Using Bluetooth Technology to Conduct Origin Destination Surveys

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Abstract. License plate and road side motorist interviews have been used for decades by transportation professionals to develop estimated origin-destination tables. However, due to the high cost of these labour intensive surveys, they are done infrequently. The introduction of Bluetooth technology provides each vehicle containing a Bluetooth device with its own unique electronic signature, and it is maybe possible to conduct origin-destination surveys automatically. Currently it is estimated that 10% of the urban vehicle fleet contains Bluetooth enabled devices and this is only expected to grow as older vehicles without Bluetooth devices are retired from active use.

Bluetooth technology could be a high tech, low cost solution for large scale projects. In practice, although Bluetooth produces a much lower capture rate, it is capable of collecting a vast amount of data points that can be utilized in numerous ways. This technology driven approach for conducting origin destination studies allows for a more flexible application of data that can be comparable to current proven methods.

As part of a self-funded research project in Vancouver, CTS conducted two origin-destination pilot surveys in tandem to compare the accuracy between a traditional manually collected license plate survey with a large sample size and one done with Bluetooth devices with a much smaller sample size. CTS will present the findings of this research pilot project and make recommendations for the future use of Bluetooth devices when being used to conduct data collection programs.

INTRODUCTION

The History of Origin Destination Surveys

Origin-Destination information of motorists has historically been collected by one of the following methods

1. Roadside interviews
2. License plate surveys
3. Postcard / mail-back surveys
4. Vehicle intercept method
5. Tag-on-vehicle method
6. Lights-on study

Origin-Destinations surveys are usually conducted when existing travel patterns of vehicles entering and exiting a study area need to be quantified. They are a critical component to develop accurate, comprehensive transportation plans for an area. In addition, origin-destination surveys also have useful applications in smaller scale studies to determine weaving and merging patterns, and in traffic calming studies for neighborhoods to quantify the volume of “external” traffic using a local road network. Therefore, the scale and budget of origin-destination surveys varies widely.

Manual License Plate Survey Procedures

Once the study area, cordon and location of external stations are selected, experienced surveyors are assigned to each location. One spare surveyor will be allocated as a contingency for late arrivals, no-shows and emergencies as every station must be counted concurrently in order to complete the cordon and ensure that the dataset is usable.

When the survey commences, typically the first four digits of the license plate of vehicles will be recorded using digital voice recorders by direction for all vehicles crossing the survey station. A “miss” will be called to indicate a missed plate. Every vehicle will be recorded by the surveyors as either a license plate or a miss in order to be able to determine the volume of traffic by direction of travel. At all survey stations, surveyors are stationed on the side of the roadway wearing full Personal Protection Equipment (PPE) to ensure surveyor safety and minimal disruption to the flow of traffic. Historically, CTS has achieved a minimum sample size of 85% using this method depending on traffic volumes, speeds and propensity for traffic platoons at each station. For busy multi-lane locations, CTS will assign one surveyor per lane per direction of travel in order to ensure a sufficient sample size. During the license plate survey, it is also important to conduct travel time runs along key origin-destination pairs in order to determine the travel time cut-off for determining which matched license plates are external-external trips and which are not.

Once the license plate data has been collected, it is transcribed into a spreadsheet and then both matches and near matches (i.e. where 3 of the 4 characters are the same and the fourth character sounds similar like “D” and “E”) are identified. The close matches are then reviewed to determine if the close match can be moved to the perfect match column. After the license plates are matched, the data is sorted by travel time in order to separate the external trips from the internal trips. Then, origin-destination tables will be prepared that will show the matched peak hour volume and percentage for each origin station for the selected design hour of analysis.

What is Bluetooth technology?

Use of Bluetooth technology in transportation studies has been gaining much interest in the recent years. It can be used primarily in two ways: Origin-destination studies and vehicle travel time studies.

The basis of this technology works similar to a manual license plate survey in that it tracks a vehicle identifier at different points of interest within a study area to determine travel patterns and travel times. The identifier used for a Bluetooth survey is a MAC Address. All devices that operate with Bluetooth technology have a unique MAC Address that can be discovered by a Bluetooth detection device. The MAC Address of any device with Bluetooth enabled is recorded and time stamped when entering one of these device's detection range, typically about 50 meters.

Devices that have Bluetooth capabilities include newer model vehicles (starting as early as 2004), smart phones and laptops. The idea is that with Bluetooth detectors setup in a study area, one can track the movements of these devices and determine an origin destination table and travel times representative of the vehicles within the area. It is not possible to capture the movements of every vehicle, and it is not guaranteed to capture only vehicles, but it is suggested that data collected in this way has practical application. **Figure 1,** below, shows an installed Bluetooth detection device mounted onto a light standard in the study area.

Figure 1 Bluetooth detection device installed on Wesbrook Mall with Close up of device.

STUDY DESCRIPTION

Site

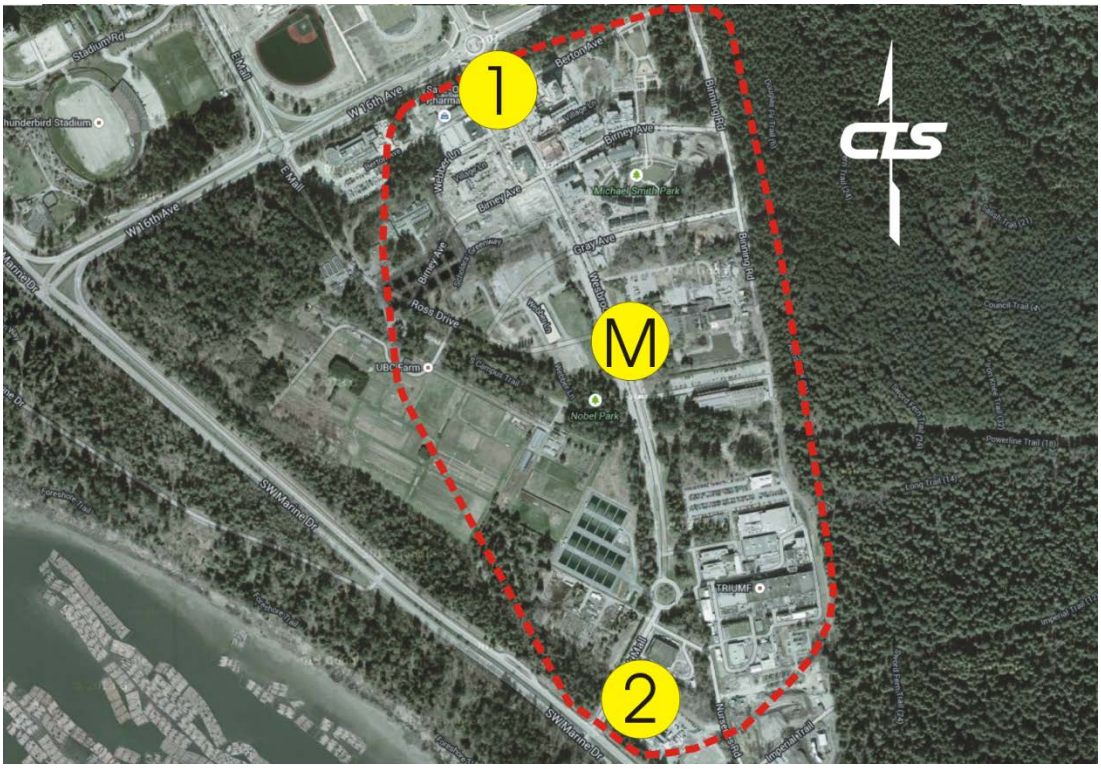
The site that was surveyed is located at the University of British Columbia's Vancouver Campus. It is a corridor along Wesbrook Mall between NW Marine Dr and W 16th Ave that stretches for approximately 1.3 kilometers in length. It is a collector road that provides access to the Wesbrook Village community and other points of interest such as the TRIUMF research centre and the UBC Farm. This corridor carries a wide range of travel modes including a heavily used bus route, a designated cycle route and significant pedestrian usage.

The intent of the original study was to identify the percentage of vehicles traveling through this corridor as having destinations within the Wesbrook Village community or simply as external or through trips.

Survey Setup

For this study, two types of surveys methodologies were used for data comparison: a manual license plate survey (LPS) and a Bluetooth survey. Three stations were used for each survey as shown in **Figure 2**.

Figure 2 Three stations selected along Wesbrook Mall



Station 1 was used to capture vehicles entering and exiting the study area from the north, *Station 2* was used to capture vehicles entering and exiting the study area from the south, and *Station M* was used for quality control and to provide data for additional analysis.

For the manual license plate survey, two field crew were stationed at each of the three locations, one to capture northbound vehicles and one to capture southbound vehicles. Field crew recorded the first four characters of the license plate of each vehicle that passed by as well as the time. Any missed license plates were noted as 'missed' so that the total vehicle volume would be known.

For the Bluetooth survey, three BlueMAC devices, provided by Digiwest and Item Ltd., were installed at the same station locations as used in the manual license plate survey. A pair of field crew was deployed to mount the units to light standards adjacent to the roadway. These devices are equipped with GPS locators, Bluetooth detection with memory storage, and cellular reception with data capabilities for online and real time data reporting to BlueMAC servers.

Survey Analysis Period

A 12 hour manual license plate survey was conducted from 7 AM to 7 PM on Wednesday October 29, 2014 and an additional manual license plate survey was conducted from 3 PM to 6 PM on Tuesday November 4, 2014. Concurrently, three Bluetooth receiving devices were installed and in use from October 28, 2014 to November 4, 2014.

For our study, three time periods were analyzed and compared: Wednesday October 29 2014 from 5 to 6 pm, Tuesday Nov 4 2014 from 5 to 6 pm, and Wednesday October 29 from 7 am to 7 pm. For both one hour analysis periods, the manual license plate survey data and Bluetooth survey data was compared directly against each other. For the 12 hour analysis period, the Bluetooth data used is the average data from all weekday data between 7AM – 7 PM. These analysis periods are referred to in this paper as *Wednesday PM, Tuesday PM,* and *Wednesday/Weekday Average* respectively.

METHODOLOGY

The objective of the study was to compare the data retrieved from the Bluetooth devices to the data collected from the traditional manual license plate survey. The following three components were compared:

1. Sample size collected by each method
2. Origin destination matrix tables
3. All matches between any of the stations

Bluetooth Sample Size

When CTS conducts a manual license plate survey, every car observed is recorded, and therefore the northbound and southbound volumes for each station are also captured. For a Bluetooth survey, total vehicle volumes are not captured. The *capture rate* of a Bluetooth detector is defined as the percentage of unique detected Bluetooth devices in relation to the real total vehicle volumes. It is generally expected that capture rates will be in the order of 10% according to BlueMAC representatives.

Origin-Destination Matrix

For the origin-destination matrix, CTS was interested only in matches at the entrances and exits of the study area and therefore only analyzed data at *Station 1* and *Station 2*.

In the manual license plate survey, matches of vehicles traveling from *Station 1* to *Station 2* were totaled and then subtracted from the total volume of entering vehicles at *Station 1*. This remaining, unmatched volume of entering vehicles was assumed to have their destination internal to the study area. The same calculation was applied to vehicles entering from *Station 2*.

In the Bluetooth survey, CTS developed an origin destination matrix. Similar to the license plate survey, matches of vehicles traveling from *Station 1* to *Station 2* were totaled. Detected Bluetooth devices at *Station 1* were used to determine the number of entering/exiting vehicles. Because a single Bluetooth device is unable to differentiate direction of travel, vehicle volume data was used to determine the percentage directional split. Entering volume at *Station 1* was determined, and the remainder after subtracting the *Station 1* to *Station 2* matches was assumed to have their destination internal to the study area. The same calculation was applied to vehicles entering from *Station 2*.

Matching Comparison

An additional way to compare the manual license plate survey data with the Bluetooth survey data was to isolate only the matches made by both survey methods. They key difference was that internal trips were not back calculated and only the observed matches were compared. For this type of comparison, our third station, *Station M*, located between *Station 1* and *Station 2*, was used.

Matches are shown in an origin destination table, and are not representative of the total number of vehicles entering or leaving the study area. The manual license plate survey data and Bluetooth survey data was analyzed the same way with total recorded matches displayed for each

analysis period. All matches are exclusive matches, in that a match between *Station 1* and *Station M* is not double counted with matches between *Station 1* and *Station 2*.

RESULTS COMPARISON

Bluetooth Sample Size

The first sets of data examined were the capture rates. **Table 1** is a summary of capture rates recorded in the *Wednesday PM*, *Tuesday PM*, and *Wednesday/Weekday Average* for each station used. Please note that for the Bluetooth capture rates, these include all devices including those on buses, cyclists, pedestrians and other passengers in a vehicle.

Table 1 Summary of Bluetooth capture rates for all devices per station and analysis periods

	Station 1	Station M	Station 2	Average*
Wednesday PM	20.4%	7.8%	30.0%	*19.4%*
Tuesday PM	26.4%	10.0%	30.2%	*22.2%*
Wednesday/Weekday Average	20.5%	9.5%	33.4%	*21.2%*
Average*	*22.4%*	*9.1%*	*31.2%*	

**Each station and analysis period weighted evenly*

Figure 3 Volume and Bluetooth Detection (all devices) Comparison – *Wednesday PM*

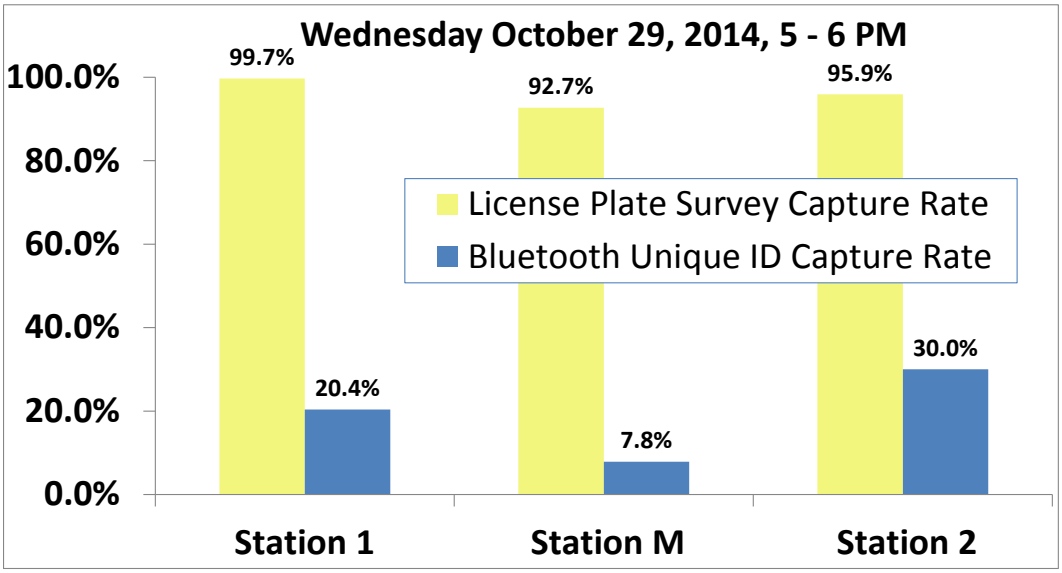


Figure 4 Volume and Bluetooth Detection (all devices) Comparison – *Tuesday PM*

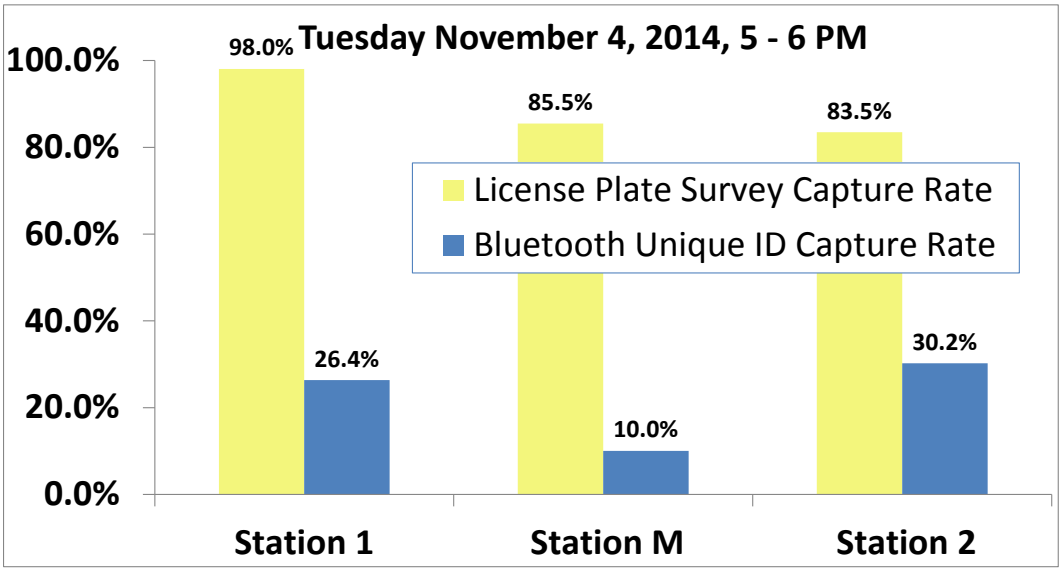
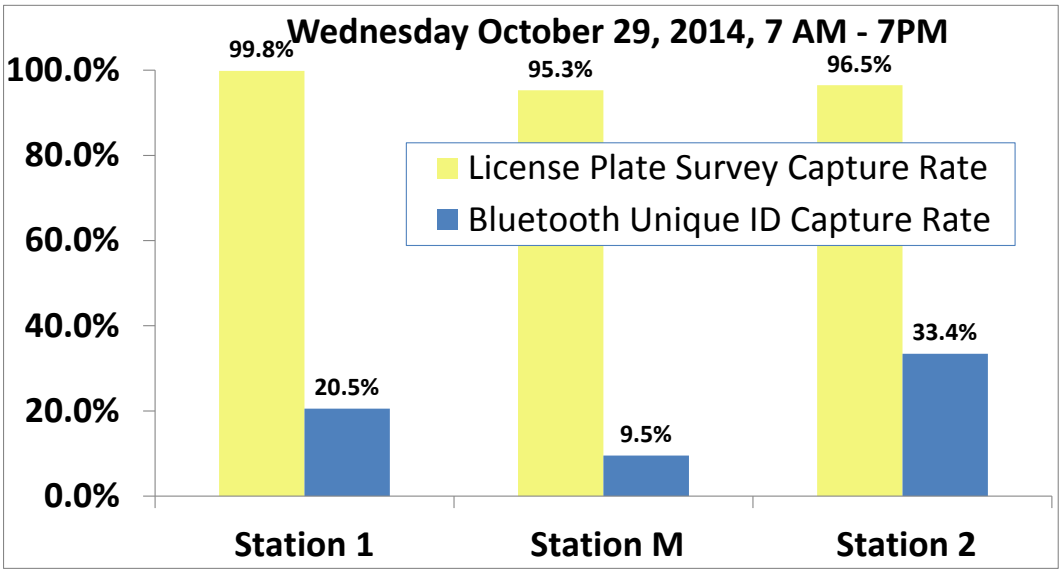


Figure 5 Volume and Bluetooth Detection (all devices) Comparison – *Wed./Weekday Average*



The capture rates for all analysis periods are relatively consistent throughout. *Station 1* and *Station 2* had capture rates that were higher than expected. It is possible that non-vehicle Bluetooth detections were picked up from the large pedestrian community and from activity on adjacent roads. *Station M* is more isolated and surrounding development was under construction during the survey; it is less likely to have unwanted Bluetooth detection. Because the rates are different at all stations, it is not appropriate to uniformly scale recorded Bluetooth data to

represent actual vehicle volumes. For this reason, the primary comparisons analyzed are the percentage distribution of trips from the different origins.

Origin Destination Matrix Comparison

The results of the data comparison between manual license plate surveys and Bluetooth surveys are presented below. **Figure 6** is a comparison of origin destination matrix values for *Wednesday PM*. **Figure 7** is a comparison of origin destination matrix values for *Tuesday PM*. **Figure 8** is a comparison of origin destination matrix values for *Wednesday/Weekday Average*. The origin destination matrix tables can be found in **Appendix A**.

Figure 6 Origin – Destination matrix comparison for *Wednesday PM (INT=Internal)*

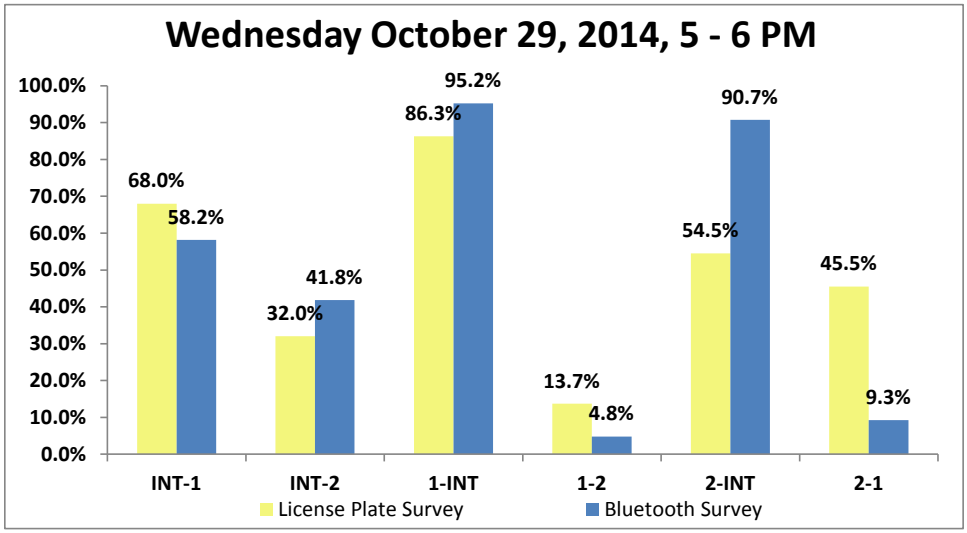


Figure 7 Origin – Destination matrix comparison for *Tuesday PM (INT=Internal)*

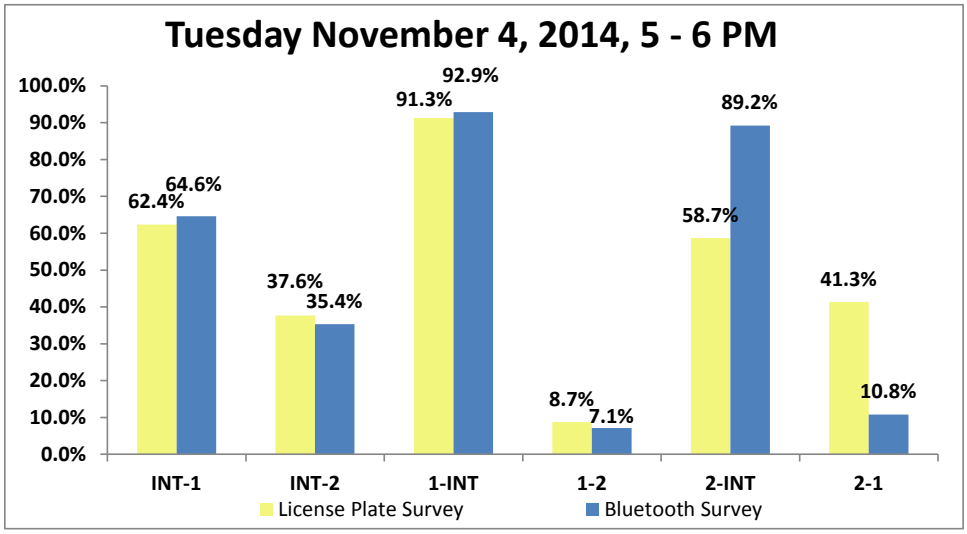
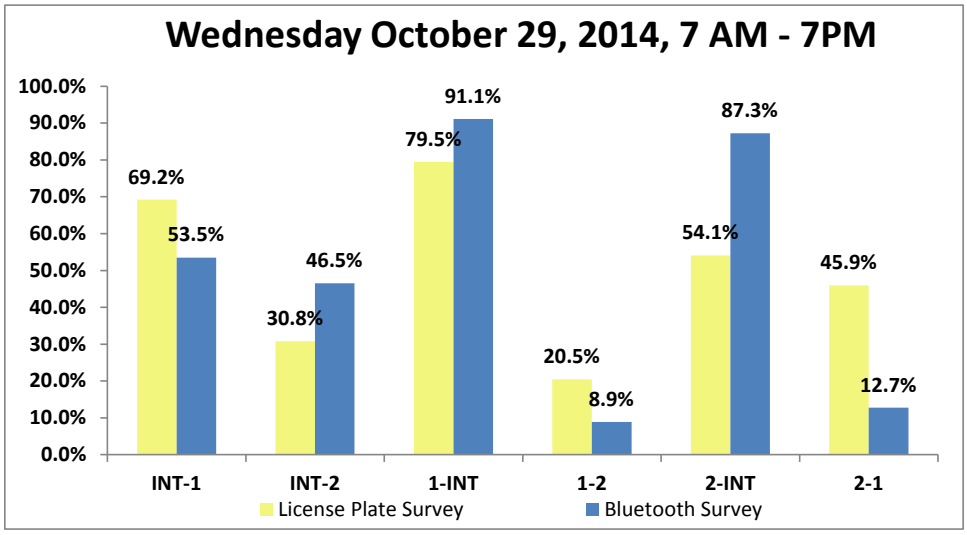


Figure 8 Origin – Destination matrix comparison for *Wed./Weekday Average (INT=Internal)*



There are significant differences when comparing the percentage distribution of trips from origin. From *Station 1*, there are differences ranging between 1.6- to 11.6%. From *Station 2*, differences in percentages range from 30.5% to 36.2%. In all scenarios, the Bluetooth surveys are significantly undercounting matches from *Station 2* to *Station 1*. The Bluetooth surveys are also significantly undercounting matches from *Station 1* to *Station 2* for two of the three scenarios.

The Bluetooth internal trips are dependent on the capture rates. As previously discussed, capture rates at both stations are higher than the expected 10%. It is possible that the capture rate is inflated and may be reducing the percentage of matches. Especially in a dense urban area where this kind of situation is more likely to occur, it appears that the capture rate cannot be reasonably used to determine entering/exiting vehicle volumes. Therefore, back calculating internal trips based on total unique detected Bluetooth devices is not recommended.

Matching Comparison

The comparative analysis was also done by evaluating only the matches made between all deployed stations. The results of the matching comparison between license plate surveys and Bluetooth surveys are presented below. **Figure 9** is a comparison of matches for *Wednesday PM*. **Figure 10** is a comparisons of matches for *Tuesday PM*. **Figure 11** is a comparisons of matches for *Wednesday/Weekday Average*. The matching tables can be found in **Appendix A.**

Figure 9 Comparison of matches for *Wednesday PM*

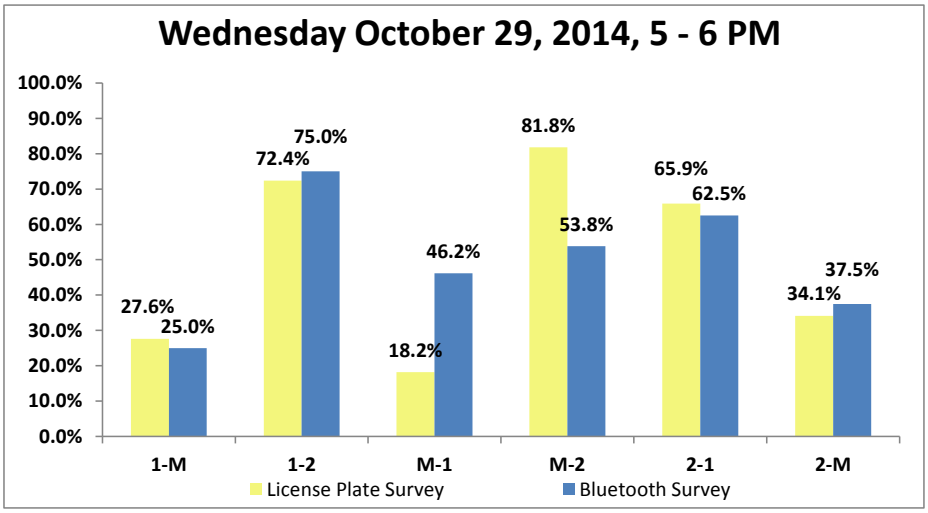


Figure 10 Comparison of matches for *Tuesday PM*

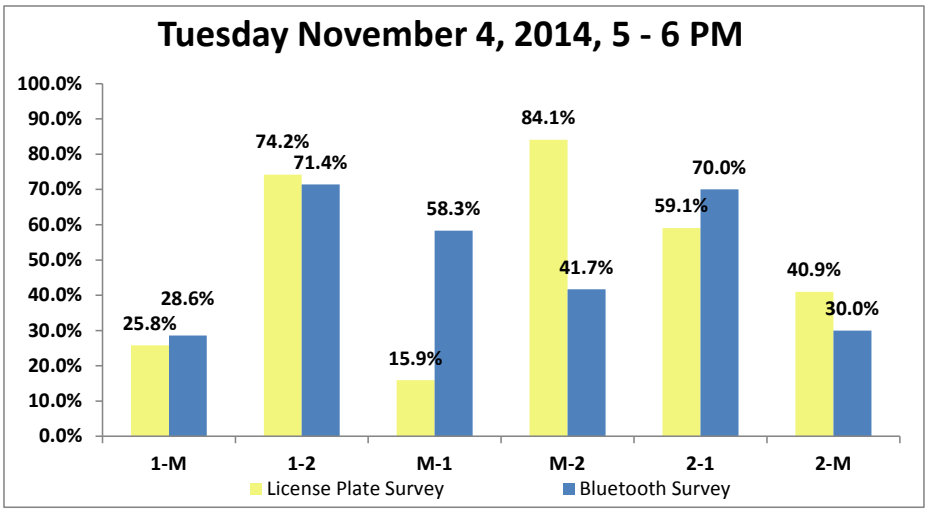
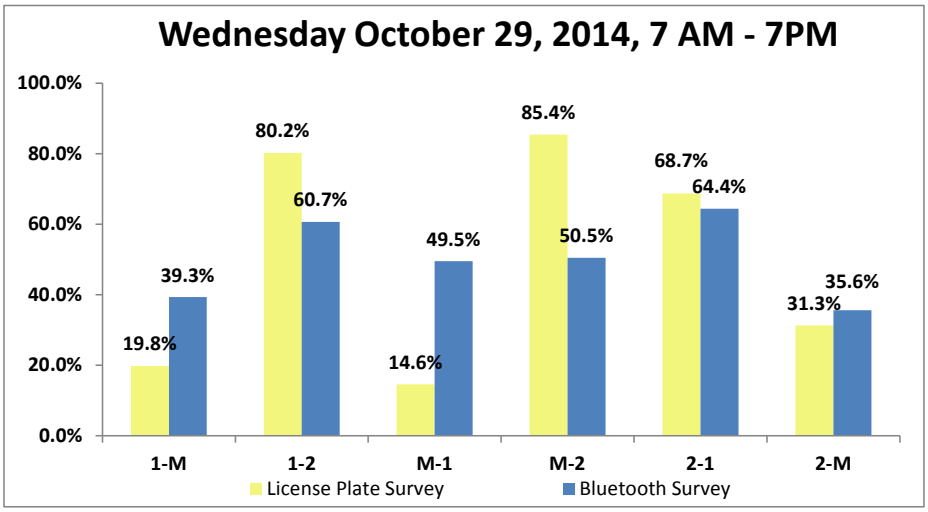


Figure 11 Comparison of matches for *Wednesday/Weekday Average*



When comparing matches using *Station M* as the origin, there are consistent differences that appear in all of the analysis periods. In the manual license plate survey, the matches from *Station M* to *Station 1* are lower than the matches from *Station M* to *Station 2*, whereas in the Bluetooth survey the differences are not as pronounced.

One possible reason for this discrepancy is that the cycle route along Wesbrook Mall does not include *Station 2*. It is possible that cyclists contributed to the Bluetooth sample size, skewing the data set. In this particular study set up, it is not possible to discern Bluetooth detections between vehicles and other devices.

CONCLUSIONS AND RECOMMENDATIONS

As part of a self-funded research project in Vancouver, CTS conducted two origin-destination pilot surveys in tandem to compare the accuracy between a traditional manually collected license plate survey with a large sample size and one done with Bluetooth devices with a much smaller sample size. The primary objective of this research project was to determine if Bluetooth devices could be used to conduct an origin-destination survey and provide comparable results to a traditional manually collected license plate survey.

The survey location selected was in a medium density urban residential neighbourhood on the south side of the University of British Columbia campus, with a significant public transit service and a bicycle route.

The two pilot surveys determined that the use of Bluetooth technology in a small study area with a high population has variable results for origin destination surveys. Active Bluetooth devices can be found in vehicles, on pedestrians, on cyclists and transit riders. Of note was the determination that the collected Bluetooth data could not be disaggregated into vehicle volumes, and all other Bluetooth enabled devices, such as smart phones, laptops and wireless speakers.

Some origin destination pairs had comparable matches, but results varied significantly and randomly. There are many, difficult to predict, factors that can influence the data in a dense urban area. A comprehensive understanding of the study area is suggested to determine the effectiveness of Bluetooth technology on a case by case basis. Therefore, it is not recommended to use the methods described in this paper to back calculate Bluetooth internal trips and develop vehicle origin-destination matrices.

Bluetooth technology may be more effective in larger, more rural study areas with closed systems having no internal trips. If considering the use of Bluetooth devices to collect data to generate an origin-destination matrix, the following is recommended by CTS:

1. Locate Bluetooth detectors mid-block to avoid picking up Bluetooth devices on adjacent roads

2. Locate Bluetooth detectors on links with few pedestrians, cyclists, and/or transit buses
3. Use road tube counters or manual counts to collect directional traffic volume at each external survey station.
4. Significant effort will be required to factor up Bluetooth sample data to represent an accurate origin-destination table.

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APPENDIX A

TABLE 2 OD Matrix from LPS and Bluetooth Survey for *Wednesday PM*

LPS	Destination			
Origin (vol)	Internal	1	2	Total
Internal		255	120	375
1	265		42	307
2	97	81		178
Total	362	336	162	

Bluetooth	Destination			
Origin (vol)	Internal	1	2	Total
Internal		64	46	110
1	60		3	63
2	49	5		54
Total	109	69	49	

LPS	Destination			
Origin (%)	Internal	1	2	Total
Internal		68.0%	32.0%	100.0%
1	86.3%		13.7%	100.0%
2	54.5%	45.5%		100.0%

Bluetooth	Destination			
Origin (%)	Internal	1	2	Total
Internal		58.2%	41.8%	100.0%
1	95.2%		4.8%	100.0%
2	90.7%	9.3%		100.0%

TABLE 3 OD Matrix from LPS and Bluetooth Survey for *Tuesday PM*

LPS	Destination			
Origin (vol)	Internal	1	2	Total
Internal		179	108	287
1	241		23	264
2	125	88		213
Total	366	267	131	

Bluetooth	Destination			
Origin (vol)	Internal	1	2	Total
Internal		64	35	99
1	65		5	70
2	58	7		65
Total	123	71	40	

LPS	Destination			
Origin (%)	Internal	1	2	Total
Internal		62.4%	37.6%	100.0%
1	91.3%		8.7%	100.0%
2	58.7%	41.3%		100.0%

Bluetooth	Destination			
Origin (%)	Internal	1	2	Total
Internal		64.6%	35.4%	100.0%
1	92.9%		7.1%	100.0%
2	89.2%	10.8%		100.0%

TABLE 4 OD Matrix from LPS and Bluetooth Survey for *Wednesday/Weekday Average*

LPS	Destination			
Origin (vol)	Internal	1	2	Total
Internal		2346	1044	3390
1	2356		607	2963
2	965	819		1784
Total	3321	3165	1651	

Bluetooth	Destination			
Origin (vol)	Internal	1	2	Total
Internal		574	499	1073
1	555		54	609
2	521	76		597
Total	1076	650	553	

LPS	Destination			
Origin (%)	Internal	1	2	Total
Internal		69.2%	30.8%	100.0%
1	79.5%		20.5%	100.0%
2	54.1%	45.9%		100.0%

Bluetooth	Destination			
Origin (%)	Internal	1	2	Total
Internal		53.5%	46.5%	100.0%
1	91.1%		8.9%	100.0%
2	87.3%	12.7%		100.0%

Table 5 Matching Table from LPS and Bluetooth Survey for *Wednesday PM*

Origin (vol)	LPS Destination			
	1	M	2	Total
1		16	42	58
M	14		63	77
2	81	42		123

Origin (vol)	Bluetooth Destination			
	1	M	2	Total
1		1	3	4
M	6		7	13
2	5	3		8

Origin (%)	LPS Destination			
	1	M	2	Total
1		27.6%	72.4%	100%
M	18.2%		81.8%	100%
2	65.9%	34.1%		100%

Origin (%)	Bluetooth Destination			
	1	M	2	Total
1		25.0%	75.0%	100%
M	46.2%		53.8%	100%
2	62.5%	37.5%		100%

Table 6 Matching Table from LPS and Bluetooth Survey for *Tuesday PM*

Origin (vol)	LPS Destination			
	1	M	2	Total
1		8	23	31
M	7		37	44
2	88	61		149

Origin (vol)	Bluetooth Destination			
	1	M	2	Total
1		2	5	7
M	7		5	12
2	7	3		10

Origin (%)	LPS Destination			
	1	M	2	Total
1		25.8%	74.2%	100%
M	15.9%		84.1%	100%
2	59.1%	40.9%		100%

Origin (%)	Bluetooth Destination			
	1	M	2	Total
1		28.6%	71.4%	100%
M	58.3%		41.7%	100%
2	70.0%	30.0%		100%

Table 7 Matching Table from LPS and Bluetooth Survey for *Wednesday/Weekday Average*

Origin (vol)	LPS Destination			
	1	M	2	Total
1		150	607	757
M	102		596	698
2	819	373		1192

Origin (vol)	Bluetooth Destination			
	1	M	2	Total
1		35	54	89
M	52		53	105
2	76	42		118

Origin (%)	LPS Destination			
	1	M	2	Total
1		19.8%	80.2%	100%
M	14.6%		85.4%	100%
2	68.7%	31.3%		100%

Origin (%)	Bluetooth Destination			
	1	M	2	Total
1		39.3%	60.7%	100%
M	49.5%		50.5%	100%
2	64.4%	35.6%		100%