How Reliable Is the Bluetooth-Based Origin-Destination Data?

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ABSTRACT

The Origin-Destination data have always been considered as the core information in transport modelling and planning as they make it possible to understand the movement patterns in a particular area of interest, during a particular period of time.

Advancements in wireless communications, in particular Bluetooth technology, made it possible for transport engineers to utilise this technology for traffic data collection. Recording the unique Media Access Control number, assigned individually to each Bluetooth device, at critical locations can provide valuable information about the traffic patterns such as Origin-Destination data.

This paper investigates the reliability of 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 sites 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 has found that further improvements are required before Bluetooth-based Origin-Destination data can be reliably used at a large scale.

Keywords: Bluetooth, Origin-Destination data, ITS

INTRODUCTION

The Origin-Destination studies have always been at the focal point of transport simulation, modelling and planning as they make 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 feeds into 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 known to be 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 examine the reliability of Bluetooth Acquired Origin-Destination data for the determination of through movement percentage at randomly selected signalised intersections within the Adelaide Metropolitan Area.

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). The MAC address serves as an electronic nickname so that electronic devices can keep track of who is who during data communications (Haghani et al., 2010). 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. 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).

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[1] (Cox, 2014).

According to Cox (2014), The hardware is mostly sourced from Micro Connect, a manufacturer of SCATS[2] 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.

[1] The coverage of 900 segments of roads, with 675 km of arterial roads, required hardware which cost less than A$300,000.00 (Cox 2014, p3).

[2] Sydney Coordinated Adaptive Traffic System

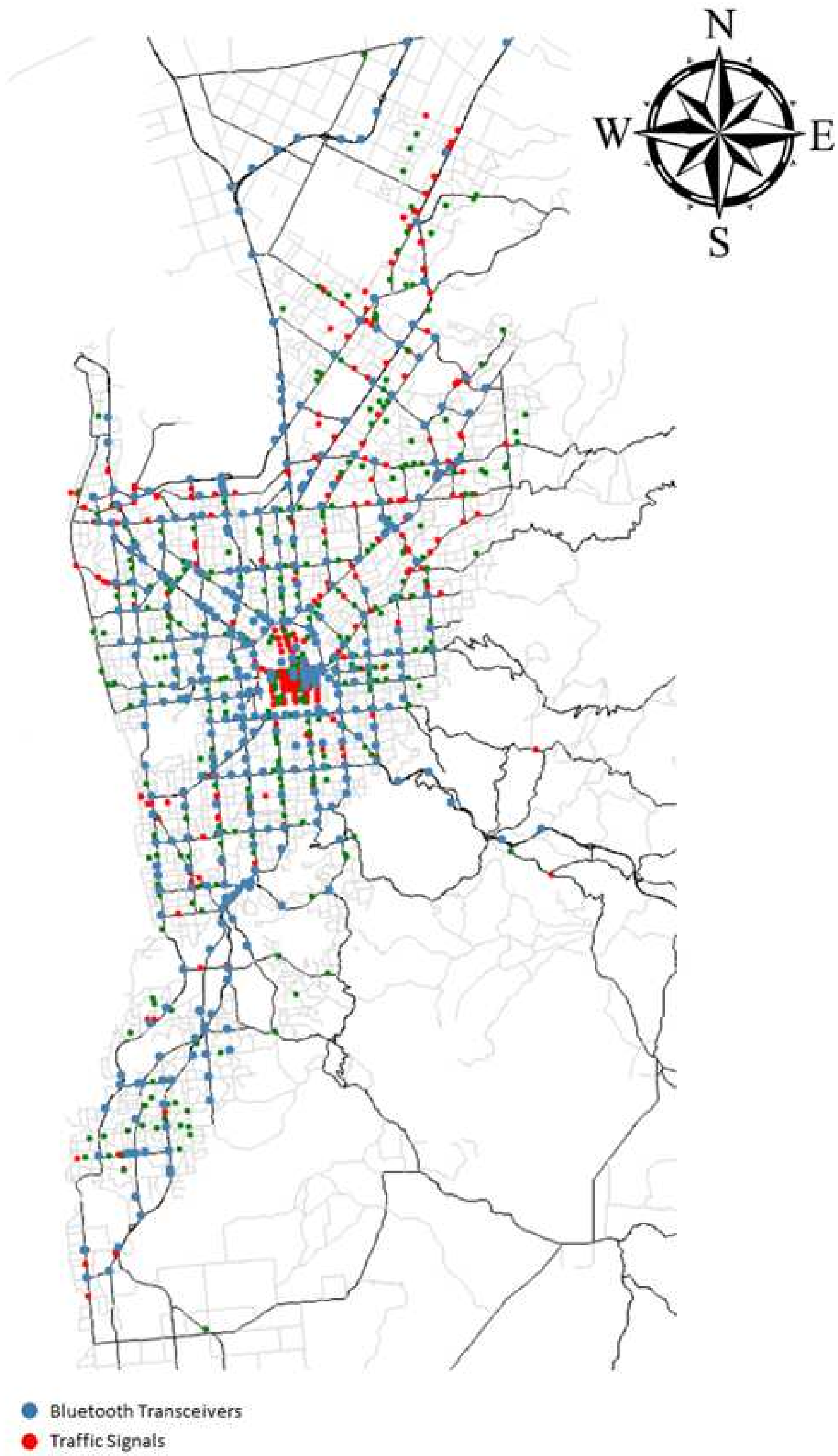

Figure 1: Extent and Locations of the installed Bluetooth Transceivers within the Adelaide Metropolitan Area

RESEARCH METHODOLOGY

As specified earlier, the aim of this research is to test the reliability of Bluetooth acquired Origin-Destination data for the determination of the through movement percentage.

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 Intersections across the Adelaide Metropolitan Area

No.	Int. ID[3]	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

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

[3] This is the intersection ID within the Adelaide Metropolitan Road Network

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.

Validation Test for Manual Turning Movement Survey

Paired comparison t-test 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). To test the accuracy of the through movement percentage, 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[4]	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

The results from the t-test at 5% level of significance and the 15-minute profiles show consistency between the two sets of data[5]. This consistency is used as evidence for the accuracy of the most recent manual survey.

Comparison between Manual Turning Movement Survey Data and Bluetooth Acquired Data

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

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

[4] This is the intersection ID within the Adelaide Metropolitan Road Network

[5] Inconsistencies were observed for the percentage of through movements at a couple of intersections based on the most recent and the second most recent manual surveys. The inconsistencies were identified to be due to the change in the layout (Southern Expressway Duplication) and not due to an inaccuracy in the surveys.

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 of through movements 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.

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.

Analyses and Results

Pair comparison t-test has been employed to compare the results for percentage of through movements based Manual Turning Movement Survey and Bluetooth counts for fifteen-minute intervals from 7:00 AM to 6:00 PM for the days of the most recent manual survey, as specified in Table 2. The results of this comparison is summarised in Table 3.

Table 3: Paired Comparison Results for 15 Minute Interval Through Movement Percentage Based on the Manual Turning Movement Survey and the Bluetooth Acquired Data for Daylight hours, i.e. 8:00 AM to 6:00 PM

Int. ID	Movement	t-Statistics	Degree of Freedom	P-Value	Statistical Evidence for Difference Exists
TS-35	1 to 3	-11.86	43	0.000	Yes
	3 to 1	-12.144	43	0.000	Yes
	2 to 4	-6.081	43	0.000	Yes
	4 to 2	-8.123	43	0.000	Yes
TS-37	1 to 3	3.855	43	0.000	Yes
	3 to 1	-3.050	43	0.004	Yes
	2 to 4	-7.640	43	0.000	Yes
	4 to 2	-3.554	43	0.001	Yes
TS-99	1 to 3	32.96	43	0.000	Yes
	3 to 1	5.49	43	0.000	Yes
	2 to 4	-7.88	43	0.000	Yes
	4 to 2	-5.32	43	0.000	Yes
TS-108	1 to 3	3.315	43	0.002	Yes
	3 to 1	7.744	43	0.000	Yes
	2 to 4	13.105	43	0.000	Yes
	4 to 2	3.515	43	0.001	Yes
TS-118	2 to 4	5.983	43	0.000	Yes
	4 to 2	8.425	43	0.000	Yes

Table 3 (Cont'd): Paired Comparison Results for 15 Minute Interval Through Movement Percentage Based on the Manual Turning Movement Survey and the Bluetooth Acquired Data for Daylight hours, i.e. 8:00 AM to 6:00 PM

Int. ID	Movement	t-Statistics	Degree of Freedom	P-Value	Statistical Evidence for Difference Exists
TS-124	1 to 3	10.205	43	0.000	Yes
	3 to 1	3.238	43	0.002	Yes
TS-165	1 to 3	-5.424	43	0.000	Yes
	3 to 1	-0.193	43	0.848	**No**
TS-241	1 to 3	3.431	43	0.001	Yes
	3 to 1	2.851	43	0.007	Yes
TS-251	1 to 2	1.550	43	0.128	**No**
	2 to 1	12.521	43	0.000	Yes
TS-331	1 to 3	3.299	43	0.002	Yes
	3 to 1	13.358	43	0.000	Yes

Table 3 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 only fails to reject (does not prove) the claim that the two datasets are consistent. 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 2 and Figure 3 show the profiles for movement 3 to1 of TS165 and movement 1 to 2 of TS251 respectively.

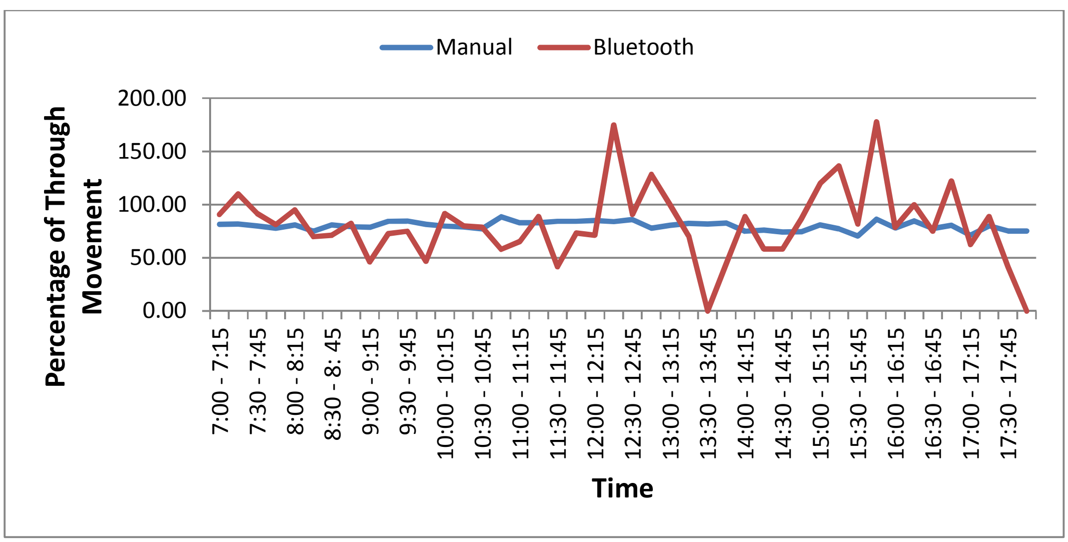

Figure 2: Through Movement Percentage Profiles – Movement 3 to 1 of TS165

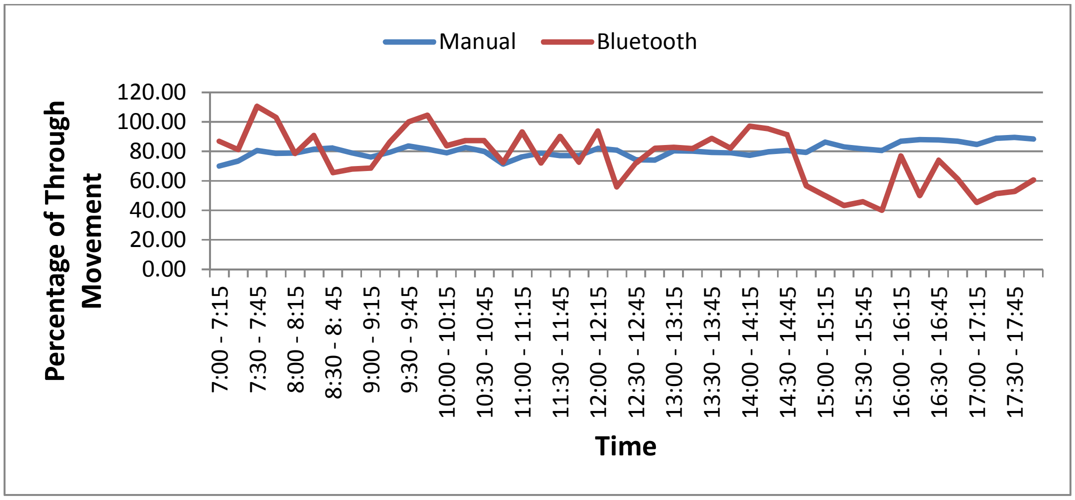

Figure 3: Through Movement Percentage Profiles – Movement 1 to 2 of TS251

As shown in both Figure 2 and Figure 3, the percentages obtained from Bluetooth data for 3 to1 movement of TS165 and 1 to 2 movement of TS251 have considerable fluctuations in the fifteen minute interval profiles. Because these fluctuations are both positive and negative around the mean of percentages from manual survey, the one sample t-test could not determine a significant difference.

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 of through movements, 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 Bluetooth percentages made the means of the percentages 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, i.e. Bluetooth-Based traffic data and the Manual Turning Movement Survey.

The author acknowledges that the main application of the Bluetooth traffic data collection system in Adelaide, installed and utilised by the South Australian Department of Planning, Transport and Infrastructure, has been assessments and analyses based on the average travel time calculations. Origin-Destination information obtained from the Bluetooth traffic data collection system, while not the main purpose behind installing the Bluetooth traffic data collection system in Adelaide, can, however, provide valuable information, if the data present an acceptable degree of reliability.

This research suggests that more investigations, analyses, adjustments and calibrations should be undertaken before the Origin-Destination data obtained from the Bluetooth traffic data collection systems can be reliably used.

Results of such analyses, adjustments and calibrations may contribute in forming installation manuals, to be used by road authorities, in order to achieve an acceptable degree of reliability in the Bluetooth-Based O-D information generation.

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 is recommended to be studied as the underlying cause for the inconsistency in the Bluetooth O-D information.

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