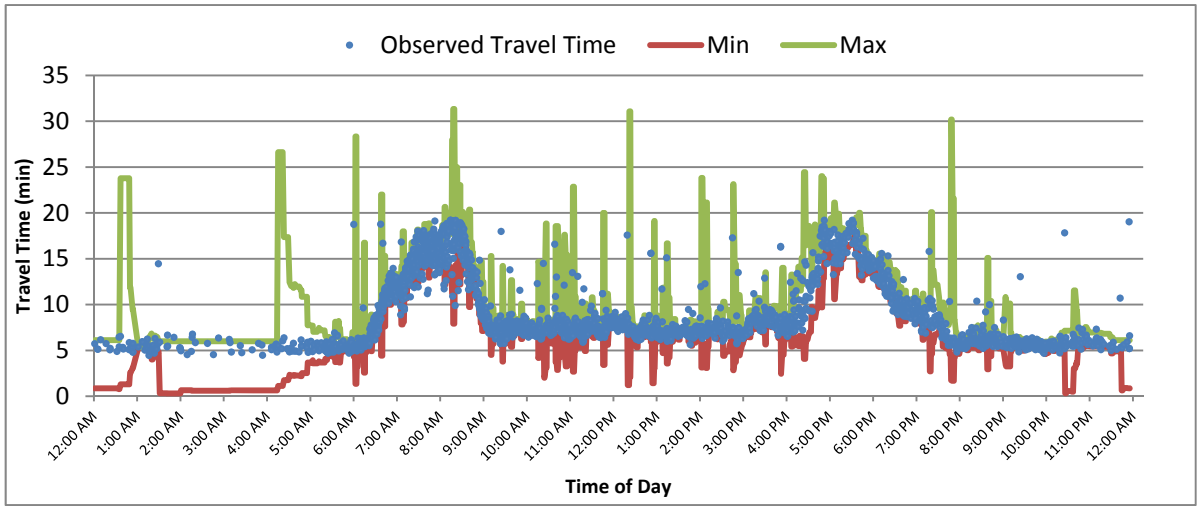


Figure 10 Application of the Filtering Algorithm (Ramp)

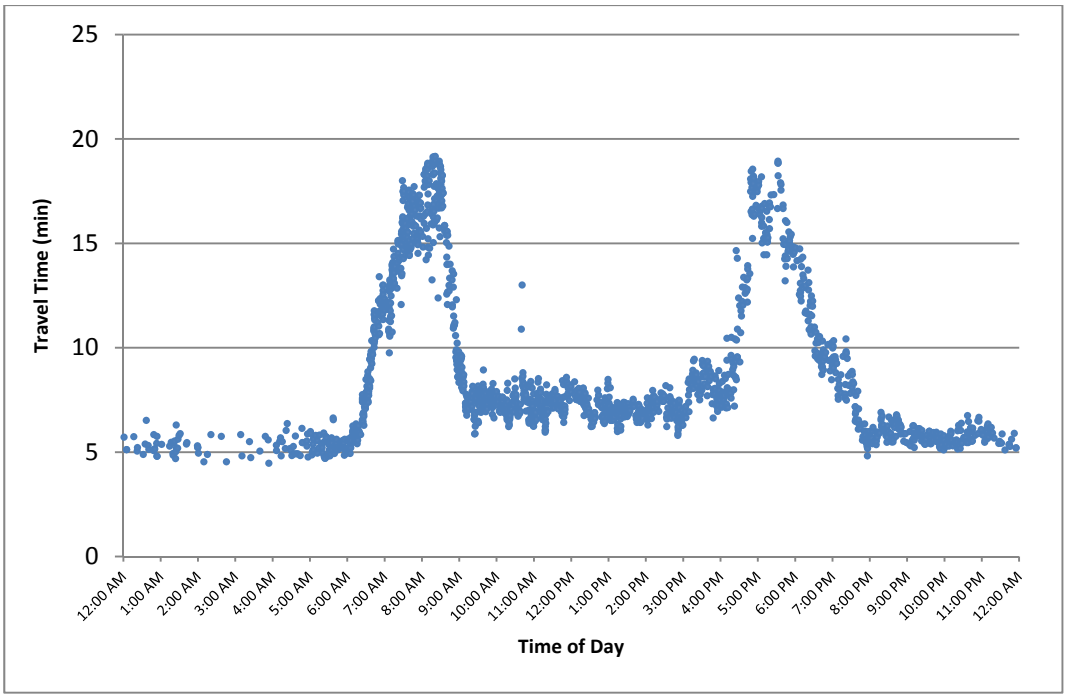


Figure 11 Processed Travel Time Data after Filtering Phase-2 (Ramp)

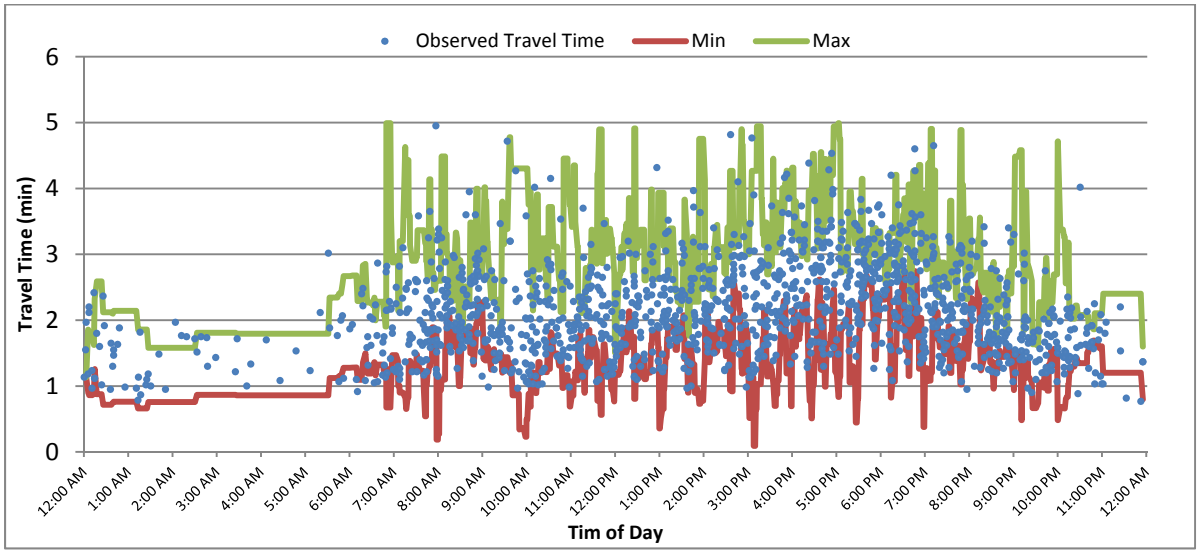


Figure 12 Application of the Filtering Algorithm (Arterial)

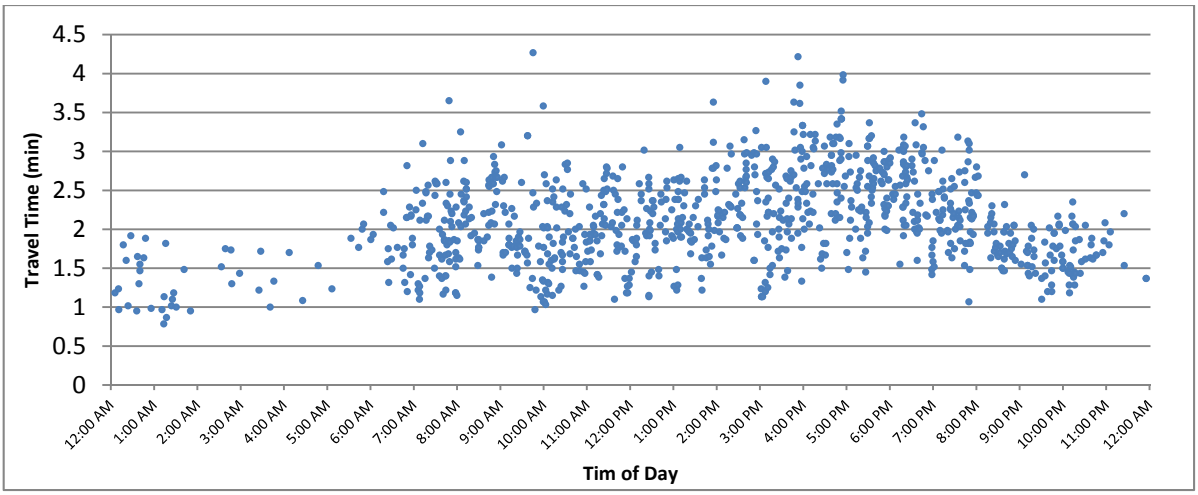


Figure 13 Processed Travel Time Data after Filtering Phase-2 (Arterial)

As a summary for ramp segments, **Table 9** presents the number of primary Bluetooth observations, acceptance percentage, and number of observations per minute after filtering phase-2. Also **Table 10** provides a summary for a sample arterial segment.

Table 9 The Effect of Filtering Algorithms on Ramp Segment

Week #	Day	Sample Size After First Filtering (<3.5 FFTT)	Acceptance Rate After Second Filtering	Accepted Observation Numbers After Second Filtering	Number of Observations per Hour
Week 1	Aug 16th	2827	69.7%	1972	82.17
	Aug 17th	2857	72.8%	2081	86.71
	Aug 18th	2936	51%	1500	62.50
Week 2-GPL	Aug 23th	2160	77.4%	1671	69.63
	Aug 24th	2045	80%	1634	68.08
	Aug 25h	2047	80.3%	1644	68.50
Week 2-HOV	Aug 23th	591	70.7%	418	17.42
	Aug 24th	720	80.8%	582	24.25
	Aug 25h	651	75.3%	490	20.42
Week 3	Aug 30th	2773	75.1%	2083	86.79
	Aug 31st	2911	75.5%	2197	91.54
	Sep 1st	2814	73.5%	2070	86.25

Table 10 The Effect of Filtering Algorithms on Arterial Segment

Week Number	Direction	Day	Segment	Number of Raw Observations	Acceptance Rate After First Filtering	Acceptance Rate After Second Filtering	Accepted Observation Numbers After Second Filtering	Number of Observations per Hour
Week 5	Eastbound	Sep 20th	B1-B2	1105	77.4%	76.4%	653	27.21
			B2-B3	1611	48.7%	71.1%	558	23.25
			B3-B4	1812	53.8%	63.5%	619	25.79
			B4-B5	1716	54.7%	80%	751	31.29
			B5-B6	774	52.8%	74.6%	305	12.71
		Sep 21st	B1-B2	1104	83%	77.8%	714	29.75
			B2-B3	1657	49.6%	67.1%	552	23.00
			B3-B4	1876	56.1%	65.7%	692	28.83
			B4-B5	1814	51.4%	75.9%	708	29.50
			B5-B6	832	55.6%	64.6%	299	12.46
		Sep 22nd	B1-B2	1071	77.4%	76%	630	26.25
			B2-B3	1634	45%	70.2%	516	21.50
			B3-B4	1817	55.8%	66%	670	27.92
			B4-B5	1829	53.9%	79.1%	780	32.50
			B5-B6	797	55.9%	70.2%	313	13.04

5.1.2 Benchmark for Evaluation of Bluetooth Data

In order to compare the data obtained from Bluetooth receivers to the benchmark, travel times for each road segment were calculated by computing the time required to travel between the Bluetooth segment boundaries, as presented in **Table 2** for ramp and arterial segments. As stated previously in this report, the benchmark was the GPS data from equipped probe vehicle which were run in conjunction with deployment of Bluetooth receivers at each location. Also MapInfo® was used to confirm the temporal and spatial distribution of the GPS data and match the GPS and Bluetooth boundary coordinates. Segment travel times were then calculated using the following equation.

$$TT_{ab} = T_a - T_b \quad (1)$$

Where,

TT_{ab} = Travel time between boundary a and boundary b;

T_a = Time at which vehicle passes boundary a;

T_b = Time at which vehicle passes boundary b;

An example of the travel time output is presented in **Table 11**.

Table 11 A Sample Travel Time Output for Yonge Street

Week #	Date	Roadway	Peak Period	Direction	Segment Length (km)	Start Point	End Point	Travel Time (sec)	
								Run 1	Run 2
4	15th of September	Yonge St.	AM	Northbound	1.03	Steeles Ave.	Clark Ave.	66	51
				Southbound		Clark Ave.	Steeles Ave.	172	255
			PM	Northbound		Steeles Ave.	Clark Ave.	157	134
				Southbound		Clark Ave.	Steeles Ave.	133	110

Statistical Validity of Sample Sizes

The minimum sample size requirements for each road segment were determined using the recommended ITE 2000 methodology for travel time studies (ITE, 2000). This methodology has been used in the previous TTS by MTO (IBI Group, 2009). Through this methodology, the minimum sample size is calculated from an average range of running speed and a permitted error at a 95% level of confidence. ITE 2000 provides a lookup table with minimum sample size requirements, which is replicated in **Table 13**. The terms of reference for this assignment specified that a 5 km/h permitted error be applied. This level of error falls within the range recommended by ITE 2000 for traffic operations, trend analysis, and economic evaluations.

Upon completion of the initial survey runs, the average range in running speeds was calculated. The average range in running speeds represents the average of the differences in individual survey speeds between consecutive survey runs (**Table 12**). The average range in running speeds were calculated from the processed data using the following equation:

$$R = \frac{\sum_{i=2}^{N} v_i - v_{i-1}}{N-1} \quad (2)$$

Where:

R = average range in running speed,

v_i = observed speed of survey run i, and

N = number of completed runs.

Table 12 Number of Required and Performed Runs during Peak Periods

Week Number	Roadway/Direction	Begins at	Ends at	AM Peak		PM Peak	
				Required # of Runs	Performed # of Runs	Required # of Runs	Performed # of Runs
1	Ramp 1-35, 36	Hwy 400 / Finch Ave	Hwy 401/Keel St.	6	11	5	8
2	Ramp 2-36 Collector	Hwy 404 / Finch Ave	Hwy 401/Leslie st.	4	27	6	19
	Ramp 2-39 Express			6	19	6	15
	Ramp 2 HOV			5	27	9	19
3	Collector	Hwy 401/Leslie	Hwy 404/Finch Ave.	5	21	4	14
	Express			3	24	5	16
4	Yonge St. NB	Moore Park	High Tech Rd.	5	14	4	10
	Yonge St. SB	High Tech Rd.	Moore Park	5	14	4	10
5	York Mills Rd. EB	Wilson Ave	Parkwoods Village Dr,	4	13	3	10
	York Mills Rd. WB	Parkwood Village Dr.	Wilson Ave.	3	12	3	10
6	Derry Rd. WB	Humberwood	West Derry	5	15	6	8
	Serry Rd. EB	West Derry	Humberwood	4	14	4	7
7	Kingston Rd. WB	Rotherglen Rd	Atona Rd	5	5	3	6
	Kingston Rd. EB	Alton Rd.	Rotherglen Rd	3	5	4	8

Note that ITE 2000 specifies that the speed differences be calculated between pairs of sequential runs. The average range in running speed often fell between or outside the speeds given in **Table 13**. In order to interpolate or extrapolate the minimum required sample size, a linear regression was performed on the data in **Table 13** (resulting in an R2 value of 0.98). The minimum required sample size could then be estimated using the regression equation and rounding the result to the nearest run. An example of the minimum sample size calculation is provided in **Table 14**.

Table 13 Approximate Minimum Sample Size Requirements for Travel Time and Delay Studies with Confidence Level of 95.0% (Source: ITE 2000)

Average Range in Running Speed (km/h)	Minimum Number of Runs for a Permitted Error of:				
	2.0 km/h	3.5 km/h	5.0 km/h	6.5 km/h	8.0 km/h
5	4	3	2	2	2
10	8	4	3	3	2
15	14	7	5	3	3
20	21	9	6	5	4
25	28	13	8	6	5
30	38	16	10	7	6

Table 14 Example of Minimum Sample Size Calculation (Week 1, PM Peak)

Run #	Travel Time	Space Mean Speed (km/h)	Difference in Speed between runs (km/h)	Calculation
1	0:08:37	63.8	0.0	
2	0:10:55	50.3	13.4	
3	0:17:28	31.5	18.9	
4	0:14:54	36.9	5.4	$R = \frac{107.4}{8-1} = 15.3$
5	0:22:56	24.0	12.9	Number of Runs Required = 5
6	0:09:13	59.6	35.7	Number of Runs Performed = 8
7	0:13:52	39.6	20.0	
8	0:13:29	40.8	1.1	
Sum of difference			107.4	

5.2 TomTom

In this study, the data obtained from TomTom needed to be temporally and spatially matched with the 2008 and 2010 MTO TTS data (the benchmark) for direct comparison between the data source and the benchmark.

5.2.1 Temporal Matching

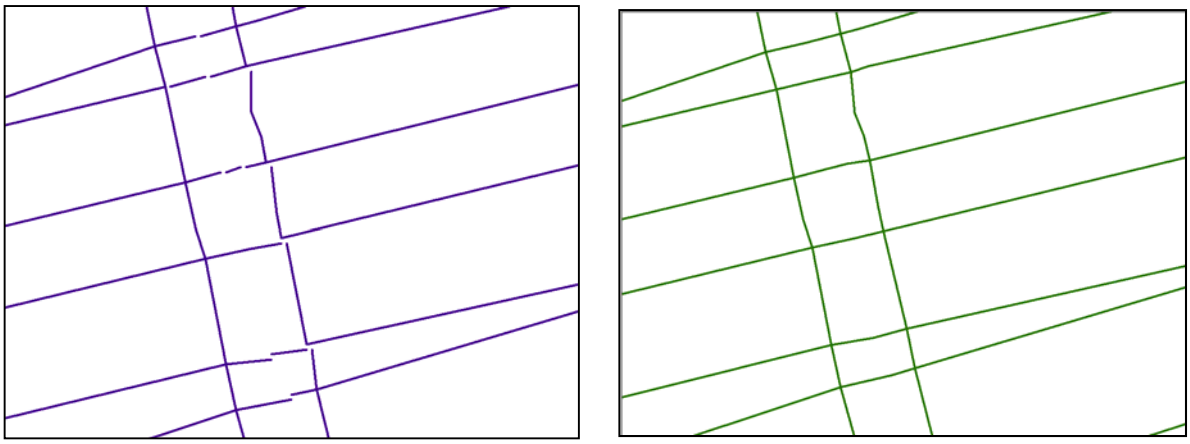
In this project, the traffic data obtained from TomTom was compared with the benchmark for AM and PM periods. Moreover, MTO collected the benchmark data in different days during the study period for different routes. TomTom supplied aggregated data for each day of weeks for the study period. Therefore, in order to directly compare each data provider with the benchmark, for each route in the study area, a one to one correspondence was established between the data collection days in the benchmark and the days of weeks for TomTom data. For example, the 2010 TTS data was collected on Tuesday October 12, 2010 and Wednesday October 13, 2010 for a route, then the TomTom traffic data for Tuesdays and Wednesdays in 2010 were used for this route. It should be noted that the TomTom data were obtained for the months of September, October, and November in 2008 and 2010 to be directly comparable with the TTS data.

5.2.2 Spatial Matching

In the benchmark data, a road segment is defined as the road section between two consecutive interchanges for freeways and two consecutive major intersections for arterials. Travel time information including average travel time, variance of travel time, average speed, and variance of speed are estimated for road segments in the benchmark data. In order to directly compare TomTom with the benchmark, travel time information for the same road segments are to be calculated using the data obtained from TomTom. It should be noted that each micro segment of the benchmark may consists of multiple links in the GIS of the vendor. Therefore, the GIS map of TomTom should be spatially matched with the benchmark segmentations. For this purpose, Network Analyst Tool, as an extension of the ArcGIS engine, is used for TomTom and INRIX network-based routing analysis, to find the sequence of links between two consecutive boundaries for each micro, meso, and macro segments, based on start-point and end-point coordination. The output of ArcGIS is then mapped with the associated traffic data. This process is called the Routing Process. It is noteworthy that the Routing Process was conducted three times for each vendor namely for micro, meso, and macro segments.

The main challenge associated with the spatial matching is that the GIS maps provided by the data vendors do not necessarily match the road segmentation of the benchmark. For TomTom network data, there were five major challenges with spatial matching:

The first issue with TomTom GIS maps is that there are many broken links along the study area, which also makes the routing impossible. This issue was resolved by using the Topology feature in ArcGIS with a predefined tolerance to connect the broken segments. **Figure 14** (a) illustrates a sample of multiple broken segments and **Figure 14** (b) presents the same connected segments.



a) Broken segments in the network b) Connected segments at broken points

Figure 14 Fixing Broken Segments in TomTom GIS maps

The second issue with this vendor is associated with data provision and coding of the data. TomTom segments were only provided if traffic data were available along these segments. In other words, if segments were not travelled in a certain day, they would not be coded in the original shapefile provided by TomTom. This resulted in 14 different GIS shapefiles (7 days of study period for 2008 and 7 days for 2010) with separate traffic data for each. This issue requires redoing the routing for the macro, meso and micro sections 14 times. As an example, **Figure 15** illustrates that 435 segments were added to one master shape file while all the 7 shape files associated with the 2008 data were aggregated.

Figure 15 Additional Segments Added to the Original Shapefile

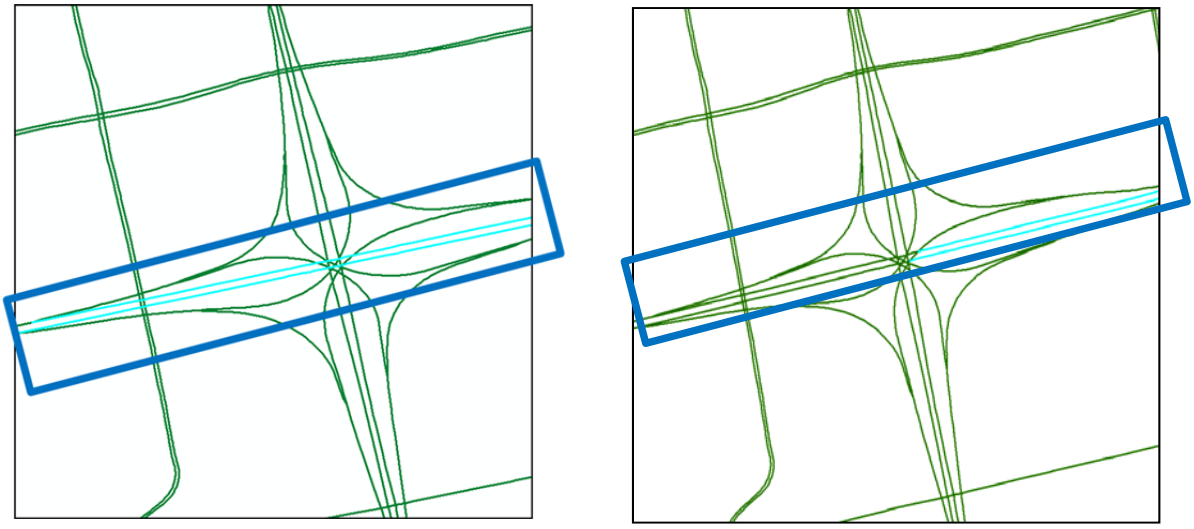
The other challenge with the shape files was that the Link IDs were different from one shape file to another shape file. In order to resolve this issue, a series of database quarries is designed to map the 14 shape files to one master shape file, and map the traffic data back to the new master shape file. In this way, the routing for the macro, meso and micro sections was created only once.

The forth and the fifth challenges are common between TomTom and INRIX and are elaborated in the INRIX section.

5.3 INRIX

Similar to TomTom, the data obtained from INRIX was temporally matched with the benchmark for direct comparison. However the traffic data validation is only conducted for 2010 because this vendor was not able to provide the traffic data associated with the study area for 2008.

The spatial matching of the INRIX GIS maps with the benchmark revealed two challenges: first, in the INRIX GIS maps, there is no node at the middle of interchanges and intersections. In other words, links were continuous through the interchanges and intersections. It was necessary to add nodes at interchanges and intersection because such nodes define the beginning or end of a given section. **Figure 16** (a) illustrates a continuous segment at an interchange and **Figure 16** (b) shows the same interchange at the middle of which the links were broken. An extension tool in ArcGIS,called “Planarize lines”, was used to automatically break segments at the middle of interchanges and interchanges.



a) Continous links through an interchnage b) Broken links at the interchange

Figure 16 Continuous Segments at an Interchange

The second issue is common between TomTom and INRIX data providers. In both GIS maps, the arterial roads which did not have physical medians had two links overlaid on top of each other where each link is associated with one direction of travel. Unfortunately, the links were not directional and the direction of travel for each link was not readily known. As shown in **Figure 17**, the blue link shows two link ID (2201 and 2203) but it is not known which one represents the northbound direction and which one is associated with the southbound direction.

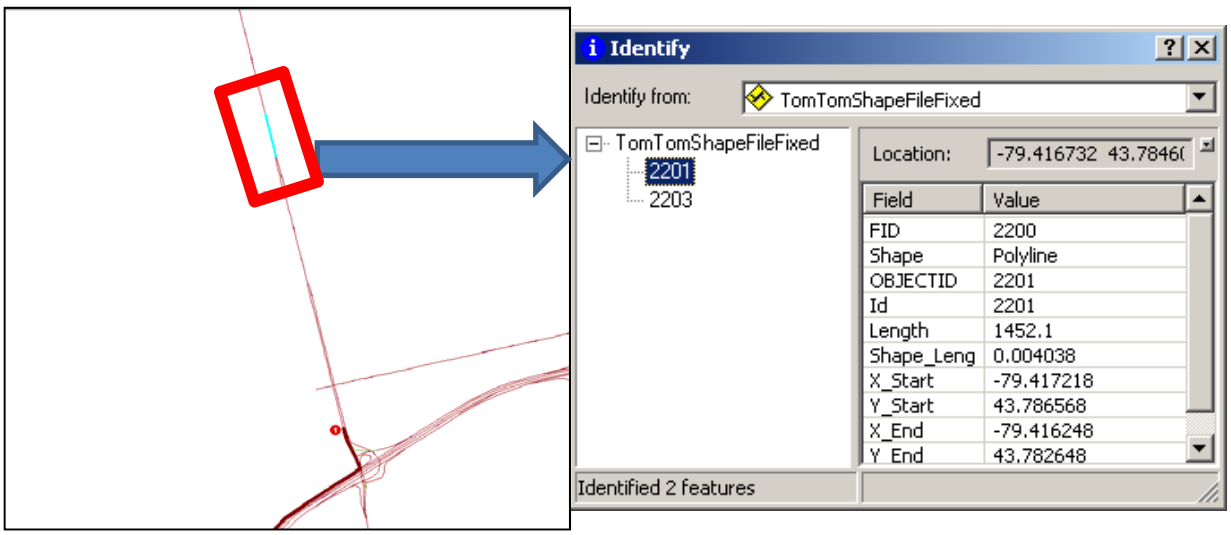
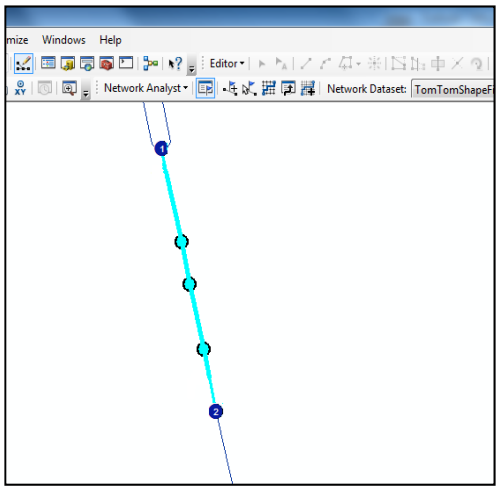


Figure 17 Over Layer Arterial Links

In order to solve this issue, the “ONEWAY” attribute with the value “FT” (From-To) was added to all elements, using “Shapefile Repair Tool” in ArcGIS. After repairing the shapefile, the segment routing is calculated using “Network Analyst Tool”, between two end points of each segment (i.e. micro, meso and macro). Finally the routing results are translated into the correct elements and

ID's in one direction using "Network Analyst Traversal Result Add-In", as another extension tool in ArcGIS. This resolved the overlaid segments issue and resulted in two separate groups of segment, for both directions in arterial sections. **Figure 18** presents an example of original overlaid segments (8 segments in total in both directions) and the results after applying extension tools in ArcGIS (two directions are separated, each with 4 segments).

ArcGIS map



Before

TomTomShapeFileFixed

FID	Shape *	OBJECTID	Id	Length	Shape_Leng	X_Start	Y_Start	X_End	Y_End	ONEWAY
881	Polyline	882	882	245.08	0.00068	-79.46672	43.76795	-79.466568	43.767288	FT
882	Polyline	883	883	245.08	0.00068	-79.466568	43.767288	-79.46672	43.76795	FT
904	Polyline	905	905	164.04	0.000458	-79.46629	43.76603	-79.466388	43.766478	FT
906	Polyline	907	907	164.04	0.000458	-79.466388	43.766478	-79.46629	43.76603	FT
907	Polyline	908	908	117.13	0.000325	-79.4665	43.76697	-79.466568	43.767288	FT
909	Polyline	910	910	117.13	0.000325	-79.466568	43.767288	-79.4665	43.76697	FT
910	Polyline	911	911	181.76	0.000505	-79.466388	43.766478	-79.4665	43.76697	FT
912	Polyline	913	913	181.76	0.000505	-79.4665	43.76697	-79.466388	43.766478	FT

4 (8 out of 24075 Selected)

TomTomShapeFileFixed

After

Table - Edges

Edges

Shape	ObjectID	SourceID	SourceOID	EID	FromPosition	ToPosition	FromJunctionID	ToJunc
Polyline	1	1	881	1232	0.195044	1	1	
Polyline	2	1	909	1232	0	1	2	
Polyline	3	1	912	1232	0	1	3	
Polyline	4	1	906	1232	0	0.464801	4	

3 (4 out of 4 Selected)

Edges

Figure 18 A Before/After Example of Overlaid Segments

6 Evaluation

The following criteria were used to evaluate each data source against the benchmark:

- Accuracy
- Coverage
- Number of observations
- Special facilities (Express vs. Collector, HOV vs. GPL)

6.1 Accuracy

This section lays out the general approach for evaluation of alternative technologies in terms of accuracy. The methodology for evaluation of Bluetooth technology is different from the one for TomTom and INRIX. The following sub-sections briefly explain the evaluation approaches.

6.1.1 Methodology

Evaluation of Bluetooth Technology

In order to evaluate the accuracy of the Bluetooth technology against the benchmark, various performance measures are estimated for both data sources. These performance measures are listed below. Also the full description of all performance measures is presented in **Appendix E**.

- Travel Time for individual vehicles,
- Total/Cumulative Travel time,
- Average link travel time for all vehicles,
- Variation of link travel time,
- Standard deviation of travel time,
- Coefficient of variation of travel time,
- Travel speed,
- Average link travel speed for all vehicles,
- Harmonic mean of link travel time,
- Variance of travel speed,
- Standard deviation of travel speed,
- Coefficient of variation of travel speed,
- Travel Time Index (TTI), and
- Buffer Time Index (BTI).

In order to evaluate whether the travel time data estimated from Bluetooth technology are statistically different from the average travel time obtain from GPS equipped probe vehicle (benchmark), F-test and t-test are conducted. The F-test is used to conduct a hypothesis test for equality of variances of the two sample (travel times from the Bluetooth receivers and the benchmark). Also the t-test is the test for equality of two means regardless the variances are equal

or different. Based on F-test, t-test, and 95% confidence interval, average travel times obtained from the Bluetooth receivers and the benchmark are compared for 7 weeks, during AM and PM peak periods.

Evaluation of TomTom and INRIX

For each road section between two consecutive interchanges or intersections, the following performance measures were calculated:

- Average travel time
- Average speed
- Variance of travel time
- Variance of speed

It should be noted that based on the data obtained from the vendors, we were not able to calculate harmonic mean of link travel time and Buffer Time Index (BTI). However, because the BTI is important for the Ministry, **Appendix F** provides an approach through which BTI can be estimated for corridors using a separate data request from TomTom and INRIX.

For both data providers, the link lengths in the study area are smaller than the micro segmentation defined in this project and used previously in TTS. As a result, multiple consecutive links in data providers' maps may constitute one micro segment in the TTS. Therefore, the traffic data of links which constitute one road segment were combined to calculate performance measures for each micro road segment.

To calculate travel time of each micro road segment, the trajectory method is used (Izadpanah, 2010). In this method, average travel time of a route is computed by building a trajectory of a typical vehicle on the basis of the reported average link speeds for each road segment constituting the route. The trajectory method is most similar to the calculation methods used in the TTS for calculating travel time of each segment. To obtain travel time information for meso and macro segments, the same approach is utilized.

Variance of travel time for each road segment was calculated as the sum of variances of links which constitute the road segment. It should be noted that the covariance of travel time associated with road segments should have been considered. But, the magnitudes of covariance terms are not known.

Average and variance of speed for each road segment were estimated based on average travel time and variance of travel time calculated for the road segment using the methodology proposed by Hayya et al., 1975. The full description of the methodology is presented in **Appendix G**.

A hypothesis test of mean (t-test) was conducted for each route (micro segments, meso segments, and macro segments) in the study area to evaluate whether there is any evidence to suggest that the average travel time of the road segment obtained from each data provider is different from the benchmark at a 95% confidence interval.

6.1.2 Accuracy Evaluation

Based on the methodologies which were described in the previous section, each data source was independently compared with the benchmark (GPS data) and the evaluation results for each technology are presented in this section.

Bluetooth Technology

The performance measures estimated for the Bluetooth technology are tabulated in **Appendix H**. Also the estimated performance measures for the benchmark (GPS data) are presented in **Appendix I**. **Table 15** provides a sample summary of Bluetooth performance measures for an arterial segment.

As stated in the methodology section, the data obtained from the Bluetooth technology and the benchmarks (GPS data) are compared using statistical tests. **Table 16** presents an example of the comparison results for a ramp segment. The full comparison results for all road segments are presented in **Appendix J**.

Based on the comparison results for all road sections (ramps and arterials) during AM and PM peak periods, there is no evidence to conclude that the average travel time obtained from the Bluetooth units and the benchmark are statistically different at a 95% confidence interval.

TomTom

Based on the innovative statistical methodology described in the **Appendix G**, TomTom traffic data was compared to the MTO TTS in 2008 and 2010. **Figure 19** and **Figure 20** represent visual comparisons of cumulative travel time and speed profile for an arterial route between the benchmark and TomTom data in 2010, during the study period respectively. Similarly, **Figure 21** and **Figure 22** can be used to visually compare travel time and speed profile for Don Valley Parkway obtained from the TomTom data and the benchmark. These routes include multiple road segments. As can be seen in these figures, the data obtained from this vendor closely match the benchmark data. The visual comparison results for traffic data in 2008 are also revealed the same results. **Appendix K** presents the comparison figures for the same sample highway and arterial routes. Also the detailed visual comparison results between TomTom and GPS data (benchmark) for ramp segments are presented in **Appendix L.**

The results of the t-test for average travel time indicated that there was no evidence to conclude that the data obtained from this data source are statistically different from the benchmark for at least 90% of freeway segments, 97% of arterial segments, and 100% of ramps. **Table 17** presents the comprehensive results for each road type and segmentation levels, based on the previously stated methodology.

It is important to note that the above results do not necessarily suggest that the data obtained for arterials are more accurate than the data obtained for freeways. Arterial road sections are characterized by traffic controls including traffic signals. Traffic control devices increase travel time variations. Consequently, the variance of travel time associated with the limited GPS equipped

probe vehicle runs is large and the probability of rejecting the null hypothesis in a t-test becomes small

Table 15 A Sample Summary of Performance Measures for Arterial Segments (Week 4, AM peak period)

Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
York Arterial - Yonge Street NB	Moore Park	Steeles Ave W	0.49	64.53	628.07	25.06	38.83	27.33	169.01	13.00	47.56	27.33	2.20	68.90
	Steeles Ave W	Clark Ave	1.03	109.41	898.73	29.98	27.40	33.89	111.45	10.56	31.15	33.89	1.77	46.24
	Clark Ave	Royal Orchard Blvd.	1.77	167.87	1561.76	39.52	23.54	37.96	83.69	9.15	24.10	37.96	1.58	44.75
	Royal Orchard Blvd.	Hwy 7	1.52	110.51	799.39	28.27	25.59	49.52	150.35	12.26	24.76	49.52	1.21	49.77
	Hwy 7	High Tech Rd.	0.59	70.14	595.07	24.39	34.78	30.28	303.37	17.42	57.52	30.28	1.98	51.13
York Arterial-Yonge Street SB	High Tech Rd.	Hwy 7	0.59	62.69	1008.79	31.76	50.66	33.88	369.31	19.22	56.72	33.88	1.77	86.63
	Hwy 7	Royal Orchard Blvd.	1.52	125.75	1239.32	35.20	28.00	43.52	102.51	10.12	23.27	43.52	1.38	65.01
	Royal Orchard Blvd.	Clark Ave	1.77	229.57	11570.32	107.57	46.86	27.76	220.10	14.84	53.45	27.76	2.16	95.59
	Clark Ave	Steeles Ave W	1.03	176.94	5894.54	76.78	43.39	20.96	186.32	13.65	65.13	20.96	2.86	77.46
	Steeles Ave W	Moore Park	0.49	99.33	1442.44	37.98	38.24	17.76	112.18	10.59	59.64	17.76	3.38	69.14

Table 16 Bluetooth and GPS Data Comparison Result (95% Significance Level)

Road type	Week #	Time of Day	F-value	F-critical	F-test result	t- value	t-critical	t-test results
Ramp	1	AM peak	0.67	0.545	Variances are different	0.421	1.96	Mean are the same
		PM peak	1.7E-08	0.494	Variances are the same	0.138		

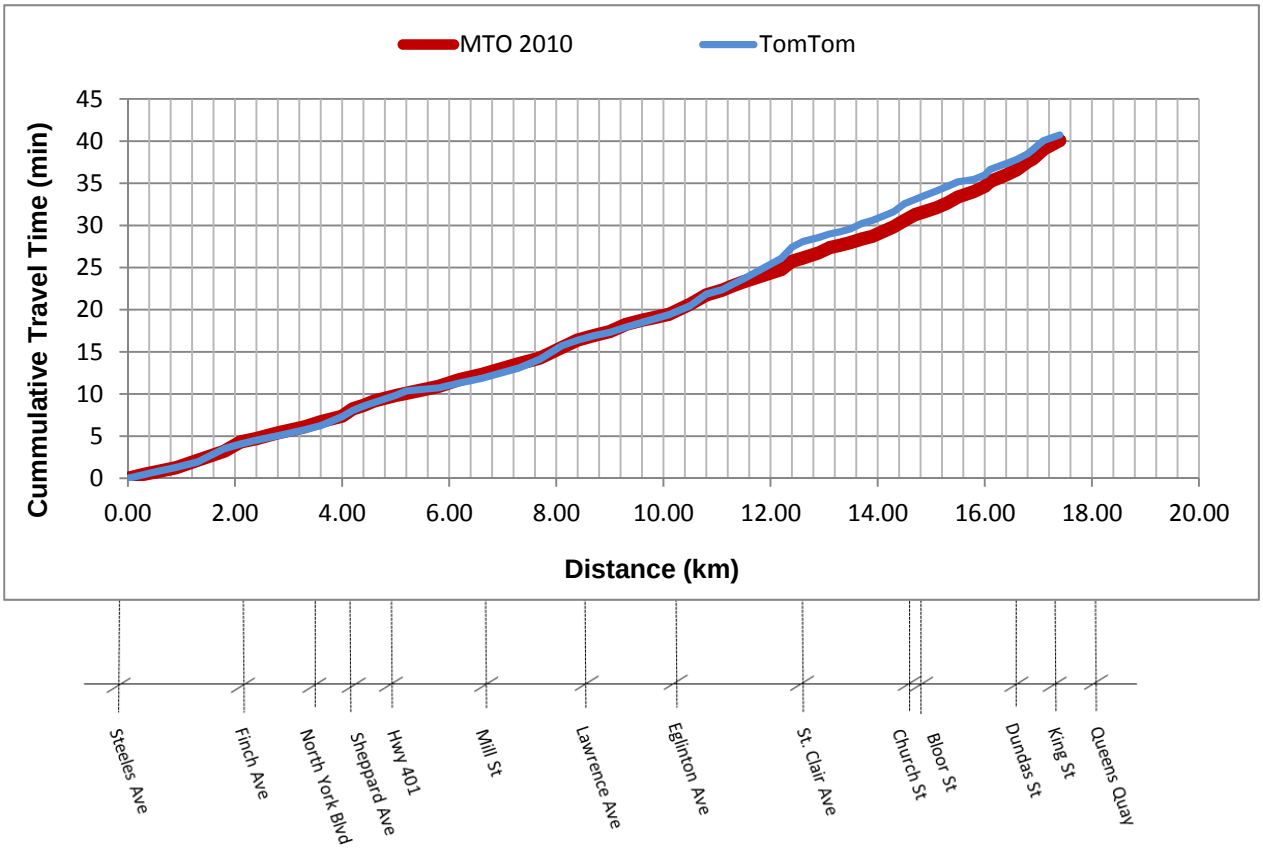


Figure 19 Cumulative Travel Time for Yonge Street Southbound During AM Peak Period

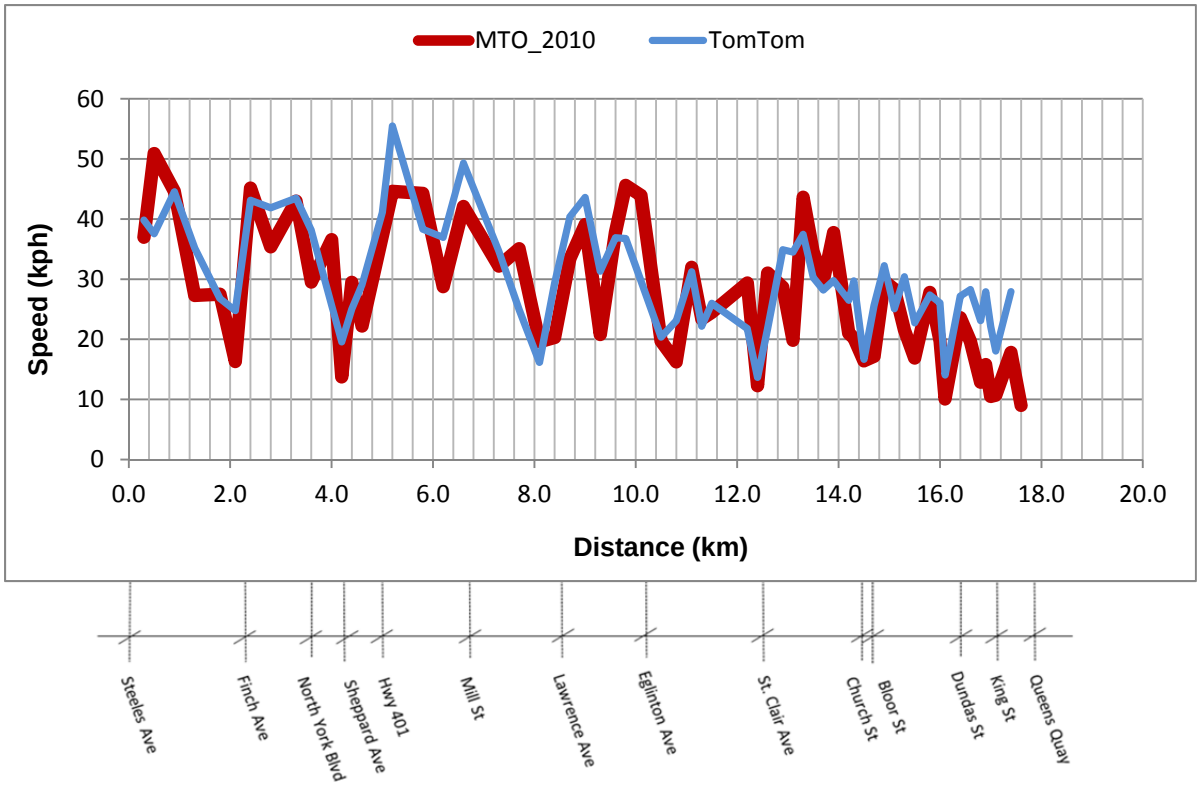


Figure 20 Speed Profile for Yonge Street Southbound During AM Peak Period

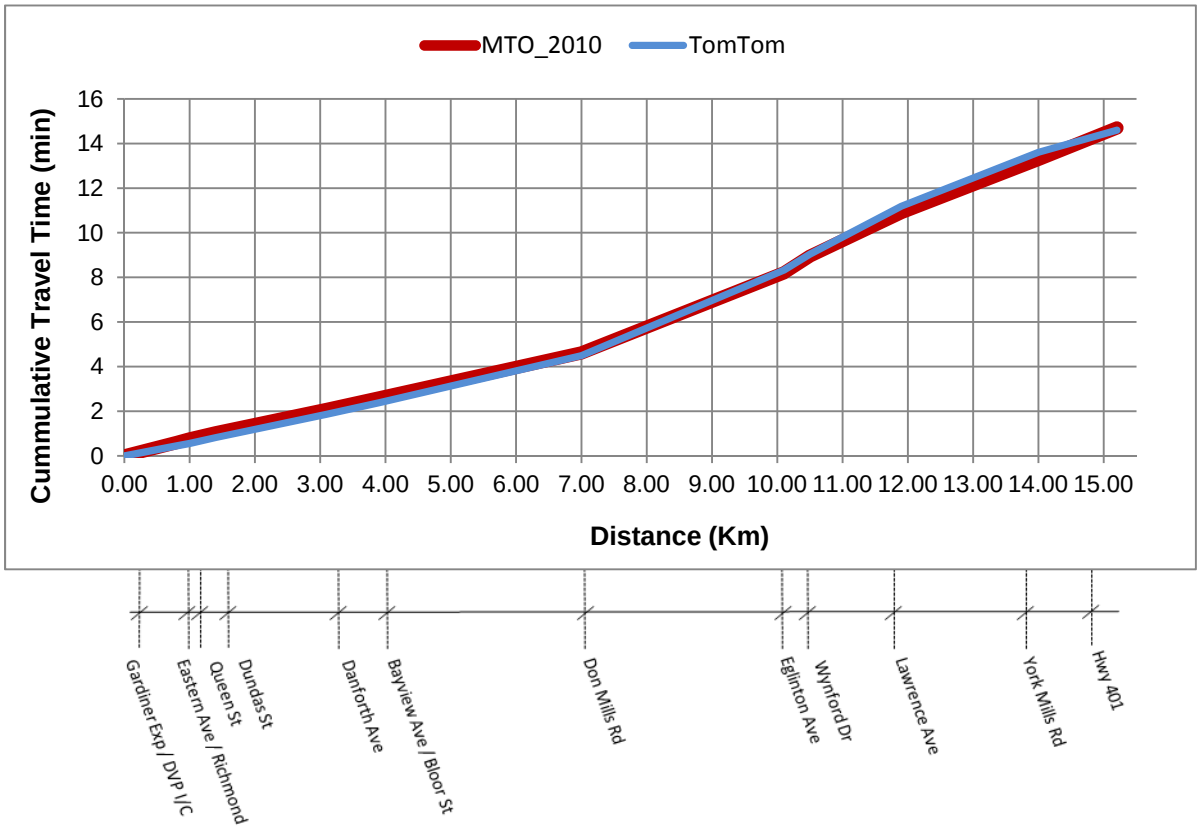


Figure 21 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

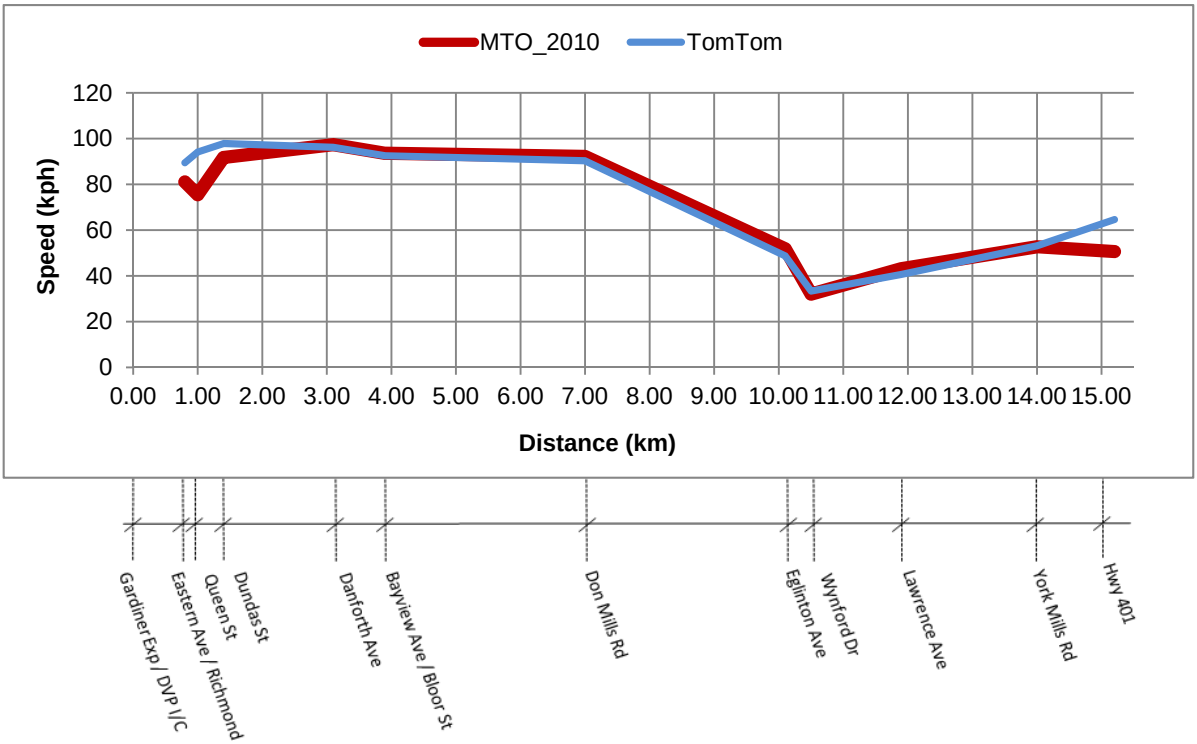


Figure 22 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

Table 17 Accuracy Evaluation of TomTom against MTO TTS

Road Type	Segmentation Level	Year of Comparison	Accuracy %
Highways	Micro	2010	90%
		2008	95%
	Meso	2010	96%
		2008	98%
	Macro	2010	98%
		2008	98%
Arterials	Micro	2010	98%
		2008	97%
	Meso	2010	98%
		2008	98%
	Macro	2010	99%
		2008	98%
Ramps	-	2010	100%
		2008	100%

INRIX

Following the same comparison methodology for TomTom, the INRIX data was evaluated against the benchmark (MTO 2010 TTS). The visual comparison results of travel time and speed profile for an arterial segment are presented in **Figure 23** and

Figure 24, respectively. Also the results for a highway segment are presented in **Figure 25** and **Figure 26**. The results of the t-test for mean suggest that there was no evidence to conclude that

the data obtained from this data source are statistically different from the benchmark for 91% of freeway segments, 98% of arterial segments, and 100% of ramps. The summary results for highways, arterials, and ramp segments are presented in

Table 18. Similar to mainline sections, the detailed visual comparison results between INRIX and GPS data (benchmark) for ramp segments are presented in **Appendix L.**

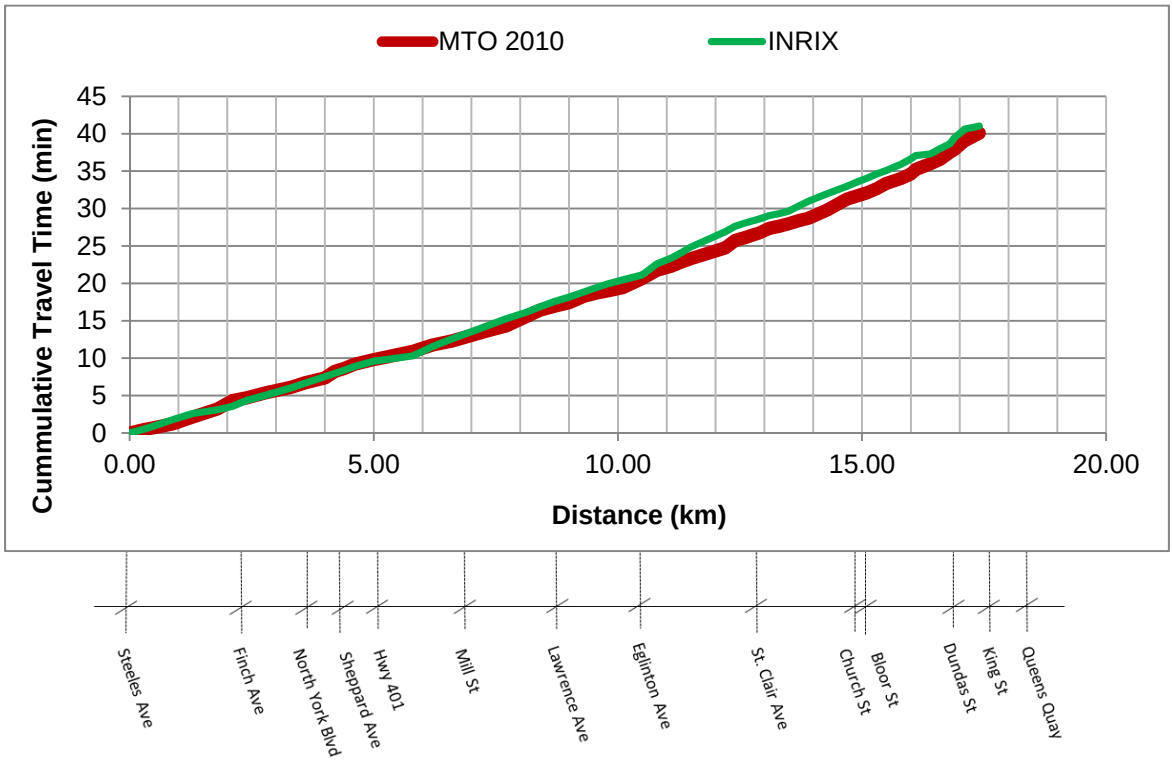


Figure 23 Cumulative Travel Time for Yonge Street Southbound During AM Peak Period

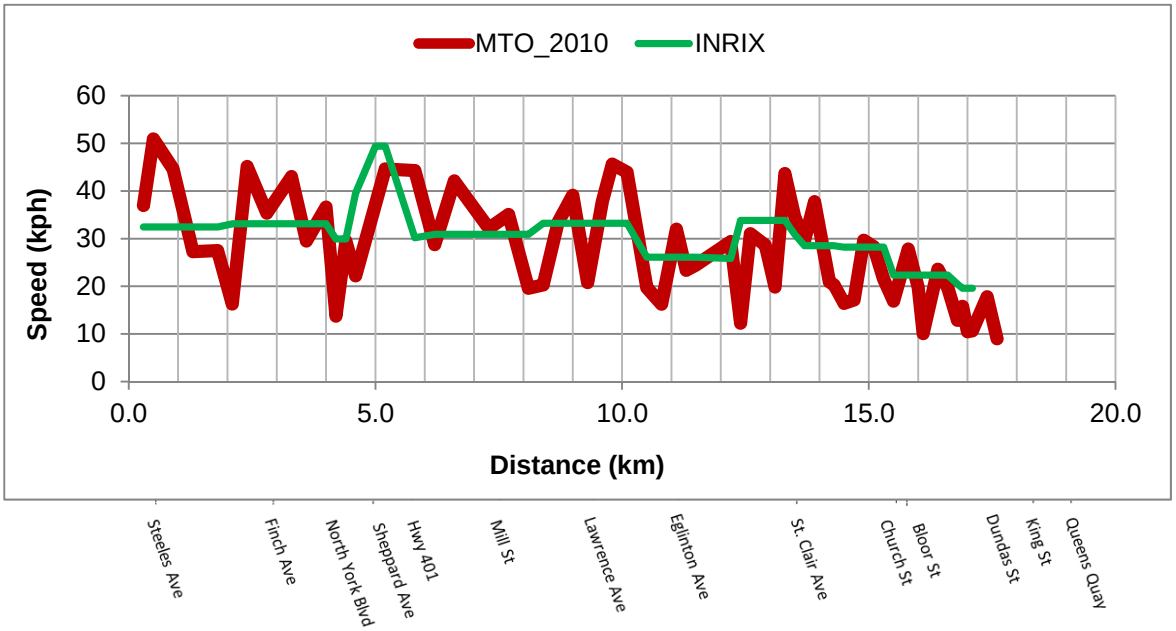


Figure 24 Speed Profile for Yonge Street Southbound During AM Peak Period

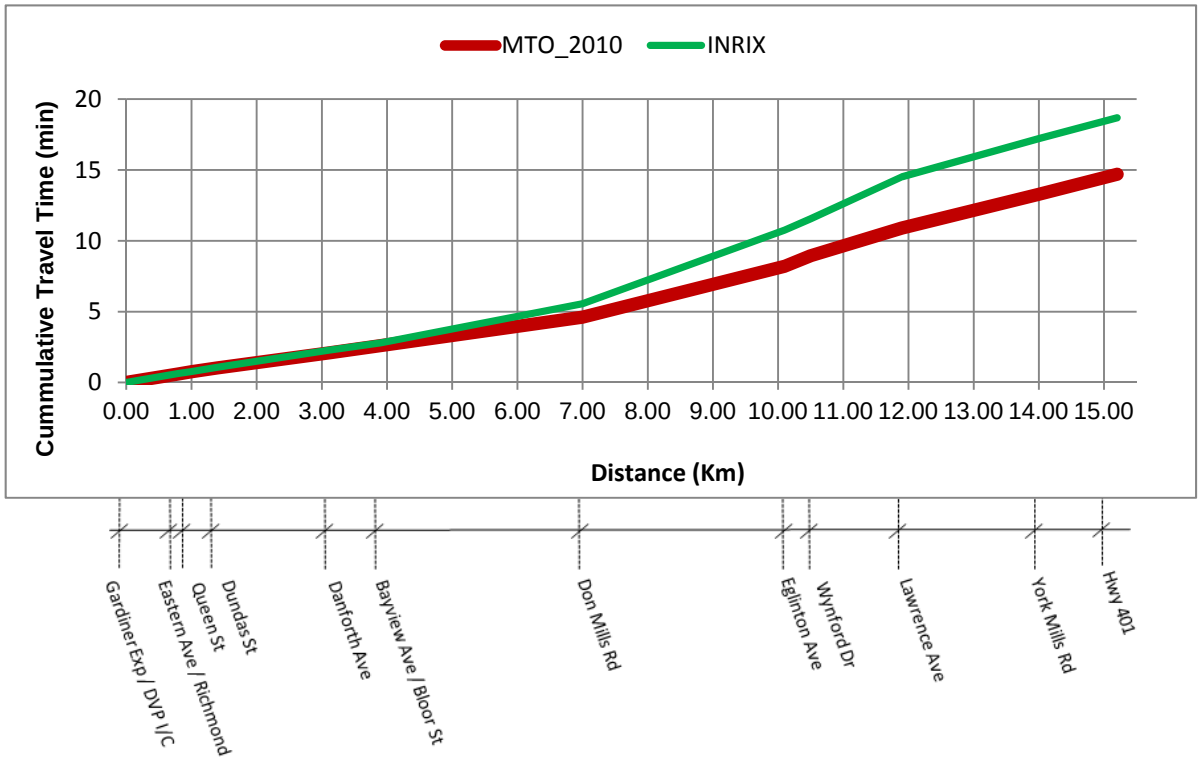


Figure 25 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

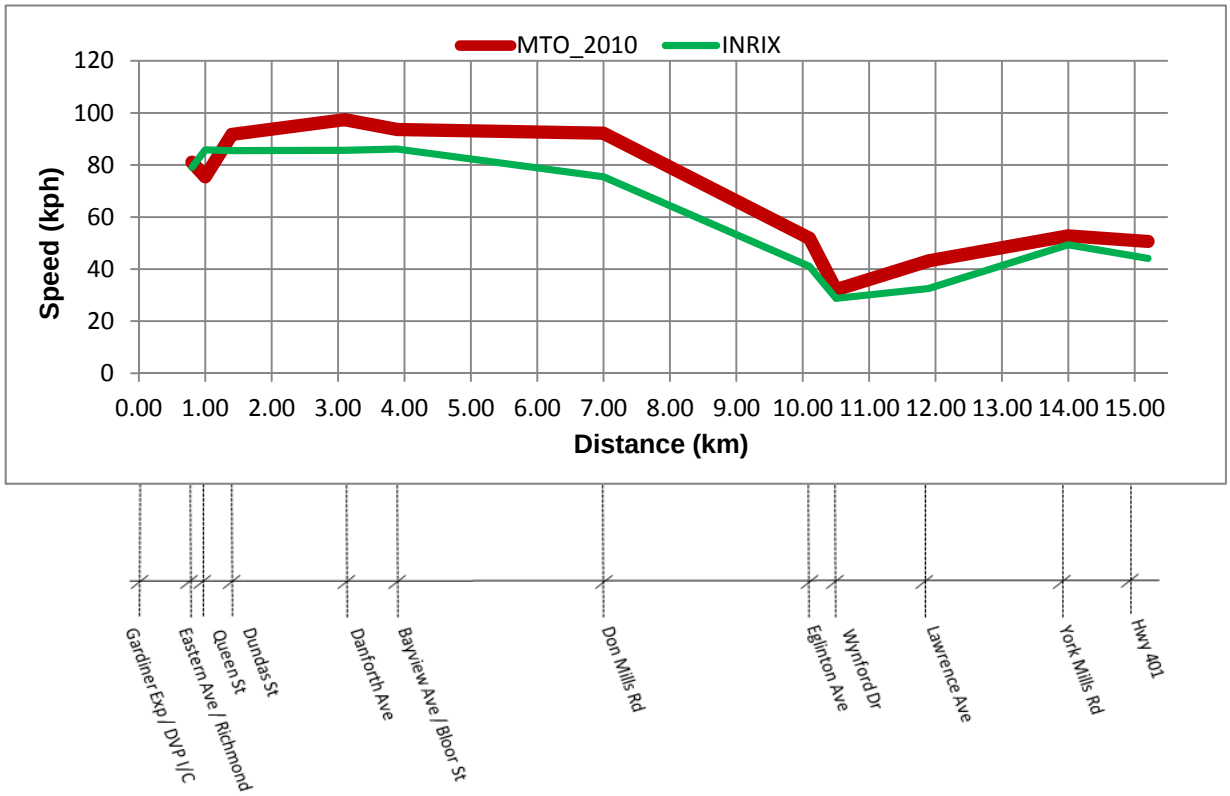


Figure 26 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

Table 18 Accuracy Evaluation of INRIX against the 2010 MTO TTS

Road Type	Segmentation Level	Accuracy %
Highways	Micro	91%
	Meso	93%
	Macro	94%
Arterials	Micro	98%
	Meso	98%
	Macro	98%
Ramps	-	100%

The detailed comparison between TomTom and INRIX data in terms of speed accuracy for highway micro segments in 2010 are provided in **Appendix M**.

6.2 Coverage

In terms of coverage, Bluetooth units can cover the area where the receivers are deployed. As for TomTom and INRIX, traffic data was generally available for the study area. However TomTom and INRIX had missing traffic and network data for 2.9 km and 9.4 km of the study area respectively. Those segments with missing data are tabulated in **Appendix N** for each data provider.

6.3 Number of observations

The average number of observations for each data source can be a measure of robustness. **Figure 27** and **Figure 28** present a side-by-side comparison of average observation per peak period between Bluetooth, TomTom, INRIX, data providers and the benchmark (MTO TTS in 2008 and 2010), for arterials and freeways respectively.

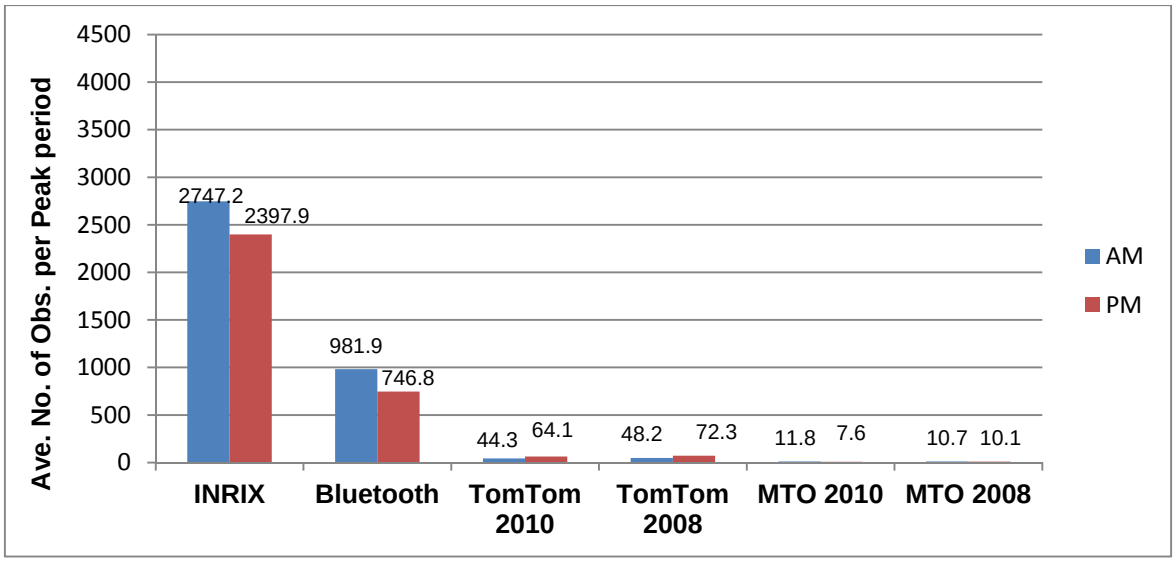


Figure 27 Average Observation per Peak Period for Arterial Sections

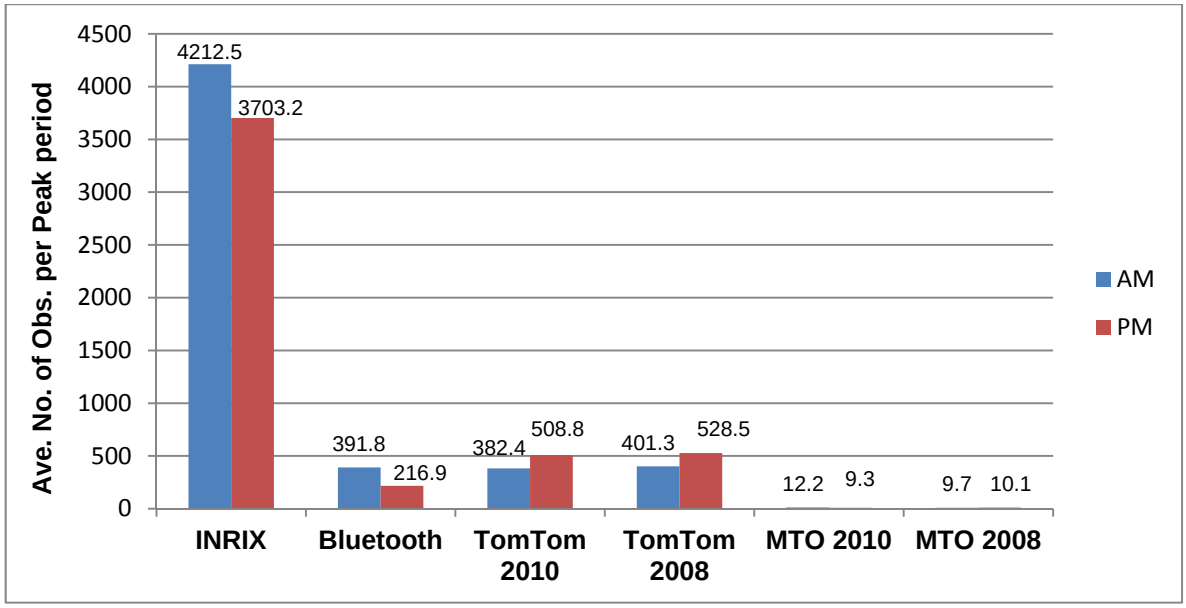


Figure 28 Average Observations per Peak Period for Highway Sections

Results from **Figure 27** and **Figure 28** revealed that sample size for INRIX is significantly higher than other providers. The difference between INRIX and TomTom data providers is particularly larger for arterial roads.

6.4 Special Facilities

Another important factor is the ability of the new technologies to differentiate between traffic data for express and collector lanes, as for Highway 401, or High Occupancy (HOV) versus General Purpose Lanes (GPL), as for Highway 403 and Highway 404.

The Bluetooth receivers are not generally able to differentiate between GPL and HOV lanes. However, if at least one of the Bluetooth receivers can be installed isolated to capture only the vehicles on collector lanes or express lanes, it is possible to differentiate between vehicles travelling on the collector lanes and express lanes. Two examples of such instances are the HOV lane tunnel on HWY 404 SB to HWY 401 WB and the ramp from HWY 401 EB to HWY 404 NB. TomTom and INRIX are able to separate traffic data for express and collector lanes. However, both data sources failed to provide data for HOV versus GPL lanes.

7 Conclusions and Recommendations

7.1 Conclusions

The main goal of this project was to evaluate three data sources against the MTO TTS in order to examine whether the existing methodology for biennial travel time studies (TTS) can be replaced or supplemented by any of these data sources.

The three data sources used in this study include: the Bluetooth technology, TomTom, and INRIX. In this project, the data obtained from these sources were evaluated against a benchmark. The benchmark was the data obtained from the 2008 and 2010 MTO TTS, and for Bluetooth data, the benchmark was concurrent GPS probe vehicle survey conducted by CIMA+. The study area was selected approximately one quarter of the biennial TTS covering approximately 725 directional km of freeway, 407 directional km of arterials, and 8 ramps within the Greater Toronto Area (GTA) in the Province of Ontario.

The Ministry deployed Bluetooth receivers at pre-defined locations in the study area and provided the raw data to the consultant. Because no historical traffic information from the Bluetooth technology was available in the study area, supplementary data collection runs using GPS equipped probe vehicles were conducted which served as the benchmark for the Bluetooth technology. The network data and the traffic data associated with the network were purchased from vendors. The data were obtained for freeways, arterials, and ramps within the study area. The analyses were conducted for three levels of network aggregation: micro, meso, and macro.

The traffic data obtained from each vendor had to be temporally and spatially matched with the benchmark for direct comparison between each data source and the benchmark. The spatial matching posed a number of challenges because the GIS maps used by vendors could not be directly matched with the micro, meso, and macro segmentations in the TTS and this study. A number of processes were used in ArcGIS to match the vendors GIS maps with the previous TTS segmentations.

Once a one-to-one correspondence between the data obtained from each data provider and the previous TTS data was created, four evaluation criteria were used: accuracy, coverage, number of observations, and ability to provide data for special facilities to compare each data source with the benchmark. To evaluate TomTom and INRIX data sources against the benchmark, an innovative statistical methodology was developed. In terms of accuracy, no sufficient evidence was found to conclude that the average travel time obtained from TomTom and INRIX are different from the average travel time from the benchmark for at least 90% of links. This finding is valid for all road types (freeway, arterials, and ramps) and all segmentation levels (micro, meso, and macro). For the Bluetooth technology, there was no evidence to conclude that the average travel times obtained from 100% of the locations are different from the benchmark. It should be noted that the benchmark in this study include limited number of observations for each road segment obtained

from probe vehicles equipped with GPS. As a result, there is no evidence to confirm that the average travel time and average variance of this benchmark are equal to the "ground truth".

In terms of coverage, the Bluetooth receivers were able to provide traffic data for the selected sub-section of the study area. On the other hand, both TomTom and INRIX were able to provide traffic data for most of the study area. TomTom and INRIX had missing traffic and network data for 2.9 km (0.25%) and 9.4 km (0.83%) of the study area respectively.

In terms of number of observations (which can be construed as a measure of robustness), INRIX had the most number of observations per road section per peak period with more than 2300 observations for arterial roads and 3700 for freeways. The Bluetooth technology ranked second and TomTom ranked third. It is noteworthy that the number of observations for the existing MTO methodology for the TTS is approximately 10 observations per link per AM and PM time periods. Any of the three data sources evaluated in this study is able to provide significantly more observations.

Both TomTom and INRIX data sources were able to provide traffic data for both collector and express facilities. However, both data sources failed to provide data for HOV lanes separate from the GPL. The Bluetooth technology is generally incapable of providing data separately for GPL and HOV or express and collector lanes. However, in special cases (e.g. the HOV tunnel from HWY 404 SB to HWY 401 WB), it is possible to separate vehicles travelling on the HOV lane from the vehicles travelling on the GPL lanes.

As a summary, the data provided by the Bluetooth technology is closest to the truth and most reliable data source, based on accuracy, number of observations, and direct measurement of performance measures from disaggregate data. As a result Bluetooth traffic data can be used to verify performance of other data sources (e.g. TomTom and INRIX). However, wide-area deployment of these receivers appears to be costly. Aside from the Bluetooth technology, the results of SWOT[2] analysis revealed the advantages, disadvantages, and limitation of TomTom and INRIX (see **Appendix O** for the detail analysis). For both vendors, for at least 90% of the TTS routes, there was no evidence to suggest that the average travel times are statistically different from the benchmark at a 95% confidence interval.

[2] Strength, Weakness, Opportunities, and Threats

7.2 Recommendations

This section provides a few recommendations based on the experience obtained from this study for the future TTS:

1. The main advantages of obtaining wide-area travel time information from vendors are:
    a. MTO can obtain traffic information which has at least the same quality as the traditional TTS method at a lower cost.
    b. MTO can extend the geographical area of the TTS.
    c. MTO can obtain data for different seasons of the year and calculate seasonal factors for travel time for the study area. The biennial TTS have been historically conducted in the months of September, October, and November as well as on the Canada Day long weekend. As a result, the seasonal factors are particularly important for routes used by tourists in summers.
2. It is recommended that the 2012 be a transition year for the TTS in which data for freeways are purchased from vendors and the traditional TTS data collection methodology is used for arterials. This approach minimizes the risk for the Ministry because:
    a. It was found that the number of observations for both TomTom and INRIX were much higher on freeways than arterials.
    b. The level of complexity of traffic operation on freeways is less than arterials.
3. The Ministry uses the Buffer Time Index (BTI) to historically compare performance of road sections at each year with their past. As stated in the report, it is not possible to calculate BTIs for routes with the type of data obtained in this study because the distributions of speed along the routes are required. Consequently, the Ministry should identify corridors for which BTIs are required in the Request for Proposal for the 2012 TTS. The distributions of speed for these corridors should be obtained separately from vendors.
4. It is recommended that a few strategic freeway routes and arterial routes be defined and Bluetooth receivers be deployed along these routes. The deployments should be during the 2012 TTS study period. The data collected along these routes will serve as “ground truth” to evaluate the data purchased from the vendors. There are a few suggestions for the strategic routes:
    a. If the Ministry chooses to follow recommendation 2, the data for the strategic arterial routes should also be purchased from the vendors.
    b. It is suggested that the length of each strategic route be approximately 5-10 km (i.e. one or two meso segments in this study). It is suggested to select at least three freeway routes and three arterial routes.
    c. Spread the strategic routes in the study area covering heavily populated areas (e.g. in the City of Toronto) and less densely populated areas. This will likely affect the number of observations obtained from the vendors.
    d. Select different arterial routes in terms of traffic signal spacing because operational performance of arterial roads is significantly affected by traffic signals and travel time variations on arterials road sections is a function of traffic signal spacing and

signal timings. Variability in the layout of arterial routes will enable the Ministry to evaluate whether the data from vendors are able to capture these variations.

5. One of the challenges with the existing study is that the covariance of travel time associated with two consecutive links is not known. As a result, variance of a route consisting of a number of smaller links was assumed to be the sum of variances of travel times. It is recommended that magnitude of travel time covariance be investigated using the Bluetooth data obtained from the strategic routes.

8 References

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Appendix A Detailed Segment Lists

Table A-1 Macro segments of the Study Area

Road Type/Region	Route	From	To	Length (KM) per Direction
Highway	QEW	Fairview St	Highway 427	41
	Highway 400	Highway 401	Highway 9	35
	Highway 401 Collector & Express	Dixie Rd	Brock Rd	126
	Highway 403	QEW	Highway 401	28
	Highway 404	DVP	Green Lane	49
	Highway 410	Highway 403	Bovaird Dr	13
	Highway 427	QEW	Highway 7	34
	Gardiner Expressway	Highway 427	DVP	20
	DVP	Gardiner Expressway	Highway 401	17
Total Distance (both directions)				**725**
Toronto Arterial	Yonge Street	Steeles Avenue	Queens Quay	18
	Dufferin Street	Steeles Avenue West	Steeprock Drive / Overbrook Place	3
	York Mills Road	Yonge Street	Victoria Park Avenue	8
	Sheppard Avenue E	Yonge Street	Port Union Road/ Highway 401	22
Total Distance (both directions)				**102**
York Arterial	Yonge Street	Steeles Avenue	Green Lane	30
	Highway 9 / Davis Drive	Bathurst Street	Highway 404 (2008) / Woodbine Ave (2010)	8
	Major MacKenzie Drive	Highway 400 (2008) /Weston Road (2010)	Highway 404 (2008) /Woodbine Ave(2010)	14
Total Distance (both directions)				**104**
Peel Arterial	Derry Road	Highway 427	Highway 407 / 9th Line	22.4
	Bovaird Drive	Airport Road	Adamson Street	17.3
	Hurontario Street	Lakeshore Road	Derry Road	14.2
Total Distance (both directions)				**108**
Durham Arterial	Highway 2	Toronto / Durham Boundary	Harmony Road	27
	Whites Road	Highway 2	Taunton Road	7
	Thickson Road	Winchester Rd	Victoria St	11
	Liverpool Road	Finch Avenue	Bayly Street	2
Total Distance (both directions)				**93**

Table A-1 Macro segments of the Study Area (Cont'd)

Road Type/Region	Route	From	To
Ramp	Hwy400 / Hwy401	Hwy 401 EB Collectors	Hwy 400 NB
		Hwy 400 SB	Hwy 401 EB Collectors
	Hwy401 / Hwy404 / DVP	Hwy401 WB Collectors	Hwy 404 NB
		Hwy401 WB Express	Hwy 404 NB
		Hwy404 SB GPL	Hwy401 WB Collector
		Hwy 401 WB Collectors	DVP SB
	Hwy401 / Hwy427	Hwy 401 EB	Hwy 427 SB
	Hwy409 / Hwy401	Hwy 409 SB	Hwy 401 EB Collector
		Hwy 409 SB	Hwy 410 EB Express

Table A-2 Highway Meso Segments of the Study Area

Route	From	To	Length (Km) Per Direction
QEW	Fairview St I/C	Royal Windsor Dr	20.8
	Royal Windsor Dr	Erin Mills/South Dn	6.8
	Erin Mills/South Dn	Hwy 427 I/C	12.9
Hwy 400	Hwy 401 I/C	Langstaff Rd I/C	10.5
	Langstaff Rd I/C	York Rd 11 I/C	12.5
	York Rd 11 I/C	Hwy 9 I/C	12.3
Hwy 401 EXP/COLL	Brock Rd I/C	Hwy 404 I/C	23.9
	Hwy 404 I/C	Hwy 400 I/C	16.2
	Hwy 400 I/C	Dixie Road I/C	12.9
Hwy 403 GPL/HOV	401/410 I/C	Winston Churchill	13.8
	Winston Churchill	QEW I/C	7.1
Hwy 404	Hwy 401 I/C	16th Ave I/C	11.6
	16th Ave I/C	Green Lane I/C	25.6
Hwy 410	Hwy 403 I/C	Bovaird Dr I/C	13.3
Hwy 427	QEW I/C	Hwy 401 I/C	7.5
	Hwy 401 I/C	Hwy 7 I/C	13.1
Gardiner Expressway	Gardiner / 427 / Browns Ln	Kipling Ave	2.4
	Kipling Ave	Islington Ave	1.3
	Islington Ave	Lake Shore Blvd (South Kingsway)	4.2
	Lake Shore Blvd (South Kingsway)	Jameson Ave	4.1
	Jameson Ave	Spadina Ave	4.0
	Spadina Ave	York St	1.2
	York St	Lower Jarvis St	0.6
	Lower Jarvis St	DVP	2.0
DVP	Gardiner / DVP I/C	Eastern Ave / Richmond St	0.5
	Eastern Ave / Richmond St	Bayview Ave / Bloor St	3.2
	Bayview Ave / Bloor St	Don Mills Rd	3.5
	Don Mills Rd	Eglinton Ave	4.0
	Eglinton Ave	Wynford Dr	0.5
	Wynford Dr	Lawrence Ave	1.6
	Lawrence Ave	York Mills Rd	2.4
	York Mills Rd	Hwy 401	1.2

Table A-3 Arterial Meso Segments of the Study Area

Region	Route	From	To	Length (Km) Per Direction
Toronto Region	York Mills Rd	Yonge St	Parkwoods Village Dr	6.9
	Parkwoods Village Dr	New_Brookbanks Dr.	Victoria Park Ave	0.9
	Yonge St	Steeles Ave	Queens Quay	17.8
	Dufferin St	Steeles Ave W	William R Allen Rd (2008) / Overbrook Pl (2010)	3.1
	Sheppard Avenue E	Yonge St	Port Union Rd / Hwy 401	22.5
York Region	Yonge Street	Steeles Avenue	Highway 7	4.0
		Highway 7	Major Mackenzie Drive	4.0
		Major Mackenzie Drive	Elgin Mills Road	2.0
		Elgin Mills Road	King Road	6.0
		King Road	Industrial Parkway S.	4.0
		Industrial Parkway S.	Wellington Road	2.0
		Wellington Street	Mulock Drive	4.0
		Mulock Drive	Davis Drive	2.0
		Davis Drive	Green Lane	2.0
	Major Mackenzie Dr	Hwy 404 (2008) / Woodbine Avenue (2010)	Leslie Street	2.0
		Leslie Street	Yonge Street	4.0
		Yonge Street	Keele Street	6.0
		Keele Street	Weston Road	4.0
	Highway 9/Davis Dr	Hwy 404 (2008) / Woodbine Avenue (2010)	Leslie Street	2.0
		Leslie Street	Yonge Street	4.0
		Yonge Street	Bathurst Street	2
Peel Region	Derry Rd	Hwy 427	GO Station	2.3
		GO Station	Airport Rd	0.2
		Airport Rd	Dixie Rd	4.1
		Dixie Rd	Kennedy Road	2.8
		Kennedy Road	Hurontario St	1.4
		Hurontario St	Mavis Rd	2.0
		Mavis Rd	John Watt Blvd/Envoy Dr	0.3
		John Watt Blvd/Envoy Dr	Atwood Ln/Bellshire Gt	2.3
		Atwood Ln/Bellshire Gt	Mississauga Rd	1.6
		Mississauga Rd	West Credit Ave	0.3
		West Credit Ave	Syntex Dr/Syntex Crt	0.3
		Syntex Dr/Syntex Crt	Ninth Line	4.4
	Bovaird Dr	Airport Rd	Torbram Rd	1.4
		Torbram Rd	Bramalea Rd	1.4
		Bramalea Rd	Dixie Rd	1.3
		Dixie Rd	Hwy 410	1.3
		Hwy 410	Kennedy Rd	1.4
		Kennedy Rd	McLaughlin Rd	2.8
		McLaughlin Rd	Fletcher's Creek Rd	0.7
		Fletcher's Creek Rd	Chinguacousy Rd	0.9
		Chinguacousy Rd	Heritage Rd	4.2
		Heritage Rd	Winston Churchill Blvd	2.0
	Hurontario St	Lakeshore Rd	The Queensway	3.0
		The Queensway	Dundas St	1.0
		Dundas St	Burnhamthorpe Rd	2.1
		Burnhamthorpe Rd	Hwy 403	1.0
		Hwy 403	Eglinton Ave	1.1
		Eglinton Ave	Britannia Rd	3.1
		Britannia Rd	Derry Rd	3.0

Region	Route	From	To	Length (Km) Per Direction
Durham Region	Kingston Road/ Dundas Street /King Street	Toronto-Durham Boundary	Whites Road	2.0
		Whites Road	Liverpool Road	2.8
		Liverpool Road	Brock Road	1.9
		Brock Road	Church Street	1.7
		Church Street	Westney Road	1.1
		Westney Road	Salem Road	2.2
		Salem Road	Lake Ridge Road	2.5
		Lake Ridge Road	Brock Street	3.7
		Brock Street	Anderson Street	1.7
		Anderson Street	Thickson Road	0.8
		Thickson Road	Stevenson Road	2.5
		Stevenson Road	Simcoe Street	1.7
		Simcoe Street	Harmony Road	2.5
	Liverpool Road	Finch Avenue	Kingston Road	1.2
		Kingston Road	Highway 401	0.6
		Highway 401	Bayly Street	0.2
	Whites Road	Taunton Road	Finch Avenue	3.7
		Finch Avenue	Kingston Road	2.4
		Kingston Road	Bayly Street	0.6
	Thickson Road	Winchester Road	Taunton Road	4.1
		Taunton Road	Rossland Road	2.1
		Rossland Road	Dundas Street	2.1
		Dundas Street	Highway 401	2.0
		Highway 401	Victoria Street	0.4

Table A-4 Highway Micro Segments of the Study Area

Route	From	To	Length (Km) Per Direction
QEW	Hwy 427	Evans Ave	0.7
	Evans Ave	Dixie Rd	1.8
	Dixie Rd	Cawthra Rd	1.8
	Cawthra Rd	Hwy 10/Hurontario St	2.2
	Hwy 10/Hurontario St	Mississauga Rd	2.1
	Mississauga Rd	Erin Mills Parkway	4.2
	Erin Mills Parkway	Winston Churchill Boulevard	2.1
	Winston Churchill Boulevard	Hwy. 403/Ford Drive	1.4
	Hwy. 403/Ford Drive	Royal Windsor Drive	3.0
	Royal Windsor Drive	Trafalgar Road	1.6
	Trafalgar Road	Dorval Road	2.1
	Dorval Road	Third Line Road	3.2
	Third Line Road	Bronte Rd (RR 25)	2.1
	Bronte Rd (RR 25)	Burloak Drive	2.0
	Burloak Drive	Appleby Line	2.0
	Appleby Line	Walkers Line	2.1
	Walkers Line	Guelph Line	2.1
	Guelph Line	Brant Street	1.9
	Brant Street	Hwy. 403/407	0.8
	Hwy. 403/407	Fairview Street	1.0
Hwy 400	Hwy. 401	Finch Avenue	4.4
	Finch Avenue	Steeles Avenue	2.0
	Steeles Avenue	Hwy. 407	1.2
	Hwy. 407	Hwy. 7	0.9
	Hwy. 7	Langstaff Road	2.0
	Langstaff Road	Bass Pro Mills Drive	1.4
	Bass Pro Mills Drive	Rutherford Road	0.7
	Rutherford Road	Major MacKenzie Drive	2.0
	Major MacKenzie Drive	York Road 11	8.3
	York Road 11	Aurora Rd/Loydtown Rd	9.1
	Aurora Rd/Loydtown Rd	Hwy. 9	3.2
Hwy 401 Exp/Coll	Dixie Road	Renforth Drive	4.4
	Renforth Drive	Hwy. 427	0.7
	Hwy. 427	Dixon Road	2.6
	Dixon Road	Hwy. 409	1.8
	Hwy. 409	Islington Avenue	0.7
	Islington Avenue	Weston Road	1.4
	Weston Road	Hwy. 400	1.4
	Hwy. 400	Keele Street	3.2
	Keele Street	Dufferin Street	2.0
	Dufferin Street	Allen Road	0.8
	Allen Road	Bathurst Street	1.4
	Bathurst Street	Avenue Road	1.1
	Avenue Road	Yonge St (Hwy 11)	1.7
	Yonge St (Hwy 11)	Bayview Avenue	2.1
	Bayview Avenue	Leslie Street	2.0
	Leslie Street	Hwy. 404/DVP	2.0

Route	From	To	Length (Km) Per Direction
Hwy 401 Exp/Coll (Cont'd)	Hwy. 404/DVP	Victoria Park Avenue	1.5
	Victoria Park Avenue	Warden Avenue	1.3
	Warden Avenue	Kennedy Road	1.7
	Kennedy Road	Brimley Road	1.7
	Brimley Road	McCowen Road	0.8
	McCowen Road	Markham Rd (Hwy 427)	1.7
	Markham Rd (Hwy 427)	Neilson Road	1.8
	Neilson Road	Morningside Avenue	1.5
	Morningside Avenue	Meadowvale Road	2.5
	Meadowvale Road	Sheppard Ave (Hwys 2-2A)	1.9
	Sheppard Ave (Hwys 2-2A)	Whites Rd (RR 38)	3.2
	Whites Rd (RR 38)	Liverpool Rd (RR 29)	2.6
	Liverpool Rd (RR 29)	Brock Road	1.7
Hwy 403	Hwy 401/410	Eglington Ave	2.5
	Eglington Ave	Hurontario St (Hwy 10)	2.7
	Hurontario St (Hwy 10)	Mavis Rd	2.1
	Mavis Rd	Erin Mills Pkwy	4.6
	Erin Mills Pkwy	Winston Churchill Blvd	1.6
	Winston Churchill Blvd	Hwy 407	2.0
	Hwy 407	Dundas	3.2
	Dundas	QEW	2.1
Hwy 404	Hwy. 401/DVP	Sheppard Avenue	0.9
	Sheppard Avenue	Finch Avenue	2.1
	Finch Avenue	Steeles Avenue	2.2
	Steeles Avenue	Hwy. 407	3.3
	Hwy. 407	Hwy. 7	0.9
	Hwy. 7	16th Avenue	2.0
	16th Avenue	Major MacKenzie Drive	2.0
	Major MacKenzie Drive	Elgin Mills Road	2.0
	Elgin Mills Road	York Rd 14/Souffville Rd	4.4
	York Rd 14/Souffville Rd	York Rd 40/Bloomington Rd	4.2
	York Rd 40/Bloomington Rd	York Rd 15/Aurora Rd	4.2
	York Rd 15/Aurora Rd	Mulock Dr/Vivian Rd (RR 74)	4.1
	Mulock Dr/Vivian Rd (RR 74)	Davis Drive	2.1
	Davis Drive	Green Lane (RR 19)	2.0
Hwy 410	Hwy 401/403	Courtney Park Dr	2.0
	Courtney Park Dr	Derry Rd	1.5
	Derry Rd	Hwy 407	1.2
	Hwy 407	Steeles Ave	2.1
	Steeles Ave	Clark Blvd	2.4
	Clark Blvd	Queen St	0.6
	Queen St	Williams Pkwy	1.6
	Williams Pkwy	Boivard Dr	1.5

Route	From	To	Length (Km) Per Direction
Hwy 427	QEW	Hwy. 5/Dundas St	1.7
	Hwy. 5/Dundas St	Burnhamthorpe Road	1.9
	Burnhamthorpe Road	Rathburn Road	1.0
	Rathburn Road	Hwy. 27 & Ramps to Hwy 401	1.8
	Hwy. 27 & Ramps to Hwy 401	Hwy. 401	0.9
	Hwy. 401	Dixon Road	2.5
	Dixon Road	Hwy. 409	1.3
	Hwy. 409	Rexdale Boulevard	2.6
	Rexdale Boulevard	Finch Avenue	1.8
	Finch Avenue	Hwy. 407	2.3
	Hwy. 407	Hwy. 7	1.8
Gardiner Expressway	Hwy 427	Kipling Ave	2.0
	Kipling Ave	Islington Ave	1.1
	Islington Ave	Lake Shore Blvd (split)	2.8
	Lake Shore Blvd (split)	Jameson Ave	4.3
	Jameson Ave	Spadina Ave	3.5
	Spadina Ave	York St	1.0
	York St	Lower Jarvis	1.0
	Lower Jarvis	DVP	1.7
DVP	Gardiner Exp / DVP I/C	Eastern Ave / Richmond St	0.8
	Eastern Ave / Richmond St	Queen St	0.2
	Queen St	Dundas St	0.4
	Dundas St	Danforth Ave	1.7
	Danforth Ave	Bayview Ave / Bloor St	0.8
	Bayview Ave / Bloor St	Don Mills Rd	3.1
	Don Mills Rd	Eglinton Ave	3.1
	Eglinton Ave	Wynford Dr	0.4
	Wynford Dr	Lawrence Ave	1.4
	Lawrence Ave	York Mills Rd	2.1
	York Mills Rd	Hwy 401	1.2

Table A-5 Arterial Micro Segments of the Study Area

Region	Route	From	To	Length (Km) Per Direction
Toronto Region	York Mills Road	Yonge St	Highland Cres	0.9
		Highland Cres	Fenn Ave	0.6
		Fenn Ave	Bayview Ave	0.4
		Bayview Ave	Harrison Rd	0.5
		Harrison Rd	Sandfield Rd	0.3
		Sandfield Rd	Chipstead Rd	0.4
		Chipstead Rd	Leslie St	0.9
		Leslie St	Scarsdale Rd	0.2
		Scarsdale Rd	Lesmill Rd	0.5
		Lesmill Rd	Don Mills Rd	0.4
		Don Mills Rd	Silverdale Cres	0.5
		Silverdale Cres	Dvp S York Mills W Ramp	0.4
		Dvp S York Mills W Ramp	Dvp N York Mills W Ramp	0.3
		Dvp N York Mills W Ramp	Sandover Dr	0.1
		Sandover Dr	Fenside Dr	0.4
		Fenside Dr	Parkwoods Village Dr	0.2
	Parkwoods Village Dr	New_Brookbanks Dr.	Gisburn Rd	0.2
		Gisburn Rd	Victoria Park Ave	0.7
	Yonge St	Lake Shore Blvd	Front St	0.3
		Front St	Wellington St	0.1
		Wellington St	King St	0.1
		King St	Adelaide St	0.1
		Adelaide St	Queen St	0.2
		Queen St	Shuter St	0.2
		Shuter St	Dundas St	0.3
		Dundas St	Gould St	0.1
		Gould St	Gerrard St	0.2
		Gerrard St	Carlton St	0.3
		Carlton St	Grosvenor St	0.2
		Grosvenor St	Wellesley St	0.2
		Wellesley St	Gloucester St	0.2
		Gloucester St	Charles St	0.2
		Charles St	Bloor St	0.2
		Bloor St	Yorkville Ave	0.2
		Yorkville Ave	Church St	0.1
		Church St	Aylmer Ave	0.3
		Aylmer Ave	Crescent Rd	0.2
		Crescent Rd	Macpherson Ave	0.2
		Macpherson Ave	Scrivener Sq	0.2
		Scrivener Sq	Shaftesbury Ave	0.2
		Shaftesbury Ave	Woodlawn Ave	0.2
		Woodlawn Ave	Rosehill Ave	0.3
		Rosehill Ave	St. Clair Ave	0.2
		St. Clair Ave	Heath St	0.2
		Heath St	Merton St	0.7
		Merton St	Chaplin Cres	0.2
		Chaplin Cres	Belsize Dr	0.2
		Belsize Dr	Manor Rd	0.3

Region	Route	From	To	Length (Km) Per Direction
Toronto Region	Yonge St (Cont'd)	Manor Rd	Eglinton Ave	0.4
		Eglinton Ave	Broadway Ave	0.4
		Broadway Ave	Castlefield Ave	0.2
		Castlefield Ave	Briar Hill Ave	0.2
		Briar Hill Ave	Blythwood Rd	0.3
		Blythwood Rd	Glengrove Ave	0.3
		Glengrove Ave	Chatsworth Dr	0.3
		Chatsworth Dr	Lawrence Ave	0.4
		Lawrence Ave	Ranleigh Ave	0.3
		Ranleigh Ave	Fairlawn Ave	0.3
		Fairlawn Ave	Yonge Blvd	0.4
		Yonge Blvd	Mill St	0.7
		Mill St	Wilson Ave	0.4
		Wilson Ave	William Carson Cres	0.4
		William Carson Cres	Lord Seaton Ramp	0.6
		Lord Seaton Ramp	Hwy 401	0.2
		Hwy 401	Avondale Ave	0.4
		Avondale Ave	Poyntz Ave	0.2
		Poyntz Ave	Sheppard Ave	0.2
		Sheppard Ave	Elmhurst Ave	0.2
		Elmhurst Ave	North York Blvd	0.4
		North York Blvd	Empress Ave	0.3
		Empress Ave	Church Ave	0.5
		Church Ave	Kempford Blvd	0.4
		Kempford Blvd	Finch Ave	0.3
		Finch Ave	Bishop Ave	0.3
		Bishop Ave	Cummer Ave	0.5
		Cummer Ave	Patricia Ave	0.4
		Patricia Ave	Madawaska Ave	0.4
		Madawaska Ave	Athabaska Ave	0.2
	Dufferin St	Athabaska Ave	Steeles Ave	0.3
		Overbrook Pl	Stanstead Dr	0.5
		Stanstead Dr	Finch Ave	0.4
		Finch Ave	Martin Ross Ave	0.7
		Martin Ross Ave	Supertest Rd	0.3
		Supertest Rd	Dolomite Dr	0.3
		Dolomite Dr	Gerry Fitzgerald Dr	0.3
	Sheppard Avenue E	Gerry Fitzgerald Dr	Steeles Ave	0.4
		Yonge St	Doris Ave	0.2
		Doris Ave	Kenneth Ave	0.3
		Kenneth Ave	Willowdale Ave	0.4
		Willowdale Ave	Wilfred Ave	0.4
		Wilfred Ave	Bayview Ave	0.6
		Bayview Ave	Barberry Pl	0.2
		Barberry Pl	Hawksbury Dr	0.2
		Hawksbury Dr	Greenbriar Rd	0.2
		Greenbriar Rd	Bessarion Rd	0.3
		Bessarion Rd	Pharmacy Ave	0.2
		Pharmacy Ave	Blue Ridge Rd	0.2
		Blue Ridge Rd	Ambrose Rd	0.2
		Ambrose Rd	Leslie St	0.6
		Leslie St	Buchan Crt	0.4
		Buchan Crt	Shaugnessy Blvd	0.5

Region	Route	From	To	Length (Km) Per Direction
Toronto Region	Sheppard Avenue E (Cont'd)	Shaugnessy Blvd	Don Mills Rd	0.5
		Don Mills Rd	Parkway Forest Dr	0.3
		Parkway Forest Dr	Farview Mall Dr	0.2
		Farview Mall Dr	Yorkland Dr	0.3
		Yorkland Dr	Brian Dr	0.5
		Brian Dr	Settlers Rd	0.4
		Settlers Rd	Victoria Park Ave	0.3
		Victoria Park Ave	Warden Ave	1.3
		Warden Ave	Aragon Ave	0.3
		Aragon Ave	Amethyst Rd	0.2
		Amethyst Rd	Birchmount Rd	0.3
		Birchmount Rd	Allanford Rd	0.4
		Allanford Rd	Plaza W. of Kennedy Rd	0.2
		Plaza W. of Kennedy Rd	Kennedy Rd.	0.2
		Kennedy Rd.	Reidmount Ave	0.4
		Reidmount Ave	Midland Ave	0.4
		Midland Ave	Glen Watford Dr	0.2
		Glen Watford Dr	Brimley Rd	0.6
		Brimley Rd	McCowan Rd.	0.8
		McCowan Rd.	Shorting Rd	0.8
		Shorting Rd	Scunthorpe Rd	0.6
		Scunthorpe Rd	Markham Rd	0.2
		Markham Rd	Malvern St	0.3
		Malvern St	Gateforth Dr	0.4
		Gateforth Dr	Lapsley Rd	0.2
		Lapsley Rd	Neilson Rd	0.8
		Neilson Rd	Murison Blvd	0.4
		Murison Blvd	Breckon Gt	0.5
		Breckon Gt	Morningside Ave	0.6
		Morningside Ave	Grand Marshall Dr	0.4
		Grand Marshall Dr	Conlins Rd	0.4
		Conlins Rd	Dean Park Rd	0.8
		Dean Park Rd	Idagrove Gt	0.4
		Idagrove Gt	Meadowvale Rd	0.4
		Meadowvale Rd	Atrium Lane	1.9
		Atrium Lane	Kingston Rd	0.4
York Region	Yonge Street	Steeles Ave	Meadowview Ave. (Doncaster) / A	0.4
		Meadowview Ave. (Doncaster) / A	Glen Cameron Rd.	0.4
		Glen Cameron Rd.	Clark Ave.	0.2
		Clark Ave.	Arnold Ave./Elgin St.	0.5
		Arnold Ave./Elgin St.	John St.	0.3
		John St.	Centre St./ Thornhill Summit Way	0.2
		Centre St./ Thornhill Summit Way	Royal Orchard Blvd.	0.7
		Royal Orchard Blvd.	Uplands Ave./ Bayview Mews Plaza	0.5
		Uplands Ave./ Bayview Mews Plaza	Highway 407	1.0
		Highway 407	Langstaff Transit Terminal	0.3
		Langstaff Transit Terminal	Highway 7	0.1
		Highway 7	Hitech Rd.	0.2

Region	Route	From	To	Length (Km) Per Direction
York Region	Yonge Street (Cont'd)	Hitech Rd.	Beresford/Westwood Lane	0.3
		Beresford/Westwood Lane	Bantry Ave. / Scott Dr.	0.2
		Bantry Ave. / Scott Dr.	Northern Heights Dr. / Oak Ave.	0.4
		Northern Heights Dr. / Oak Ave.	Carrville Rd./ 16th Ave.	0.3
		Carrville Rd./ 16th Ave.	Hillcrest Mall Ent./ Super Centr	0.3
		Hillcrest Mall Ent./ Super Centr	Baif Blvd./ Observatory Lane	0.3
		Baif Blvd./ Observatory Lane	Weldrick Rd.	0.2
		Weldrick Rd.	May Ave./ Richmond Hill Plaza	0.4
		May Ave./ Richmond Hill Plaza	Harding Blvd.	0.3
		Harding Blvd.	Major Mackenzie Dr.	0.5
		Major Mackenzie Dr.	Arnold Cres. / Lorne Ave.	0.3
		Arnold Cres. / Lorne Ave.	Centre St.	0.2
		Centre St.	Dunlop St. / Wright St.	0.2
		Dunlop St. / Wright St.	Crosby Ave.	0.2
		Crosby Ave.	Levendale Rd.	0.3
		Levendale Rd.	Industrial Rd. /Oxford St.	0.5
		Industrial Rd. /Oxford St.	Elgin Mills Rd.	0.3
		Elgin Mills Rd.	Bernard Ave. / Canyon Hill Ave.	0.6
		Bernard Ave. / Canyon Hill Ave.	Brookside Rd. / Silverwood Ave.	0.4
		Brookside Rd. / Silverwood Ave.	Devonsleigh Blvd./ Nottingham Dr	0.7
		Devonsleigh Blvd./ Nottingham Dr	Gamble Rd. / 19th Ave.	0.3
		Gamble Rd. / 19th Ave.	Jefferson Commercial Entrance	0.4
		Jefferson Commercial Entrance	Jefferson Forest Rd./Tower Hill	0.3
		Jefferson Forest Rd./Tower Hill	Jefferson S/R	0.9
		Jefferson S/R	Stouffville Rd.	0.4
		Stouffville Rd.	The Oak Ridges Moraine Trail Pat	1.0
		The Oak Ridges Moraine Trail Pat	Estate Garden Dr./ Old Colony Rd	0.5
		Estate Garden Dr./ Old Colony Rd	King Rd.	0.5
		King Rd.	Aubrey Ave./North Lake Rd.	0.2
		Aubrey Ave./North Lake Rd.	Ashfield Dr. / Maple Grove Ave.	0.2
		Ashfield Dr. / Maple Grove Ave.	Blackforest Dr. / Worthington Av	0.7
		Blackforest Dr. / Worthington Av	Bloomington Rd.	0.9
		Bloomington Rd.	Industrial Parkway South	2.0
		Industrial Parkway South	Allaura Blvd. / Henderson Dr.	0.3
		Allaura Blvd. / Henderson Dr.	Edward St. / Murray Dr.	0.3

Region	Route	From	To	Length (Km) Per Direction
York Region	Yonge Street (Cont'd)	Edward St. / Murray Dr.	Dunning Ave. / Golf Links Dr.	0.4
		Dunning Ave. / Golf Links Dr.	Kennedy St.	0.4
		Kennedy St.	Mosley St. - (Pedestrian Signals	0.4
		Mosley St. - (Pedestrian Signals	Wellington St.	0.2
		Wellington St.	Aurora Heights Dr. / Mark St.	0.5
		Aurora Heights Dr. / Mark St.	Batson Dr. / Orchard Heights	0.5
		Batson Dr. / Orchard Heights	St. Andrews College	0.6
		St. Andrews College	St. John's Sdrd.	0.5
		St. John's Sdrd.	Joe Persechini Dr./Savage Rd. S.	0.7
		Joe Persechini Dr./Savage Rd. S.	Savage Rd. North / Sawmill Valle	0.7
		Savage Rd. North / Sawmill Valle	Mulock Dr.	0.7
		Mulock Dr.	Clearmeadow Blvd. / William Roe	0.4
		Clearmeadow Blvd. / William Roe	Eagle St.	0.6
		Eagle St.	Gladman Ave./ York Administratio	0.4
		Gladman Ave./ York Administratio	Millard Ave.	0.2
		Millard Ave.	Yonge - Davis Centre/ KFC Plaza	0.2
		Yonge - Davis Centre/ KFC Plaza	Davis Dr.	0.3
		Davis Dr.	Upper Canada Mall Ent.	0.3
		Upper Canada Mall Ent.	Dawson Manor Dr. / Kingston Rd.	0.4
		Dawson Manor Dr. / Kingston Rd.	Bonshaw Dr. / London Rd.	0.4
		Bonshaw Dr. / London Rd.	Aspenwood Dr. / Bristol Rd.	0.4
		Aspenwood Dr. / Bristol Rd.	Yonge-Green Lane Centre Ent.	0.3
		Yonge-Green Lane Centre Ent.	Green Lane	0.2
	Major Mackenzie Dr	Highway 404 N/B On Ramp	Highway 404 S/B On Ramp	0.3
		Highway 404 S/B On Ramp	Leslie St.	0.8
		Leslie St.	Commercial Plaza (west of Leslie	0.2
		Commercial Plaza (west of Leslie	Forestwood St.	0.2
		Forestwood St.	Boake Trail / Shirley Dr.	0.4
		Boake Trail / Shirley Dr.	Frank Endean Way / Spadina Rd.	0.5
		Frank Endean Way / Spadina Rd.	Comercial Centre (Walmart) (e/o	0.5
		Comercial Centre (Walmart) (e/o	Bayview Ave.	0.3
		Bayview Ave.	Colborne Ave. (Pedestrian Signal	0.2
		Colborne Ave. (Pedestrian Signal	Sussex Ave.	0.3
		Sussex Ave.	Essex Ave./ Newkirk Rd.	0.3

Region	Route	From	To	Length (Km) Per Direction
York Region	Major Mackenzie Dr (Cont'd)	Essex Ave./ Newkirk Rd.	Cedar St.	0.3
		Cedar St.	Yonge St.	0.8
		Yonge St.	Arnold Cres.	0.5
		Arnold Cres.	Harding Blvd./ Trench St.	0.5
		Harding Blvd./ Trench St.	Don Head Village Blvd. / Headdon	0.7
		Don Head Village Blvd. / Headdon	Bathurst St.	0.4
		Bathurst St.	Dufferin St.	2.1
		Dufferin St.	McNaughton Rd. East/Peter Rupert	1.0
		McNaughton Rd. East/Peter Rupert	Keele Valley Landfill Site Entra	0.3
		Keele Valley Landfill Site Entra	Entrance to Vaughan Municipal Of	0.5
		Entrance to Vaughan Municipal Of	Keele St.	0.4
		Keele St.	Killian/ Netherford Rds.	0.7
		Killian/ Netherford Rds.	Avro Rd./ McNaughton Rd.	0.6
		Avro Rd./ McNaughton Rd.	Melville Ave.	0.4
		Melville Ave.	Fortinos / Longos Entrance	0.2
		Fortinos / Longos Entrance	Jane St.	0.2
		Jane St.	Highway 400 N/B On Ramp	0.5
		Highway 400 N/B On Ramp	Highway 400 S/B On Ramp	0.7
	Highway 9/Davis Dr	Highway 404 Northbound Offramp	Highway 404 Southbound Offramp	0.4
		Highway 404 Southbound Offramp	Harry Walker Parkway	0.3
		Harry Walker Parkway	Forhan Dr./ Ent. to 404 Town Centre	0.3
		Forhan Dr./ Ent. to 404 Town Centre	Leslie St.	0.2
		Leslie St.	Ashton Rd./ Carlson Dr.	0.6
		Ashton Rd./ Carlson Dr.	Alexander Rd./ Huron Heights Dr.	0.5
		Alexander Rd./ Huron Heights Dr.	Patterson St./ Roxborough Rd.	0.4
		Patterson St./ Roxborough Rd.	Lundy's Ln./ Prospect St.	0.4
		Lundy's Ln./ Prospect St.	The Tannery Entrance	0.4
		The Tannery Entrance	Main Street	0.2
		Main Street	Lorne Ave.	0.4
		Lorne Ave.	Longford Dr.	0.5
		Longford Dr.	Barbara Rd./ Newmarket Plaza	0.2
		Barbara Rd./ Newmarket Plaza	George St.	0.3
		George St.	Yonge St.	0.2
		Yonge St.	Eagle St./Upper Canada Mall Entrance	0.4
		Eagle St./Upper Canada Mall Entrance	Bathurst St.	1.7

Region	Route	From	To	Length (Km) Per Direction
Peel Region	Derry Rd	Hwy 407	9th Line	0.4
		9th Line	Rosehurst Dr. / Lisgar Dr	0.3
		Rosehurst Dr. / Lisgar Dr	Terragar Blvd. / Forest Park Dr	0.6
		Terragar Blvd. / Forest Park Dr	10th Line W	0.3
		10th Line W	Danton Prom	0.3
		Danton Prom	Winston Churchill Blvd	0.3
		Winston Churchill Blvd	Copenhagen Rd. / Shelter Bay Rd	0.4
		Copenhagen Rd. / Shelter Bay Rd	Glen Erin Dr	0.3
		Glen Erin Dr	Copenhagen Rd. / Montevideo Rd	0.3
		Copenhagen Rd. / Montevideo Rd	Millcreek Dr	0.3
		Millcreek Dr	Argentia Rd	0.6
		Argentia Rd	Syntex Dr	0.5
		Syntex Dr	W Credit Ave	0.3
		W Credit Ave	Mississauga Rd	0.3
		Mississauga Rd	Financial Dr	0.3
		Financial Dr	Creditview Rd	0.5
		Creditview Rd	Atwood Ln	0.9
		Atwood Ln	John Watt Blvd. / Envoy Dr	2.3
		John Watt Blvd. / Envoy Dr	Mavis Rd	0.3
		Mavis Rd	McLaughlin Rd	0.6
		McLaughlin Rd	Derrycrest Dr. / Maritz Dr	1.0
		Derrycrest Dr. / Maritz Dr	Hurontario St	0.3
		Hurontario St	Edwards Blvd	0.4
		Edwards Blvd	Beckett Dr. / Kenderry Gt	0.5
		Beckett Dr. / Kenderry Gt	Kennedy Rd	0.5
		Kennedy Rd	Hwy 410 SB Exit Ramp	0.5
		Hwy 410 SB Exit Ramp	Hwy 410 NB Exit Ramp	0.4
		Hwy 410 NB Exit Ramp	Tomken Rd	0.4
		Tomken Rd	Cardiff Blvd. / Columbus Rd	0.9
		Cardiff Blvd. / Columbus Rd	Dixie Rd	0.5
		Dixie Rd	Telford Way / Menkes Dr	0.7
		Telford Way / Menkes Dr	Bramalea Rd	0.7
		Bramalea Rd	Vanguard Dr	0.9
		Vanguard Dr	Torbram Rd	0.5
		Torbram Rd	Cattrick St	0.7
		Cattrick St	Airport Rd	0.6
		Airport Rd	Hull St	0.1
		Hull St	GO Station Entrance	0.3
		GO Station Entrance	Legion Rd. / Professional Crt	0.4
		Legion Rd. / Professional Crt	Goreway Dr	0.6
		Goreway Dr	Apt. Bldg. Entrance	0.2
		Apt. Bldg. Entrance	Rexwood Rd	0.3
		Rexwood Rd	Hwy 427 SB Exit Ramp	0.5

Region	Route	From	To	Length (Km) Per Direction
Peel Region	Bovaird Dr	Adamson St	Heritage Rd	2.0
		Heritage Rd	Mississauga Rd	1.4
		Mississauga Rd	Ashby Field Rd	0.9
		Ashby Field Rd	Worthington Ave	1.1
		Worthington Ave	Pertosa Dr. / Brisdale Dr	0.4
		Pertosa Dr. / Brisdale Dr	Chinguacousy Rd	0.5
		Chinguacousy Rd	Edenbrook Hill Dr. / Fletchers Creek Blvd	0.6
		Edenbrook Hill Dr. / Fletchers Creek Blvd	East of Fletchers Creek	0.3
		East of Fletchers Creek	McLaughlin Rd	0.4
		McLaughlin Rd	Van Kirk Dr. / Royal Orchard Dr	0.3
		Van Kirk Dr. / Royal Orchard Dr	Gillingham Dr	0.7
		Gillingham Dr	Hurontario St	0.3
		Hurontario St	Sunforest Dr. / Yellow Brick Rd	0.4
		Sunforest Dr. / Yellow Brick Rd	Conestoga Dr. / Hinchley Wood Gr	0.6
		Conestoga Dr. / Hinchley Wood Gr	Kennedy Rd. N	0.4
		Kennedy Rd. N	Richvale Dr. S / Langston Dr	0.4
		Richvale Dr. S / Langston Dr	Heart Lake Rd. / Southlake Blvd	0.4
		Heart Lake Rd. / Southlake Blvd	Hwy 410 SB Exit Ramp	0.4
		Hwy 410 SB Exit Ramp	Hwy 410	0.3
		Hwy 410	Great Lakes Dr	0.5
		Great Lakes Dr	Dixie Rd	0.6
		Dixie Rd	Mackay St. N / Fernforest Dr	0.5
		Mackay St. N / Fernforest Dr	Bramlea Rd	0.9
		Bramlea Rd	Sunny Meadow Blvd	0.7
		Sunny Meadow Blvd	Torbram Rd	0.7
		Torbram Rd	Sunnyvale Gt. / Mountainash Rd	0.5
		Sunnyvale Gt. / Mountainash Rd	Mall Entrance	0.4
		Mall Entrance	Airport Rd	0.5
	Hurontario St	Lakeshore Rd	Park St	0.2
		Park St	Inglewood Dr	0.4
		Inglewood Dr	Mineola Rd	0.4
		Mineola Rd	Pinetree Way	0.9
		Pinetree Way	N Service Rd	0.4
		N Service Rd	Bronte College Ct	0.3
		Bronte College Ct	The Queensway	0.3
		The Queensway	Paisley Blvd E	0.3
		Paisley Blvd E	King St	0.4
		King St	Dundas St	0.3
		Dundas St	Hillcrest Ave	0.4
		Hillcrest Ave	Fairview Rd E	0.7
		Fairview Rd E	Central Pkwy W	0.2
		Central Pkwy W	Elm Dr E	0.3
		Elm Dr E	Matthews Gate	0.2
		Matthews Gate	Burnhamthorpe Rd	0.2
		Burnhamthorpe Rd	East Driveway	0.2

Region	Route	From	To	Length (Km) Per Direction
Peel Region	Hurontario St (Cont'd)	East Driveway	Robert Speck Pkwy	0.2
		Robert Speck Pkwy	Sherwoodtowne Blvd	0.5
		Sherwoodtowne Blvd	Hwy 403	0.3
		Hwy 403	Elia Ave	0.4
		Elia Ave	Plaza Entrance	0.2
		Plaza Entrance	Eglinton Ave	0.1
		Eglinton Ave	Nahini Way	0.5
		Nahini Way	Glenn Hawthorne Blvd	0.5
		Glenn Hawthorne Blvd	Bristol Rd E	0.3
		Bristol Rd E	Barondale Dr	0.5
		Barondale Dr	Matheson Blvd	0.4
		Matheson Blvd	Milverton Dr	0.3
		Milverton Dr	Traders Blvd	0.2
		Traders Blvd	Sandstone Dr	0.4
		Sandstone Dr	Britannia Rd	0.3
		Britannia Rd	401 EB Offramp	0.5
		401 EB Offramp	401 WB Offramp	0.3
		401 WB Offramp	World Dr	0.4
		World Dr	Annagem Blvd	0.2
		Annagem Blvd	Courtneypark Dr W	0.3
		Courtneypark Dr W	Ambassador Dr	0.3
		Ambassador Dr	Skyway Dr	0.3
		Skyway Dr	Longside Blvd	0.4
		Longside Blvd	Derry Rd	0.5
Durham Region	Kingston Road/ Dundas Street /King Street	Toronto-Durham Boundary	Altona Rd. (R.R.27)	0.2
		Altona Rd. (R.R.27)	Rougemount Dr.	0.3
		Rougemount Dr.	Rosebank Rd.	0.6
		Rosebank Rd.	Steeple Hill	0.6
		Steeple Hill	Whites Rd. (R.R.38)	0.3
		Whites Rd. (R.R.38)	Boyer Plaza / Delta	0.2
		Boyer Plaza / Delta	Hwy 401 WB Ramp (E. Of Whites Rd.)	0.3
		Hwy 401 WB Ramp (E. Of Whites Rd.)	FairPort Rd.	0.4
		FairPort Rd.	Dixie Rd.	0.9
		Dixie Rd.	Walnut Lane	0.3
		Walnut Lane	Liverpool Rd. (R.R.29)	0.7
		Liverpool Rd. (R.R.29)	Glenanna Rd.	0.4
		Glenanna Rd.	Valley Farm Dr.	0.6
		Valley Farm Dr.	Brock Rd. (R.R.01)	0.9
		Brock Rd. (R.R.01)	Bainbridge Dr.	0.4
		Bainbridge Dr.	Notion Rd.	0.5
		Notion Rd.	Elizabeth St.	0.4
		Elizabeth St.	Church St. (R.R.24)	0.5
		Church St. (R.R.24)	Rotherglen Rd.	0.8
		Rotherglen Rd.	Westney Rd. (R.R.31)	0.3
		Westney Rd. (R.R.31)	Westney Plaza Entrance	0.2
		Westney Plaza Entrance	Ritchie Ave./Chapman Dr.	0.3
		Ritchie Ave./Chapman Dr.	Best Buy Ent. (W. Of R.R.44)	0.6
		Best Buy Ent. (W. Of R.R.44)	Harwood Ave. (R.R.44)	0.2

Region	Route	From	To	Length (Km) Per Direction
Durham Region	Kingston Road/ Dundas Street /King Street (Cont'd)	Harwood Ave. (R.R.44)	Durham Centre Ent. (Ajax)	0.3
		Durham Centre Ent. (Ajax)	Costco Entrance (Ajax)	0.2
		Costco Entrance (Ajax)	Salem Rd. (R.R.41)	0.3
		Salem Rd. (R.R.41)	First Professional Entrance	0.3
		First Professional Entrance	Alexander'S Crossing	1.1
		Alexander'S Crossing	Audley Rd.	0.3
		Audley Rd.	Lake Ridge Rd. (R.R.23)	0.8
		Lake Ridge Rd. (R.R.23)	White Oaks Ct.	1.9
		White Oaks Ct.	Jeffery St./McQuay Blvd.	0.2
		Jeffery St./McQuay Blvd.	Fire Hall (IPS)	0.6
		Fire Hall (IPS)	Cochrane St. (R.R.43)	0.3
		Cochrane St. (R.R.43)	Henry St. (R.R.45)	0.4
		Henry St. (R.R.45)	Brock St.	0.4
		Brock St.	Hickory St.	0.4
		Hickory St.	Garden St.	0.5
		Garden St.	Lupin Dr.	0.2
		Lupin Dr.	Hopkins/anderson St. (R.R.36)	0.7
		Hopkins/anderson St. (R.R.36)	Glen Hill Dr.	0.6
		Glen Hill Dr.	Thickson Rd. (R.R.26)	0.3
		Thickson Rd. (R.R.26)	Kathleen St.	0.3
		Kathleen St.	Garrard Rd./Kendalwood Rd.	0.5
		Garrard Rd./Kendalwood Rd.	Thornton Rd. (R.R.52)	0.8
		Thornton Rd. (R.R.52)	Stevenson Rd. (R.R.53)	0.8
		Stevenson Rd. (R.R.53)	Gibbons St.	0.4
		Gibbons St.	Park Rd. (R.R.54)	0.4
		Park Rd. (R.R.54)	Midtown Dr.	0.4
		Midtown Dr.	Mcmillan Dr.	0.2
		Mcmillan Dr.	Centre St. (R.R.2A)	0.1
		Centre St. (R.R.2A)	Simcoe St. (R.R.02)	0.2
		Simcoe St. (R.R.02)	Mary St.	0.3
		Mary St.	Division St. (Oshawa) (I.P.S.)	0.3
		Division St. (Oshawa) (I.P.S.)	Ritson Rd. (R.R.16)	0.3
		Ritson Rd. (R.R.16)	Central Park Blvd.	0.5
		Central Park Blvd.	Wilson Rd. (R.R.35)	0.4
		Wilson Rd. (R.R.35)	Farewell Ave. (I.P.S.)	0.4
		Farewell Ave. (I.P.S.)	Harmony Rd. (R.R.33)	0.4
	Liverpool Road	Bayly St. (R.R.22)	Highway 401 WB Ramp	0.4
		Highway 401 WB Ramp	Pickering Parkway	0.2
		Pickering Parkway	Highway 2	0.3
		Highway 2	Glenanna Dr.	0.4
		Glenanna Dr.	Finch Ave. (R.R.37)	0.8
	Whites Road	Taunton Rd. (R.R.04)	Finch Ave. (R.R.37)	3.7
		Finch Ave. (R.R.37)	New/Highview St.	0.6
		New/Highview St.	Strouds Lane	0.5
		Strouds Lane	Bayfield St./Briarwood Gt.	0.4

Region	Route	From	To	Length (Km) Per Direction
Durham Region	Whites Road (Cont'd)	Bayfield St./Briarwood Gt.	Sheppard Ave.	0.5
		Sheppard Ave.	Highway 2	0.4
		Highway 2	Highway 401 EB Ramp	0.5
		Highway 401 EB Ramp	Bayly St. (R.R.22)	0.2
	Thickson Road	Victoria St. (R.R.22)	Highway 401 EB Ramp	0.3
		Highway 401 EB Ramp	Highway 401 WB Ramp	0.3
		Highway 401 WB Ramp	Consumers Dr. (R.R.25)	0.2
		Consumers Dr. (R.R.25)	Burns St.	0.6
		Burns St.	Nichol Ave.	0.6
		Nichol Ave.	Whitby Mall	0.3
		Whitby Mall	Dundas St.	0.2
		Dundas St.	Crawforth St.	0.2
		Crawforth St.	Manning Rd. (R.R.58)	0.8
		Manning Rd. (R.R.58)	Canadian Oaks Dr.	0.5
		Canadian Oaks Dr.	Rossland Rd. (R.R.28)	0.6
		Rossland Rd. (R.R.28)	Winterberry Dr.	0.5
		Winterberry Dr.	Dryden Blvd.	0.6
		Dryden Blvd.	Taunton Rd. (R.R.04)	0.9
		Taunton Rd. (R.R.04)	Conlin Rd.	2.0
		Conlin Rd.	Winchester Rd. (R.R.03)	2.1

Appendix B Detailed Arterial Bluetooth Information for Each Segment and Traffic Direction

Week #	Direction	Begins At	Ends At	Segment Length (km)
Week 4	Northbound	Moore Park (B1)	Steeles Ave W (B2)	0.49
		Steeles Ave W (B2)	Clark Ave (B3)	1.03
		Clark Ave (B3)	Royal Orchard Blvd. (B4)	1.77
		Royal Orchard Blvd. (B4)	Hwy 7 (B5)	1.52
		Hwy 7 (B5)	High Tech Rd. (B6)	0.59
	Southbound	High Tech Rd. (B6)	Hwy 7 (B5)	0.59
		Hwy 7 (B5)	Royal Orchard Blvd. (B4)	1.52
		Royal Orchard Blvd. (B4)	Clark Ave (B3)	1.77
		Clark Ave (B3)	Steeles Ave W (B2)	1.03
		Steeles Ave W (B2)	Moore Park (B1)	0.49
Week 5	Eastbound	Wilson Ave (B1)	Yonge St (B2)	0.75
		Yonge St (B2)	Bayview Ave (B3)	1.88
		Bayview Ave (B3)	Leslie St (B4)	2.05
		Leslie St (B4)	Don Mills Rd (B5)	1.09
		Don Mills Rd (B5)	Parkwoods Village Dr. (B6)	1.93
	Westbound	Parkwoods Village Dr. (B6)	Don Mills Rd (B5)	1.93
		Don Mills Rd (B5)	Leslie St (B4)	1.09
		Leslie St (B4)	Bayview Ave (B3)	2.05
		Bayview Ave (B3)	Yonge St (B2)	1.88
		Yonge St (B2)	Wilson Ave (B1)	0.75

Week #	Direction	Begins At	Ends At	Segment Length (km)
Week 6	Westbound	Humberwood (B1)	Hwy 427 (B2)	0.54
		Hwy 427 (B2)	Airport Rd (B3)	2.64
		Airport Rd. (B3)	Bramela (B4)	2.69
		Bramela (B4)	Dixie Rd. (B5)	1.37
		Dixie Rd. (B5)	West Derry Rd. (B6)	0.64
	Eastbound	West Derry Rd. (B6)	Dixie Rd. (B5)	0.64
		Dixie Rd. (B5)	Bramela (B4)	1.37
		Bramela (B4)	Airport Rd (B3)	2.69
		Airport Rd (B3)	Hwy 427 (B2)	2.64
		Hwy 427 (B2)	Humberwood (B1)	0.54
Week 7	Westbound	Rotherglen Rd (B1)	Church St (B2)	0.87
		Church St (B2)	Brock Rd (B3)	1.68
		Brock Rd (B3)	Liverpool Rd (B4)	1.9
		Liverpool Rd (B4)	Whites Rd (B5)	2.8
		Whites Rd (B5)	Atona Rd (B6)	2.41
	Eastbound	Atona Rd (B6)	Whites Rd (B5)	2.41
		Whites Rd (B5)	Liverpool Rd (B4)	2.8
		Liverpool Rd (B4)	Brock Rd (B3)	1.9
		Brock Rd (B3)	Church St (B2)	1.68
		Church St (B2)	Rotherglen Rd (B1)	0.87

Appendix C A Survey Run Log Sheet and Incident Report Log

Table C-1: Travel Time Survey Run Log Sheet

Name of Surveyor: _____
Last Name First Name

Survey Date: _____ **Survey Route:** _____

Check if applicable and indicate detail where specified		Event #				
		1	2	3	4	5
Event Type	**Incident**					
	Construction - 1 *Collision - 2* *Debris - 3*					
	Lanes Blocked?					
	 *Left – L* *Centre – C* *Right – R*					
	Weather Condition					
	Heavy Rain - 1 *Fog - 2* *Heavy Winds - 3*					
	GPS Equipment Failure					
	Vehicle Breakdown					
Begin Time of Event:						
End Time of Event:						
Begin Location of Event:						
End Location of Event:						
Comments:						

Table C-2: Incident Report Log

Driver _____ Date _____ GPS Unit Serial Number _____

Run No.	Route Description	Direction	Start Time	End Time	Incident (Y/N)

Appendix D Description of Phase-2 Filtering Algorithm

Dion and Rakh (2006)[1] described a low-pass adaptive filtering algorithm for predicting average roadway travel times that is found to be superior comparing to previous existing filtering approaches (e.g. Transguide, TranStar, and Transmit algorithms). The algorithm is unique in three aspects. First, it is designed to handle both stable (constant mean) and unstable (varying mean) traffic conditions. Second, the algorithm can be successfully applied for low levels of market penetration (less than 1%). Third, the algorithm works for both freeway and signalized arterial roadways. The proposed algorithm utilizes a robust data-filtering procedure that identifies valid data within a dynamically varying validity window. The size of the validity window varies as a function of the number of observations within the current sampling interval, the number of observations in the previous intervals, and the number of consecutive observations outside the validity window. The algorithm implementation details are described in the following sub-sections.

Expected Interval Average Travel Time and Travel Time Standard Deviation

Within the filtering algorithm, the expected smoothed average travel time *tts* and smoothed travel time variance $\sigma^2{}_{sst}$ between a pair of readers A and B for a given sampling interval *k* are computed using a robust exponential smoothing low-pass filter. As shown in Equation 1, the technique estimates the expected average travel time within a given sampling interval based on a set of n_{vk} valid observations in the previous sampling interval *(k-1)*, and the smoothed average travel time tts_{ABk-1} that was estimated at the end of the previous interval using an adaptive exponential smoothing filter. A similar process is used to estimate the expected standard deviation in Equation 2. It should be noted at this point that a more detailed description of how the variance is computed is provided later in the next section.

$$tts_{ABk} = \begin{cases} e^{[(\alpha).\ln(tt_{ABk-1})+(1-\alpha).\ln(tts_{ABk-1})]} & if\ n_{vk-1} > 0 \\ tts_{ABk-1} & if\ n_{vk-1} = 0 \end{cases} \quad (1)$$

$$\sigma^2{}_{st_{AB}k} = \begin{cases} \alpha.(\sigma^2{}_{tt_{ABk-1}}) + (1-\alpha).(\sigma^2{}_{stt_{ABk-1}}) & if\ n_{vk-1} > 0 \\ \sigma^2{}_{st_{AB}k-1} & if\ n_{vk-1} = \{0,1\} \end{cases} \quad (2)$$

In both equations the expected average travel time and travel time variance are calculated assuming a lognormal travel time distribution to reflect the fact that travel times are skewed towards longer travel times. The exponential smoothing factor α used in both equations is a low-pass filter that accentuates lower frequencies and suppresses higher noise frequencies for better travel time forecasts. Due to the stochastic nature of traffic, significant fluctuations in estimated travel times may be observed, particularly if the sampling intervals are very short. In turn, these fluctuations make it difficult to recognize underlying trends, thus creating a need for such a filter. To do so, the proposed procedure utilizes an adaptive exponential smoothing factor α that varies depending on the number of

[1] Dion F., and H., Rakha. (2006). Estimating dynamic roadway travel times using automatic vehicle identification data for low sampling rates. Transportation Research Part B: Methodological, 40 (9), pp. 745-766.

observations in the sampling interval under consideration based on the value attributed to a sensitivity parameter β, as demonstrated in Equation 3.

(3)

Figure B.1 illustrates the variation in the smoothing factor based on the value assigned to the sensitivity parameter β and the number of valid observations in the current sampling interval. As can be observed, values for the smoothing factor typically vary between 0 and 1. A value of 0 means that no confidence is put on the estimated travel time from the current interval and that no fraction of this estimate should be used to update the smoothed travel time. The algorithm considers smoothing factors of 0 when no valid observations are recorded within an analysis interval. In such a case, the algorithm assigns the previously smoothed travel time to the current interval. Alternatively, a value of 1 means that full confidence should be put on the average travel time that is estimated from the current sampling interval and that this estimate should replace, in its entirety, the moving average. Any value between 0 and 1 would finally result in the calculation of an updated moving average travel time that is a weighted combination between the previously computed moving average travel time and the average estimated travel time from the current interval. The sensitivity parameter β has not been assigned a fixed value, thus allowing the user to calibrate the smoothing parameter to local conditions under consideration. Based on recommended values for the parameter β in the paper, and the database condition, desirable value for parameter β is chosen to be 0.3.

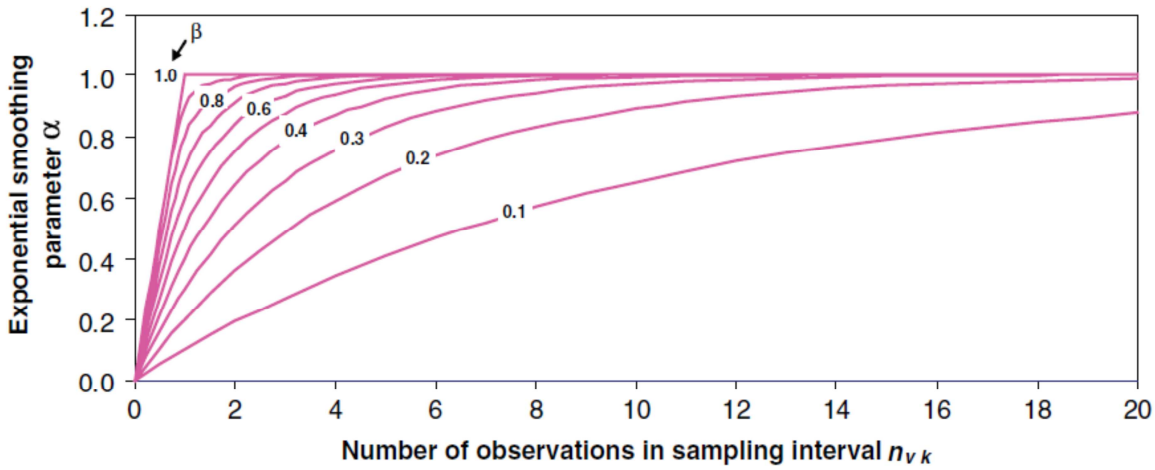

Figure B.1. Value of smoothing factor as a function of number of observations in sampling interval and sensitivity parameter β

Travel Time Estimation within Basic Data Validity Window

Within each sampling interval, the basic data validity window is computed based on a confidence interval that is estimated using a user-defined number of standard deviations above and below the expected interval average travel time, , as defined in Equations 4 and 5.

$$\boldsymbol{tt_{ABmin}k} = \boldsymbol{e}^{[\ln(\boldsymbol{tts_{ABk}}) - \boldsymbol{n_\sigma}.\ln(\sigma_{\boldsymbol{sst_{AB}k}})]} \quad (4)$$

$$\boldsymbol{tt_{ABmax}k} = \boldsymbol{e}^{[\ln(\boldsymbol{tts_{ABk}}) + \boldsymbol{n_\sigma}.\ln(\sigma_{\boldsymbol{sst_{AB}k}})]} \quad (5)$$

In the above equations, the parameters $tt_{ABmin}k$ and tt_{ABmax}k represent the lower and upper limits for the valid travel time observations, while t_k represents the time at the end of each interval k at which the calculation takes place. In computing the confidence limits for the next time interval, the average travel time and travel time standard deviation of all valid observations within the current sampling interval must be known as these two elements are used in Equations 1 and 2. In developing the basic data filtering process, Equation 6 is used to estimate the average travel time for the current time interval between a pair of readers, tt_{ABk}, while Equation 7 is used to estimate the travel time standard deviation for the current time interval, $\boldsymbol{\sigma^2}_{\boldsymbol{tt_{AB}k}}$.

$$tt_{ABk} = \frac{\sum_{i=1}^{n_{vk}}(t_{Bi} - t_{Ai})}{n_{vk}} \quad (6)$$

$$\sigma^2{}_{tt_{AB}k} = \begin{cases} 0 & for\ n_{vk} = 0 \\ \frac{[\ln(t_{Bi} - t_{Ai})_k - \ln(tts_{ABk})]^2}{n_{vk}} & for\ n_{vk} = 1 \\ \frac{[\sum_{i=1}^{n_{vk}}[(t_{Bi} - t_{Ai})_k - \ln(tts_{ABk})]^2}{n_{vk}-1} & for\ n_{vk} \geq 2 \end{cases} \quad (7)$$

While the number of standard deviations that define the size of the validity window is user-definable in Equations 4 and 5, it is envisioned that basic validity ranges encompassing two or three standard deviations be utilized. The use of a search window that is two standard deviations wide would mean that all data points within a 95% lognormal confidence interval are to be considered as valid and that all other points falling outside this range are to be rejected from consideration when estimating average link travel times. Similarly, the use of a validity window that is three standard deviations wide would mean that all data points within a 99%confidence interval are to be considered as valid. For the purpose of this study, a value of 3 is assigned for the parameter $\boldsymbol{n_\sigma}$. Also the travel time information is updated every 2 minutes. The application of the filtering algorithm (phase-2) demonstrated successful results for both ramp and arterial sections, that is able to track the sudden increase in travel times that occurs during AM and PM peak period.

Appendix E Performance Measures

After removing outliers from Bluetooth data, we created separate tables for all roadway segments, and computed performance measures based on description provided in Table E-1.

In the 2006 Travel Time Study, MTO added two new performance measures to improve its ability to describe congestion on roads included in the study area. These two performance measures are the Travel Time Index (TTI) and Buffer Time Index (BTI). The TTI is a comparison between peak period and free-flow travel conditions. This index provides the ratio of actual average travel time for a given roadway to the travel time at free-flow condition. For consistency, free-flow speed was assumed to be presented by posted speed limits. TTI is calculated as follows:

$$TTI = \frac{Tavel\ time\ during\ peak\ period}{Travel\ time\ at\ posted\ speed\ limit}$$

The BTI provides the extra travel time needed to finish a trip 19 times out of 20 attempts (95^{th} percentile travel rate) in relation to the average travel time for that trip. The BTI is calculated as follows

$$BTI = \frac{95^{th} percentile\ travel\ rate\ \left(\frac{min's}{km}\right) - average\ travel\ rate\ \left(\frac{min's}{km}\right)}{average\ travel\ rate\ \left(\frac{min's}{km}\right)}$$

The TTI and BTI can be aggregated to represent entire routes by calculating weighted average index values. The weighted average indices were calculated by the following formula:

$$Average\ Index\ Value = \frac{\sum_{i=1}^{n} TTI_i \times d_i}{\sum_{i=1}^{n} d_i}$$

Where,

TTI_i =TTI calculated for segment *i*;

di = length of segment *i*;

n = Number of segments included in aggregation

Table E-1 General Performance Measure Calculations

Performance Measure	Description
Travel Time	The time required for a vehicle to travel road segment *ab* (boundary *a* to boundary *b*) during for vehicle *y*: $\boldsymbol{TT_{aby} = TT_{ay} - TT_{by}}$
Total/Cumulative Travel time	The summation of average travel times for each roadway segment within a specified route.
Average link travel time for all vehicle	The arithmetic average of travel times for road segment *ab*: $\boldsymbol{\overline{TT}_{ab} = \frac{1}{n}\sum_{y=1}^{n} TT_{aby}}$ Where, y = Vehicle number; and n = Total number of vehicles
Variation of link travel time	Variance of travel time *(VTT)* on road segment *ab*: $\boldsymbol{VTT_{ab} = \frac{\sum_{y=1}^{n}(TT_{aby} - \overline{TT}_{ab})^2}{(n-1)}}$
Standard deviation of travel time	Standard Deviation of Travel Time *(STT)* on road segment *ab*: $\boldsymbol{STT_{ab} = \sqrt{VTT_{ab}}}$
Coefficient of variation of travel time	Coefficient of Variation of Travel Time *(CVTT)* on road segment *ab*: $\boldsymbol{CVTT_{ab} = \frac{STT_{ab}}{\overline{TT}_{ab}} \times 100}$
Travel speed	The space-mean-speed *(SMS)* of road segment *ab* for vehicle *y*: $\boldsymbol{SMS_{aby} = \frac{D_{ab}}{TT_{aby}}}$
Average link travel speed for all vehicles	Average Space-mean-speed *(ASMS)* of road segment ab using average travel time over all vehicles: $\boldsymbol{ASMS_{ab} = \frac{D_{ab}}{\overline{TT}_{ab}}}$
Harmonic mean of link travel time	Harmonic mean of speed *(HMS)* of road segment ab: $\boldsymbol{HMS_{ab} = \frac{n}{\sum_{y=1}^{n}\frac{1}{SMS_{aby}}}}$
Variance of travel speed	Variance of travel speed (VS) on road segment ab: $\boldsymbol{VS_{ab} = \frac{\sum_{y=1}^{n}(SMS_{aby} - SMS_{aby})^2}{(n-1)}}$
Standard deviation of travel speed	Standard Deviation of Travel speed *(VS)* on road segment *ab*: $\boldsymbol{SS_{ab} = \sqrt{VS_{ab}}}$
Coefficient of variation of travel speed	Coefficient of Variation of Travel speed *(CVS)* on road segment *ab*: $\boldsymbol{CVS_{ab} = \frac{SS_{ab}}{HMS_{ab}} \times 100}$

Appendix F Buffer Time Index for Aggregated Data

The Buffer Time Index (BTI) provides the extra travel time needed to finish a trip 19 times out of 20 attempts (95th percentile travel rate) in relation to the average travel time for that trip.

Initially with the aggregate data structure of TomTom and INRIX, 95th percentile travel time and speed cannot be calculated. However both TomTom and INRIX vendors are able to provide the travel time percentages for each segment of the macro route defined in RFP (e.g. QEW from Fairview St. to Hwy 427).

Calculation of BTI from TomTom

"Custom Travel Times" is a product available from TomTom to calculate travel times and speeds along trajectories, with intersections or irregular congestion in between. The algorithm that calculates the route-based travel time and distribution in form of percentiles is filtering out measurements that 'disturb' the results (e.g. vehicle A and C in the figure F-1). The product uses a concept called 'smearing' where the travel time of the entire trace is taken into account rather than each single segment travel time separately, while still keeping the ability to add measurements that have only partly driven the route.

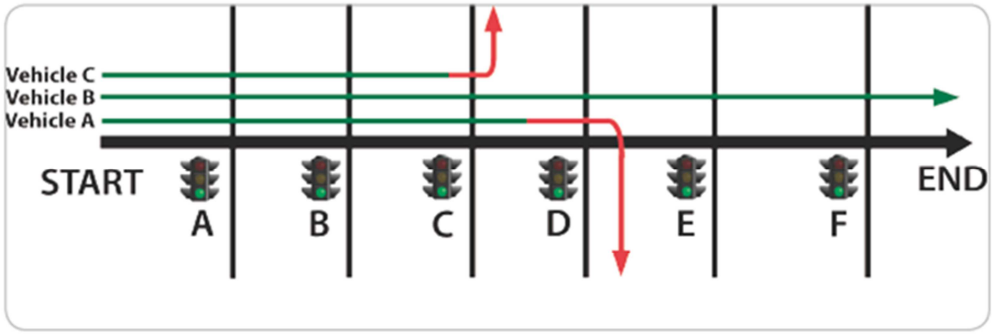

Figure F-1

Calculation of BTI from INRIX

INRIX is also able to provide the speed and travel time percentile along the selected macro routes defined in RFP (while the start and end point of the route is identified). However the methodology has not been explained in details.

Appendix G Methodology for Evaluation

In previous MTO bi-annual Travel Time Studies (TTS), the travel time of an individual vehicle was measured (initially using a stop-watch and then in more recent TTS using GPS data loggers) over a defined road segment. On the basis of a sample of observations (i.e. travel times measured from a number of trips over the same road segment) the following traffic metrics were calculated for each road segment:

1. Average link travel time,
2. Variance of link travel time,
3. Standard deviation of travel time,
4. Coefficient of Variation of travel time,
5. Average link speed,
6. Harmonic mean of speed,
7. Variance of travel speed,
8. Standard deviation of speed
9. Coefficient of Variation of speed,
10. Travel Time Index, and
11. Buffer Time Index (BTI).

Unlike the previous TTS, the data obtained from data providers (i.e. INRIX, TomTom, and IMS) area aggregated data and consequently, the travel times associated with individual trips are not known. As a result, the following measures cannot be calculated as part of this study:

- Harmonic mean of speed, and
- Buffer Time Index (BTI).

MTO is interested in conducting the analysis for the following three segment types:

1. Micro segments: micro sections are broken down by the interchange-by-the interchange level aggregation for highways and the intersection-by-intersection level aggregation for arterial roads.
2. Meso segments: Meso segments are combination of several micro sections and were defined in the Request for Proposal (RFP).
3. Macro segments: Macro segments are combination of several meso sections and were defined in the RFP.

The road sections defined by data providers' mapping systems (we will refer to these sections as links) are not consistent with each other and most often are shorter than the micro segments defined by MTO. Therefore, before any evaluation of the data obtained from the data providers can be conducted, traffic information associated with the three segmentation levels (i.e. micro, meso, and macro) must be assembled based on traffic information associated with each section.

Consider route *r* consisting of *l* links as shown in Figure 1. The length of route r can be computed as the sum of the lengths of the individual links that make up the route.

$$L_r = \sum_{i=1}^{l} L_i$$

Where,

L_i = Length of link *i*, $\forall i = 1, \cdots, l$.

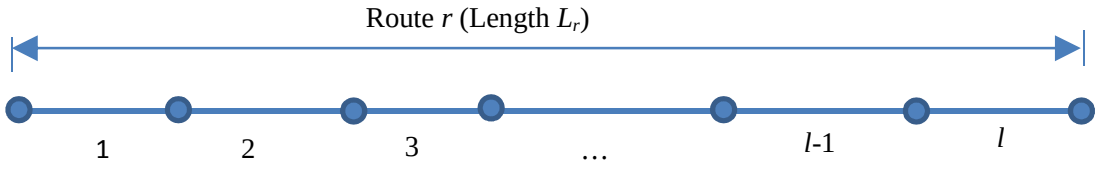

Figure 1: Definition of a route and segments

For each link *i* the following traffic metrics are available:

$\bar{T}_i(t)$ = Average travel time for link *i* during time interval *t*,
$S_i^T(t)$ = Standard deviation of travel time for link *i* during time interval *t*,
$V_i^T(t)$ = Variance of travel time for link *i* during time interval *t*,
$\bar{u}_i(t)$ =Average speed for link *i* during time interval *t*,
$S_i^u(t)$ = Standard deviation of speed for link *i* during time interval *t*,
$V_i^u(t)$ = Variance of speed for link *i* during time interval *t*,
$U_{p,i}(t)$ = *p* percentile speed for link *i* during time interval *t*, and
n_i^t = Number of observations for link *i* and time interval *t*.

It is necessary to utilize these link level metrics provided by the data providers to compute metrics associated with each of the three segment types defined by MTO.

The average travel time for vehicles which entered route r during time interval *t* can be computed by building a trajectory of a typical vehicle on the basis of the reported average link speeds. This method is referred to as the trajectory method in this document. The trajectory method is most similar to the calculation methods used in the MTO TTS where travel times obtained from probe vehicles are used to calculate travel time of each route. In this method travel time of the route for time interval *t* is built by adding travel time of links associated with the time interval when the average vehicle which departed the route in time interval *t* arrives to the link. Figure 2 (a) shows a trajectory of an average hypothetical vehicle and Figure 2 (b) illustrates travel time of each link while the average vehicle is travelling on it.

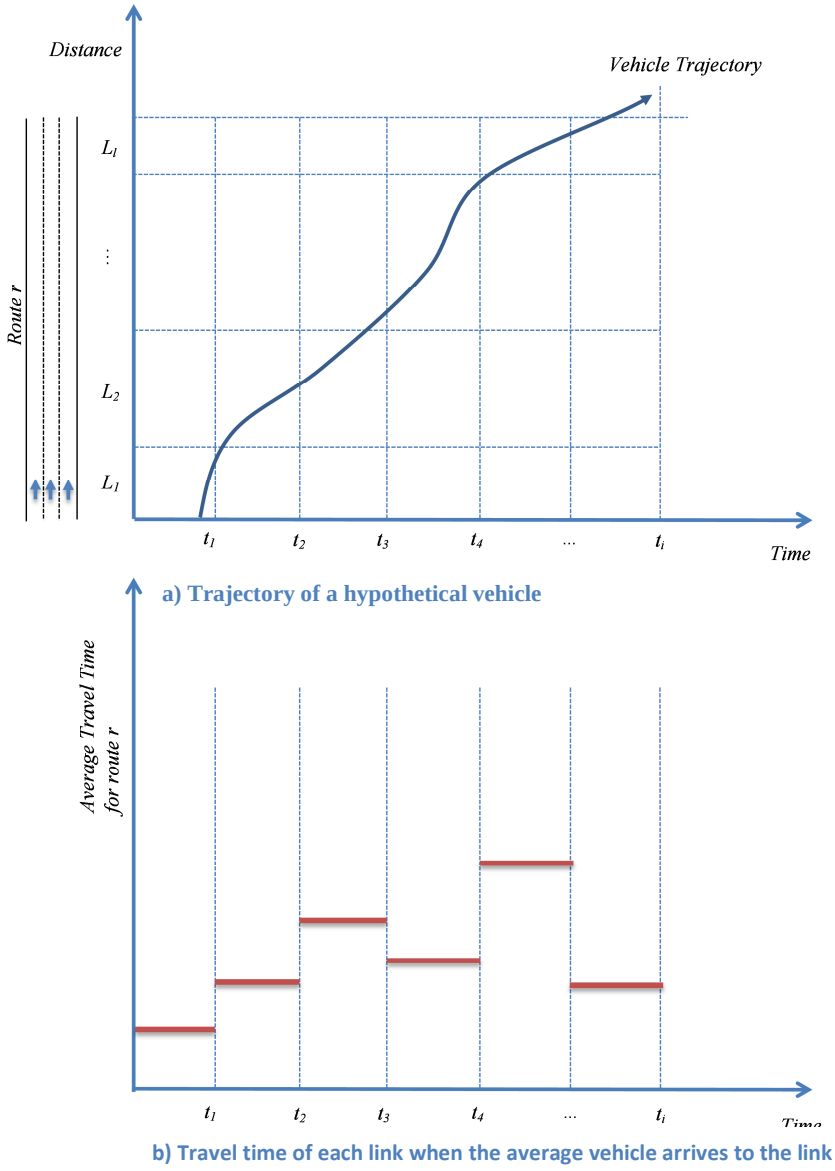

Figure 2: Travel time estimation using the trajectory method

The average travel time that a hypothetical average vehicle experiences on link *i* when the vehicle departs route *r* during time interval *t* is denoted by $\tau_i(t)$ which can be calculated using the following equation:

$$\tau_1(t) = \overline{T}_1(t)$$
$$\tau_2(t) = \overline{T}_2\left(t + \tau_1(t)\right)$$
$$\vdots$$
$$\tau_l(t) = \overline{T}_l\left(t + \tau_1(t) + \cdots + \tau_{l-1}(t)\right)$$

Consequently, the average travel time of vehicles which depart route *r* during time interval *t* can be calculated using the following equation:

$$\overline{T}_r(t) = \sum_{i=1}^{l} \tau_i(t)$$

The previous MTO TTS are conducted for AM and PM Peaks rather than travel time associated with a time interval. Therefore, average travel times calculated for route *r* associated with each time interval must be aggregated to calculate average travel time of vehicles for each time period (i.e. AM and PM). The following equation can be used to calculate average travel time of vehicles for route *r* during time period *p*:

$$\overline{T}_r^{\,p} = \frac{1}{t^*} \sum_{t=1}^{t^*} \overline{T}_r(t)$$

Where,

t^* denotes number of time intervals in time period *p*.

The variance of travel time for link *i* and time period *p* can be calculated using the following equation:

$$V_{pooled,i}^{T,p} = \frac{\sum_{t=1}^{t^*} \left(n_i^t - 1\right) V_i^T(t)}{\sum_{t=1}^{t^*} \left(n_i^t - 1\right)}$$

The following equation can be used to calculate variance of travel time for route *r* for time period *p* assuming the travel times on individual links along the route are independent from each other. In other words, it is assumed that links constituting a route do not have any covariance. Note that the assumption of independence is likely not valid under some conditions (particularly when congestion is forming or dissipating). However, if this assumption is not made, then it is necessary to include a covariance term in the calculation and no methods currently exist by which this covariance term can be estimated.

$$V_r^{T,p} = \sum_{i=1}^{l} V_{pooled,i}^{T,p}$$

Average speed in the TTS is calculated as average travel speed which is simply the ratio of the total route length over the average travel time of the route:

$$\bar{u}_r^p = \frac{L_r}{\bar{T}_r^p}$$

Variance of speed can be calculated using the following equation (Hayya et. al.):

$$V_r^{u,p} = \frac{V_r^{T,p}}{\left(\bar{T}_r^p\right)^4} \times \left(L_r\right)^2$$

The next step after calculation of the variance for speed and travel time is to compare the subject technology with the 2010 MTO TTS. In order to do that, we need to calculate the degree of freedom of variance of speed and travel time. Suppose that we are interested in comparing the travel time observations of two different technologies along route *r*.

a,b: number of segments along route r for technology A and B, respectively.

$T_{i,A}, T_{i,B}$ = The estimated average travel time on link *i* for technology A and B

$V_{i,A}, V_{i,B}$ = The estimated variance of average travel time on link i for technology A and B

$T_{r,A}, T_{r,B}, V_{r,A}, V_{r,B}$ = The estimated average travel time and its variance along route r for technology A and B

$$T_{r,A} = \sum_{i=1}^{a} T_{i,A}$$

$$V_{r,A} = \sum_{i=1}^{a} V_{i,A}$$

$$df_{r,A} = \frac{\left(\sum_{i=1}^{a} V_{i,A}\right)^2}{\sum_{i=1}^{a} \frac{V_{i,A}^2}{df_i}}$$

The same equation can be implemented to calculate the degree of freedom of variance of average travel time along route r for technology B.

$\mu_{r,A}, \mu_{r,B}$ = The mean of average travel along route r for technology A and B

$\sigma_{r,A}^2, \sigma_{r,B}^2$ = The variance of average travel along route r for technology A and B

The hypothesis test for comparing means:

$$\left| \frac{T_{r,A} - T_{r,B}}{\sqrt{V_{r,A} + V_{r,B}}} \right| > t_{v,\alpha/2} \quad \text{Reject } \mu_{r,A} = \mu_{r,B}$$

$$v = \frac{(V_{r,A} + V_{r,B})^2}{\frac{V_{r,A}}{df_{r,A}} + \frac{V_{r,B}}{df_{r,B}}}$$

The hypothesis test for comparing variances:

$$\frac{V_{r,A}}{V_{r,B}} > F\left(\alpha, df_{r,A}, df_{r,B}\right) \quad \text{Reject } \sigma_{r,A}^2 = \sigma_{r,B}^2$$

It should be noted that the above equations provide an approximation to the degree of freedom. Furthermore, the test for comparing variances is an approximate F test.

Appendix H Bluetooth Performance Measures

Table H-1 Summary of Bluetooth Performance Measures for Ramp Segments

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
AM	1	400 SB to 401 EB	Hwy 400 / Finch Ave	Hwy 401 / Weston Rd	9.16	650.93	38788.20	196.95	30.26	50.66	263.24	16.22	32.03	50.66	1.97	59.31
	2	404 SB to 401 WB (GPL)	Hwy 404/ Finch Ave	Hwy 401 / Leslie Ave	5.59	371.14	12486.11	111.74	30.11	54.22	289.42	17.01	31.38	54.22	1.84	56.01
		404 SB to 401 WB (HOV)			5.63	233.58	467.15	21.61	9.25	86.77	61.59	7.85	9.04	86.77	1.15	15.59
	3	401 EB to 404 NB (Exp/Coll)	Hwy 401 / Leslie Rd	Hwy 404 / Shepperd Ave	6.04	255.61	945.37	30.75	12.03	85.07	91.09	9.54	11.22	85.07	1.18	22.53
PM	1	400 SB to 401 EB	Hwy 400 / Finch Ave	Hwy 401 / Weston Rd	9.16	727.67	43102.77	207.61	28.53	45.32	215.33	14.67	32.38	45.32	2.21	48.90
	2	404 SB to 401 WB (GPL)	Hwy 404/ Finch Ave	Hwy 401 / Leslie Ave	5.59	447.27	17463.44	132.15	29.55	44.99	293.47	17.13	38.07	44.99	2.22	48.01
		404 SB to 401 WB (HOV)			5.63	314.34	10802.51	103.94	33.06	64.48	398.46	19.96	30.96	64.48	1.55	61.29
	3	401 EB to 404 NB (Exp/Coll)	Hwy 401 / Leslie Rd	Hwy 404 / Shepperd Ave	6.04	350.44	7641.97	87.42	24.95	62.05	217.67	14.75	23.78	62.05	1.61	50.67

Table H-2 Summary of Bluetooth Performance Measures for Arterial Segments (Week 4)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
PM	York Arterial - Yonge Street NB	Moore Park	Steeles Ave W	0.49	120.65	3073.84	55.44	45.95	14.62	124.67	11.17	76.37	14.62	4.10	79.86
		Steeles Ave W	Clark Ave	1.03	147.15	1025.09	32.02	21.76	25.20	37.64	6.13	24.35	25.20	2.38	35.58
		Clark Ave	Royal Orchard Blvd.	1.77	226.62	1345.76	36.68	16.19	28.12	24.48	4.95	17.60	28.12	2.13	27.97
		Royal Orchard Blvd.	Hwy 7	1.52	121.25	267.61	16.36	13.49	45.13	33.65	5.80	12.85	45.13	1.33	25.78
		Hwy 7	High Tech Rd.	0.59	73.17	1078.47	32.84	44.88	29.03	210.48	14.51	49.98	29.03	2.07	83.13
	York Arterial - Yonge Street SB	High Tech Rd.	Hwy 7	0.59	74.23	550.87	23.47	31.62	28.61	126.79	11.26	39.35	28.61	2.10	60.32
		Hwy 7	Royal Orchard Blvd.	1.52	132.74	419.46	20.48	15.43	41.22	41.67	6.46	15.66	41.22	1.46	29.96
		Royal Orchard Blvd.	Clark Ave	1.77	206.58	1073.86	32.77	15.86	30.84	22.83	4.78	15.49	30.84	1.95	26.34
		Clark Ave	Steeles Ave W	1.03	157.05	3092.06	55.61	35.41	23.61	48.77	6.98	29.58	23.61	2.54	72.23
		Steeles Ave W	Moore Park	0.49	81.14	1673.62	40.91	50.42	21.74	150.25	12.26	56.38	21.74	2.76	107.68

Table H-3 Summary of Bluetooth Performance Measures for Arterial Segments (Week 5)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
AM	Toronto Arterial - York Mills Road EB	Wilson Ave	Yonge Street	0.75	67.01	525.32	22.92	34.21	40.30	174.75	13.22	32.81	40.30	1.49	66.40
		Yonge St.	Bayview Ave	1.88	246.40	6586.56	81.16	32.94	27.47	95.38	9.77	35.56	27.47	2.18	63.55
		Bayview Ave	Leslie St	2.05	240.02	5623.29	74.99	31.24	30.61	119.39	10.93	35.69	30.75	1.95	57.07
		Leslie St	Don Mills Rd	1.09	166.58	5470.08	73.96	44.40	23.18	106.62	10.33	44.54	23.56	2.55	89.10
		Don Mills Rd	Parkwoods Village Dr	1.93	214.09	1744.23	41.76	19.51	32.45	37.34	6.11	18.83	32.45	1.85	32.19
	Toronto Arterial - York Mills Road WB	Parkwoods Village Dr	Don Mills Rd	1.93	344.57	17215.44	131.21	38.08	20.16	80.18	8.95	44.41	20.16	2.98	67.17
		Don Mills Rd	Leslie St	1.09	182.43	6324.30	79.53	43.59	21.51	116.11	10.78	50.10	21.51	2.79	90.76
		Leslie St	Bayview Ave	2.05	272.91	11292.21	106.26	38.94	27.04	121.33	11.01	40.73	27.04	2.22	77.35
		Bayview Ave	Yonge Street	1.88	255.56	7481.76	86.50	33.85	26.48	79.91	8.94	33.75	26.48	2.27	61.21
		Yonge Street	Wilson Ave	0.75	85.67	1045.75	32.34	37.75	31.52	182.94	13.53	42.92	31.52	1.90	65.75

Table H-3 Summary of Bluetooth Performance Measures for Arterial Segments (Week 5)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
PM	Toronto Arterial - York Mills Road EB	Wilson Ave	Yonge Street	0.75	73.00	671.23	25.91	35.49	36.92	185.21	13.61	36.86	36.99	1.62	67.12
		Yonge Street	Bayview Ave	1.88	245.47	5010.38	70.78	28.84	27.57	68.67	8.29	30.05	27.57	2.18	60.51
		Bayview Ave	Leslie St	2.05	232.37	2828.54	53.18	22.89	32.49	53.71	7.33	22.56	31.76	1.89	48.47
		Leslie St	Don Mills Rd	1.09	247.91	11965.94	109.39	44.12	15.83	70.52	8.40	53.05	15.83	3.79	90.19
		Don Mills Rd	Parkwoods Village Dr	1.93	244.56	2106.23	45.89	18.77	28.41	29.50	5.43	19.12	28.41	2.11	34.94
	Toronto Arterial - York Mills Road WB	Parkwoods Village Dr	Don Mills Rd	1.93	229.05	3063.53	55.35	24.16	30.33	60.06	7.75	25.55	30.33	1.98	48.00
		Don Mills Rd	Leslie St	1.09	198.42	9960.99	99.80	50.30	19.78	125.49	11.20	56.65	19.78	3.03	100.08
		Leslie St	Bayview Ave	2.05	322.83	37122.14	192.67	59.68	22.86	111.17	10.54	46.12	22.86	2.62	145.64
		Bayview Ave	Yonge Street	1.88	285.20	18199.70	134.91	47.30	23.73	81.55	9.03	38.05	23.73	2.53	105.12
		Yonge Street	Wilson Ave	0.75	95.49	1162.83	34.10	35.71	28.27	155.73	12.48	44.14	28.27	2.12	61.27

Table H-4 Summary of Bluetooth Performance Measures for Arterial Segments (Week 6)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
AM	Peel Arterial - Derry Rd. EB	Hwy 427	Humberwood	0.54	33.89	66.76	8.17	24.11	57.36	159.20	12.62	22.00	57.36	1.05	44.57
		Airport Rd	Hwy 427	2.64	217.70	1903.91	43.63	20.04	43.66	84.55	9.19	21.06	43.66	1.37	37.81
		Bramela	Airport Rd	2.69	218.72	1247.64	35.32	16.15	44.28	51.47	7.17	16.20	44.28	1.36	29.85
		Dixie Rd.	Bramela	1.37	110.10	1240.72	35.22	31.99	44.80	247.47	15.73	35.12	44.80	1.34	54.40
		West Derry	Dixie Rd.	0.64	66.83	1441.80	37.97	56.82	34.48	415.72	20.39	59.14	34.48	1.74	100.51
	Peel Arterial - Derry Rd. WB	Dixie Rd.	West Derry	0.64	63.74	1627.29	40.34	63.29	36.15	839.32	28.97	80.14	36.15	1.66	128.28
		Bramela	Dixie Rd.	1.37	150.14	3099.74	55.68	37.08	32.85	153.13	12.37	37.67	32.85	1.83	67.84
		Airport Rd	Bramela	2.69	211.63	2054.71	45.33	21.42	45.76	103.62	10.18	22.25	45.76	1.31	38.92
		Hwy 427	Airport Rd	2.64	248.98	1367.42	36.98	14.85	38.17	33.99	5.83	15.27	38.17	1.57	26.92
		Humberwood	Hwy 427	0.54	34.21	116.89	10.81	31.60	56.82	299.33	17.30	30.45	56.82	1.06	66.60

Table H-4 Summary of Bluetooth Performance Measures for Arterial Segments (Week 6)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
PM	Peel Arterial - Derry Rd. EB	Hwy 427	Humberwood	0.54	34.86	72.11	8.49	24.36	55.77	162.35	12.74	22.85	55.77	1.08	46.31
		Airport Rd	Hwy 427	2.64	230.65	2680.67	51.78	22.45	41.21	106.03	10.30	24.99	41.21	1.46	39.17
		Bramela	Airport Rd	2.69	241.53	2297.57	47.93	19.85	40.09	62.18	7.89	19.67	40.09	1.50	37.04
		Dixie Rd.	Bramela	1.37	118.25	1560.49	39.50	33.41	41.71	247.81	15.74	37.74	41.71	1.44	57.29
		West Derry	Dixie Rd.	0.64	98.73	2089.89	45.72	46.30	23.34	224.20	14.97	64.17	23.34	2.57	80.28
	Peel Arterial - Derry Rd. WB	Dixie Rd.	West Derry	0.64	64.06	1531.00	39.13	61.08	35.96	585.57	24.20	67.29	35.96	1.67	112.29
		Bramela	Dixie Rd.	1.37	227.68	7394.26	85.99	37.77	21.66	122.09	11.05	51.01	21.66	2.77	59.88
		Airport Rd	Bramela	2.69	250.91	3626.63	60.22	24.00	38.60	68.06	8.25	21.38	38.60	1.55	37.50
		Hwy 427	Airport Rd	2.64	287.03	1543.29	39.28	13.69	33.11	22.00	4.69	14.16	33.11	1.81	25.77
		Humberwood	Hwy 427	0.54	41.61	263.79	16.24	39.04	46.73	340.53	18.45	39.49	46.73	1.28	77.86

Table H-5 Summary of Bluetooth Performance Measures for Arterial Segments (Week 7)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
AM	Durham Arterial - Kingston Rd WB	Rotherglen Rd	Church St	0.87	67.77	304.75	17.46	25.76	46.21	97.77	9.89	21.40	46.21	1.30	54.93
		Church St	Brock Rd	1.68	135.64	862.31	29.37	21.65	44.59	88.37	9.40	21.08	44.59	1.35	36.02
		Brock Rd	liverpool Rd	1.90	166.44	1138.47	33.74	20.27	41.09	71.21	8.44	20.53	41.09	1.46	34.58
		liverpool Rd	Whites Rd	2.80	218.95	1029.77	32.09	14.66	46.04	42.30	6.50	14.13	46.04	1.30	28.57
		Whites Rd	Atona Rd	2.41	144.93	1090.63	33.02	22.79	59.86	181.29	13.46	22.49	59.86	1.00	42.82
	Durham Arterial - Kingston Rd EB	Atona Rd	Whites Rd	2.41	168.85	3169.68	56.30	33.34	51.38	127.92	11.31	22.01	51.38	1.17	39.18
		Whites Rd	liverpool Rd	2.80	229.35	1242.75	35.25	15.37	43.95	47.82	6.92	15.73	43.95	1.37	26.88
		liverpool Rd	Brock Rd	1.90	176.69	2983.92	54.63	30.92	38.71	117.68	10.85	28.02	38.71	1.55	50.54
		Brock Rd	Church St	1.68	156.65	3164.02	56.25	35.91	38.61	121.49	11.02	28.55	38.61	1.55	69.17
		Church St	Rotherglen Rd	0.87	68.10	552.70	23.51	34.52	45.99	212.69	14.58	31.71	45.99	1.30	54.18

Table H-5 Summary of Bluetooth Performance Measures for Arterial Segments (Week 7)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI (%)	BTI (%)
PM	Durham Arterial - Kingston Rd WB	Rotherglen Rd	Church St	0.87	72.87	319.44	17.87	24.53	42.98	103.17	10.16	23.63	42.98	1.40	46.83
		Church St	Brock Rd	1.68	158.45	1324.37	36.39	22.97	38.17	84.66	9.20	24.10	38.17	1.57	40.43
		Brock Rd	liverpool Rd	1.90	159.13	1320.65	36.34	22.84	42.98	82.70	9.09	21.16	42.98	1.40	47.68
		liverpool Rd	Whites Rd	2.80	258.72	1766.59	42.03	16.25	38.96	40.31	6.35	16.30	38.96	1.54	20.79
		Whites Rd	Atona Rd	2.41	147.51	1849.91	43.01	29.16	58.82	316.60	17.79	30.25	58.82	1.02	47.79
	Durham Arterial - Kingston Rd EB	Atona Rd	Whites Rd	2.41	254.44	13362.86	115.60	45.43	34.10	171.87	13.11	38.45	34.10	1.76	103.58
		Whites Rd	liverpool Rd	2.80	279.24	2201.52	46.92	16.80	36.10	38.42	6.20	17.17	36.10	1.66	30.89
		liverpool Rd	Brock Rd	1.90	245.63	3280.65	57.28	23.32	27.85	40.31	6.35	22.80	27.85	2.15	47.38
		Brock Rd	Church St	1.68	232.31	7680.92	87.64	37.73	26.03	78.35	8.85	34.00	26.03	2.30	84.24
		Church St	Rotherglen Rd	0.87	111.91	5970.33	77.27	69.05	27.99	334.08	18.28	65.31	27.99	2.14	129.66

Appendix I Performance Measures for GPS Equipped Probe Vehicle

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	1	Ramp 1 - 35, 15	Hwy 400-Finch Ave	35 Start	5.16	409	409	48969.09	221.28	54.10	45.42	740.66	27.21	59.91	56.66	2.20	86.55
			35 Start	35 end	0.83	102	511	1755.65	41.90	41.07	29.19	523.38	22.88	78.37	36.61	3.41	45.44
			35 end	Hwy 401-Keel St.	3.17	158	669	2227.09	2227.09	1409.55	72.26	589.51	24.28	33.59	78.39	1.38	44.30
	2	Ramp 2-36 Collector	Hwy 404 / Finch Ave. ([COL]	36 start	3.31	274	274	15397.82	124.09	45.29	43.51	672.48	25.93	59.60	53.22	2.30	79.20
			36 start	36 End	1.15	46	320	10.62	3.26	7.08	90.66	45.15	6.72	7.41	91.12	1.11	10.87
			36 End	Hwy 401/Leslie st.	1.06	38	358	20.26	4.50	11.84	101.71	108.76	10.43	10.25	102.87	1.00	7.89

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments (Continued)

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	2	Ramp 2-39 Express	Hwy 404/ Finch Ave. [EXP]	39 start	3.31	288	288	20045.04	141.58	49.16	41.44	600.89	24.51	59.15	50.95	2.42	85.85
			39 start	39 End	1.22	50	338	43.84	6.62	13.24	87.47	96.19	9.81	11.21	83.58	1.14	15.50
			39 End	Hwy 401/Leslie st.	1.06	48	386	624.58	24.99	52.07	78.89	1056.67	32.51	41.20	92.55	1.26	95.83
		Ramp 2-HOV	Hwy 404 / Finch Ave.	39 start	3.31	117	117	228.00	15.10	12.91	101.56	141.58	11.90	11.72	103.00	0.98	19.66
			36 start	Tunnel Start	0.43	15	132	6.18	2.49	16.57	104.75	309.31	17.59	16.79	97.52	0.97	20.00
			Tunnel Start	Tunnel End	0.15	7	139	7.97	2.82	40.33	74.39	1207.63	34.75	46.72	85.06	1.30	82.86
			Tunnel End	401/Don Mills	0.68	25	164	9.72	3.12	12.47	99.69	155.74	12.48	12.52	101.20	1.02	20.00
			401/Don Mills	Hwy 401/Leslie	1.06	37	201	9.00	3.00	8.11	103.14	69.94	8.36	8.11	103.78	0.97	13.51

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments (Continued)

Peak period	Week	Route	Begins at	Ends at	Dist. (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	3	Collector	Hwy 401/Leslie (B1) [Col]	72 Start (B2)	2.37	102	102	518.76	22.78	22.33	83.80	12.04	3.47	4.14	86.99	1.20	34.31
			72 Start (B2)	(B4)	0.38	18	120	14.66	3.83	21.27	74.04	12.20	3.49	4.72	77.06	1.32	38.89
			(B4)	Hwy 404/Sheppard Ave E (B5)	1.45	56	176	14.16	3.76	6.72	94.01	1.91	1.38	1.47	94.42	1.07	8.93
			Hwy 404/Sheppard Ave (B5)	Hwy 404/Finch Ave. (B6)	1.84	63	239	21.26	4.61	7.32	105.94	2.80	1.67	1.58	106.48	0.95	9.52
		Express	Hwy 401/Leslie (B1) [Exp]	72 Start (B3)	2.41	97	97	157.83	12.56	12.95	89.44	140.54	11.86	13.25	90.89	1.12	20.62
			72 Start (B3)	(B4)	0.37	18	115	6.20	2.49	13.83	75.04	106.42	10.32	13.75	76.40	1.35	16.67
			(B4)	Hwy 404/Sheppard Ave E (B5)	1.43	56	171	23.22	4.82	8.60	91.93	59.59	7.72	8.40	92.56	1.09	12.50
			Hwy 404/Sheppard(B5)	Hwy 404/Finch(B6)	1.84	63	234	26.07	5.11	8.10	105.77	76.25	8.73	8.26	106.45	0.95	9.52

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	1	Ramp 1 - 35, 15	Hwy 400-Finch Ave	35 Start	5.16	407	407	52335.27	228.77	56.21	45.66	313.66	17.71	38.79	53.09	2.19	85.26
			35 Start	35 end	0.83	98	505	6142.13	78.37	79.97	30.53	1405.87	37.49	122.82	50.89	3.28	112.86
			35 end	Hwy 401-Keel St.	3.17	330	834	18026.84	134.26	40.69	34.62	326.74	18.08	52.21	40.24	2.89	55.39
	2	Ramp 2-36 Collector	Hwy 404 / Finch Ave. ([COL]	36 start	3.31	335	335	17842.05	133.57	39.87	35.56	515.30	22.70	63.83	42.81	2.81	58.21
			36 start	36 End	1.15	54	389	518.65	22.77	42.17	76.29	279.62	16.72	21.92	82.09	1.30	12.96
			36 End	Hwy 401/Leslie st.	1.06	75	464	2991.56	54.70	72.93	50.88	2208.50	46.99	92.36	75.32	1.97	129.33

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments (Continued)

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	2	Ramp 2-39 Express	Hwy 404/ Finch Ave. [EXP]	39 start	3.31	406	406	22741.03	150.80	37.14	29.34	222.77	14.93	50.88	33.83	3.41	53.69
			39 start	39 End	1.22	92	498	15436.00	124.24	135.05	47.74	1631.26	40.39	84.60	72.03	2.09	166.30
			39 End	Hwy 401/Leslie st.	1.06	163	661	54349.00	233.13	143.02	23.41	3887.99	62.35	266.34	65.33	4.27	311.20
		Ramp 2-HOV	Hwy 404 / Finch Ave.	39 start	3.31	166	166	6799.15	82.46	49.67	71.97	855.73	29.25	40.65	83.91	1.39	118.07
			36 start	Tunnel Start	0.43	18	184	24.89	4.99	27.72	84.52	608.36	24.66	29.18	82.10	1.28	50.00
			Tunnel Start	Tunnel End	0.15	8	192	8.23	2.87	35.86	70.27	1669.62	40.86	58.15	82.40	1.48	50.00
			Tunnel End	401/Don Mills	0.68	30	222	267.78	16.36	54.55	81.60	949.06	30.81	37.75	95.08	1.23	136.67
			401/Don Mills	Hwy 401/Leslie	1.06	63	285	1792.26	42.34	67.20	60.12	1352.26	36.77	61.17	78.60	1.65	138.10

Table I-1 Summary of GPS Equipped Probe Vehicle Performance Measures for Ramp Segments (Continued)

Peak period	Week	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Std. Dev. of Seg. speed	Coef. of var. (%) of Seg. speed	Ave. Range in Speed (km/h)	TTI	BTI (%)
PM	3	Coll.	Hwy 401/Leslie (B1) [Col]	72 Start (B2)	2.37	158	158	960.09	30.99	19.61	54.12	8.94	2.99	5.53	56.09	1.85	31
			72 Start (B2)	(B4)	0.38	21	179	15.36	3.92	18.66	64.70	8.92	2.99	4.62	66.57	1.54	28.5
			(B4)	Hwy 404/Sheppard Ave E (B5)	1.45	57	236	9.41	3.07	5.38	91.92	1.73	1.31	1.43	92.17	1.09	7.0
			Hwy 404/Sheppard Ave (B5)	Hwy 404/Finch Ave. (B6)	1.84	86	322	1568.15	39.60	46.05	77.02	62.44	7.90	10.26	88.21	1.30	97.6
		Express	Hwy 401/Leslie (B1) [Exp]	72 Start (B3)	2.41	125	125	6625.45	81.40	65.12	69.34	592.22	24.34	35.10	81.06	1.44	76.0
			72 Start (B3)	(B4)	0.37	16	142	13.05	3.61	22.58	81.34	247.65	15.74	19.35	84.40	1.20	37.5
			(B4)	Hwy 404/Sheppard Ave E (B5)	1.43	56	198	43.46	6.59	11.77	91.22	77.35	8.80	9.64	92.16	1.09	17.8
			Hwy 404/Sheppard(B5)	Hwy 404/Finch(B6)	1.84	92	290	2763.00	52.56	57.14	72.20	990.67	31.47	43.60	86.25	1.39	97.3

Table I-2 Summary of GPS Equipped Probe Vehicle Performance Measures for Arterial Segments (Week 4)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	York Arterial - Yonge Street NB	Moore Park	Steeles Ave W	0.49	50	50	482.34	21.96	43.92	35.13	328.16	18.12	51.57	41.69	1.7	64.0
		Steeles Ave W	Clark Ave	1.03	89	139	3519.21	59.32	66.65	41.60	332.15	18.23	43.81	50.09	1.4	84.3
		Clark Ave	Royal Orchard Blvd.	1.77	125	265	602.13	24.54	19.63	50.92	113.52	10.65	20.92	52.78	1.2	30.4
		Royal Orchard Blvd.	Hwy 7	1.52	93	357	256.59	16.02	17.22	58.93	90.24	9.50	16.12	60.40	1.0	18.3
		Hwy 7	High Tech Rd.	0.59	72	429	429.57	20.73	28.79	29.59	236.38	15.37	51.96	33.42	2.0	30.6
	York Arterial - Yonge Street SB	High Tech Rd.	Hwy 7	0.59	47	47	750.92	27.40	58.30	45.19	625.89	25.02	55.36	53.36	1.3	102.1
		Hwy 7	Royal Orchard Blvd.	1.52	97	144	145.72	12.07	12.44	56.29	1297.86	36.03	64.00	57.07	1.1	18.6
		Royal Orchard Blvd.	Clark Ave	1.77	173	318	8175.65	90.42	52.27	36.73	361.88	19.02	51.80	44.60	1.6	91.9
		Clark Ave	Steeles Ave W	1.03	161	479	4733.30	68.80	42.73	22.99	1036.85	32.20	140.06	26.61	2.6	64.6
		Steeles Ave W	Moore Park	0.49	50	529	404.80	20.12	40.24	35.43	272.90	16.52	46.62	41.38	1.7	46.0

Table I-2 Summary of GPS Equipped Probe Vehicle Performance Measures for Arterial Segments (Week 4)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	York Arterial - Yonge Street NB	Moore Park	Steels Ave W	0.49	113	113	6649.07	81.54	72.16	15.58	416.02	20.40	130.89	25.02	3.844	116.37
		Steels Ave W	Clark Ave	1.03	135	248	902.23	30.04	22.25	27.41	52.48	7.24	26.43	28.77	2.184	28.89
		Clark Ave	Royal Orchard Blvd.	1.77	199	448	3721.21	61.00	30.65	32.00	90.89	9.53	29.79	34.43	1.874	50.25
		Royal Orchard Blvd.	Hwy 7	1.52	113	561	137.43	11.72	10.37	48.38	31.05	5.57	11.52	48.90	1.239	11.50
		Hwy 7	High Tech Rd.	0.59	70	631	1212.01	34.81	49.73	30.21	471.58	21.72	71.87	38.65	1.977	62.86
	York Arterial - Yonge Street SB	High Tech Rd.	Hwy 7	0.59	43	43	189.29	13.76	32.00	49.17	529.33	23.01	46.79	52.95	1.215	52.33
		Hwy 7	Royal Orchard Blvd.	1.52	144	188	623.61	24.97	17.34	37.87	374.62	19.36	51.11	38.97	1.579	23.26
		Royal Orchard Blvd.	Clark Ave	1.77	221	408	2857.16	53.45	24.19	28.88	122.66	11.07	38.34	30.58	2.081	34.84
		Clark Ave	Steels Ave W	1.03	280	689	240241.79	490.14	175.05	13.23	919.01	30.32	229.16	29.59	4.531	235.36
		Steels Ave W	Moore Park	0.49	49	737	325.39	18.04	36.81	36.37	199.80	14.13	38.86	40.79	1.667	52.04

Table I-3 Summary of GPS Equipped Probe Vehicle Performance Measures for Arterial Segments (Week 5)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	Toronto Arterial - York Mills Road EB	Wilson Ave	Young Street	0.75	112	112	3179.73	56.39	50.35	24.04	188.51	13.73	57.11	29.63	2.5	71.4
		Young Street	Bayview Ave	1.88	222	334	9316.59	96.52	43.48	30.54	208.07	14.42	47.23	35.69	2.0	69.4
		Bayview Ave	Leslie St	2.05	209	543	4458.19	66.77	31.95	35.27	189.90	13.78	39.07	39.01	1.7	48.3
		Leslie St	Don Mills Rd	1.09	116	660	2313.09	48.09	41.46	33.72	194.74	13.96	41.39	38.35	1.8	63.4
		Don Mills Rd	Parkwoods Village Dr,	1.93	167	827	1200.42	34.65	20.75	41.51	71.47	8.45	20.37	43.04	1.4	7.5
	Toronto Arterial - York Mills Road WB	Parkwoods Village Dr,	Don Mills Rd	1.93	347	347	18728.63	37.01	10.67	23.39	2192.06	46.82	200.18	23.27	3.0	47.8
		Don Mills Rd	Leslie St	1.09	169	516	3784.08	61.33	36.29	27.08	195.96	14.00	51.70	25.57	2.6	39.9
		Leslie St	Bayview Ave	2.05	236	752	12217.17	110.53	46.84	36.47	256.56	16.02	43.92	37.65	1.9	61.0
		Bayview Ave	Young Street	1.88	214	966	3761.36	61.51	28.75	36.91	134.41	11.59	31.41	33.92	1.9	20.6
		Young Street	Wilson Ave	0.75	53	1019	1369.89	136.85	258.21	64.95	1609.18	40.11	61.76	60.63	1.2	100.0

Table I-3 Summary of GPS Equipped Probe Vehicle Performance Measures for Arterial Segments (Week 5)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	Toronto Arterial - York Mills Road EB	Wilson Ave	Young Street	0.75	95	95	1935.57	44.00	46.31	28.33	140.68	11.86	41.86	32.66	2.111	73.16
		Young Street	Bayview Ave	1.88	250	345	4515.33	67.20	26.88	27.07	101.88	10.09	37.28	29.30	2.216	38.40
		Bayview Ave	Leslie St	2.05	200	545	1571.12	39.64	19.82	36.96	56.14	7.49	20.27	38.26	1.626	26.50
		Leslie St	Don Mills Rd	1.09	263	808	7784.77	88.23	33.55	14.93	25.48	5.05	33.82	16.33	4.021	53.42
		Don Mills Rd	Parkwoods Village Dr,	1.93	200	1008	1095.12	33.09	16.55	34.69	46.52	6.82	19.66	35.68	1.727	19.25
	Toronto Arterial - York Mills Road WB	Parkwoods Village Dr,	Don Mills Rd	1.93	250	250	4815.88	8.69	3.47	27.80	862.47	29.37	105.63	30.22	2.159	32.80
		Don Mills Rd	Leslie St	1.09	168	418	6209.60	77.06	45.87	23.41	91.31	9.56	40.81	26.97	2.569	78.27
		Leslie St	Bayview Ave	2.05	262	679	33571.73	183.23	69.93	28.19	183.59	13.55	48.07	34.76	2.130	105.34
		Bayview Ave	Young Street	1.88	233	913	5937.57	78.80	33.82	29.01	143.35	11.97	41.27	31.38	2.066	46.78
		Young Street	Wilson Ave	0.75	48	961	75.43	69.40	144.58	56.37	1122.77	33.51	59.45	58.00	1.067	23.96

Table I-4 Summary of Bluetooth Performance Measures for Arterial Segments (Week 6)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	Peel Arterial - Derry Rd. WB	Humberwood	Hwy 427	0.54	57	57	309.78	17.60	30.88	34.92	76.98	8.77	25.12	34.62	1.8	43.9
		Hwy 427	Airport Rd	2.64	227	285	1111.50	33.34	14.69	44.33	41.11	6.41	14.46	42.21	1.4	18.1
		Airport Rd	Bramela	2.69	192	477	1117.40	33.43	17.41	54.06	93.98	9.69	17.93	52.07	1.2	27.6
		Bramela	Dixie Rd.	1.37	114	591	1418.12	37.66	33.03	44.86	216.85	14.73	32.82	46.14	1.4	43.0
		Dixie Rd.	West Derry	0.64	34	625	256.10	16.00	47.07	71.85	384.66	19.61	27.30	75.67	0.9	108.8
	Peel Arterial - Derry Rd. EB	West Derry	Dixie Rd.	0.64	76	76	2070.00	45.50	59.86	30.32	1966.75	44.35	146.29	40.65	2.0	89.1
		Dixie Rd.	Bramela	1.37	99	175	833.30	28.87	29.16	49.67	282.34	16.80	33.83	53.93	1.2	40.4
		Bramela	Airport Rd	2.69	223	398	4435.14	66.60	29.86	43.48	227.19	15.07	34.66	47.34	1.4	46.2
		Airport Rd	Hwy 427	2.64	191	589	776.86	27.87	14.59	49.85	60.96	7.81	15.66	50.89	1.2	21.5
		Hwy 427	Humberwood	0.54	25	613	25.17	5.02	20.07	78.89	2967.38	54.47	69.05	81.29	0.8	24.0

Table I-4 Summary of Bluetooth Performance Measures for Arterial Segments (Week 6)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	Peel Arterial - Derry Rd. WB	Humberwood	Hwy 427	0.54	68	68	1942.29	44.07	64.81	28.59	654.01	25.57	89.46	40.03	2.099	96.32
		Hwy 427	Airport Rd	2.64	283	351	1644.27	40.55	14.33	33.54	21.02	4.58	13.67	34.10	1.787	17.84
		Airport Rd	Bramela	2.69	184	536	1769.70	42.07	22.86	52.52	117.69	10.85	20.65	54.60	1.140	32.07
		Bramela	Dixie Rd.	1.37	282	818	10851.41	104.17	36.94	17.47	37.85	6.15	35.22	19.30	3.431	57.09
		Dixie Rd.	West Derry	0.64	31	849	22.50	4.74	15.30	74.93	119.06	10.91	14.56	76.38	0.807	20.97
	Peel Arterial - Derry Rd. EB	West Derry	Dixie Rd.	0.64	138	138	3529.57	59.41	43.05	16.66	82.70	9.09	54.58	19.67	3.594	48.55
		Dixie Rd.	Bramela	1.37	100	238	1065.90	32.65	32.65	49.46	213.83	14.62	29.56	53.48	1.217	45.50
		Bramela	Airport Rd	2.69	266	504	3979.95	63.09	23.72	36.46	102.66	10.13	27.79	38.43	1.648	23.68
		Airport Rd	Hwy 427	2.64	181	684	643.62	25.37	14.02	52.63	81.07	9.00	17.11	53.57	1.143	14.92
		Hwy 427	Humberwood	0.54	95	779	7522.62	86.73	91.30	20.56	1506.71	38.82	188.83	40.37	2.932	128.42

Table I-5 Summary of Bluetooth Performance Measures for Arterial Segments (Week 7)

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
AM	Durham Arterial - Kingston Rd WB	Rotherglen Rd	Church St	0.87	99	99	763.30	27.63	27.91	31.76	100.67	10.03	31.59	33.93	1.9	28.0
		Church St	Brock Rd	1.68	144	242	605.20	24.60	17.08	42.06	76.70	8.76	20.82	43.24	1.4	13.2
		Brock Rd	liverpool Rd	1.9	169	411	110.70	10.52	6.23	40.52	7.12	2.67	6.59	40.65	1.5	5.3
		liverpool Rd	Whites Rd	2.8	205	616	379.80	19.49	9.51	49.27	29.39	5.42	11.00	49.68	1.2	5.1
		Whites Rd	Atona Rd	2.41	138	753	128.30	11.33	8.21	63.05	27.86	5.28	8.37	63.40	1.0	8.3
	Durham Arterial - Kingston Rd EB	Atona Rd	Whites Rd	2.41	1332	1332	316531.20	562.61	42.24	6.51	4583.48	67.70	1039.24	8.75	9.2	36.9
		Whites Rd	liverpool Rd	2.8	223	1555	1074.70	32.78	14.70	45.24	1580.64	39.76	87.88	46.09	1.3	15.4
		liverpool Rd	Brock Rd	1.9	122	1677	789.30	28.09	23.03	55.88	120.28	10.97	19.63	57.84	1.1	29.5
		Brock Rd	Church St	1.68	114	1791	1387.70	37.25	32.68	52.96	402.36	20.06	37.88	56.88	1.1	42.3
		Church St	Rotherglen Rd	0.87	45	1837	170.30	13.05	29.00	68.99	5728.08	75.68	109.71	72.65	0.9	38.9

Table I-5 Summary of Bluetooth Performance Measures for Arterial Segments (Week 7)-Continued

Peak period	Route	Begins at	Ends at	Segment Length (km)	Average travel time (sec)	Cumulative Travel Time	Variance of travel time (sec^2)	Standard deviation of travel time (sec)	Coefficient of var. (%) of travel time	Harmonic mean of speed [km/h]	Variance of segment speed (sec^2)	Standard Deviation of segment speed'	Coefficient of var. (%) of segment speed	Average Range in Speed (km/h)	TTI	BTI (%)
PM	Durham Arterial - Kingston Rd WB	8	Church St	0.87	85	85	462.27	21.50	25.29	36.99	97.09	9.85	26.64	39.01	1.628	27.06
		Church St	Brock Rd	1.68	137	222	1115.77	33.40	24.38	44.09	256.48	16.02	36.32	46.53	1.359	24.82
		Brock Rd	liverpool Rd	1.9	124	346	599.87	24.49	19.75	55.31	611.09	24.72	44.69	57.14	1.088	20.56
		liverpool Rd	Whites Rd	2.8	234	579	2039.37	45.16	19.30	43.11	139.74	11.82	27.42	44.47	1.393	20.94
		Whites Rd	Atona Rd	2.41	187	766	1017.87	31.90	17.06	46.48	255.50	15.98	34.39	47.97	1.293	13.37
	Durham Arterial - Kingston Rd EB	Atona Rd	Whites Rd	2.41	1591	1591	518986.50	720.41	45.28	5.45	1032.83	32.14	589.25	8.75	11.003	50.22
		Whites Rd	liverpool Rd	2.8	282	1873	1857.41	43.10	15.28	35.70	78.97	8.89	24.89	36.43	1.679	18.44
		liverpool Rd	Brock Rd	1.9	220	2093	2885.07	53.71	24.41	31.13	67.76	8.23	26.45	32.81	1.930	35.00
		Brock Rd	Church St	1.68	202	2295	7526.27	86.75	42.95	29.89	156.80	12.52	41.90	34.30	2.004	70.92
		Church St	Rotherglen Rd	0.87	84	2379	2070.55	45.50	54.17	37.45	2268.41	47.63	127.17	46.20	1.609	87.20

Appendix J The Comparison Results for All Road Segments

Table J-1 F-Test and t-Test Results for Ramp Segments

Road Type	Week Number	Roadway	Peak	Tests	Results
Ramp	Week 1	400 SB to 401 EB	AM	F-test	×
				T-test	✓
			PM	F-test	✓
				T-test	✓
	Week 2_GPL	404 SB to 401 WB (GPL)	AM	F-test	✓
				T-test	✓
			PM	F-test	✓
				T-test	✓
	Week 2_HOV	404 SB to 401 WB (HOV)	AM	F-test	×
				T-test	✓
			PM	F-test	✓
				T-test	✓
	Week 3	401 EB to 404 NB (Exp/Coll)	AM	F-test	×
				T-test	✓
			PM	F-test	✓
				T-test	✓

Note: ×: Statistically significant difference

✓: Not statistically significant difference

Table J-2 F-Test and t-Test Results for Arterial Segments

Road Type	Week Number	Roadway	Direction	Peak	Tests	Section (As Defined in Appendix B)				
						B1-B2	B2-B3	B3-B4	B4-B5	B5-B6
Arterial	Week 4	Yonge St.	NB	AM	F-test	✓	✓	×	×	✓
					T-test	✓	✓	✓	✓	✓
				PM	F-test	✓	✓	✓	✓	×
					T-test	✓	✓	✓	✓	✓
			SB	AM	F-test	×	✓	✓	×	✓
					T-test	✓	✓	✓	✓	✓
				PM	F-test	×	✓	✓	×	×
					T-test	✓	✓	✓	✓	✓
	Week 5	York Mills Rd.	EB	AM	F-test	✓	×	✓	×	✓
					T-test	✓	✓	✓	✓	✓
				PM	F-test	✓	✓	✓	✓	✓
					T-test	✓	✓	✓	✓	✓
			WB	AM	F-test	×	✓	×	✓	×
					T-test	✓	✓	✓	✓	✓
				PM	F-test	×	×	✓	✓	×
					T-test	✓	✓	✓	✓	✓
	Week 6	Derry Rd.	EB	AM	F-test	×	×	✓	✓	×
					T-test	✓	✓	✓	✓	✓
				PM	F-test	✓	×	×	✓	×
					T-test	✓	✓	✓	✓	✓
			WB	AM	F-test	✓	✓	✓	×	×
					T-test	✓	✓	✓	✓	✓
				PM	F-test	✓	×	✓	×	×
					T-test	✓	✓	✓	✓	✓
	Week 7	Kingston Rd.	EB	AM	F-test	✓	×	✓	×	✓
					T-test	✓	✓	✓	✓	✓
				PM	F-test	✓	✓	✓	×	✓
					T-test	✓	✓	✓	✓	✓
			WB	AM	F-test	×	✓	×	✓	×
					T-test	✓	✓	✓	✓	✓
				PM	F-test	×	×	×	✓	×
					T-test	✓	✓	✓	✓	✓

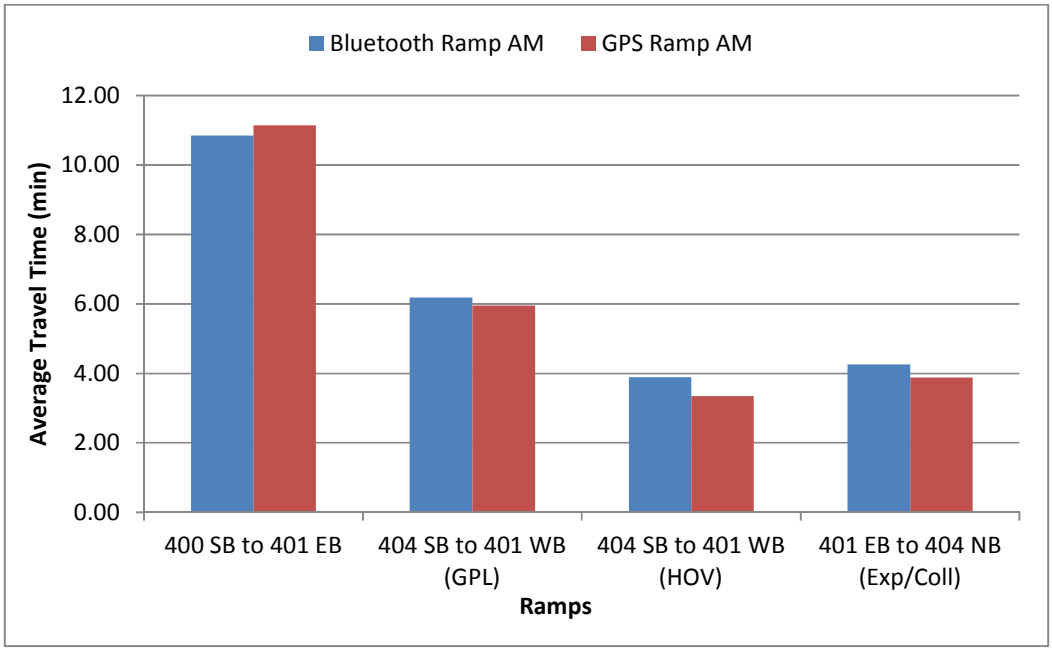

Figure J-1 Comparison between Bluetooth and GPS for Ramps Segments (AM Peak)

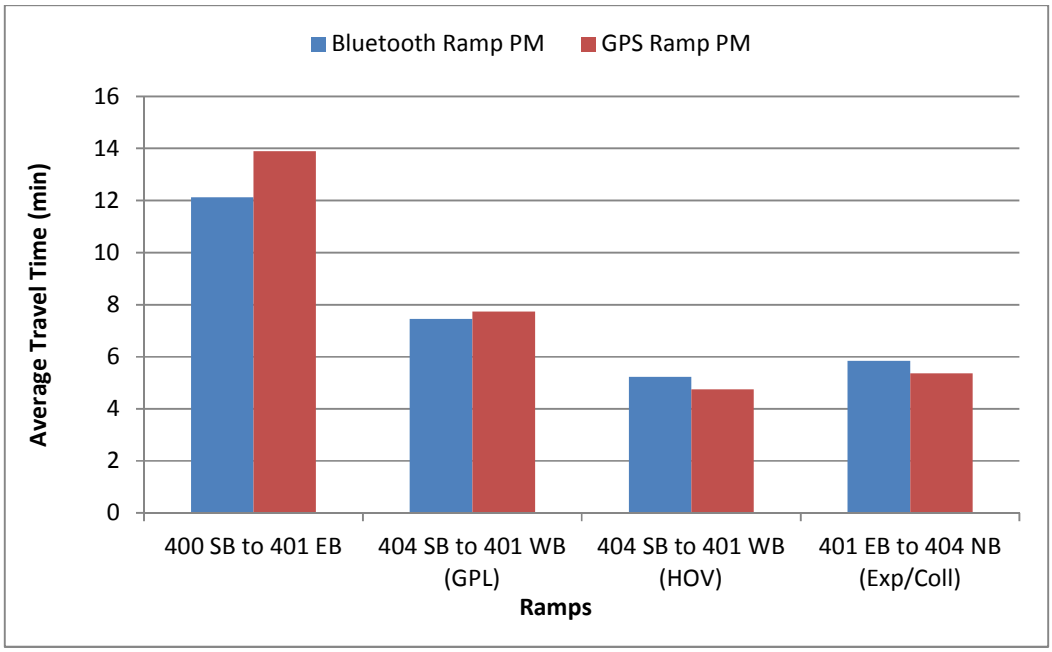

Figure J-2 Comparison between Bluetooth and GPS for Ramps Segments (PM Peak)

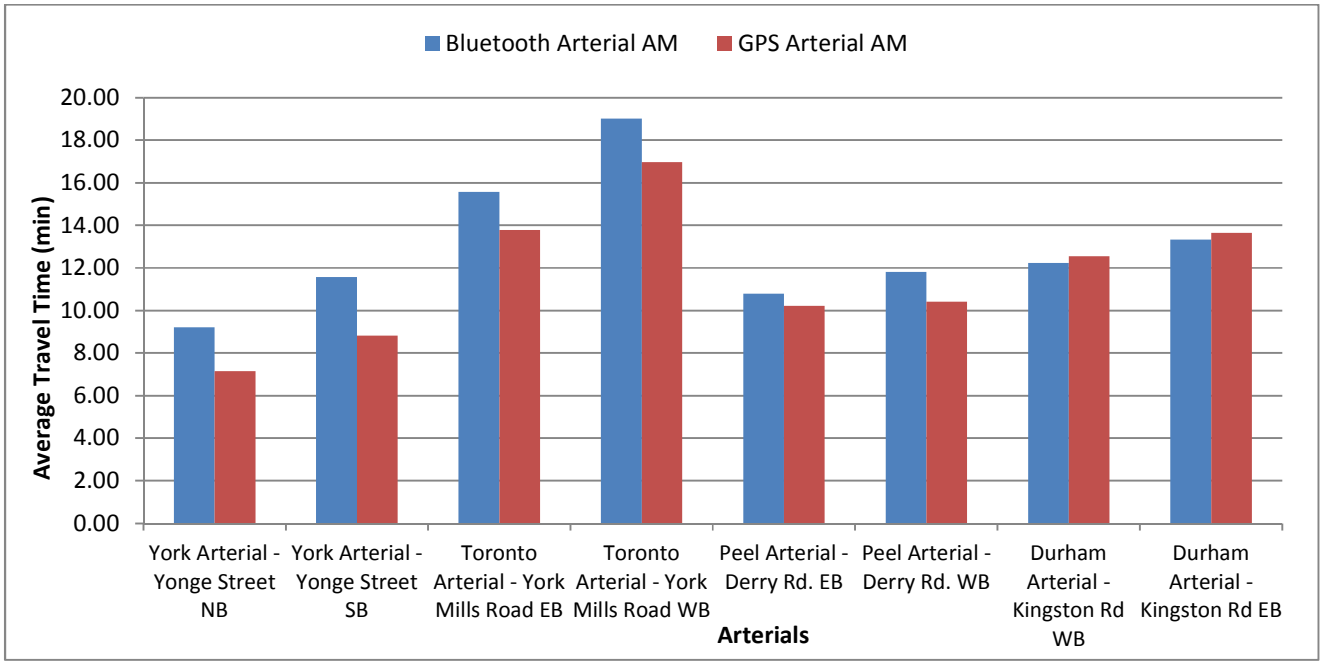

Figure J-3 Comparison between Bluetooth and GPS for Arterial Segments (AM Peak)

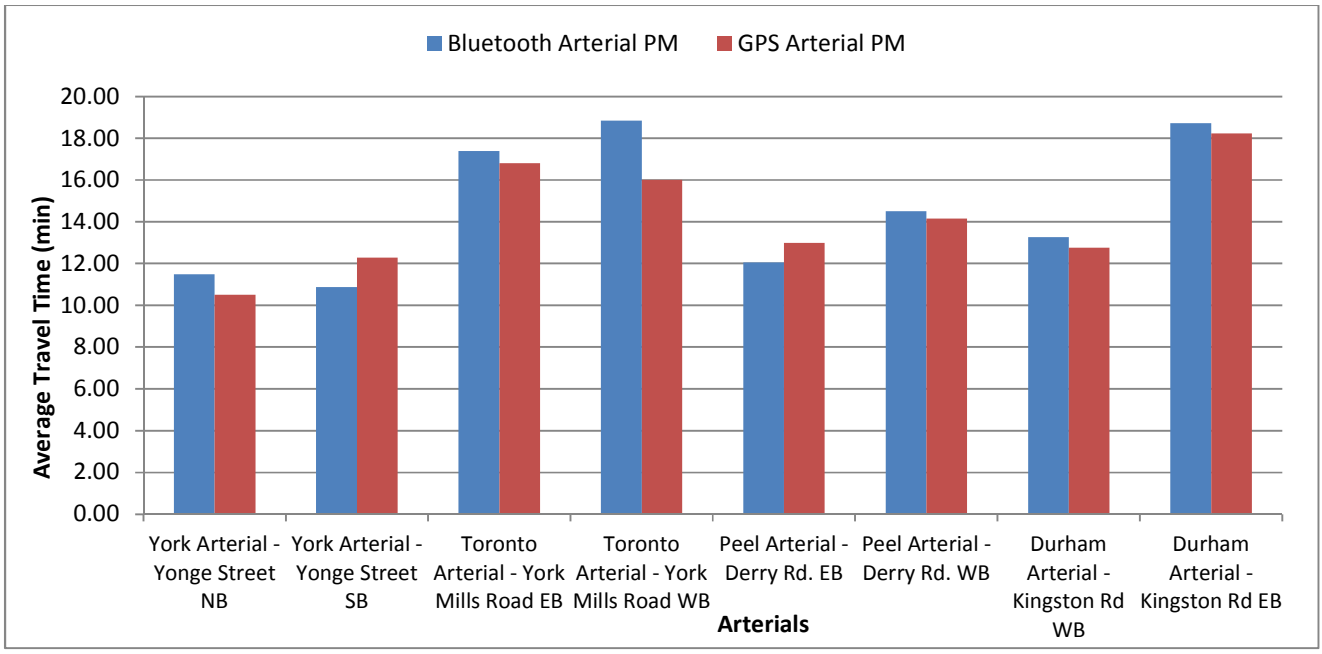

Figure J-4 Comparison between Bluetooth and GPS for Arterial Segments (PM Peak)

Appendix K Visual Comparison Results for TomTom 2008

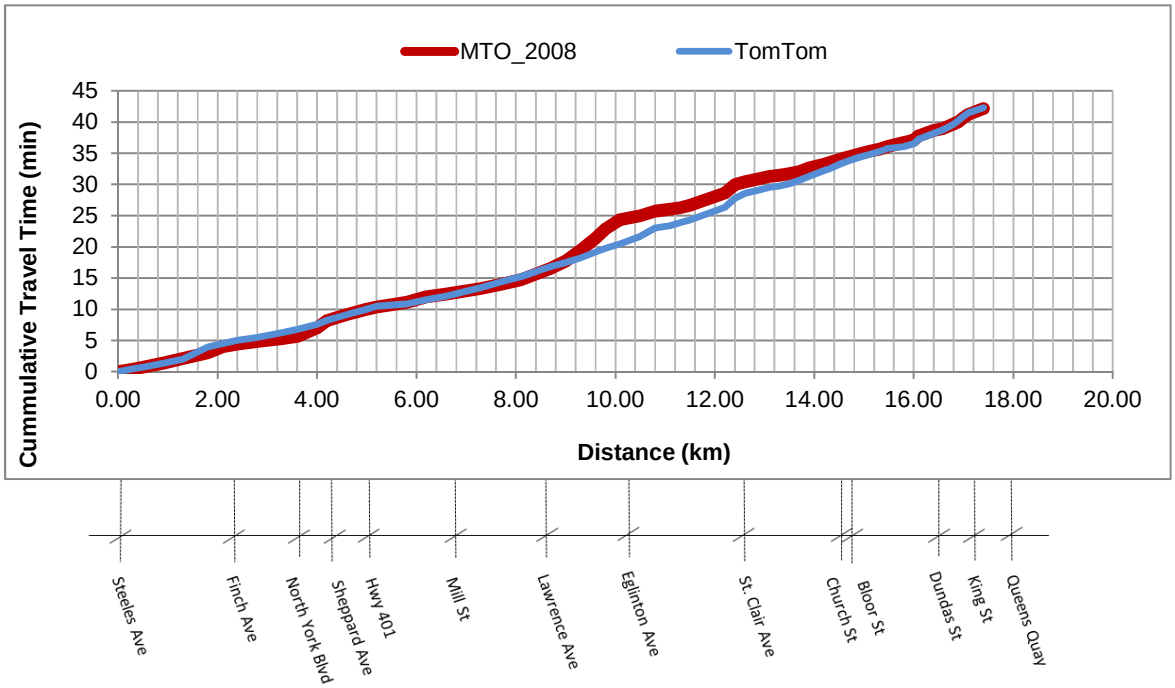

Figure K-1 Cumulative Travel Time for Yonge Street Southbound During AM Peak Period

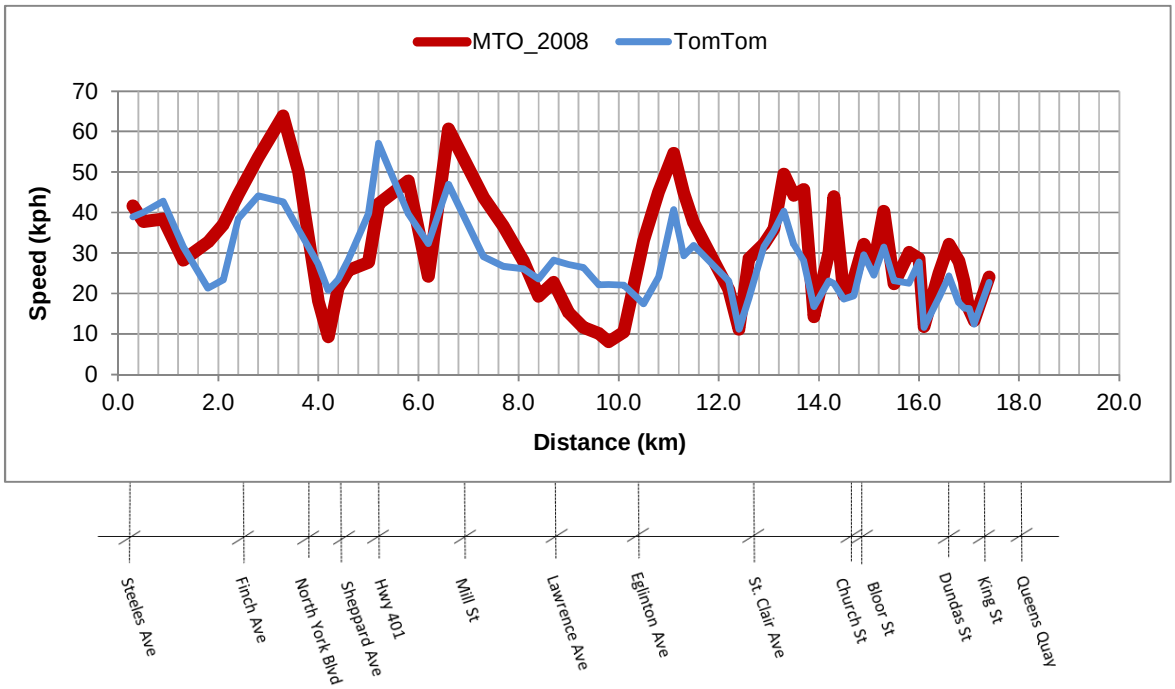

Figure K-2 Speed Profile for Yonge Street Southbound During AM Peak Period

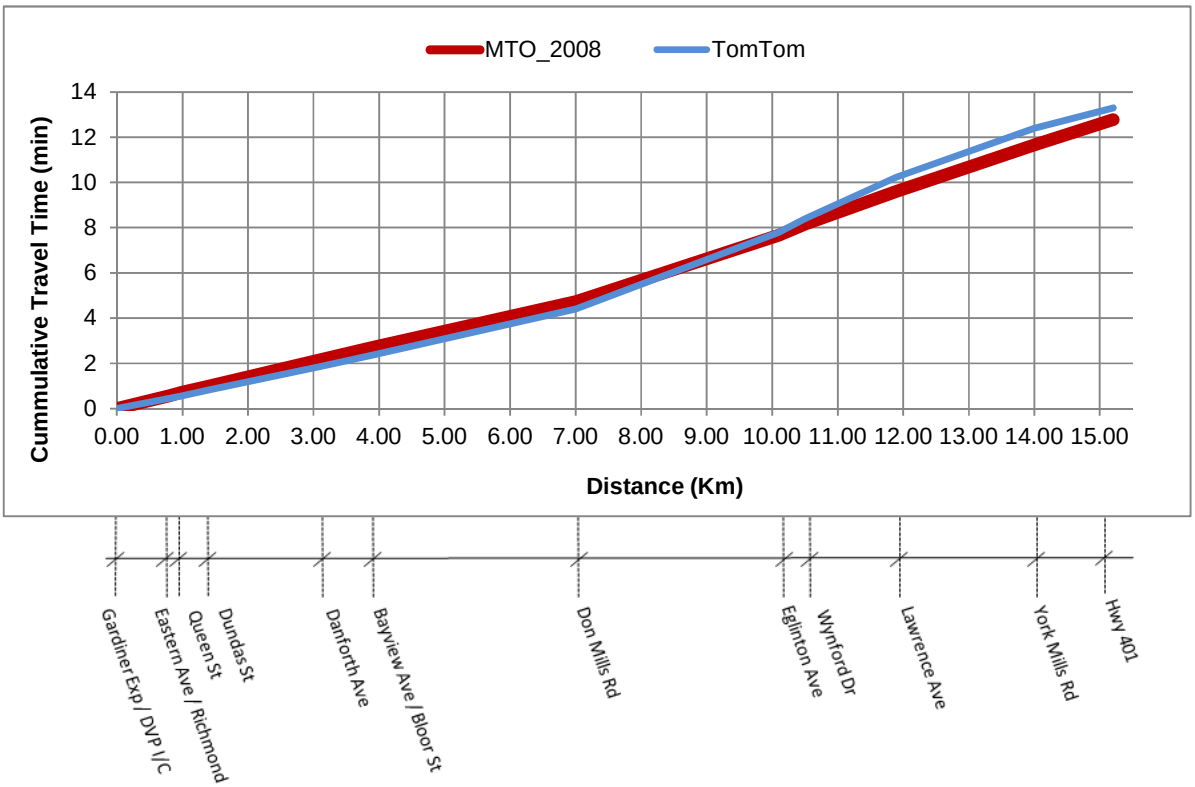

Figure K-3 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

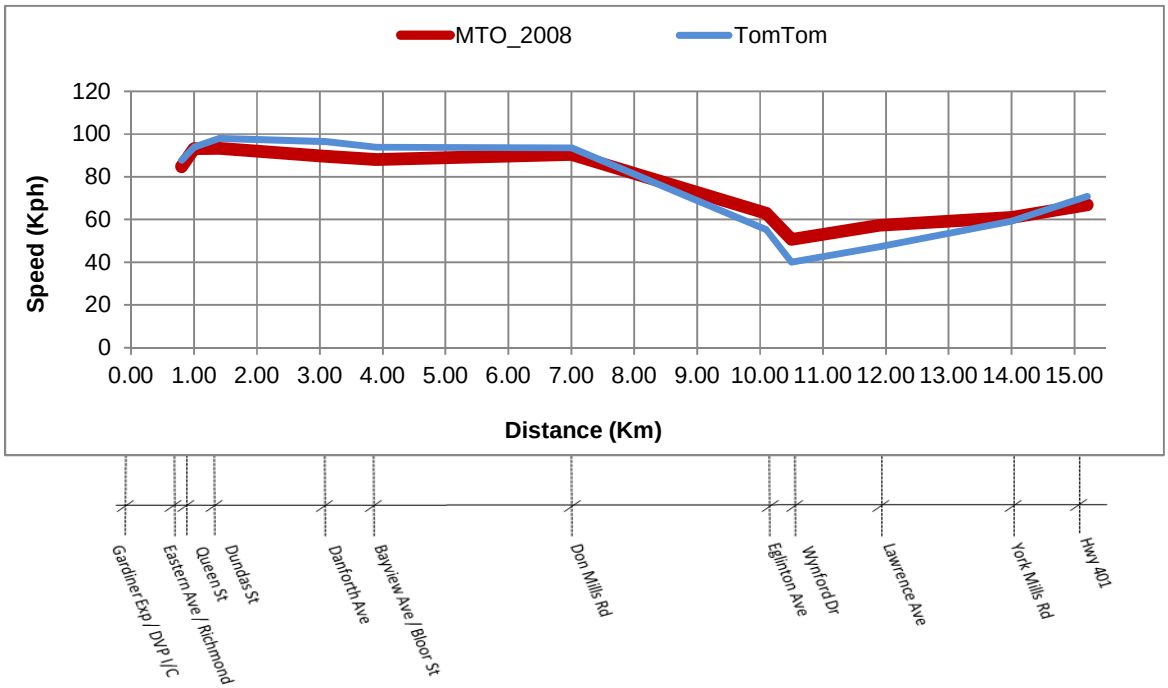

Figure K-4 Cumulative Travel Time for Don Valley Parkway Northbound During AM Peak Period

Appendix L Visual Comparison of Ramp Segments for INRIX and TomTom Data In 2010

Table L-1: MTO Ramps

RAMP	BEGINS AT	ENDS AT
Ramp 2 - 51, 59	Hwy 401 / Weston Rd	Hwy 400 / Finch Ave
Ramp 2 - 35, 15	Hwy 400 / Finch Ave	Hwy 401 / Keele St
Ramp 4 - 53	Hwy 401 / Dixie Rd	Hwy 427 / Rathburn Rd
Ramp 5 - 57	Hwy 409 / Kipling Ave	Hwy 401 / Weston Rd
Ramp 5 - 59	Hwy 409 / Kipling Ave	Hwy 401 / Weston Rd
Ramp 6 - 34, 36	Hwy 404 / Sheppard Ave	Hwy 401 / Leslie St
Ramp 6 - 62, 27	Hwy 401 / Victoria Park Ave	Hwy 404 / Sheppard Ave
Ramp 6 - 61, 29, 22	Hwy 401 / Victoria Park Ave	Hwy 404 / Sheppard Ave
Ramp 6 - 63	Hwy 401 / Victoria Park Ave	DVP / York Mills Rd

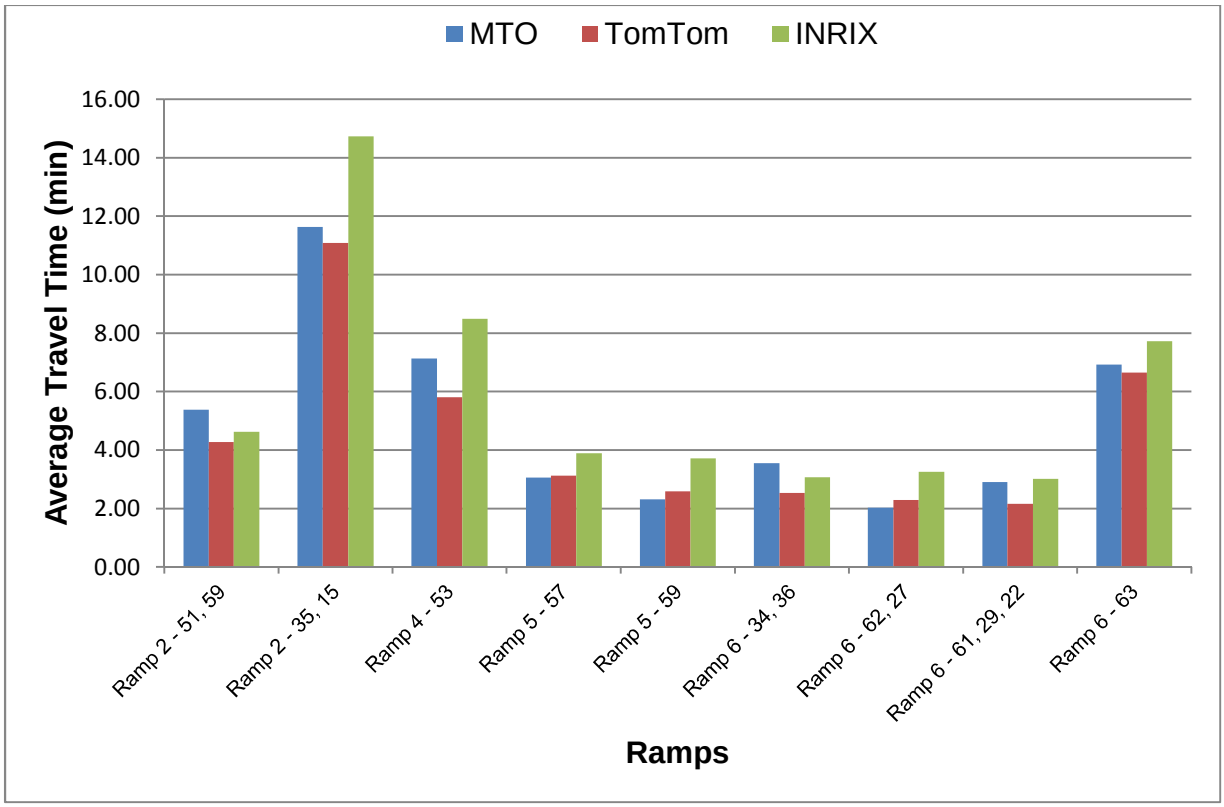

Figure L-1: Visual Comparison of Ramp Segments for INRIX and TomTom Data In 2010 (AM Peak)

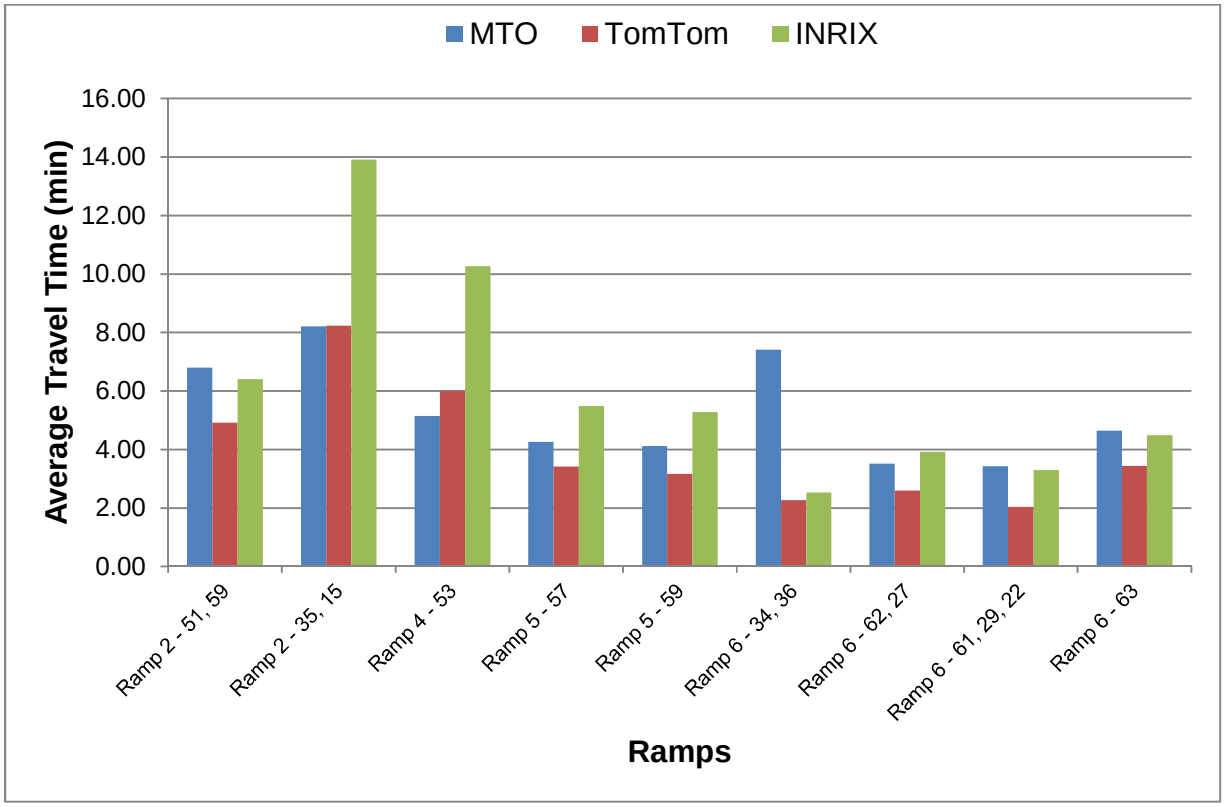

Figure L-2: Visual Comparison of Ramp Segments for INRIX and TomTom Data In 2010 (PM Peak)

Appendix M The Detailed Plot of the Speed Difference vs. Link Length for Highway Micro Segments in 2010 for Each Data Provider

Appendix M The Detailed Plot of the Speed Difference vs. Link Length for Highway Micro Segments in 2010 for Each Data Provider

Figure M-1 shows the percentage of micro links of each data provider for which their average speed difference with the benchmark is less than a certain number. For example, in this figure, average speed difference between INRIX micro links and the benchmark for 61% of all micro links is less than 10 km/h.

The detailed plot of the speed difference vs. link length for highway micro segments in 2010 for each data provider is presented in Figure M-2 to M-5. The results suggest that the difference in speed of each provider and previous MTO GPS data is independent of associated segment length.

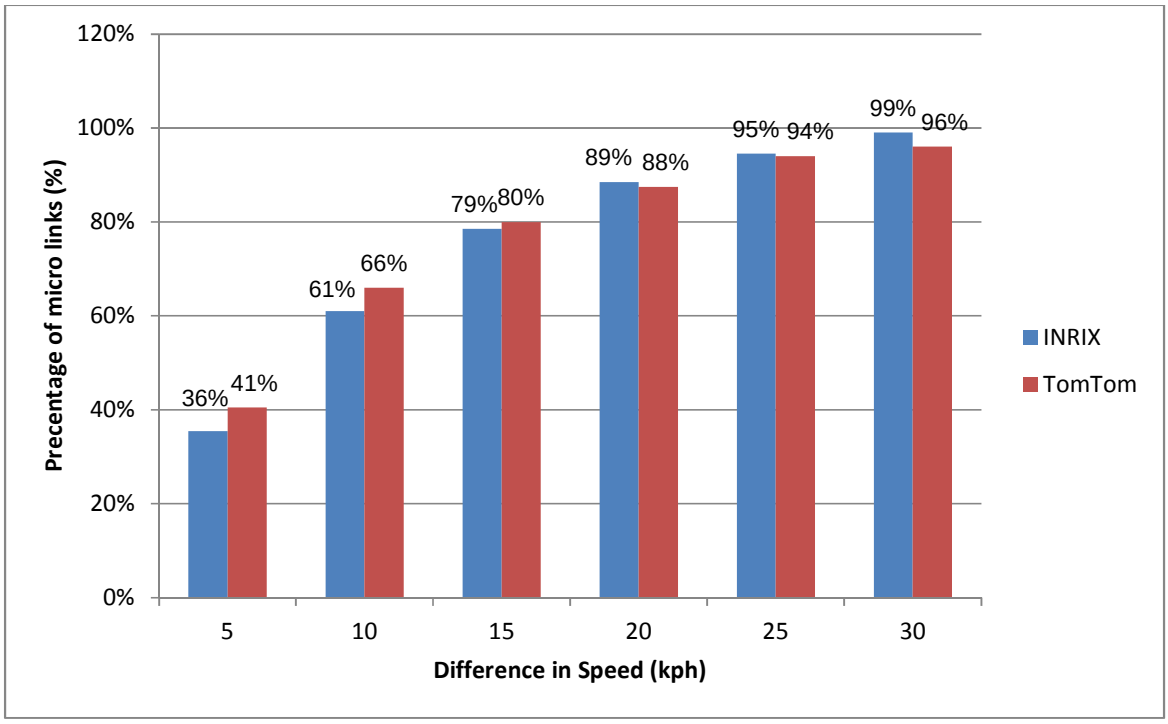

Figure M-1 The Relationship between Micro Links Percentage and Expectable Difference in Speed for 2010

Appendix M The Detailed Plot of the Speed Difference vs. Link Length for Highway Micro Segments in 2010 for Each Data Provider

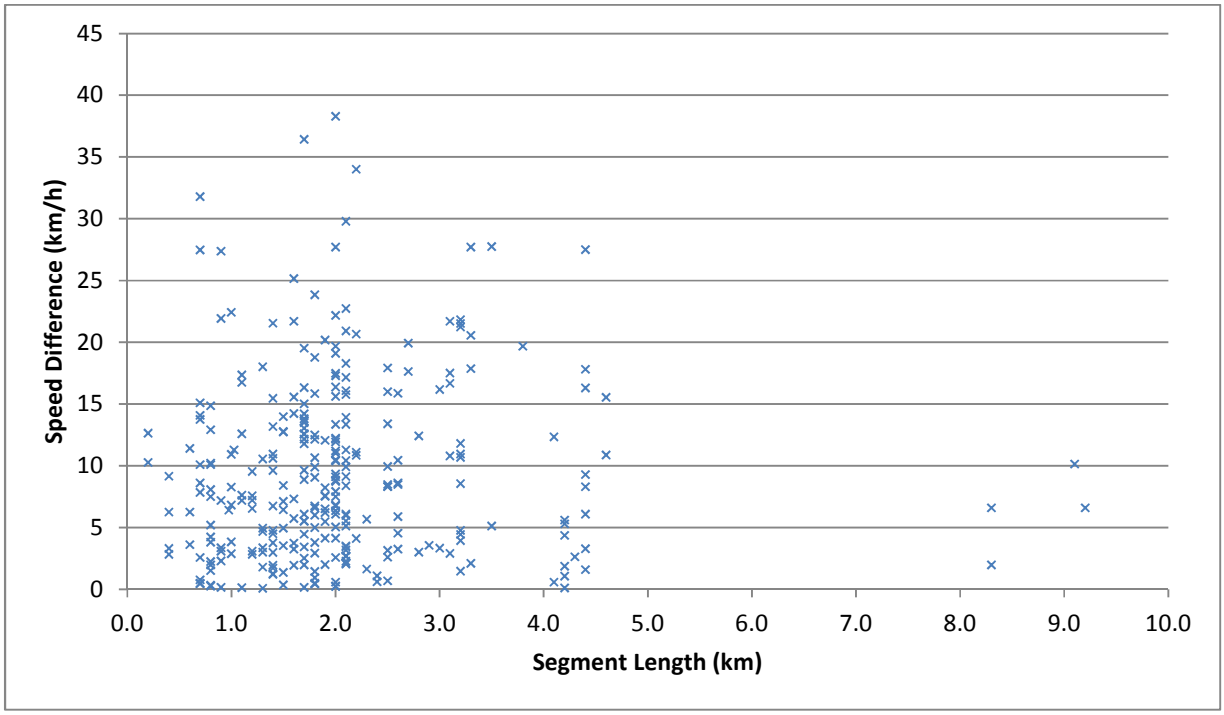

Figure M-2: Relationship between Segment Length and Difference in the Average Speed (INRIX_AM Peak)

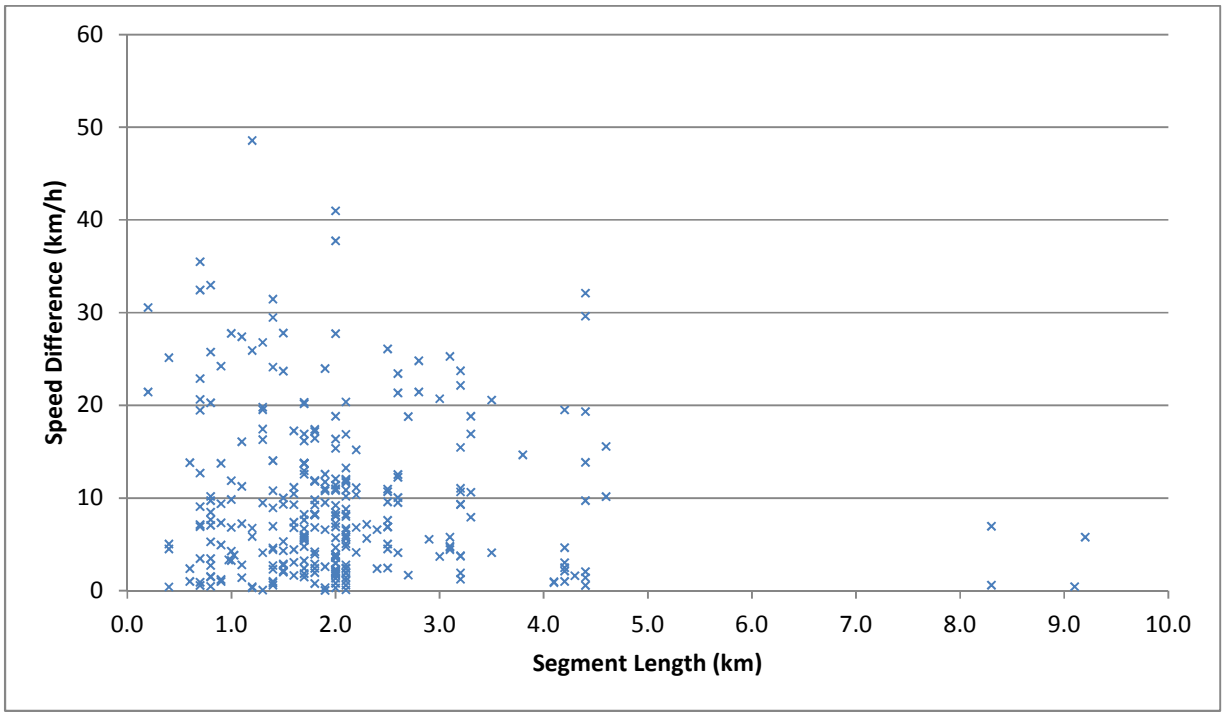

Figure M-3: Relationship between Segment Length and Difference in the Average Speed (INRIX_PM Peak)

Appendix M The Detailed Plot of the Speed Difference vs. Link Length for Highway Micro Segments in 2010 for Each Data Provider

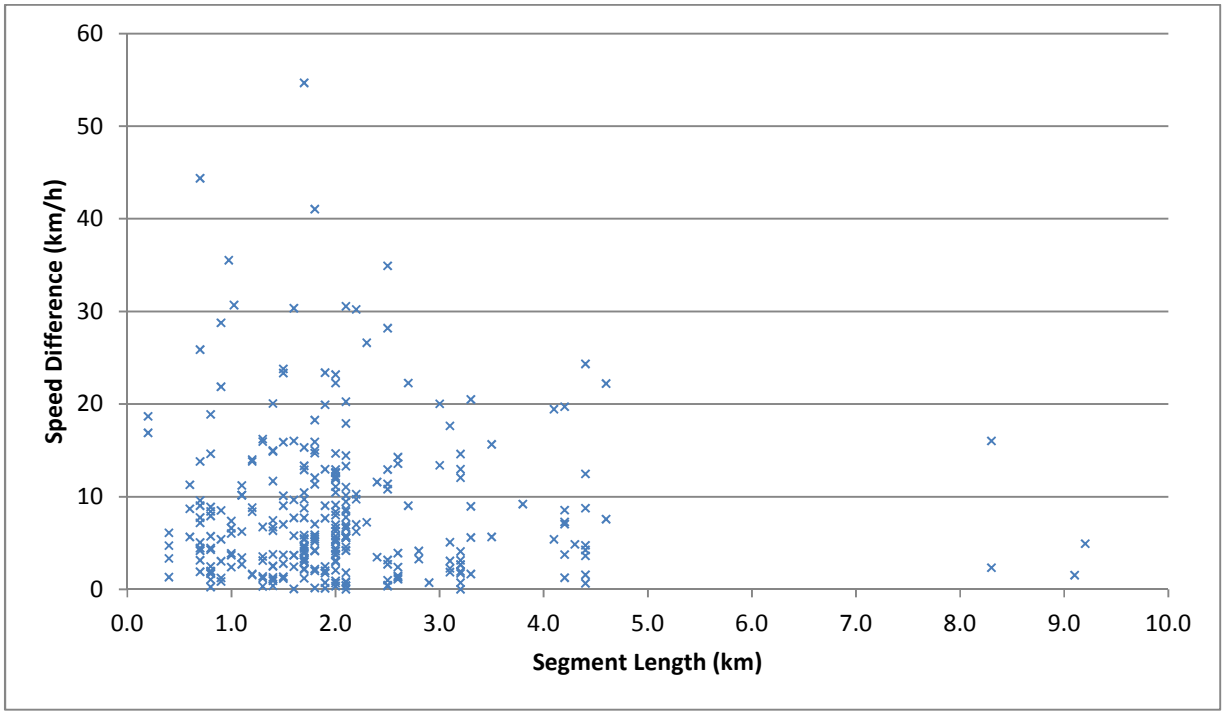

Figure M-4: Relationship between Segment Length and Difference in the Average Speed (TomTom_AM Peak)

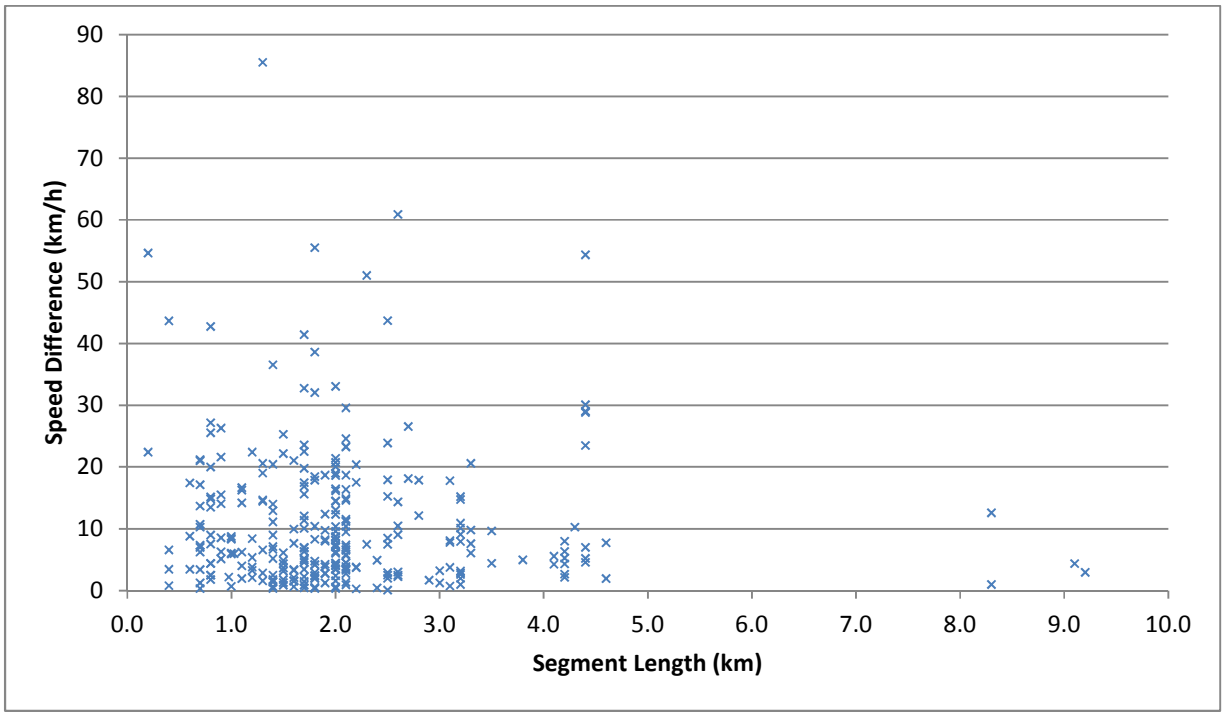

Figure M-5: Relationship between Segment Length and Difference in the Average Speed (TomTom_PM Peak)

Appendix N Segment with Missing Traffic Data

Table N -1 Segment with Missing Traffic Data (INRIX)

Data Provider	Segment type	Route Name	From	To	Length of Segment with Missing Data (Meters)
INRIX	Highway	QEW	Hwy 403	Brant St.	1679
			Brant St.	Hwy 403	1336
		Hwy 427	Hwy 407	Hwy 7	679.5
			Hwy 7	Hwy 407	621.4
		Hwy 403	Eglinton Ave.	Hwy 401	1143
		Hwy 410	Williams Pkwy	Boivard Blvd.	570
			Boivard Blvd.	Williams Pkwy	524
		Hwy 404	Davis Dr.	Green Line	500
		Gardiner	Lake Shore Blvd.	Jameson	498.3
			Jameson	Lake Shore Blvd.	507.8
	Ramp	Hwy 401/DVP	401 WB	DVP SB	410
		Hwy 409/Hwy 401	409 EB	401 EB	430
		Hwy 401/Hwy 427	401 EB	427 SB	509.1
Summation of missing highway links without traffic data					8059.7
Summation of missing ramps without traffic data					1349.1
Total length of segment with missing data					9408.8

Table N-2 Segment with Missing Traffic Data (TomTom)

Data Provider	Segment type	Route Name	From	To	Length of Segment with Missing Data (Meters)
TomTom	Highway	DVP_NB	Lawrence	York Mills	44.1
		Hwy 404_NB	Stouffville	Bloomington	3.4
		Hwy 403_WB	Mavis	Erin Mills	501
	Arterials	York Mills Rd.	Bayview	Fenn Ave.	55
			Lesmill Rd.	Don Mills Rd.	58.2
		Major MacKenzie Dr.	Dufferin St.	Bathurst St.	623.4
			Bathurst St.	Dufferin St.	623.4
		Derry Rd.	Meadowvale Blvd.	Mavis Rd.	212.2
		Bovaird Dr.	Conestoga Dr.	Sunforest Dr.	97
		Whites Rd.	Sheppard Ave.	Kingston Rd.	40.5
		Kingston Rd.	Alton Rd.	Whites Rd.	201.9
			Park Rd.	Stevenson Rd.	415.5
Summation of missing highway links without traffic data					548.5
Summation of missing arterial without traffic data					2327.2
Total length of segment with missing data					2875.7

Appendix O SWOT Analysis Results

TomTom			
Data Source: GPS In-Vehicle Navigation Systems			
Strength	Weakness	Opportunity	Threat
• For at least 90% of routes, no evidence was found to suggest any difference between TTS and TomTom data. • Performance of TomTom data was evaluated against two TTS. • Excellent customer service	• Number of observations for arterials is generally low. • Provides smallest sample size in comparison with the other sources. • Data are aggregated for each 7 days of the week during the study period. • TomTom mapping system is challenging to work with which increases data processing cost for the Ministry. • TomTom GIS map needs to be broken at interchanges and intersections to match TTS sections. • Link lengths are smaller than INRIX and require more aggregation to estimate performance measures. This can potentially cause error in calculations of variances. • Data latency is a few months.	• TomTom is able to provide the Ministry the data to calculate some of the traditional performance measures such as TTI and BTI for future travel time studies. • It is capable of providing additional information such as OD information. • It has the potential to provide data for HOV lanes because most users are passenger vehicles.	• Number of observations depends on the willingness of users to provide and share the data. As a result there is no guarantee of enough sample size.

INRIX			
Data Source: GPS from In-Vehicle Navigation Systems, smart phones, and commercial fleet as well as fixed point sensors.			
Strength	Weakness	Opportunity	Threat
• For at least 91% of routes, no evidence was found to suggest any difference between TTS and INRIX data. • Sample size is significantly larger than TomTom but not as large as Bluetooth. • Data latency is approximately 15 days.	• INRIX mapping system does not have HOV lanes at this time. • INRIX GIS map needs to be broken at interchanges and intersections to match TTS sections. • Data are aggregated for each 7 days of the week during the study period. • INRIX technical staff is not responsive.	• INRIX is able to provide the Ministry the data to calculate some of the traditional performance measures such as TTI and BTI for future travel time studies. • INRIX uses commercial fleet in their engine and are able to provide data for movement of goods and commercial fleet specific travel time information.	

Bluetooth			
Data Source: Detection of Bluetooth enabled devices.			
Strength	Weakness	Opportunity	Threat
• For all road sections in the study area on which Bluetooth receivers were deployed, no evidence was found to suggest any difference between TTS and Bluetooth data. • Provides much larger sample size with respect to TomTom and INRIX. • Can directly measure travel time of individual vehicles. • All performance measures which are traditionally calculated in TTS can be estimated using the Bluetooth technology.	• Devices need to be deployed along the study area. • It is challenging to measure travel time for long routes with multiple exit locations. • A reliable filtering algorithm is required. • It is unlikely that HOV and GPL travel times can be captured by Bluetooth except for special HOV lanes (HWY 404 – HWY 401 Tunnel).	• The data provided by Bluetooth could be closest to the “truth.” As a result can be used to verify performance of other data sources.	• Technology might change in the future. • Performance of the Bluetooth technology was not evaluated on highways in this study. • Differentiation between express and collector facilities could be challenging.