A Study of Bluetooth-Based Origin-Destination Data

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Abstract: Origin-Destination information is of crucial importance within the transport modelling and planning space as it makes it possible to understand the movement patterns in a particular area of interest, during a particular period of time.

Advancements in wireless communications, specifically Bluetooth, made it possible for transport engineers to utilise this technology for traffic data collection, including Origin-Destination data.

This paper investigates the Origin-Destination data obtained from the Bluetooth-Based data collection system in Adelaide for the data collected in the years 2014 and 2015. Twenty eight through movements for ten randomly selected intersections were studied. The percentages of through movements calculated based on the data obtained from the Bluetooth-based traffic data collection system were compared against the percentages of through movements calculated based on the data obtained from Manual Turning Movement Surveys.

This research suggests that further improvements are required before Bluetooth-based Origin-Destination data can be used for detailed movement analysis.

Keywords: Bluetooth, Origin-Destination data, ITS

1. INTRODUCTION

Origin-Destination information is of crucial importance within the transport modelling and planning space as it makes it possible to understand the movement patterns in a particular area of interest, during a particular period of time (Blogg et al., 2010, Guy and Fricker, 2005, Michau et al., 2013).

The costly nature of conventional methods for collecting Origin-Destination data, e.g. manual surveys, reinforces the need for searching for alternative, more cost effective methods of collecting such data (Blogg et al., 2010, Guy and Fricker, 2005).

Advancement in telecommunication engineering, in particular wireless communications and Bluetooth technology opened some promising avenues for transport engineers and planners to utilise this new technology for collecting transport related data (Araghi et al., 2014, Bhagwat, 2001, Blogg et al., 2010, Buttery and Sago, 2003).

The use of Bluetooth technology for collecting transport related data in South Australia is relatively new. Planning and design for installation of the Bluetooth transceivers began in 2012. The South Australian Department of Planning, Transport and Infrastructure (DPTI) now has over 280 receivers, continuously recording and analysing data for over 900 road segments with almost 700 km of arterial road network (Cox, 2014).

Movement patterns across the road network can provide valuable information which supports transport planning and traffic modelling (Alibabai and Mahmassani, 2008, Jang et al., 2004, Ortúzar and Willumsen, 2011). At the micro level, Manual Turning Movement Surveys are the most commonly practiced conventional method of collecting the Origin-Destination data, albeit resource intensive and costly (Blogg et al., 2010, Guy and Fricker, 2005, Michau et al., 2013). If the Bluetooth technology can provide reliable Origin-Destination data, it will provide a considerable cost saving opportunity in the area of traffic data collection. However, issues such as multiple detections, dropped signals, and outliers are observed in different trials (Carpenter et al., 2012, Chitturi et al., 2014, Porter et al., 2013).

In this research we aim to study the Bluetooth Acquired Origin-Destination data for the determination of through movement as a proportion of total approach volume, expressed as a percentage, at randomly selected signalised intersections within the Adelaide Metropolitan Area.

2. LITERATURE REVIEW

Jang et al. (2004) state that "knowledge of the travel patterns for a defined jurisdiction of roadway network is an important aspect in transportation planning." There are different methodologies used in studying traffic patterns, one of them being Origin-Destination (O-D) survey. The Origin-Destination matrix is the main information for transport simulation, modelling and planning (Carpenter et al., 2012, Guy and Fricker, 2005). Wang (cited in Guy and Fricker 2005) states that O-D studies are conducted to understand the pattern of the movement of persons and goods in a particular area of interest during a particular period of time.

Conventional methods of collecting Origin-Destination data, including manual turning movement surveys, are resource intensive and costly (Blogg et al., 2010, Guy and Fricker, 2005, Michau et al., 2013). This leads the professionals in the field of traffic and transportation engineering to look at alternative means of collecting such data (Michau et al., 2013).

The recent decade has seen a significant advancement in the area of computer, mobile and wireless communications (Bidgoli, 2008, Foulds et al., 2013). These advancements in the wireless communication technology created opportunities for professionals in the field of traffic and transportation engineering to look into possible areas to employ this technology for the purpose of collecting some valuable data, including travel time and Origin-Destination information (Araghi et al., 2014, Blogg et al., 2010, Michau et al., 2013).

According to Chitturi et al. (2014), Wasson, Studevant and Bullock were the first to report using Bluetooth to track vehicles, pedestrians, and wait times at airport security lines in 2008. In the same year, i.e. 2008, the Centre for Advanced Transportation Technology at the University of Maryland developed a portable Bluetooth monitoring system (Young, 2008).

Identity of each Bluetooth device is specified by a unique number assigned to each individual device, known as Media Access Control address. Abbreviated to "MAC address", the Media

Access Control address is a 48-bit, 12 alpha-numeric character, unique identifier assigned to each Bluetooth device (Araghi et al., 2014).

Bluetooth readers on the roadside wirelessly detect the Bluetooth enabled devices in discoverable mode as vehicles passes (Blogg et al., 2010). The uniqueness of the MAC address for each Bluetooth device makes it possible to read this unique number at an upstream location and then as the Bluetooth device passes another Bluetooth transceiver at a downstream location, its MAC address is recoded again. By matching the MAC address at the two locations, information in relation to travel time and Origin-Destination can be extracted (Blogg et al., 2010).

Upon the detection of a Bluetooth device by a roadside Bluetooth transceiver, the detection time is stamped. When the same MAC address is detected at another point downstream, the detection time at the second point is also stamped. The time difference between the two observations can be used to estimate the travel time (Araghi et al., 2014).

In addition to the average travel time, the detection and recording of the Bluetooth MAC addresses at two different locations can be utilised to supply vehicle Origin-Destination data (Blogg et al., 2010). This data can be used to generate the Origin-Destination matrix when the MAC-Volume ratio is known (Carpenter et al., 2012). However, issues such as multiple detections, dropped signals, and outliers are observed in different trials (Carpenter et al., 2012, Chitturi et al., 2014, Porter et al., 2013).

Chitturi et al. (2014) have studied the Bluetooth-Based Origin-Destination data at the Park Street interchange with the Beltline freeway (US 12/18) in Madison, Wisconsin, USA. The study which was conducted for the Wisconsin Department of Transportation used the Bluetooth and manual traffic volume counts at the aforementioned interchange for a one week period in July 2012 to compare and validate the Bluetooth acquired data (Chitturi et al., 2014).

The results from the comparison of manual traffic counts and Bluetooth counts at the interchange of Park Street with Beltline Freeway in Madison, Wisconsin, showed that the Bluetooth capture rates varied from 2.3% to 7.2% (Chitturi et al., 2014).

3. ADELAIDE BLUETOOTH TRAFFIC DATA COLLECTION SYSTEM

For South Australian freeways, there are systems available which can monitor speeds and detect incidents. The high expense associated with these facilities is justified for critical segments of road infrastructure; however, considering the number and length of arterial roads, it is not possible to justify the freeway type of measurement systems for a large scale arterial road network. Regardless of financial matters, compatibility of freeway type measurement facilities, which are designed for free-flow speed operation, is another constraint for the utilisation of freeway type devices on metropolitan road networks, particularly during the peak hours, when the free-flow operations are rare. In South Australia, this gap was filled by utilising the Bluetooth traffic data collection system, making it possible for nearly 700 km of arterial roads to be monitored, by installing over 280 Bluetooth transceivers with a considerably low cost (Cox, 2014).

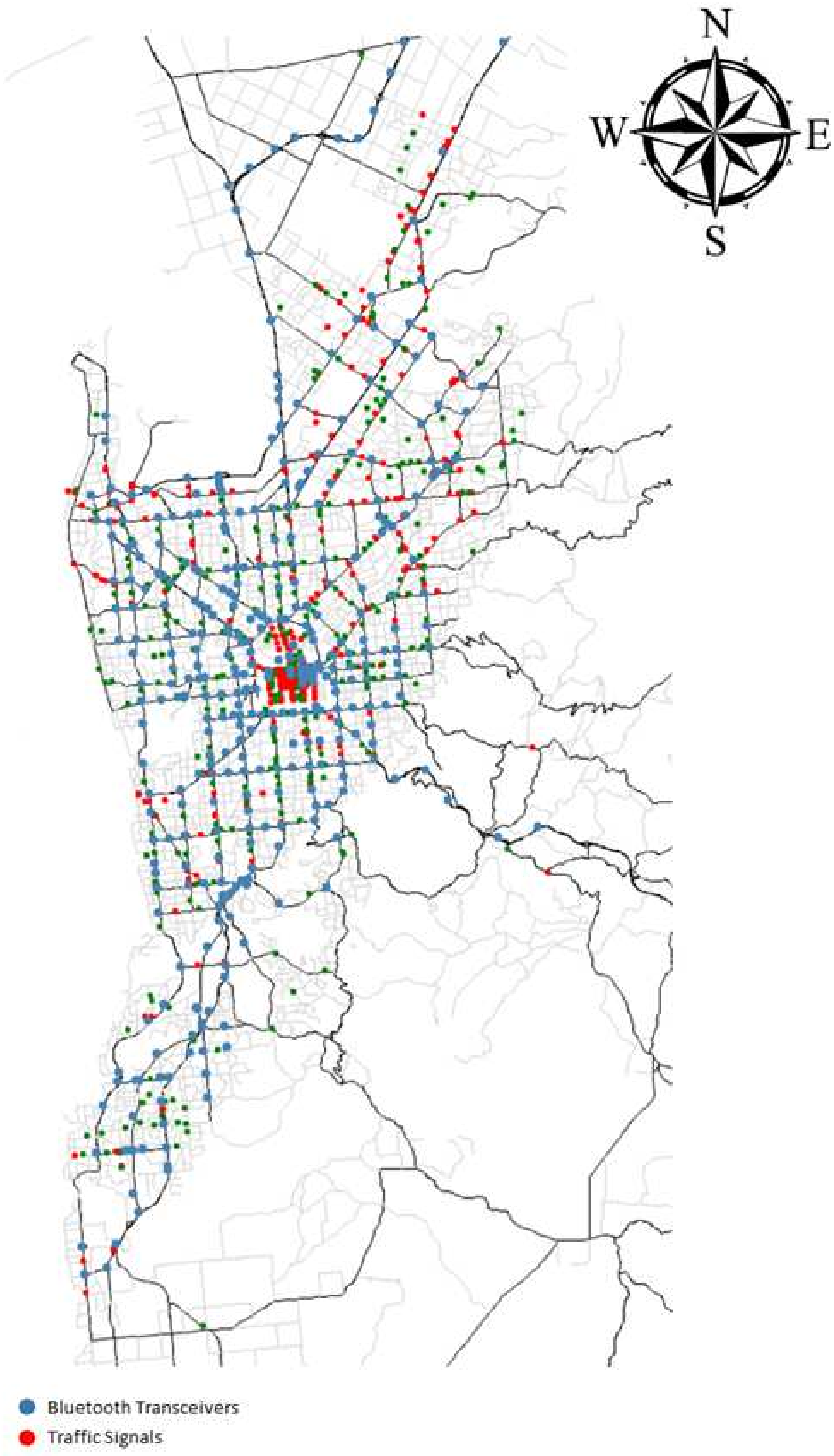

Figure 1: Extent and Locations of the installed Bluetooth Transceivers within the Adelaide Metropolitan Area

According to Cox (2014), the hardware is mostly sourced from Micro Connect, a manufacturer of SCATS compatible traffic signal communication devices. Micro Connect devices are commonly used in countries which use SCATS system.

Adelaide's Bluetooth traffic data collection system has a desktop application to extract origin-destination data, analyse the routes used by vehicles to travel between distant destinations and to plot time series profiles of travel times between any two Bluetooth transceivers in the network. The software also includes many features to analyse flow data from SCATS that can be coupled with the travel time data to generate statistics such as vehicle-hour delay, total travel time, and total vehicle-kilometres travelled for any subarea in the network (Cox, 2014).

Figure 1 depicts the extent and locations of the installed Bluetooth transceivers in Adelaide Metropolitan Area.

4. RESEARCH METHODOLOGY

4.1. SITE SELECTION

As specified earlier, the aim of this research is to study the Bluetooth acquired Origin-Destination data for the determination of the through movement percentage of total approach volume.

In this research, ten intersections are randomly selected across the Adelaide arterial road network where Bluetooth transceivers are installed. Both upstream and downstream locations of the selected intersections are also equipped with Bluetooth transceivers.

Table 1 provides information in relation to the selected intersections and their locations.

Table 1: Randomly Selected Intersection across the Adelaide Metropolitan Area

No.	Int. ID	Intersecting Roads	Suburb
1	TS35	South Road / Torrens Road	Croydon
2	TS37	Port Road / Park Terrace / Adam Street	Hindmarsh
3	TS99	Anzac Highway / Marion Road	Plympton
4	TS108	South Road / Daws Road	Edwardstown
5	TS118	Morphett Road / Sturt Road	Oaklands Park
6	TS124	Oaklands Road / Diagonal Road	Warradale
7	TS165	Main South Road / Flaxmill Road / Wheatsheaf Road	Morphett Vale
8	TS241	Main South Road / Beach Road / Doctors Road	Morphett Vale
9	TS251	Grand Junction Road / Eastern Parade	Ottaway
10	TS331	Main North Road / Elder Smith Road / Maxwell Road	Para Hills West

4.2. DATA

Bluetooth data is extracted from AdInsight ver 2.0.1.20, utilised by the South Australian Department of Planning, Transport and Infrastructure (DPTI). The number of Bluetooth counts for through movement is extracted by selecting the immediate upstream location as origin and the immediate downstream location on the same direction as destination. The number of Bluetooth counts from the Origin to the intersection is extracted in a similar manner with the difference of selecting the Bluetooth transceiver at the intersection itself as the destination. The proportion of through movement, as estimated from the Bluetooth system, is the first divided by the latter device counts.

The most recent Manual Turning Movement Surveys for each of the intersections are used as the baseline. The number of through movement and the total number of vehicles travelling to the intersection from the same approach arm, as in the Bluetooth device counts, will be used for comparison. The proportion of through movement for each arm, based on the Manual Turning Movement Survey, is the number of through movements, originated from an approach arm of the intersection divided by the summation of movements, originated from the same approach arm.

4.3. VALIDATION TEST FOR MANUAL TURNING MOVEMENT SURVEY

Paired comparison t-test as introduced by William Sealy Gossett in 1908 is known to be a common method for comparing two sets of data, which are the results of two different tests on an object (Ankarali et al., 2012, Hedberg and Ayers, 2015, Linnet, 1999). To test the accuracy of the through movement percentage of the total approach volume, we have used a paired comparison t-test between the outcomes resulted from the most recent Manual Turning Movement Survey and the results obtained from the available Manual Turning Movement Survey immediately prior to the most recent, which we have called the second most recent. Dates of the two most recent Manual Turning Movement Surveys for each of the selected intersections are provided in Table 2.

Table 2: Dates of the Two Most Recent Manual Turning Movement Surveys

No.	Int. ID	Date of the Most Recent Manual Turning Movement Survey	Date of the Manual Turning Movement Survey Immediately before the Most Recent Survey
1	TS35	21 May 2014	26 November 2013
2	TS37	6 November 2014	2 August 2011
3	TS99	12 May 2015	29 November 2011
4	TS108	30 June 2015	26 October 2011
5	TS118	25 March 2015	4 April 2012
6	TS124	6 November 2014	13 May 2010
7	TS165	3 March 2015	3 February 2011
8	TS241	24 February 2015	23 September 2010
9	TS251	5 June 2014	21 June 2011
10	TS331	30 July 2014	27 October 2010

Shapiro-Wilk test of normality has been performed on the set of data for the difference between the percentages of through movements based on the most recent and the second most recent manual turning movement surveys for each of the corresponding movements for each of the studied intersections. At 5% level of significance, Shapiro-Wilk test of normality fails to reject the assumption that the data is from normal populations. In other words, the data is assumed to be from normal populations.

With the data for the difference between the percentages of through movements based on the recent and the second most recent manual turning movement surveys assumed normal, paired comparison t-test has been performed to compare the percentages of through movements based on the most recent and the second most recent manual turning movement surveys. Based on the results from paired comparison t-test at 5% level of significance, not enough statistical evidence was found to claim a difference between the percentages of through movements resulted from the most recent manual survey and the one immediately before the most recent. 15-minute profiles also show consistency between the two sets of data. This consistency is used as evidence for the accuracy of the most recent manual survey.

4.4. COMPARISON BETWEEN MANUAL TUNING MOVEMENT SURVEY DATA AND BLUETOOTH ACQUIRED DATA

Upon accepting the accuracy of the most recent Manual Turning Movement Survey data, results obtained from the most recent Manual Turning Survey against those obtained from the Bluetooth technology are compared.

As mentioned before, Ankarali et al. (2012), among others (Hedberg and Ayers, 2015, Linnet, 1999), believe that paired comparison t-test is one of the most popular methods for comparing two datasets in order to determine whether a statistically significant difference exists between the means of two datasets when the datasets are the results of two experiments on one object. In this research, using paired comparison t-test, percentages for through movements of the total approach volumes are analysed for the two discussed methods, i.e. one based on the Manual Turning Movement Survey data and the other based on the Bluetooth acquired data. In this respect, the null hypothesis will be the existence of no difference between the percentages of through movements obtained from the Bluetooth acquired data and those obtained from the Manual Turning Movement Survey. The test will be run at 5% level of significance.

5. UTILISED SOFTWARE PACKAGES

IBM SPSS Statistics 22, developed by IBM Corporation, and Microsoft Excel 2010, developed by Microsoft Corporation are used for the purpose of data analysis.

6. ANALYSES AND RESULTS

Pair comparison t-test has been employed to compare the results for percentage of through movements based on Manual Turning Movement Survey and Bluetooth counts for fifteen-minute intervals from 7:00 AM to 6:00 PM for the days on which the most recent manual surveys have been conducted as specified in Table 2.

Details of paired comparison t-test, including the test of normality of data, are explained in Section 6.1 for movement 1 to 3 of TS99 as an example. Table 5 in Section 6.2 provides a summary of findings for the studied movements of the randomly selected intersections.

6.1. PAIRED COMPARISON T-TEST STEPS FOR MOVEMENT 1 TO 3 OF TS99

6.1.1. NORMALITY CHECK OF THE DATA FOR MOVEMENT 1 TO 3 OF TS99

Shapiro-Wilk test of normality has been performed on the set of data for the difference between the 15 minute interval through movement percentage based on the manual turning movement survey and the Bluetooth acquired data for the period between 7:00 AM to 6:00 PM for movement 1 to 3 of TS99.

With a P-Value of 0.181, Shapiro-Wilk test of normality fails to reject the assumption that the data is from normal populations at 5% level of significance.

Figure 2 illustrates the normal Q-Q Plot of the difference between the percentages of through movements obtained from the most recent manual turning movement survey and the Bluetooth technology for movement 1 to 3 of TS99 for the data collected on 12 May 2015.

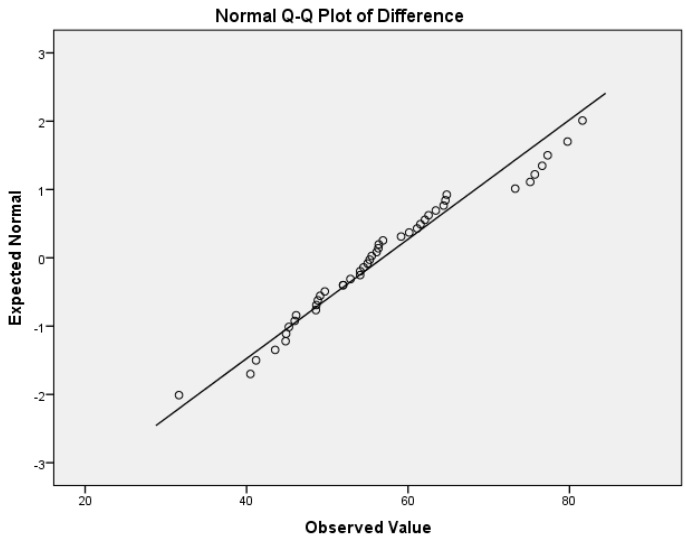

Figure 2: Normal Q-Q Plot of Difference between the Bluetooth Method and the Manual Method – Movement 1 to 3 of TS99

Based on the results from the Shapiro-Wilk test of normality and the Normal Q-Q Plot, the data is assumed normal and appropriate for paired comparison t-test.

6.1.2. HYPOTHESES TESTING FOR MOVEMENT 1 TO 3 OF TS99

i. Hypotheses:

H_0: $\mu_D = 0$

H_1: $\mu_D \neq 0$

ii. Significance Level: The test is run at 5% level of significance, i.e. α=0.05.

iii. Assumptions:

The data arise as follows:

Treatment 1: $x_{11}, x_{12}, x_{13}, \dots \dots, x_{1n}$

Treatment 2: $x_{21}, x_{22}, x_{23}, \dots \dots, x_{2n}$

where pair (x_{1i}, x_{2i}) are observations made on the same subject.

Data is assumed to be from normal populations as per the results of the S-W test, explained in Section 6.1.1.

iv. Test Statistic:

Tables 3 and 4 provide the results of Descriptive Statistics and One-Sample Test (t-test) for paired comparison (difference) between the results for through movement percentage based on the most recent manual turning movement survey and the Bluetooth data for 15 minute intervals between 7:00 AM to 6:00 PM.

Table 3: One Sample Descriptive Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Difference	44	56.8791	11.44567	1.72550

Table 4: One-Sample Test

	Test Value = 0					
			Sig.	Mean	95% Confidence Interval of the Difference	
	t	df	(2-tailed)	Difference	Lower	Upper
Difference	32.964	43	.000	56.87909	53.3993	60.3589

Results of the analysis presented in Table 4 show the t statistic of 32.964 and a P-Value of 0.000. The 95% Confidence Interval has lower and upper limits of 53.39 and 60.35 respectively.

v. Decision Rule:
If P-Value ≤ α then H_o is rejected.
If P-Value > α then the test fails to reject H_o.

$$\begin{cases} P - Value = 0.000 \\ \alpha = 0.05 \end{cases}$$

vi. Managerial claim:
At 5% level of significance, there is enough statistical evidence to claim that there is a difference between the results of the percentage of through movements resulted from the manual turning movement survey and the percentage of through movements resulted from the Bluetooth data for movement 1 to 3 of TS99.

6.2. PAIRED COMPARISON T-TEST RESULT SUMMARY FOR ALL STUDIED MOVEMENTS OF THE RANDOMLY SELECTED INTERSECTIONS

Results of the paired comparison t-test, performed on the data for the percentage of through movement of total approach volumes obtained from the most recent manual turning movement survey and the Bluetooth method for each of the studied movements at each of the randomly selected intersections, are summarised in Table 5.

Table 5: Paired Comparison Results for 15 Minute Interval Through Movement Percentage of the Total Approach Volume Based on the Manual Turning Movement Survey and the Bluetooth Acquired Data for 7:00 AM to 6:00 PM

Int. ID	Movement	Normal Data Based on S-W Test	t-Statistics	Degree of Freedom	P-Value	Statistical Evidence for Difference Exists
TS-35	1 to 3	Yes	-11.86	43	0.000	Yes
	3 to 1	Yes	-12.144	43	0.000	Yes
	2 to 4	Yes	-6.081	43	0.000	Yes
	4 to 2	Yes	-8.123	43	0.000	Yes
TS-37	1 to 3	Yes	3.855	43	0.000	Yes
	3 to 1	Yes	-3.050	43	0.004	Yes
	2 to 4	Yes	-7.640	43	0.000	Yes
	4 to 2	Yes	-3.554	43	0.001	Yes

Table 5 (Cont'd): Paired Comparison Results for 15 Minute Interval Through Movement Percentage of the Total Approach Volume Based on the Manual Turning Movement Survey and the Bluetooth Acquired Data for 7:00 AM to 6:00 PM

Int. ID	Movement	Normal Data Based on S-W Test	t-Statistics	Degree of Freedom	P-Value	Statistical Evidence for Difference Exists
TS-99	1 to 3	Yes	32.96	43	0.000	Yes
	3 to 1	Yes	5.49	43	0.000	Yes
	2 to 4	Yes	-7.88	43	0.000	Yes
	4 to 2	Yes	-5.32	43	0.000	Yes
TS-108	1 to 3	Yes	3.315	43	0.002	Yes
	3 to 1	Yes	7.744	43	0.000	Yes
	2 to 4	Yes	13.105	43	0.000	Yes
	4 to 2	Yes	3.515	43	0.001	Yes
TS-118	2 to 4	Yes	5.983	43	0.000	Yes
	4 to 2	Yes	8.425	43	0.000	Yes
TS-124	1 to 3	Yes	10.205	43	0.000	Yes
	3 to 1	Yes	3.238	43	0.002	Yes
TS-165	1 to 3	Yes	-5.424	43	0.000	Yes
	3 to 1	Yes	-0.193	43	0.848	**No**
TS-241	1 to 3	Yes	3.431	43	0.001	Yes
	3 to 1	Yes	2.851	43	0.007	Yes
TS-251	1 to 2	Yes	1.550	43	0.128	**No**
	2 to 1	Yes	12.521	43	0.000	Yes
TS-331	1 to 3	Yes	3.299	43	0.002	Yes
	3 to 1	Yes	13.358	43	0.000	Yes

Table 5 shows that for movement 3 to 1 of TS165 and movement 1 to 2 of TS251, the difference between the results from Manual Survey and the Bluetooth data for through movement percentage was not significant. It should, however, be noted that paired comparison t-test compares the means of two datasets. While existence of statistical evidence for the difference in the means is used to reject the claim that the two datasets are consistent, the absence of statistically significant difference in the means fails to reject the claim that the two datasets are consistent; however, it does not prove consistency between the two datasets. In this respect, fifteen-minute interval profiles are drawn for the percentages of through movements based on Bluetooth acquired data compared against the manual turning movement survey. Figure 3 and Figure 4 show the profiles for movement 3 to1 of TS165 and movement 1 to 2 of TS251 respectively.

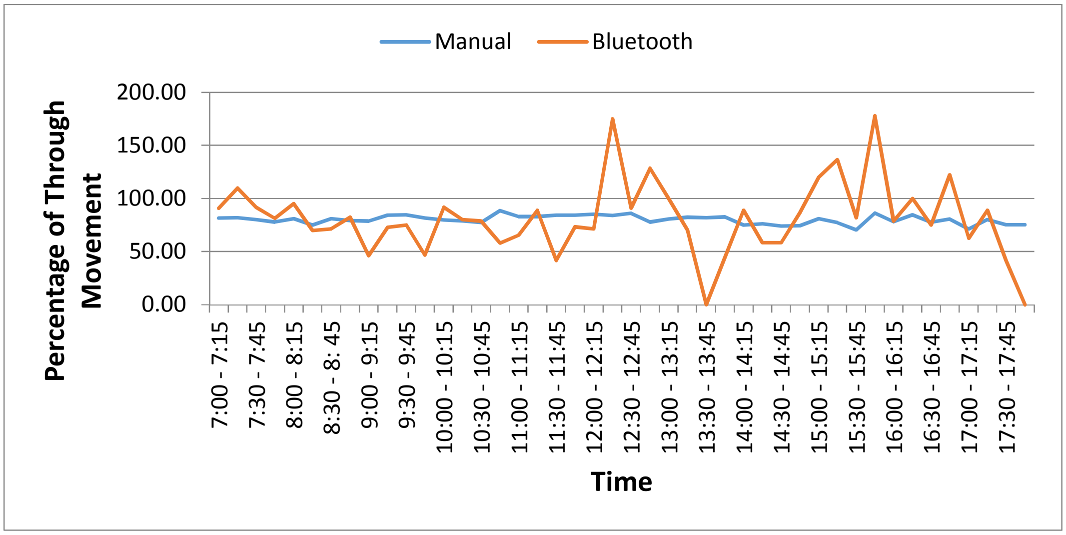

Figure 3: Through Movement Percentage Profiles – Movement 3 to 1 of TS165

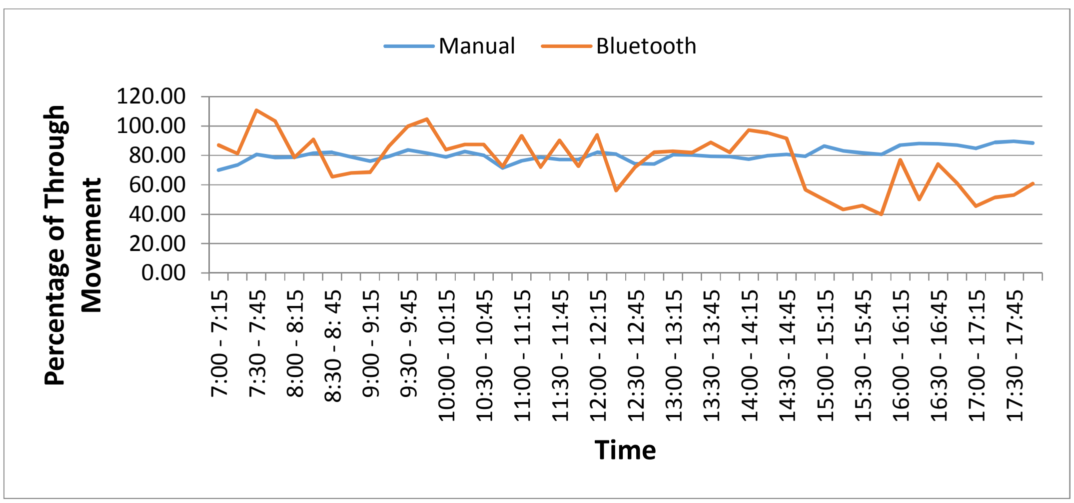

Figure 4: Through Movement Percentage Profiles – Movement 1 to 2 of TS251

7. CONCLUSIONS AND RECOMMENDATIONS

In this research, the most recent Manual Turning Movement Survey for each of the ten randomly selected intersections has been compared against the second most recent Manual Turning Movement Survey. The one sample t-test (paired comparison) and the fifteen minute interval profiles of through movement percentages showed consistency in the two sets of manual surveys. This exercise has been performed to show the accuracy of the manual survey data to be used as the baseline data.

This research showed that for 26 out of 28 through movements at 10 randomly selected intersections across the Adelaide Metropolitan Area, the difference between the percentages for through movements of total approach volumes, resulted from the Manual Turning Movement Survey data and the Bluetooth data, is statistically significant at 5% level of significance, using paired comparison t-test.

The two movements, i.e. movement 3 to 1 of TS165 and movement 1 to 2 of TS251, for which the significance of difference in the results obtained from Bluetooth data and Manual Turning Movement Survey was not observed in the paired comparison t-test, were further analysed. For both movements, the fifteen minute interval profiles showed that the existence of positive and negative fluctuations in the analysed data made the means of the percentages for through movement of total approach volumes obtained from the Bluetooth data and the Manual Survey not have a statistically significant difference. However, as illustrated in the profiles, this failure in rejecting the absence of difference in the means does not provide enough evidence to accept the existence of consistency between the two datasets.

This research suggests that more investigations, analyses, adjustments and calibrations should be undertaken for using the Origin-Destination data obtained from the Bluetooth traffic data collection systems. Results of such analyses, adjustments and calibrations may contribute in forming installation manuals, to be used by road authorities, in order to improve the Bluetooth-based Origin-Destination information.

While the causes for the inconsistencies in O-D information can be sought in different influencing factors, including the location of the Bluetooth transceivers and existence of interfering infrastructures, variations in the Bluetooth capture rates at different locations are recommended to be studied as the underlying cause for the inconsistency in the Bluetooth O-D information.

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