A SYSTEM FOR REAL-TIME MONITORING OF TRUCK GPS, TRUCK ENGINE AND BLUETOOTH DEVICE DATA ON AN URBAN FREEWAY

Matthew J. Roorda, Assistant Professor, University of Toronto,
Colin Warkentin, COO, Turnpike Global Technologies,
Phil Masters, Head, Advanced Traffic Management Section - Ministry of Transportation of Ontario
Bryce Sharman, PhD Student, University of Toronto

Introduction

Transportation systems in the urban areas of Canada have experienced continuous and dramatic increases in congestion over time, which has given rise to the need for improved traffic management techniques designed to make better use of existing roadway capacity. In the Toronto Area, the Ministry of Transportation of Ontario (MTO) has developed the COMPASS system of traffic management, which primarily relies on real-time measurements of traffic volume, speed and occupancy collected from loop detector sensors embedded in the roadway pavement, and real-time camera video streams collected at the roadside. These data streams are transmitted to the MTO's traffic operations centre, where decisions are made to dispatch emergency vehicles when incidents occur, and to provide information to roadway users about traffic conditions via variable message signs and the web. The MTO is actively exploring ways to improve/augment the current system of data collection to improve data reliability, data accuracy, geographical scope and the costs associated with data collection. A variety of technologies for measuring traffic performance are currently available, many of which rely on data systems that have been developed for other ends, and thus require cooperation with external data providers. Some of these technologies include Bluetooth, Global Positioning Systems (GPS), Radio Frequency Identification (RFID), and cellular telephone technology.

This paper describes a pilot system of freeway data collection using Bluetooth and GPS technology that has been jointly developed by the University of Toronto's Urban Transportation Research Advancement Centre (UTRAC); Turnpike Global Technologies, Ltd., a private firm that provides fleet management services to commercial vehicle operators; and the Advanced Traffic Management Section of the MTO. The paper begins by describing the objectives of the system, emphasizing the how all of the involved partners are intended to benefit from the system. The architecture of the system is then summarized, followed by a more detailed description of the test system that has been installed. The paper then provides some preliminary test results and our plans for future analysis.

Objectives

A primary objective of the test system that has been developed is to ensure that all three partners receive significant value from the system in exchange for their investments of infrastructure, data and human resources. Such "win-win-win" scenarios are essential in any cooperative relationship, but are of particular importance when considering the expenditure of public funds and the use of private data information systems. For this project, the primary roles and objectives of each partner are as follows:

MTO:

Primary Role:

- Provide access to existing roadside and communications infrastructure; install devices.

Primary Objectives:

- Obtain reliable, accurate, information about real-time traffic conditions to augment their current system of data collection, and ultimately to improve the performance of the highway system.
- Pass on those benefits to highway users in the form of reduced traffic congestion, improved information systems, and quicker response times to traffic incidents.

Turnpike Global Technologies:

Primary Role:

- Provide access to existing technological system and data; refine technology for real-time data acquisition; guide proper installation of devices.

Primary Objectives:

- Improve service to their clients (commercial fleet operators) by allowing them to access information about their trucks more quickly without additional cost.
- Maintain confidentiality of their clients' data.

University of Toronto:
Primary Role:
- Overall project management; Provide funding (through grants obtained from the Canadian, Provincial and University funding sources); Systems analysis.

Primary Objectives:
- Obtain information necessary to develop better understanding of highway operations, commercial fleet operations in urban areas and the benefits and disbenefits of technology for data acquisition.
- Obtain data resources for graduate and undergraduate research training.

System Architecture
The relevant system architecture prior to the installation of the test system is described in Figure 1. Prior to the new technology installations, the MTO has relied on loop detectors and traffic cameras for assessing traffic conditions. These data are transmitted to the MTO traffic operations centre via the MTO's fibre optic network. The MTO has a previous data sharing relationship with the University of Toronto ITS Centre and Testbed (part of UTRAC), such that real time camera and loop detector data are transmitted in real time via fibre optic cable (although this data transfer is now being upgraded to allow for internet transmission). The Turnpike Global Technology system, which had been entirely isolated from the MTO's system of data collection, involves the installation of RouteTracker™ devices on the dashboard of their clients' commercial vehicles (over 20,000 in total). RouteTrackers are Bluetooth/GPS-enabled devices that collect and store satellite positioning information and information from the truck's engine computer. When these trucks pass within range of a base station, they automatically transmit this information to the base station via Class I Bluetooth communications, which is subsequently

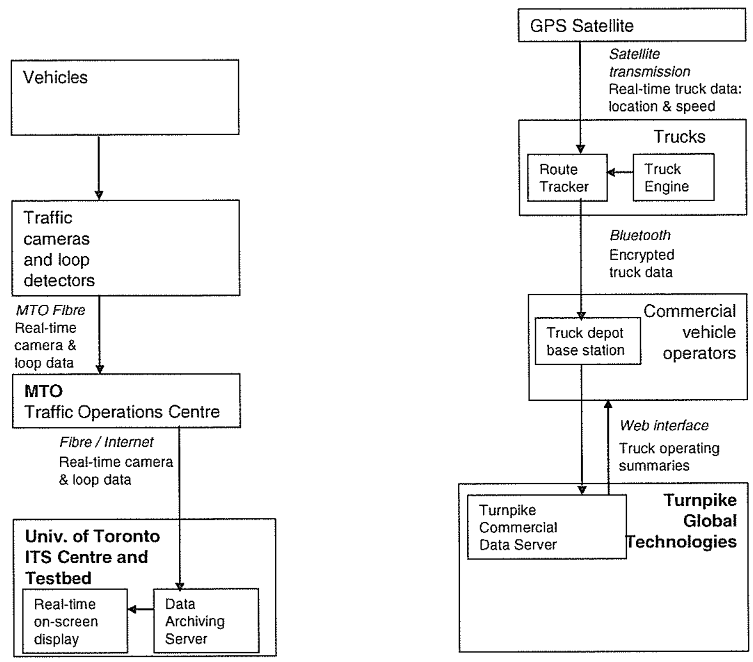


Figure 1 – Existing Systems Architecture

sent to Turnpike's commercial data server via the internet. Base stations are generally installed at the truck depot of each of Turnpike's client commercial vehicle operators, thereby allowing transmission of data only at the end of commercial vehicle tours. Turnpike processes that information and returns (non-real-time) summaries to their customers via secure web interface.

Figure 2 shows the architecture of the new test system of data communications that links the MTO, Turnpike and University of Toronto systems. The new hardware that has been installed includes a series of roadside base stations that are physically attached to MTO's traffic camera poles, obtain power from the camera control cabinet, and are linked to the MTOs local area ethernet network via the MTO's fibre optic cables that run along the freeways. These new base stations are capable of communicating with RouteTrackers via

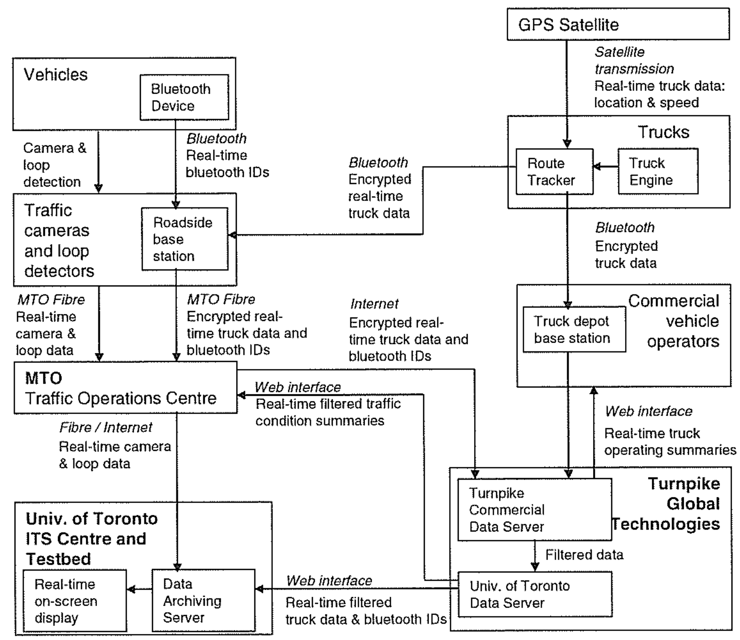


Figure 2 – New Systems Architecture

Bluetooth at highway speeds, downloading the most recent GPS location and speed data that the RouteTracker has collected upstream of the base station. These base stations are also capable of downloading device IDs of activated Bluetooth-enabled devices that pass within range of the base station. These devices include cellular telephones, laptop computers, etc. that are in both passenger and commercial vehicles travelling on the highway. Although the system collects Bluetooth device IDs, there exists no centralized database that links a device ID to its owner, thereby preserving the privacy of each highway traveller. Roadside base stations then transmit encrypted files containing these data through the MTO fibre optic network to the MTO Traffic Operations Centre, and the data are subsequently sent to the Turnpike Commercial data server on which the data are processed. To maintain privacy for Turnpike's clients, the data are then filtered to remove all identifying information, and sent to the University of Toronto's data processing server which is located in the Turnpike office. From this server, web interfaces are provided to both the MTO traffic operations centre (containing real-time summaries of traffic conditions based on the filtered data), and to the University of Toronto ITS centre and Testbed (containing real-time filtered truck data and bluetooth IDs). Turnpike Global Technologies is then able to provide truck data to their customers in real-time, rather than at the end of their commercial vehicles tours.

It is noted that the data in this system are only "real-time" in the sense that closely spaced base stations provide very frequent updates of truck location and speed data. Outside the geographic scope of the roadside base station system, no real-time information is acquired.

Test System Installation

The test system consists of 5 base stations installed on December 16, 2008 on camera poles along the south side of Highway 401 in the City of Toronto, between Highway 400 and the eastern city limit, as shown in Figure 3. An additional 25 base stations will be installed once the success of the 5 test stations has been evaluated, in order to ensure the system operates successfully, to refine our method for choosing appropriate installation locations, and to refine the configuration of the base stations for wireless data transfer. Figure 4 is a photograph of a completed base station installation.

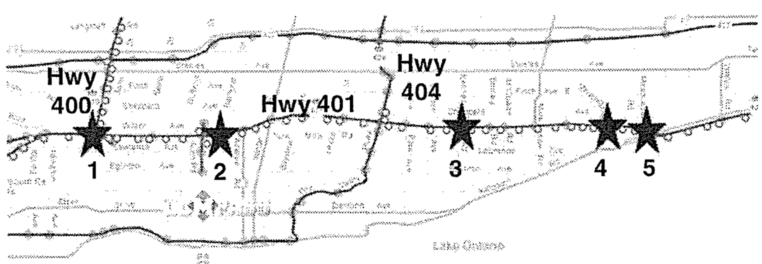


Figure 3 – Test Base Station Installation Locations

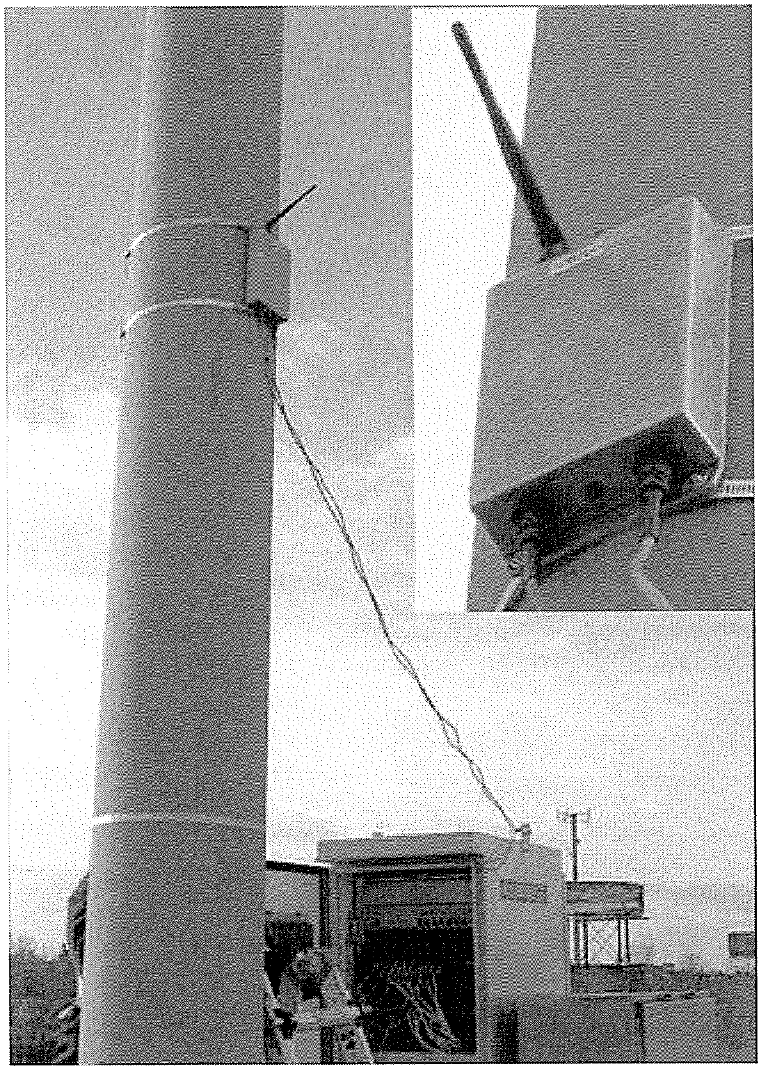


Figure 4 – Base Station Installation

The choice of appropriate locations for the installation of the 5 test base stations was constrained by the following factors.

- Each installation required a physical structure on which to mount the base station. To minimize the risk of theft, base stations were preferably located well out of reach of potential thieves. Camera poles were ideal for this, although one of the 5 base stations was mounted at the top of a noise barrier.
- Each installation needed to be located as close to the travelled lanes as possible to maximize the time that vehicles would be in range of the base station. Locations were also chosen that were free of physical obstructions such as overpasses.
- The best highway locations were those where the right of way is narrow. Figure 5 shows one installation site, overlayed with the estimated 100m transmission range of a Class I Bluetooth device. At other locations, where the right of way is wider, the right-most westbound lanes would fall outside this range or would have only a limited time window in which to transmit data. On Highway 401, most camera poles are located on the south side of the highway, so we recognize that better transmission characteristics are to be expected for eastbound travel.
- The installations are limited to those locations nearby a traffic camera controller cabinet that has an Ethernet switch installed.
- To test the system as a whole all base stations needed to be on a contiguous stretch of highway.

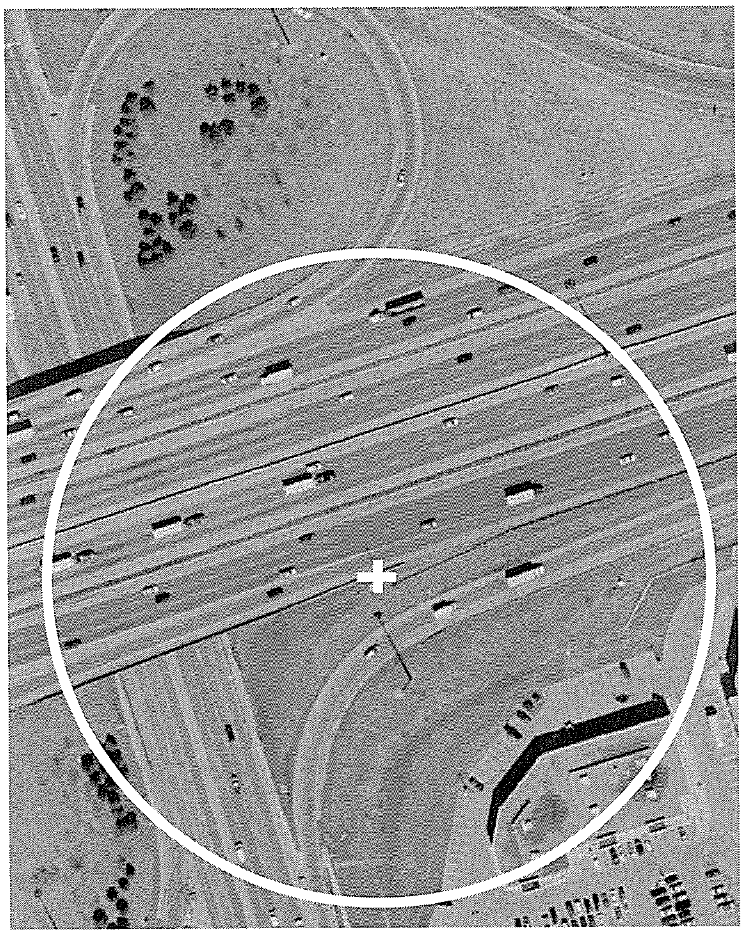


Figure 5 - Class 1 Bluetooth 100m Published Range for One Base Station Installation Location

Preliminary Results

The data collected at the roadside base stations were accumulated from the time period of January 1 to February 24, 2009. Given how recently the system was installed, only very preliminary analyses have been accomplished thus far, with an emphasis on the Bluetooth detections, rather than the available GPS data.

Prior to analysis, a simple screening algorithm was developed in order to remove multiple records of unique Bluetooth devices detected at the same base station (within a threshold of 2 minutes, compared to the usual time between Bluetooth transmissions from the same device of 10 – 30 seconds), and to remove pairs of device detections at consecutive base stations between which the travel time exceeded a threshold of 1 hour (to remove detections on multiple trips, for example, a stop for coffee). Our preliminary analysis of the test data is summarized as follows:

Number of successful device detections.

The 5 base stations were all able to successfully identify a significant number of Bluetooth devices (1500 to 3900 per day) and RouteTrackers (22 to 500 per day) over the course of the test period as shown in Table 1. The number of Bluetooth devices that transmitted their ID to the base station was on average approximately 1% of total (2-way) vehicles on Highway 401 at each base station location. This proportion was found to be slightly higher on weekends than on weekdays. The number of detections of trucks equipped with RouteTracker units was also significant. Approximately 2 times as many RouteTrackers were detected on weekdays than on weekends, and a significantly higher number were detected at the western-most station, which is located closest to Peel Region, where many of Turnpike's customers are based.

Device detection at multiple base stations

Of key interest for this study was the proportion of these Bluetooth devices and RouteTrackers that were detected at multiple base stations, since comparison of arrival times at multiple base stations allows for the estimation of travel times. Of a total of 837,000

Bluetooth device detections over the 55 day period, 283,000 (34%) were detected at two stations within 1 hour, resulting in 141,500 pairs of detections. These detection pairs could easily be classified into eastbound and westbound traffic. Eastbound traffic represented 58% of these pairs of detections, indicating that the closer proximity of eastbound lanes to the base stations (located on the south side of the road) yielded a higher detection rate.

RouteTrackers resulted in much lower numbers of detections but better detection properties. Of 70,160 total detected RouteTrackers, 91% were detected at consecutive base stations. 49% of these pairs were detected in the eastbound direction, and 51% in the westbound direction, an even directional split reflecting the better range of RouteTrackers (Class 1 Bluetooth), compared to the variety of ranges of other Bluetooth devices.

Another measure of the detection rate is the number of detection pairs that are at consecutive base stations, in comparison to the number that for some reason "skip" an intermediate base station. Consecutive base station detections comprised 71% of all Bluetooth detection pairs, and 68% of all RouteTracker detection pairs. We are as yet uncertain of the reason for this, however we hypothesize that it could be due to temporary divergence off of the freeway, obstruction of the Bluetooth signal from other vehicles, drivers turning off the Bluetooth device temporarily, or transmission issues at the base stations.

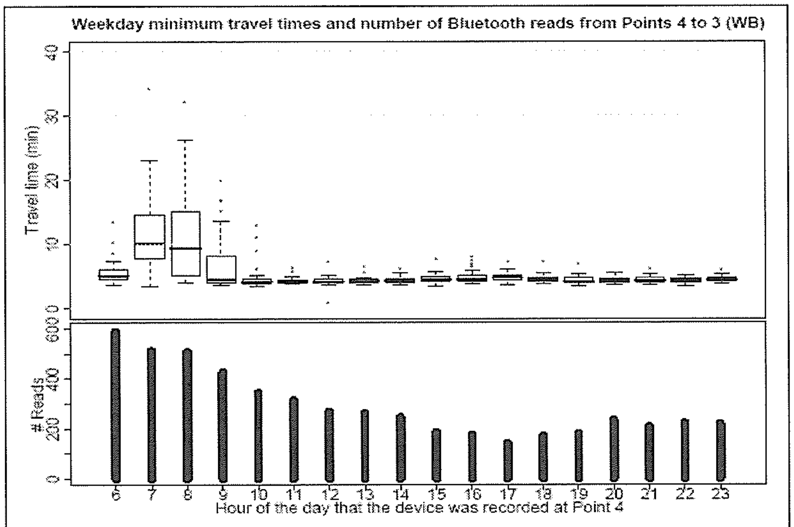
Travel Times

Figure 6 shows the inbound (westbound) and outbound (eastbound) travel times computed from Bluetooth devices detected at stations 3 (Kennedy Rd) and 4 (Morningside Rd). Each graph shows the distribution of the minimum travel time observed per hour over the weekdays in the study period. Box plots in Figure 6 show the median (horizontal line in box), the inter-quartile range (the box) and the minimum of the extent of the observed values and 1.5 times the interquartile range (the whiskers). Expected travel speed reductions in the AM (inbound) and PM (outbound) can be seen from these graphs with significant deviations from the median, especially in the AM.

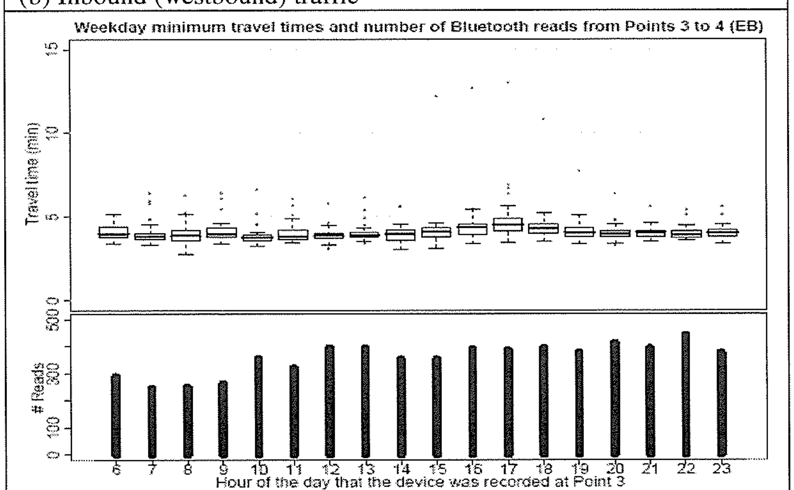
Table 1 – Daily number of successful Bluetooth and RouteTracker transmissions (January 1 to February 24, 2009)

			Base station Location				
			1	2	3	4	5
			Hwy 400	Bathurst	Kennedy	Morning-side	Hwy 2A
Total Bluetooth Reads	Total Trips	Avg.	3376	3568	3223	2692	2363
		Min	2916	3161	2752	1547	1986
		Max	3771	3860	3550	2917	2672
		St. Dev.	201	143	189	235	190
		Traffic Count	377030	343174	297948	233589	233589
		% BT devices	0.90%	1.04%	1.08%	1.15%	1.01%
	Weekday Trips	Avg.	3394	3590	3297	2692	2433
		Min	2916	3319	2925	1547	2025
		Max	3771	3860	3550	2917	2672
		St. Dev.	203	120	143	235	154
		Traffic Count	390104	354085	307531	241057	241057
		% BT devices	0.87%	1.01%	1.07%	1.12%	1.01%
	Weekend Trips	Avg.	3334	3516	3040	2483	2193
		Min	3036	3161	2752	1708	1986
		Max	3728	3802	3296	2740	2579
		St. Dev.	194	181	165	248	162
		Traffic Count	344347	315899	273986	214920	214920
		% BT devices	0.97%	1.11%	1.11%	1.16%	1.02%
BlueTooth Reads From Turnpike Tracker Equipped Vehicles	Total Trips	Avg.	325	227	202	240	281
		Min	36	22	24	34	32
		Max	501	335	313	332	391
		St. Dev.	117	79	66	76	83
	Weekday Trips	Avg.	384	267	233	274	320
		Min	36	22	24	34	32
		Max	501	335	313	332	391
		St. Dev.	82	56	52	61	64
	Weekend Trips	Avg.	180	131	127	160	187
		Min	126	74	86	117	133
		Max	224	176	191	201	236
		St. Dev.	31	27	26	27	34

*Traffic counts are from the nearest of the Ministry of Transportation of Ontario's loop detectors to each base station and are spring counts from 2008.



(b) Inbound (westbound) traffic



(a) Outbound (eastbound) traffic

Figure 6 - Distribution of minimum weekday hourly station-to-station travel time and device detections (January 1 to February 24, 2009)

Conclusions and Future Work

The test system of base station installations and data communications, as described in this paper has on the whole been successful, and gives strong indications that the objectives of each of the partners involved in the system set up will be achieved. This will solidify the significant three-way private/public/ university partnership that was necessary to initiate this project.

Based on a very preliminary analysis, it can be concluded that:

- All of the base stations for the test system have been successful in downloading data from trucks at highway speeds and have successfully identified unique RouteTracker and Bluetooth device IDs in both highway directions. This lends confidence to our selection criteria for appropriate base station locations.
- Significant data cleaning / processing is required in order to screen consecutive Bluetooth detections that are not on the same trip, and to focus on the most appropriate data pairs for travel time estimation.
- Travel time estimates can be obtained by observing either RouteTracker-enabled trucks or other vehicles carrying a Bluetooth device at consecutive locations on the highway in both directions.
- For Bluetooth devices, the number of consecutive device detections in the westbound direction is significantly lower than the eastbound direction for Bluetooth devices, due to the installation of base stations on the south side of the Highway. No difference is found for RouteTrackers, reflecting the greater transmission range than a typical Bluetooth device.
- Approximately 30% of RouteTrackers and other Bluetooth devices appear to be missed at at least one intermediate base station between two other base stations where they were successfully detected. The reasons for this have not yet been verified.
- Preliminary assessment of travel times identified by the system appear to conform to expected patterns of congestion, with the highest hourly minimum travel times occurring in the peak

direction during the AM peak hour on weekdays and free flow conditions occurring off peak.

Clearly there is much more work to be done to extract the full value of the installed system. The following research is of the highest priority and is currently underway at the University of Toronto.

- Isolate the reasons for lack of data transmission at some locations, and develop refined criteria for installation site selection.
- Utilize these refined criteria towards the selection of sites for the 25 additional base stations to be installed in Phase II of this pilot project.
- Validate the travel times estimated as an outcome of the system against travel time estimates from other sources, including truck GPS data, probe vehicles, loop detector data, consecutive camera images.
- Refine the algorithms for travel time estimation based on these comparisons.
- Develop visualization techniques for information display, with the intent of providing real-time congestion avoidance information to Turnpike truck dispatchers and to the public.
- Undertake unique behavioural research made possible by this technology including travel repetitiveness, commercial vehicle routing, and congestion avoidance behaviour.

Acknowledgements
The funding for this project has been provided by the Canadian Foundation for Innovation (Leaders Opportunity Fund), the Ontario Ministry of Research and Innovation (Ontario Research Fund) and the Department of Civil Engineering at the University of Toronto. In-kind contributions were made by Turnpike Global Technologies, Dell and the Ministry of Transportation of Ontario. We are grateful for the help of Loretta Wong (MTO), Lawrie King (Turnpike) and the other MTO staff that helped with base station installations (in sub-zero degree weather!), and the technical staff at University of Toronto, MTO and Turnpike that have helped with the data communications system.