Travel Time Reliability Estimation using GPS and GIS Integration

By

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DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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ABSTRACT

The evaluation of road network performance in traffic management is certainly important as it could have profound effects on the transportation pricing, economy as well as commuter confidence. Furthermore, the spatial characteristics of traffic data allows for the use of Geographic Information System (GIS) and Global Positioning System (GPS) in the analysis of traffic.

In this study, the travel time duration and reliability for the different routes with the same start and stop points was analysed and compared. The routes which are Marion Road and South Road have slightly different characteristics and are located in Metropolitan Adelaide. This was done with the aim of estimating the travel time duration as well as the reliability of it estimate.

This was carried out by calculating various traffic parameters such as travel time duration and traffic indices using data acquired via GPS. This was subsequently analysed using Quantum GIS (QGIS) software. The congestion indices which include mean velocity, acceleration noise, proportion stopped time and congestion index were calculated and compared for the two routes for different periods of the day.

Results revealed no statistical different in the congestion indices of the two routes. However, the Marion Road routes features lower travel time as a result of its shorter length as well as less number of intersections and links.

Key words: Travel Time Reliability, Congestion, Spatial Analysis, GPS, GIS.

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CHAPTER I: INTRODUCTION

1.0 Background of the Study

It is an established fact that travel time reliability is one of the most important concerns to the traveller (De Jong et al. 2007). For this reason, it is necessary to evaluate the performance of the various time travel estimation methods available today. The importance of time travel estimation as well as its impact on travel cost and tolling has been established by various researchers. Brownstone & Small (2005) highlighted the importance of time travel reliability on road pricing. Needless to say, the performance of time travel estimation methods could have profound implications on transportation pricing and commuter confidence. The spatial characteristics of traffic data allow for the development of Geographic Information Systems (GIS) and Global Position Systems (GPS) based travel time estimation methods.

The introduction and development of GIS and GPS has brought about diverse changes and possibilities. Over the years, various GIS and GPS based time travel estimation methods have been developed. Morgul et al. (2013) conducted a study in which GPS data from multiple sources was used to develop time travel estimation for urban networks. Similarly Hadachi (2013) carried out a study where sparely sampled GPS data was used to estimate travel time. Jenelius and Koutsopoulos (2013) presented a statistical model for the urban road network travel time estimation using vehicle trajectory obtained from low frequency GPS probes. These and many more studies demonstrate the applicability of GIS and GPS to travel time estimation.

1.1 Problem Statement

Factors such as congestion, accidents, and unforeseen road closure amongst others contribute to the stochastic nature of the vehicular movement duration. An analysis of the factors influencing travel time estimation shows that these factors can be broadly classified into reoccurring and random factors. Reoccurring factors have the most effect in the morning and the evening (peak periods) where there is huge traffic volume. It is not uncommon to see a 20 minutes journey in off peak periods, take 30 minutes in peak periods. On the other hand, random events such as accidents, unforeseen road closures etc. also contribute to the challenging estimation of travel time. These random events increase not only travel time but also the stochasticity of travel time. This makes the estimation of travel time challenging as well as contributes to the unreliability of current methods of travel time estimation.

1.2 Objectives of the Study

The aim of this study is to estimate travel time and its reliability in Metropolitan Adelaide, using a GPS based model. By utilizing GPS positional data and mathematical modeling techniques, accurate travel time estimates can be obtained. This will be carried out using GPS positional data from both peak and off peak period in selected routes within Metropolitan Adelaide. Data will be obtained during fieldwork by the student who plies the routes.

1.3 Significance of the Study

As previously discussed, the reliability of travel time estimates is crucial. This makes the need for accurate time estimation considerably significant. Data acquired from GPS (2017) reveals that on the average, working commuters lose 2.6% of their annual income amounting $1,344 to congestion each year. It is also estimated that commuters also in the city of Adelaide, spend up to 42% of travel time during peak periods (Nankervis, 2017). It is therefore desirable that this situation is corrected so that commuters can enjoy higher levels of productivity and standard of living.

City	Morning Peak Congestion (Extra Travel Time)	Average Commute to Work (Mins)	Extra Time Taken to Travel to Work Per Day (Mins)[1]	Working days (Per Year)	Extra Time Taken to Travel to Work Per Year (Weeks)[2]	Average Hourly Pay (Net After Tax)[3]	Earnings Lost to Congestion Per Year (Net After Tax)	% of Earnings Lost to Congestion Per Year
Sydney	66%	43.0	28.4	254	3.0	$27.52	$3,308.30	5.9%
Melbourne	52%	36.0	18.7	254	2.0	$27.27	$2,158.32	3.9%
Brisbane	43%	42.6	18.3	254	2.0	$25.18	$1,950.26	3.8%
Perth	44%	39.0	17.1	254	1.8	$26.36	$1,910.28	3.6%
Adelaide	42%	30.1	12.6	254	1.3	$25.16	$1,344.49	2.6%

Figure 1. Earnings lost to traffic congestion in major Australian cities. (GPS, 2017)

1.4 Outline of Following Sections

The succeeding sections in the study are

- Literature review – Where relevant literature, similar research in the same area, etc. is reviewed
- Methodology – Here, the study methodology will be developed and explained in detail.
- Results – In this section, results obtained from the resulting model is discussed.
- Conclusion – Conclusions and recommendations draw from the obtained results are discussed.

CHAPTER II: BACKGROUND AND LITERATURE REVIEW

2.0 Introduction

As a result of the alarming rate of increase in the number of vehicles on roads, the performance of urban road traffic systems has become a challenging issue for transportation planners, users as well as the entire urban community. The increase in traffic volumes and limited public resources has made all important to anticipate and plan for growth. Accuracy and reliability of collected traffic data allow for the definition of various performance measures (Tong, Merry, & Coifman, 2005). According to Taylor, (2013) "*travel time reliability has become a major issue for transport planners and transport system managers, to the extent that the predictability of travel time is now seen by many as a concomitant measure of performance along with an average travel time. No longer is it sufficient to know the expected time required to make a journey, but also knowledge of the possible variation in that travel time may be required*".

Over the last few decades, there has been a progressive shift away from conventional methods of traffic data accquisition and analysis such as the floating car method (Wardrop and Charlesworth, 1954) to modern technology based systems such as Bluetooth, GPS and GIS. This shift is primarily driven by factors such as increased access to these technologies, the need for cost efficient systems as well as the need for real time acquisition of traffic data as well as analysis.

As earlier sated, the accessibilities as well as reach, of the systems such as the Global Positioning System (GPS) and Bluetooth have increased partly due to the advent of smartphones. Various traffic engineering applications are being invented to make use of the GPS and Bluetooth technology. In order to reduce traffic congestion, it is important to have information about actual speeds, travel times on the road. This will, in turn, assist in planning and design and real-time traffic monitoring. It is, however, important to state that when used for civilian purposes, the GPS system provides results that are less accurate than obtained for military purposes. The GPS system which is maintained by the U.S Department of Defence (DoD) strives to provide an accuracy of +- 7.8m in civilian applications around 95% of the time. However, typical accuracies of the GPS system exceed this specification, with GPS (2017) reporting that GPS enabled smartphones are accurate to within -+4.9m 95% of the time. GPS (2017) also reports that global average User Range Error (URE) was less than 0.175m, 95% of the time. General access to the system may be cut off by the DoD during military operation (Lin, Zito, & Taylor, 2005).

Today, travel time reliability is an important aspect of transportation management and forecasting. Travel time reliability is of utmost importance to travelers with countries such as The Netherlands, United Kingdom and the United States of America making significant efforts to improve time travel reliability (Li, Hensher, & Rose, 2010)

2.1 Bluetooth in Traffic Analysis

Although the use of Bluetooth technology for traffic analysis purposes such as Origin – Destination (OD) survey and travel time estimation is relatively new, several studies have been carried out to assess its potential as a cost effective method of traffic data acquisition and analysis. Studies such as Blogg et al. (2010), Haghani et al. (2010), Araghi et al. (2014) have extensively demonstrated the ability of Bluetooth to serve as a viable source of traffic data.

Essentially, most of the Bluetooth traffic data systems have the same components and rely on the detection of the unique 48 bit Bluetooth Media Access Control (MAC) address of devices such as inbuilt Bluetooth receivers, Smartphones, Laptops etc. by Bluetooth detection devices strategically placed along the route of interest. However, these unique are not stored in a central database for privacy reasons but are instead converted into an ID for processing and future referencing purposes (Haghani, 2010). Privacy concerns can also be overcome by the use of character filtering of the MAC address, which entails the storage of a few of the characters of the MAC addresses whilst allowing very high level of certainty matches (Blogg, 2010). Bluetooth technology allows for the wireless transfer of information between the ranges of 1 – 100m depending on the class of technology (Haghani, 2010). These Bluetooth devices transmit their MAC addresses in "inquiry" mode to these receivers hereby enabling the travel times to be calculated based on the space between station and the time expended. Fig 2 shows the Bluetooth traffic monitoring concept.

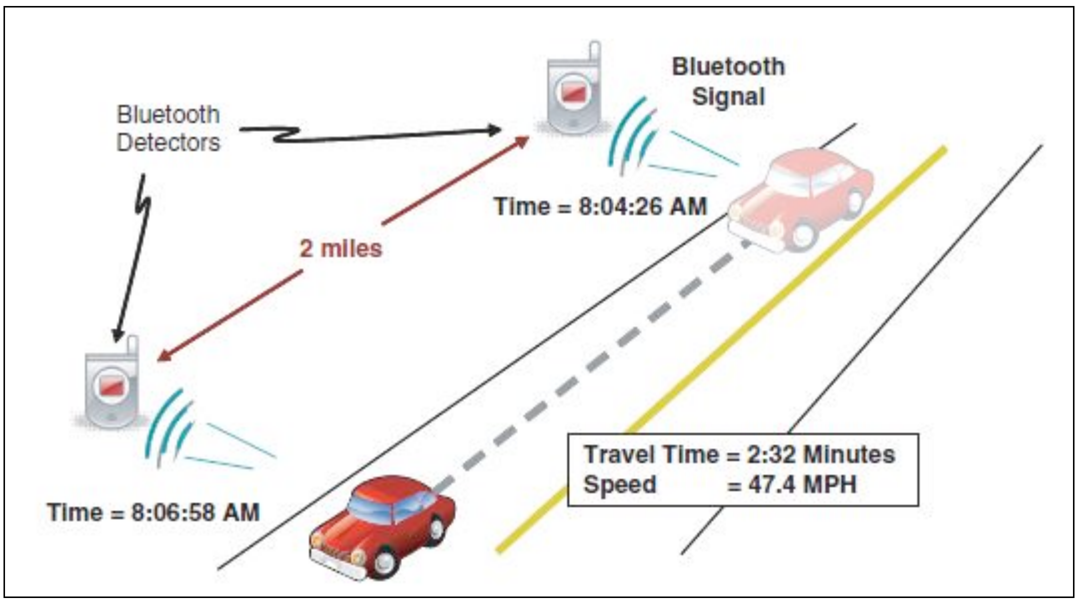


Figure 2. Bluetooth Monitoring Concept. (Haghani, 2010)

As stated earlier, although the use of Bluetooth in traffic studies is a novel, cost effective method of traffic data acquisition, it is not without its limitations. The consequences of limitations such as relatively low sampling rate and position detection error have been researched and documented in the studies highlighted above. Studies comparing the ground truth data obtained from Bluetooth detection sources with conventional traffic data analysis such as the floating car technique have also been carried out, with results indicating that Bluetooth technology can serve as an accurate source of traffic data (Araghi et al, 2014).

Friesen (2014) described a reference Bluetooth intelligent traffic system (ITS) design using relatively simple components which included an Arduino Uno development board, an Xbee module and a Bluetooth module both of which are connected to the development board. This system which is pictured in Fig 3, uses a 3 - layer system of information transmission. Here, traffic data gathered from various Bluetooth sensors is gathered and transmitted using the XBee protocol to a master node. From there, it is finally transmitted to a master server via GSM, where processing and analysis is executed. This system was implemented successfully, with test results revealing that traffic data was successfully obtained at traffic speeds of up to 80Km/h. This shows that Bluetooth based Traffic Intelligent Systems can be successfully implemented using relatively cheap and easily accessible components. Intricate details of this basic design can be found in (Friesen, 2014). However, commercial systems intended for much larger purposes would require more expensive and reliable components. Nonetheless, it would still remain a cost effective option.

Blogg (2010) also identifies the critical factors of penetration rate, capture rate and MAC noise in the analysis of Bluetooth traffic systems. The penetration rate which is a measure of the number of available MAC devices is critical to establishing the maximum vehicle capture under ideal conditions while the capture rate is an aggregate measure of the factors affecting the capture of traffic data. Capture rate are obtained by comparing traffic counts to MAC hits. MAC noise concerns the capture of data from non – vehicular sources.

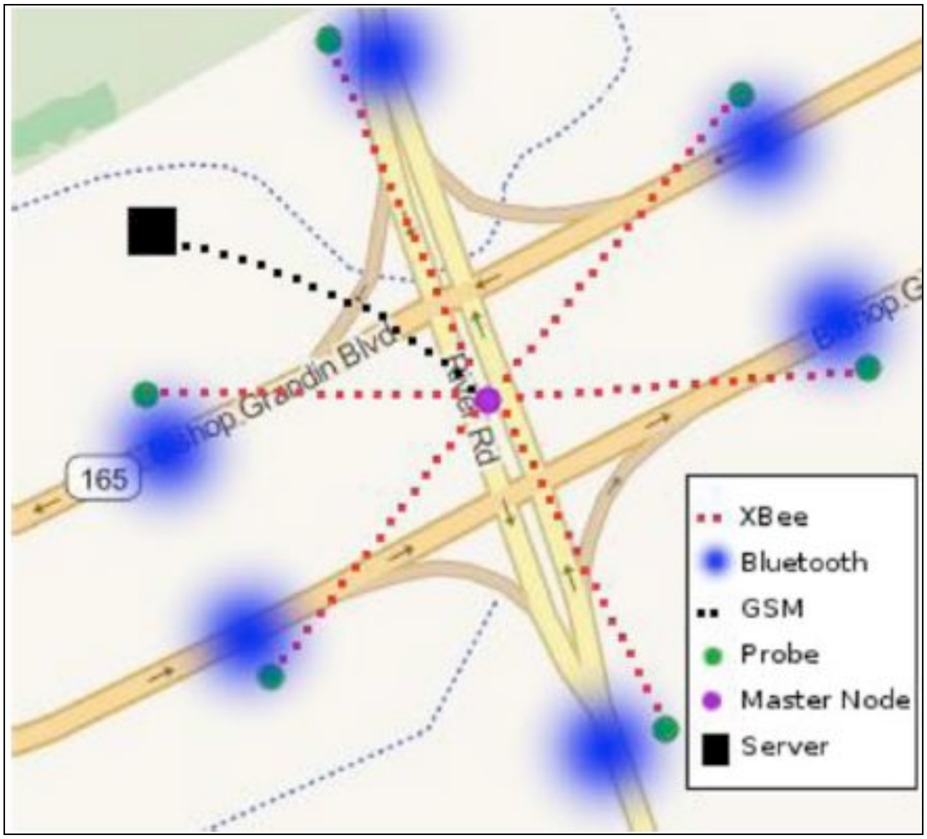


Figure 3. Bluetooth ITS Concept. (Freisen, 2014)

According to Friesen (2014), some of the earliest studies involving the use of Bluetooth in traffic studies were Barceló (2010) and Wang (2010). Since then various similar studies have been conducted. These studies highlight the strong points of Bluetooth technology in traffic purposes as its inexpensiveness as well as its hands free operation making it safe and convenient for drivers.

Most recently, public Bluetooth ITSs were deployed throughout the city of Adelaide. This project known as Addinsight, is the first of its kind worldwide, was sponsored by the Government of South Australia. The system which was implemented using over 400 Bluetooth receivers strategically located all over the city is accessible to end users through the Addinsight smartphone app (Addinsight, 2017). According to Addinsight (2017), the app can be used in hands free mode and requires no input from the driver. Travel time estimates and updates are provided via audio alert to the driver. Travel time estimates are also provides on Variable Message Signs (VMS). These VMS also serve as beacons, which are activated on detection of traffic congestion and are de-activate when the congestion clears. Additional information such as school zones, maintenance works and incidences are also provided on the VMS as well as on the smartphone app via audio alert. The Bluetooth receivers were estimated to cost around $1000 each (Addinsight, 2017). The ITS also allow for the integration of its estimates with various web applications and GIS software via a Representational State Transfer (REST) Application Programming Interface (API) (Addinsight, 2017).

2.2 GPS & GIS in Traffic Analysis

Today, GPS is a widely used tool due to the fact that a lot of people have GPS capable smartphones. As a result of this, data collected via GPS is constantly increasing constantly and nowadays a large quantity of GPS data can be collected from a large number of GPS users. GIS techniques have also become widely used in different instances dealing with spatial data. Due to the ability to merge different kinds of data, GIS techniques can increase the speed of analysis in traffic studies. Studies that address the issue of GPS and GIS integration in traffic analysis have been conducted are can found in the relevant literature. Some of these studies include Taylor et al. (2000), Faghri & Hamad (2002), Thompson (2003), Tong et al. (2005), Susilawati et al. (2008), Faghri & Li (2012) and Racca & Brown (2012).

According to Taylor et al. (2000), the first study dealing with the integration of GPS data and GIS was conducted by Quiroga & Bullock (1998). Here, GPS is the main source of traffic data to be incorporated into the GIS environment. GPS data can provide both dynamic and static information about vehicles. The use of GIS in transportation management allows for the integration and storage of large amounts of data. It also allows data to be easily updated in the case of modifications. GIS also allows data to be analysed and displayed in tables and spatial representations such as maps (Taylor et al., 2000).

In order to have accurate data regarding travel services, temporal and spatial information should be collected. GPS allows us to collect data regarding travel time and space with usually highly accurate results in most of the situations. Despite this high accuracy, there are also errors in GPS acquired data (Tong et al., 2005).

The use of GPS has been proven to be an important and efficient tool for traffic data collection. Collecting travel data with GPS allows for the evaluation of road network performance thus serving verifying if transportation-planning objectives are fulfilled. The main advantages of GPS in traffic congestions analysis include low costs, accurate data and the possibility of establishing a schedule to repeat measurements all over the year (Faghri & Hamad, 2002).

Traffic data and transportation network are described by spatial attributes, such as point of origin and point of destination, the route travelled or time of travel for that route. Besides these, there is also data, which includes accident reports, travel speed, delay data or turning movements at intersections. All these spatial attributes can be stored and integrated into a GIS environment in order to merge them with a map of the study region (Taylor et al., 2000).

Where conventional databases are not able to handle and use spatial attributes of different data sets, including transportation data sets, Geographic Information Systems (GIS) as a tool can store large amount of data, correlate data attributes with spatial location and also merge data with other important information for a particular study area (Taylor et al., 2000). Because congestion data have spatial and temporal data, GIS techniques are very useful in analysing traffic congestions. Using GIS in traffic congestions provides the ability to integrate the entire data that was collected from the roads regarding traffic congestions, analyse the data and finally get a spatial representation (Taylor et al., 2000).

One advantage of GIS in transport management stems from the fact that GIS operates in layers thus, analysts can choose which data is important in their analysis at a certain moment. GIS environment can include analysis of different kinds of data, such as numerical attributes, text information, and spatial information. GIS can handle a multitude of data such as topographical data, land use coverage, roadways networks, demographic data, buildings data, traffic flows and impact analysis. This data is incorporated into GIS as separate layers (Figure 4) (Taylor et al., 2000).

There are many concerns today, regarding the amount of emissions generated by traffic. It is estimated that about 15% of greenhouse gas emissions can be attributed to transportation causes (Susilawati et al., 2008). Using travel data, traffic congestion information and fuel consumption data in the GIS environment, the loss to the whole community can be measured. This loss can be quantified as increase in travel time, increase in travel cost and also increase in fuel consumption leading to increased levels of gas emissions (Susilawati et al., 2008).

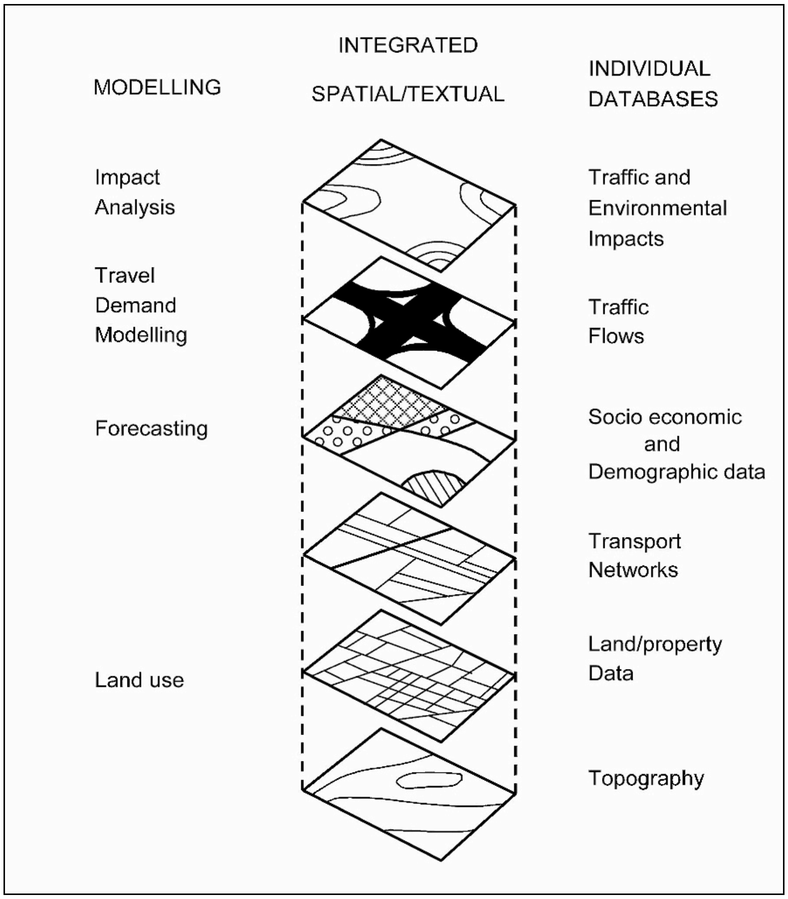


Figure 4. Data layers introduced into GIS in transportation analysis (Taylor et al., 2000).

To increase the efficiency of travel time prediction using GPS data, GPS data could be combined with a map in a GIS environment (Zito et al., 1995). When speed data and directions are represented on a map, the overall image regarding travel time prediction can be easily seen using GIS methods, such as network analysis. Integration of GPS data with GIS is also not a time consuming process as GPS data can be easily imported into GIS software in order to can out various traffic studies.

In the integration of GPS data with GIS, the overall accuracy of the will not only be influenced by the density of data collected in the field, but also by the spatial resolution of the base map that used in our analysis. The most important parameters that should be carefully considered when choosing a map include scale, coordinate system, projection of the map as well as datum. (Thompson, 2003).

Digital maps have different characteristics from paper maps. Digital maps in GIS environment may be represented in vector or raster form. Vector maps use features such as points, lines or polygons, while raster maps are based on continuous data that is made from a huge number of pixels having different value accordingly to the parameter being represented by the map (Thompson, 2003).

Combining GPS data and GIS maps have presents several challenges. For example, there are instances where GPS data is not perfectly matched with digital maps, however there are GIS techniques that can fix this problem, such as snapping technique, which allows a perfect overlay between the base map and field data (Thompson, 2003). Another restrictive factor in using GIS in traffic analysis is the lack of spatial data for the study area, data such as road network, land use or different maps of the region. An important challenge is ensuring that modifications to roadways network are updated as GIS database is often very large (Taylor et al., 2000).

Integrating GPS data and GIS maps provides access to a large variety of thematic maps that can be easily used by decisions makers in traffic system planning. Integration of travel speed and direction in GIS environments provides both temporal and spatial data that are overlaid on the road network. With access to this kind of data, traffic analysts could obtain important information regarding traffic congestion (Thompson, 2003). There are several advantages that are arise from using GPS and GIS, such as the ability of instantaneously accessing position data and speed data; the ability to integrate traffic data with other datasets (land use, demographic data, and socio-economic data) and analyse them together; the ability to interpret and display travel data with other datasets for the study area; and finally, the possibility of transferring the GPS device to other vehicles such as bicycles or freight vehicles (Taylor et al., 2000). Combining GPS and GIS can reduce the costs that are generated by traffic analysis and management. Instead of using monitoring detectors on all the roads, GPS measurements can be used to collect traffic data. As can see from the above, there are many reasons strengthening the idea of integrating GPS and GIS in traffic studies. Besides the issues that could appear in such an approach, the advantages are most significant and most valuable.

2.3 Travel Time Relaibilty Studies

Studies on travel time reliability were pioneered by the U.S. Department of Transportation Federal Highway Administration (Racca & Brown, 2012). According to the Transportation Federal Highway Administration, travel time reliability can be defined as "the consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day" (Racca & Brown, 2012). Nicholson, Schmöcker, Bell, & Iida (2003), report that as, travel time variation increases, travel time reliability decreases. This relationship allows perfect time travel reliability to be alternatively defined as the total absence of time travel variation. As long as travel time reliability is ignored in transport management, there will be continued economic loss of road networks (Li et al., 2010). De Jong et al (2009) conducted a study where total benefits increased by 23% after travel time reliability was improved.

In the effort to classify time travel reliability of various roads, the Transportation Federal Highway Administration devised four methods to measure travel time reliability. These methods are less technical and are much easier to explain to the general public. These travel time reliability measurements are the frequency of congestion, buffer index, planning time index and the 90th/95th percentile travel times (Racca & Brown, 2012). Travel time reliability measurements imply repeated measurements on repeated trips (Li et al., 2010). The frequency of congestion measurements, which are carried out to evaluate travel time reliability primarily, use two variables to find out travel time reliability: speed and time. This method involves finding instances where the speed falls below a certain value or the amount of time, in minutes, that the usual travel time is exceeded for a particular route. The Buffer index method adds time (buffer time) to the median time travel for a certain route, in order to compensate for any factor, which may affect travel time. The Planning time index is essentially a buffer value added to the estimated travel time and is a ratio between the worst travel time and free flow travel time. The method of “90th or 95th percentile travel times” method is based on the discovery that for most journeys, the actual travel time is between 90% and 95% of the estimated travel time (Racca & Brown, 2012).

In travel time reliability, the origin and destination of a certain route have an immense impact on the travel time estimate. According to Racca & Brown, (2012), GPS could be useful in finding out which intersections cause the most crucial delays during travel. Another challenge in the estimation of travel time is the measurement of free flow travel time or the ideal travel time for a certain route. Also noteworthy about travel time reliability studies is that such studies are usually focused only on a certain travel corridor which does not often cover the entire field of study (Racca & Brown, 2012).

A novel study conducted on road network reliability by Abma (2014), further developed the aforementioned methods by the consideration of additional characteristics asides the general characteristics of the travel time reliability measurement. These addition characteristics allow for meaningful, easy to understand, easy to compute, travel time measurements (Hellinga, 2011). The additional criteria which include average road condition, levels of variation in travel time as well as extreme travel time values. The study is based on two ideas. The first idea is that good travel time reliability will afford travelers the opportunity to predict their travel time while second is that the expected travel time should equal the average travel time for a particular section of the road. In this approach, new indicators regarding travel time reliability were defined. During three different periods of the day, which are peak-morning, peak afternoon and peak evening, information regarding average travel time, variation travel time and extreme travel time were obtained. (Abma, 2014).

Travel time reliability measurements are extremely important in a society that relies extensively on vehicular movement. As reliable road networks tend to result in lower transportation cost, time travel reliability studies should be carried out where there is a lot of congestion.

2.4 Travel Time Variability

The traffic congestions are a common occurrence in the everyday life especially in large cities such as Adelaide. The repetitiveness of such congestion however seem to indicate that there are deficiencies in the road network system and as such can be considered as vulnerabilities Traffic congestions create variations in travel time, hence their perceived importance. Travel time variability can be defined as the daily variation of travel time generated randomly by a large variety of factors that are not necessarily special incidents. Travel time variation can be measured using the standard deviation of travel time (Eliasson, 2006). Besides the route that travelers are choosing, travel time variability can also be impacted by trip departure time and travel mode (Li et al., 2010).

According to Bates et al. (1997), there are three different types of travel time variability, which are (a) inter-day variability, which are generated by daily and seasonal traffic variations, (b) inter-period variability that are described by time departure differences or congestions changes and (c) inter-vehicle variability, which is influenced by traffic system and driving styles (Li et al., 2010).

Eliasson (2006) proposed a method that analysed the relationship between several traffic characteristics such as free-flow travel time, travel time and standard deviation of travel time. Traffic fluctuation can be attributed to many elements some of which are daily fluctuations and are caused by different factors such as population driving styles, weather conditions, road network geometry, time of the day, season, traffic management or unpredictable incidents (Li et al., 2010). Figure 5 shows the factors influencing travel time distribution.

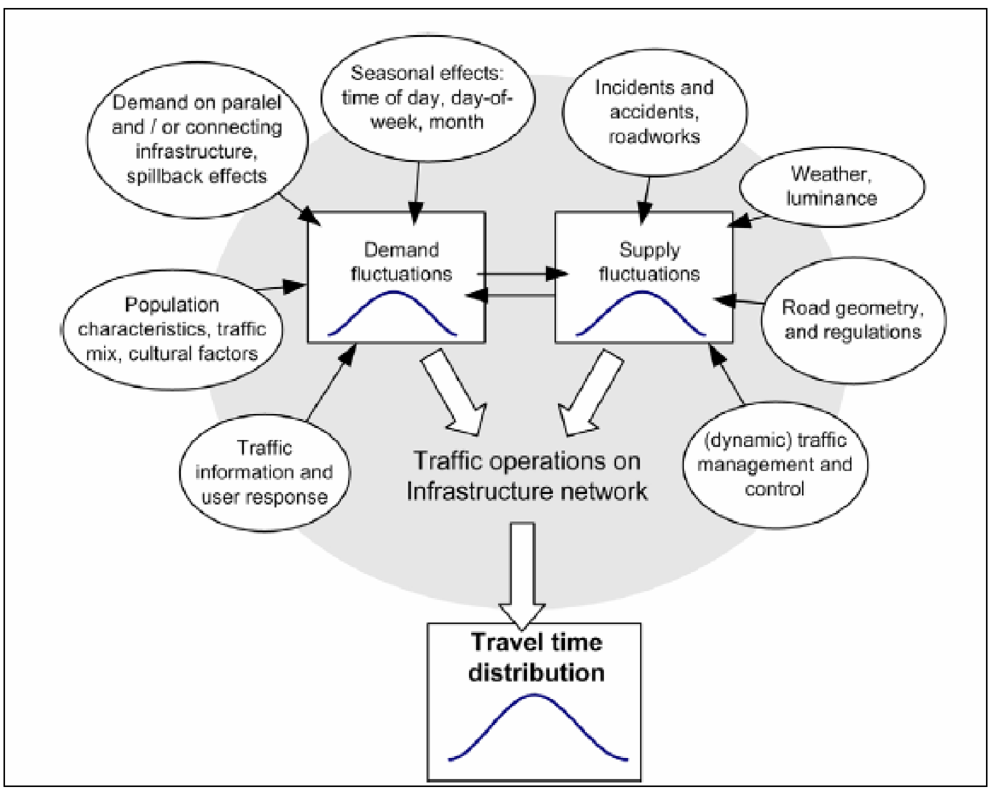


Figure 5. Factors that impact on travel time distribution (Li et al., 2010).

Two characteristics of travel time variability are unpredictability and randomness. Despite effort by transportation management to tackle travel time variability, there still remains risks regarding this transportation issue (Li et al., 2010). Susilawati et al., (2008) conducted a study where travel time variability was measured by both GPS and GIS techniques. This involved the use of a GPS probe with the aim of investigating the speed-time and speed-distance relationship.

2.4.1 Road Network Vulnerability

If a road network is not reliable, then we may speak about road network vulnerability. Road vulnerability is described in different manners by researchers. Road vulnerability can be defined as the weaknesses reducing road network performance and those events that degrading roadways facilities for the community (Susilawati et al., 2008). According to Taylor et al. (2006), the road network vulnerability concept could be considered as an alternative method to solve the issues that are identified in the traffic reliability, especially the negative impacts that those issues may have on the community (Susilawati et al., 2008). Road network vulnerability can be studied in two stages (Jenelius, 2007). The first step is to identify a decisive link in the future road network appearance, while the second step is focusing on quantifying the consequences to the community that would arise if that link is interrupted. The assessment of road network vulnerability is important in transportation planning and road arterials maintenance. This assessment could represent a useful tool for transportation system management (Susilawati et al., 2008).

2.4.2 Traffic congestions: causes and consequences

Meyer & Miller (2001) describes one of the major characteristics of modern urban transportation as dependence on the automobile, a dependence that is generating a rapid growth of traffic volume. Even as urban planners are trying to improve roads network, the number of the vehicle on the roads is increasing much faster and improving transportation conditions in urban communities remains a challenge for urban planners (Tong et al., 2005). One of the main problems of traffic in urban areas is represented by traffic congestion. Because traffic congestion reduces accessibility and contributes to increased travel costs (Rao & Rao, 2012), As a result, countries such as Sweden, UK, and the Netherlands are studying travel costs using cost-benefit analysis (Eliasson, 2006). There are various definitions of traffic congestion, such as Rosenbloom (1978), Rothenberg (1985), Vuchic & Kikuchi (1994), and more recently Downs (2004) and Kockelman (2004). Defines travel congestion as situations when the travel speed is below the permitted speed for a certain roadway.

According to Taylor et al. (2000), there are several deductions can be made from the various definitions of traffic congestions. These deductions include,

- Travelers facing congestion indirectly pay extra costs;
- Traffic congestion happens in situations when the request of particular roads sections exceeds the road capacity;
- Reoccurring traffic congestions can be linked to a cycle of socio-economic activities;
- Unpredictable and irregular incidents that occur on the roadways also create traffic congestion.

Not only the duration, location, and level of congestion, but also the causes and consequences of congestion, are important issue for decision makers in transportation system management. As earlier discussed, one characteristic of traffic congestion is that it can appear in any section of the transportation system at any moment. However there are particular moments when the transportation system is more vulnerable and prone to record traffic congestion. The best-known moments vulnerable to traffic congestion are represented by peak hours in urban traffic (Taylor et al., 2000). Residents and commuters in these areas commonly face traffic congestion problems, especially in the morning and evening. This peak hour traffic is mostly generated due to the working hours and work-related journeys (McGroarty, 2010). It is almost impossible to improve all the causes of traffic congestions (McGroarty, 2010). But there are several solutions that should improve these issues.

2.5 Measures of Traffic Congestion

Implementing the best measures to mitigate traffic congestions involves several steps, the first of which is identifying those factors generating the traffic congestions (Rao & Rao, 2012). According to Rao & Rao (2012), efficient methods of traffic congestion measurement should fulfill certain criteria such as being clear as well as being simple to understand. It should provide information about the actual traffic conditions as well as estimate future conditions. The methodology should involve the use of statistical approaches and finally, it should be applicable to different periods and facilities as well as in modes. Currently, there are different practices around the world in dealing with the congestion problem. Rao & Rao (2012) presented a comparison of such practices in countries such as the United States of America, South Korea, Japan, and India. Each of these countries has their own characteristics regarding traffic conditions and congestion problem management. Data on the occurrence of traffic congestion include travel time and delay time.

According to Rao & Rao (2012), the base criteria in congestion measurement should be related to travel speed. This is because this parameter is highly sensitive and is also strongly related to transportation costs. Rao & Rao (2012) states that there are three major elements influencing the supply side of roads. The first one is road capacity while the two others include the functionality of the road network and unexpected incidents such as road works or accidents. In order to have a detailed representation of traffic congestions, there are several methods of measurements that can be used: (1) basic measurement of analysing delay and delay estimation, (2) ratio measures, which use the ratio between travel time and delay factor, (3) level of service, which uses traffic characteristics such as vehicle density, ratio between traffic volume and roads capacity, average speed and intersection delay, and (4) indices. Of course, each one of these measurements approaches has advantages and disadvantages in traffic congestions analysis (Aftabuzzaman, 2007). By understanding the causes of traffic congestion, we may find the most effective solutions to most traffic problems. Congestion analysis involving traveling speed, travel time and average speed studies usually involves a congestion index. If the congestion index has a value close to zero, then we have a very low congestion. On the other hand, if this value of this index exceeds 2, then there is high traffic congestion (Tong et al., 2005). This and several other measures of congestion will be subsequently introduced and discussed in detail.

2.5.1 Congestion Index

One of the most useful measures of congestion is the congestion index. Originally described by Richardson & Taylor (1978), the congestion index CI is calculated as the ratio of the difference between actual travel time and the free flow travel time.

$$CI = \left(T - T_0\right)/T_0 \qquad \text{…. (1)}$$

Where,

CI = Congestion Index

T = Actual travel time

T_0 = Free flow travel time

If the congestion index has values equal to zero, then it means that the actual travel time is the same as the free flow travel time. On the other hand, an index that has value 1 represents the situation when the actual travel time is double of the free flow travel time (Taylor et al., 2000). The advantage of using this traffic congestion index is that this index is not dependent on route characteristics such as geometry, length, capacity and intersections, and it permits the possibility to make a comparison between delays on different routes (Taylor et al., 2000).

2.5.2 Proportion stopped time

Another useful measure of congestion is the Proportion Stopped Time (PST). Defined as the ratio of stopped time to the total journey time, the PST as a measure of congestion can also be used to compare different routes, links and networks segment.

$$PST = T_S / T \qquad \text{.... (2)}$$

Where,

PST = Proportion Stopped Time

T_s = Time total time stopped

T = Total travel time

The stopped time is taken as any period in which the vehicle is moving less than a threshold speed. Zito, D'Este & Taylor (1995) suggests a threshold of 2km/hr. PST as a parameter provides useful insight into the amount of queuing along a route. The importance of PST is more emphasised when the need for a measure of queuing along a route, link or intersection is recognised as it is practically impossible to directly observe queue length at many network points. Along with other measures such as CI and Acceleration noise (AN), traffic congestion and its complexities can be adequately analysed.

2.5.3 Acceleration Noise (AN)

The speed of a vehicle as its moves along a route, normally varies with road and traffic conditions as well as driver and vehicle characteristics. Typically a road with free flowing traffic and favorable driving conditions such as good weather and roadway conditions features relatively very small variations in driving speed. However, a change from these favorable conditions, due to factors such as increased road demand accompanied with increased congestion results in large variations in travel speed. This produces an acceleration pattern that varies with time. The measurement of the speed time profile using GPS has already been demonstrated in Zito, D'Este &Taylor (1995). Suggested by Underwood (1968), *AN* is particularly useful in modeling fuel consumption and emissions performance of vehicles. (Biggs and Akcelik, 1986), (Taylor and Young, 1996). Defined as the as a measure of the amount of acceleration and deceleration used by a driver when travelling along a road (Taylor, Woolley and Zito, 2000), AN provides a way to measure the quality of traffic flow and thus of the level of congestion. Journeys completed at relatively steady speed will have low values of AN, with the reserve holding true. Mathematically, AN can be represented as,

$$AN^2 = \frac{1}{T_r}\sum_{i=1}^{n}\frac{\Delta v_i^2}{\Delta t_i} \qquad \text{…. (3)}$$

where Δti is the time interval taken for a speed change Δvi and T_r is the total running time. AN provides a useful parametric measure of the level of congestion when overall average travel speed ($\bar{v}$) exceeded 30 km/h (Underwood, 1968), indicating that it could be used as a measure of the quality of traffic progression along a route (Taylor, Woolley and Zito, 2000).

2.5.4 Mean Velocity Gradient (MVG)

Alternatively, the mean velocity gradient (MVG) could be used as a measure of speed variation instead of the AN parameter. It was suggested by Underwood (1968), who also believed it to be applicable to a wider range of traffic conditions. Mathematically, mean velocity gradient (MVG) is defined as

$$MVG = AN / \bar{v} \qquad \text{.... (4)}$$

and, using the usual definition of a mean value (Taylor, Woolley and Zito, 2000).

$$\bar{v} = \frac{1}{T}\int_0^T v dt \qquad \text{.... (5)}$$

Where T is the total travel time.

Taylor, Woolley and Zito (2000) suggested a multi-faceted approach to the traffic congestion problem using combination of the aforementioned parameters. This would involve the use of,

- The congestion index (CI) as am overall measure of the congestion on a route
- The proportion stopped time (PST) as a measure of amount of time spent in queues during the journey
- The acceleration noise (AN) as s measure of the quality of traffic flow on the journey, in terms of the speed variations along a route.

This would provide a solid basis for the assessment of congestion performance of road networks. This would also enable different road networks to be compared as well as highlight the comparative advantages of various road networks against each other. This multi-pronged approach in conjunction with GPS and GIS technique presents a most insightful way to analyse traffic data. This would combine the advantages of GPS/GIS with the robustness of the aforementioned measures of congestion. Some of the advantages to be expected include low cost, ability to work with very large datasets, ease of modification, etc. This is demonstrated in the later sections of this paper.

CHAPTER III: METHODOLOGY

In order to ensure that the findings of this study are reproducible and verifiable, it is necessary to outline and discuss the study methodology. The two routes of interest in this study are first introduced and discussed. Then, using a GPS capable handheld device, travel time data was gathered during different times of the day for a period of three months (May –August 2016). This data was then processed to generate velocity data for each of the routes. Route and road shape files were obtained from the South Australian Government Directory (Data.sa.gov.au. 2017). These were used in the calculation of travel time variables for the entire routes and for the individual sections along the route. Values for travel time variables such as total trip time, shortest path along the route, total travel distance and total daytime travel information were obtained using QGIS. Implementing a Python® plugin, the other travel time variables of mean journey speed, stop time period, proportion stopped time, acceleration noise, mean velocity gradient and congestion index were calculated. The results for both routes were then graphically and statistically analysed in order to estimate the travel time as well its reliability.

3.1 Routes of Interest

For the purposes of this study, two different routes with the same start and end points were chosen. The two routes, which are pictured in Figure 6 and Figure 7, starts in Parkholme and ends at Tonsley, Adelaide. The first route, which is, pictured in Figure 1 take the South Rd to its destination. The second route uses Marion Rd to get to Tonsley. These two routes have slightly different characteristics, as the South Rd is plied by more commercial and heavy commercial vehicles (Susilawati et al., 2008). since it serves as an arterial road to the Southern Expressway. However, the two roads have a maximum speed limit of 60km/hr and are double lane roads.

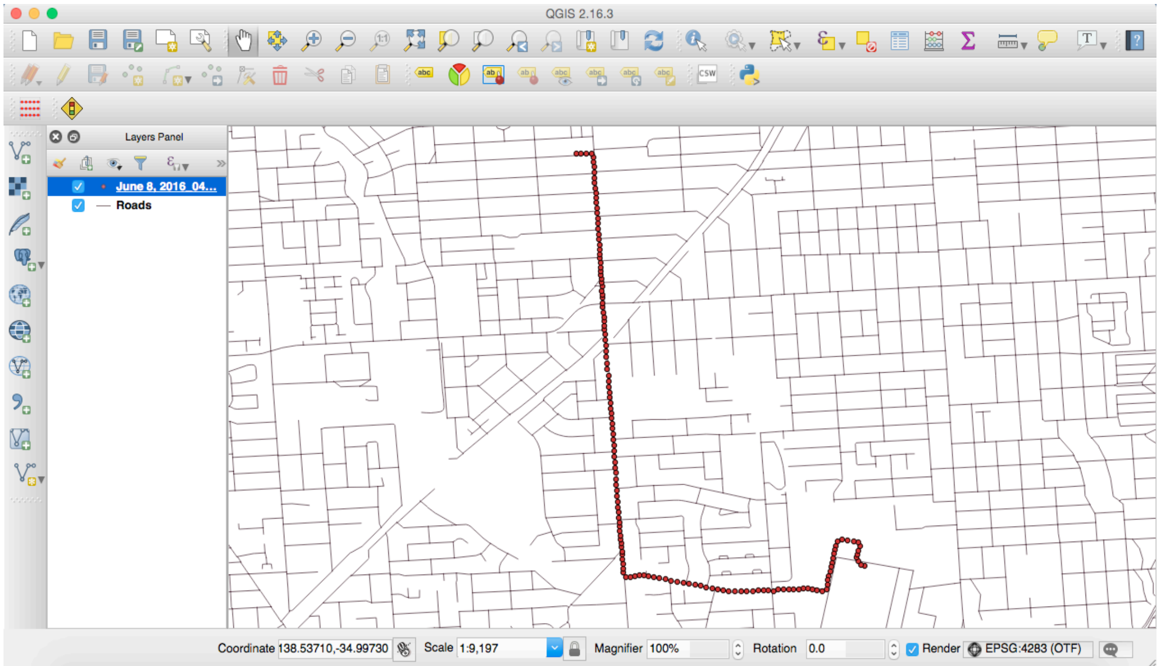


Figure 6. GPS points displayed on QGIS for the first route - Marion Rd

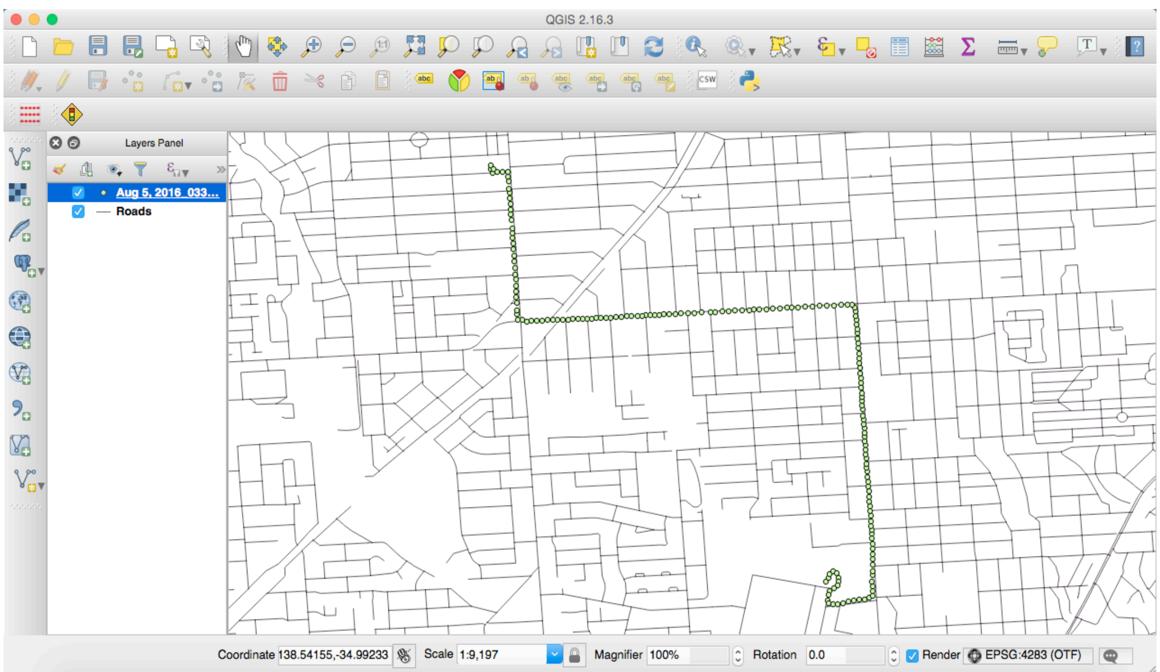


Figure 7. GPS points displayed on QGIS for the second route - South Rd

3.2 Collection of Data

To gather the required travel data using GPS, data was gathered over a three month period spanning from April to June 2016 on the previously described routes twice a day (back and forth). This was done using the inbuilt GPS feature of a smartphone. As has been previously discussed, the use of modern technologies such as Bluetooth and GPS allows the cost effective collection of traffic data when compared with conventional methods such as the floating car method. This comparative advantage was one of the major reasons for employing this data gathering system, as it provided an easy, inexpensive but accurate system of data collection. Actual data gathering was done using the GPS Stone Trip tracker application installed on an Apple iPhone 6s smartphone. The GPS Stone Application developed by Francois Lamboley, intermittently collects travel information at extremely short intervals during a journey when placed in record mode. It is able to collect data on the variables of longitude, latitude, altitude , time elapsed between consecutive readings during the journey, etc. It is also capable of exporting recorded data into the GPS exchange format (.gpx). The GPX file which has an Extended Markup Language (XML) structure is converted into plain ASCII text files using Garmin® Map Source Software. This is finally converted into a spreadsheet compatible '.csv' format using a Visual Basic (VB) script. The conversion process as well as relevant source code are available in the Appendix. The operations of the application are unhindered by the simultaneous use of the phone for other functions such as making phone calls, hence the data collection process was unaffected by the simultaneous use of the phone for other purposes. Certain precaution were observed during the data collection process in order to ensure the integrity of the study.

1. In order to avoid errors concerning the start time of the travel time recording, the application was set in recording mode immediately the vehicle was set in motion, and not before.

2. No unnecessary stops such as petrol refills or offering lifts to bystanders during the journey.

3. Strict adherence to traffic rules and regulations.

4. The end point of the journey was set to a particular point near of the journey as the true end of the journey changed constantly due to factors such as available parking etc.

5. Data collected was exported daily to avoid data loss.

This exported '.csv' file was subsequently analyzed in order to make an accurate forecast of the travel time of the two different routes. In order to get the average travel velocity in between the readings, the distance covered was divided by the elapsed time according to this formula.

$$v = \frac{D_1 - D_0}{T} \quad \text{…. (6)}$$

Where,

D_1 = Displacement at the subsequent reading

D_0 = Displacement at the initial reading

T = Time elapsed between readings

The original .csv files were then augmented to include the calculated speed information. The respective route shapefiles were generated using QGIS and the travel data file. The Road shape file was obtained from the South Australian Government Directory (Data.sa.gov.au. 2017). The shapefile contains information on the section, links, and intersections along the route and is vital in detecting bottlenecks along the route. The three input files (travel data file, route shapefile, and the road shapefile) were then processed to obtain results. All the source files used during the course of this study are included in the appendix.

3.3 Data Processing

The travel data and shape files for the individual routes were then processed using QGIS. To ensure uniformity and consistency, all the shape files used the WGS 84 Web Mercator

Coordinate Reference System (CRS). The data processing for the two routes in this study can be broadly divided into three parts which are:

- Calculation of travel time variables for the entire routes.
- Calculation of travel time variables for each intersection.
- Calculation of road links, which are any road segment between two intersections.

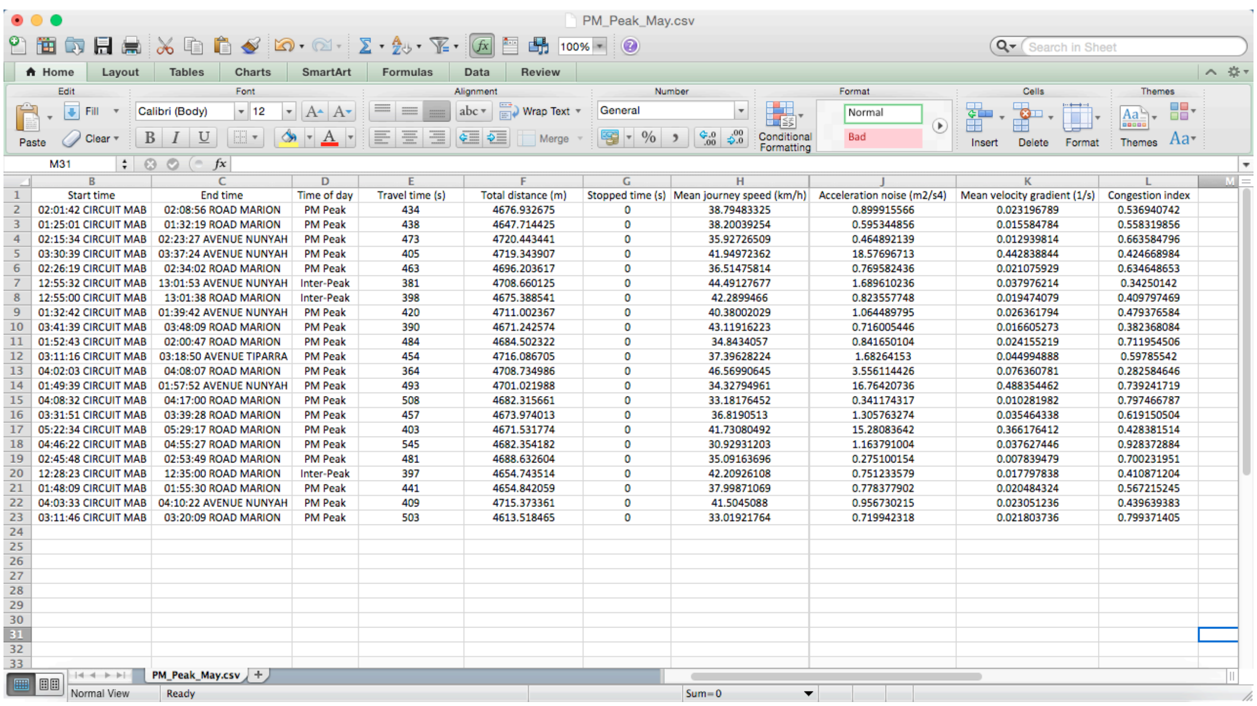
To carry out the first part, the travel time variables of total drive time, shortest path along the route, total travel distance and total daytime travel information were calculated.

1. To calculate the total drive time, the initial start time is subtracted form the travel end time.
2. To find the shortest path along the routes, the QGIS graph analysis function from the QGIS network analysis library was employed. By indicating the start and end point of the route on a shape file, the graph analysis tool was used to find the shortest path between those two points.
3. The total distance travelled was also calculated using the graph analysis function. The shape file used in finding the shortest path along the route was used as the start and end route points were already marked.
4. Daytime Time of day information was based on the travel start time.

To execute the second part of the data processing, a Python® script was implemented to calculate the required parameters. This was done by importing the plugin through the QGIS Python® interface. The source code is included in the Appendix. The values of mean journey speed, stop time period, proportion stopped time, acceleration noise, mean velocity gradient and congestion index were calculated using the Python® plugin.

3.4 Data Analysis

The values for mean journey speed, stop time period, proportion stopped time, acceleration noise, mean velocity gradient and congestion index were tabulated for convenient presentation and generated in a “results” folder as shown in Figure 8 below. Their statistical means and standard deviations were also calculated. Speed time profiles were plotted for the two routes. Speed –time profiles provide additional insight into the speed variation during travel. The calculated mean values of the congestion indices were statically tested to find out whether there was any significant difference from their mean values. Conclusions were subsequently drawn from the results.



Start time	End time	Time of day	Travel time (s)	Total distance (m)	Stopped time (s)	Mean journey speed (km/h)	Acceleration noise (m2/s4)	Mean velocity gradient (1/s)	Congestion index
02:01:42 CIRCUIT MAB	02:08:56 ROAD MARION	PM Peak	434	4676.932675	0	38.79483325	0.899915566	0.023196789	0.536940742
01:25:01 CIRCUIT MAB	01:32:19 ROAD MARION	PM Peak	438	4647.714425	0	38.20039254	0.595344856	0.015584784	0.558319856
02:15:34 CIRCUIT MAB	02:23:27 AVENUE NUNYAH	PM Peak	473	4720.443441	0	35.92726509	0.464892139	0.012939814	0.663584796
03:30:39 CIRCUIT MAB	03:37:24 AVENUE NUNYAH	PM Peak	405	4719.343907	0	41.94972362	18.57696713	0.442838844	0.424668984
02:26:19 CIRCUIT MAB	02:34:02 ROAD MARION	PM Peak	463	4696.203617	0	36.51475814	0.769582436	0.021075929	0.634648653
12:55:32 CIRCUIT MAB	13:01:53 AVENUE NUNYAH	Inter-Peak	381	4708.660125	0	44.49127677	1.689610236	0.037976214	0.34250142
12:55:00 CIRCUIT MAB	13:01:38 ROAD MARION	Inter-Peak	398	4675.388541	0	42.2899466	0.823557748	0.019474079	0.409797469
01:32:42 CIRCUIT MAB	01:39:42 AVENUE NUNYAH	PM Peak	420	4711.002367	0	40.38002029	1.064489795	0.026361794	0.479376584
03:41:39 CIRCUIT MAB	03:48:09 ROAD MARION	PM Peak	390	4671.242574	0	43.11916223	0.716005446	0.016605273	0.382368084
01:52:43 CIRCUIT MAB	02:00:47 ROAD MARION	PM Peak	484	4684.502322	0	34.8434057	0.841650104	0.024155219	0.711954506
03:11:16 CIRCUIT MAB	03:18:50 AVENUE TIPARRA	PM Peak	454	4716.086705	0	37.39628224	1.68264153	0.044994888	0.59785542
04:02:03 CIRCUIT MAB	04:08:07 ROAD MARION	PM Peak	364	4708.734986	0	46.56990645	3.556114426	0.076360781	0.282584646
01:49:39 CIRCUIT MAB	01:57:52 AVENUE NUNYAH	PM Peak	493	4701.021988	0	34.32794961	16.76420736	0.488354462	0.739241719
04:08:32 CIRCUIT MAB	04:17:00 ROAD MARION	PM Peak	508	4682.315661	0	33.18176452	0.341174317	0.010281982	0.797466787
03:31:51 CIRCUIT MAB	03:39:28 ROAD MARION	PM Peak	457	4673.974013	0	36.8190513	1.305763274	0.035464338	0.619150504
05:22:34 CIRCUIT MAB	05:29:17 ROAD MARION	PM Peak	403	4671.531774	0	41.73080492	15.28083642	0.366176412	0.428381514
04:46:22 CIRCUIT MAB	04:55:27 ROAD MARION	PM Peak	545	4682.354182	0	30.92931203	1.163791004	0.037627446	0.928372884
02:45:48 CIRCUIT MAB	02:53:49 ROAD MARION	PM Peak	481	4688.632604	0	35.09163696	0.275100154	0.007839479	0.700231951
12:28:23 CIRCUIT MAB	12:35:00 ROAD MARION	Inter-Peak	397	4654.743514	0	42.20926108	0.751233579	0.017797838	0.410871204
01:48:09 CIRCUIT MAB	01:55:30 ROAD MARION	PM Peak	441	4654.842059	0	37.99871069	0.778377902	0.020484324	0.567215245
04:03:33 CIRCUIT MAB	04:10:22 AVENUE NUNYAH	PM Peak	409	4715.373361	0	41.5045088	0.956730215	0.023051236	0.439639383
03:11:46 CIRCUIT MAB	03:20:09 ROAD MARION	PM Peak	503	4613.518465	0	33.01921764	0.719942318	0.021803736	0.799371405

Figure 8. Generated results from the Python script for the month of May - PM Peak

CHAPTER IV: RESULTS

4.1 Average Speed

When travel time averages for the two routes are compared, it would appear that the Marion Road route is the quicker route, as it requires on the average 475.55 seconds when compared to the South Route which require 518.6 seconds. This saves 44 seconds of travel time when compared to the South Road during the AM Peak period. During the PM Peak period, this travel time saving increases to 59.9 seconds ≈ 60 seconds, as the Marion Road again appears to be the shorter route, thus requiring 455.9 seconds when compared to the South Road Route that requires 515.8 seconds in the same time period. These savings can be majorly attributed to the difference in length as well as other traffic characteristics of the roads in terms of congestion as well as level of busyness. The average length of the Marion road route was calculated to be 4680m against 5600m for the South Road Route. To place this into perspective, this difference of 920m, when travelled at a speed of 60km/h (16.66m/s) equates to a 57.5 seconds of travel time. These alone accounts for over 95% of the difference in travel time. This suggests that on a kilometer for kilometer basis, the South Road route might not be slower than the Marion Road route. To determine whether this assertion was correct, the two routes were compared using their average speeds. When the two routes were statically compared using their average speeds, results revealed that during the AM peak period, average speeds for the two routes were significantly different at 5 percent level reinforcing the assertion that the average speeds on the two routes differed. Similar analysis done in the PM peak period, revealed no significant difference in the average speeds of the two routes, suggesting that there was no significant difference in the average speeds of the two routes during this time period. The test statistics for this comparison are provided in Table 2. Also the full meaning of the abbreviations used in this study can be found in Table 1.

Table 1. Codes used for the comparison of routes

CODE	Description
MR	Marion road route
SR	South Road route
MRAM	Marion road route morning peak period (am)
SRAM	South road route morning peak period (am)
MRPM	Marion road route evening peak period (am)
SRPM	South road route evening peak period (pm)

Table 2. Statistical differences in mean values of the average speeds of the two routes.

Period	Average Speed
Am peak	
t-statistic	-2.36862
t-critical (α= 0.05)	2.039513
degrees of freedom	31
result	**
Pm peak	
t-statistic	-1.39705
t-critical (α= 0.05)	2.068658
degrees of freedom	23
result	!!!

!!! Not significantly different at five per cent level

** Significantly different at five per cent level

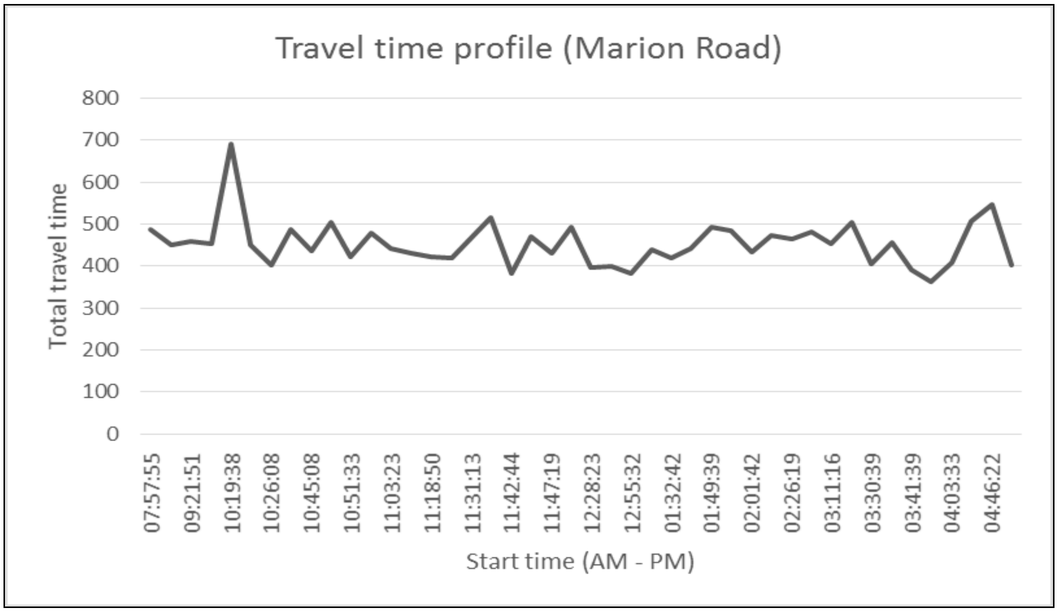


Figure 9. Averege Speed Time Profile for Marion Road Route

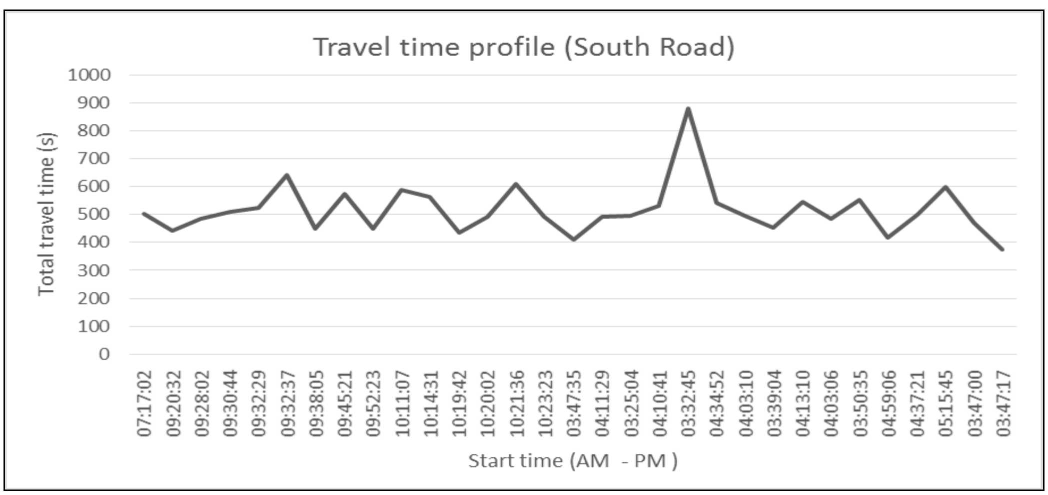


Figure 10. Averege Speed Time Profile for South Road Route

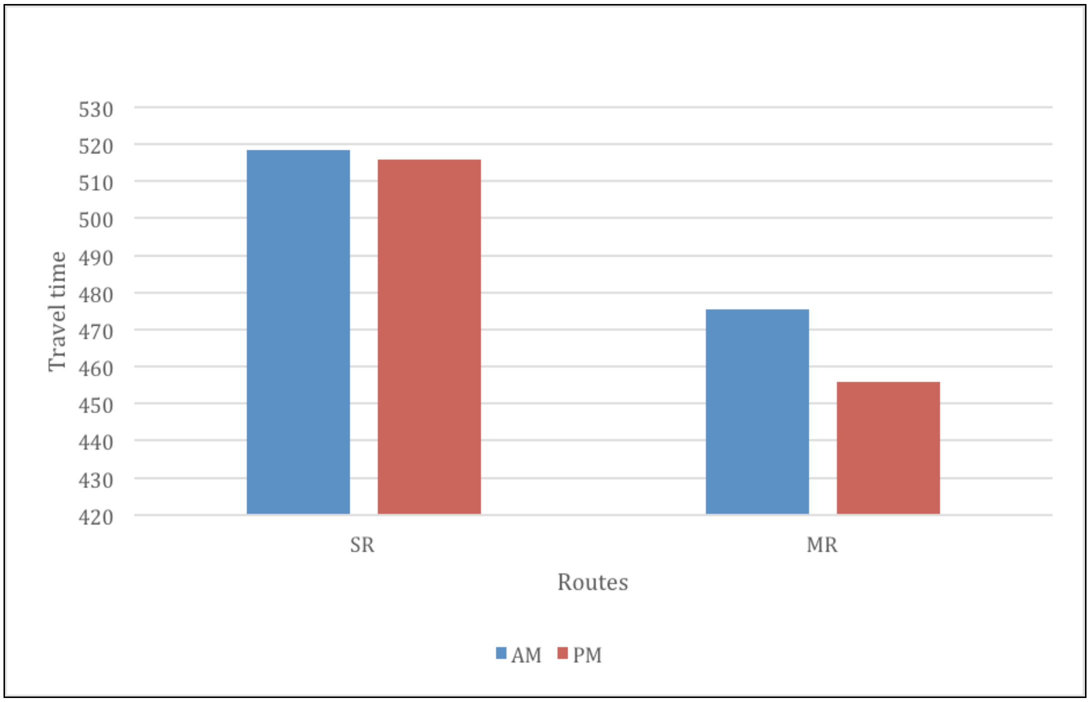


Figure 11. Comparison of travel time for the different routes

Further analysis into variation of travel time with weekday, revealed that weekday averages remained consistently higher for the South Road Route when compared with individual weekday averages for the Marion Road route. This is consistent with previous findings, which revealed that the Marion Road Route travel times are lower than the South Road Rout travel time. Figure 10 and 11 compares the individual weekday travel time averages for the two routes.

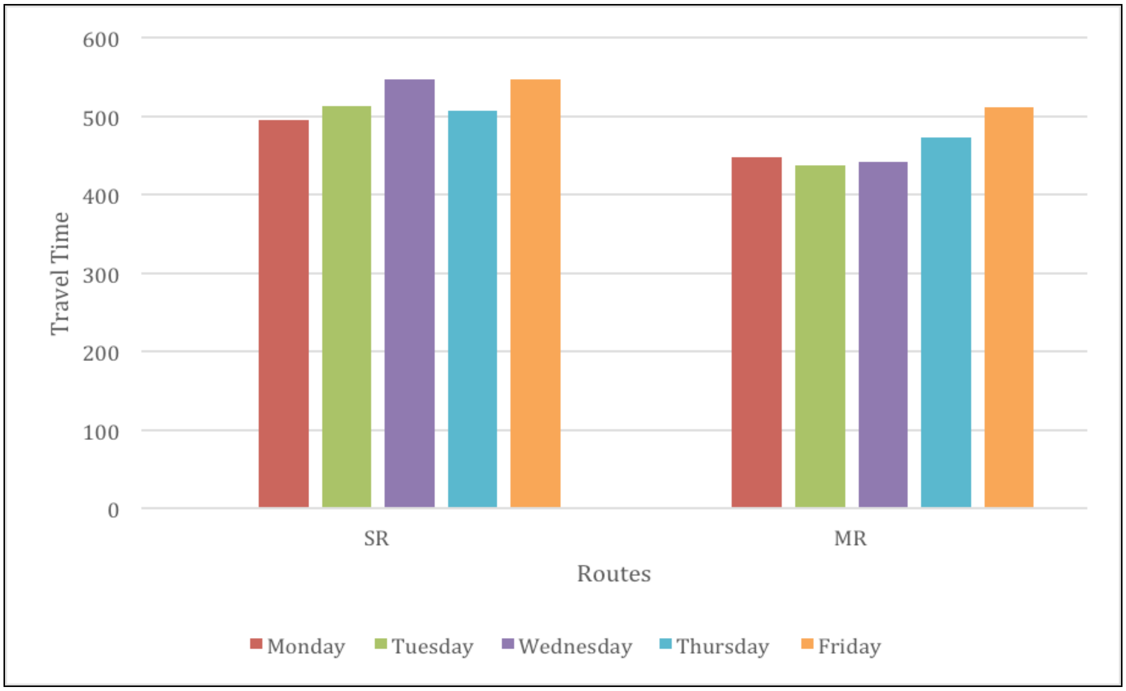


Figure 12. Comparison of travel time during weekdays for the different routes (AM peak)

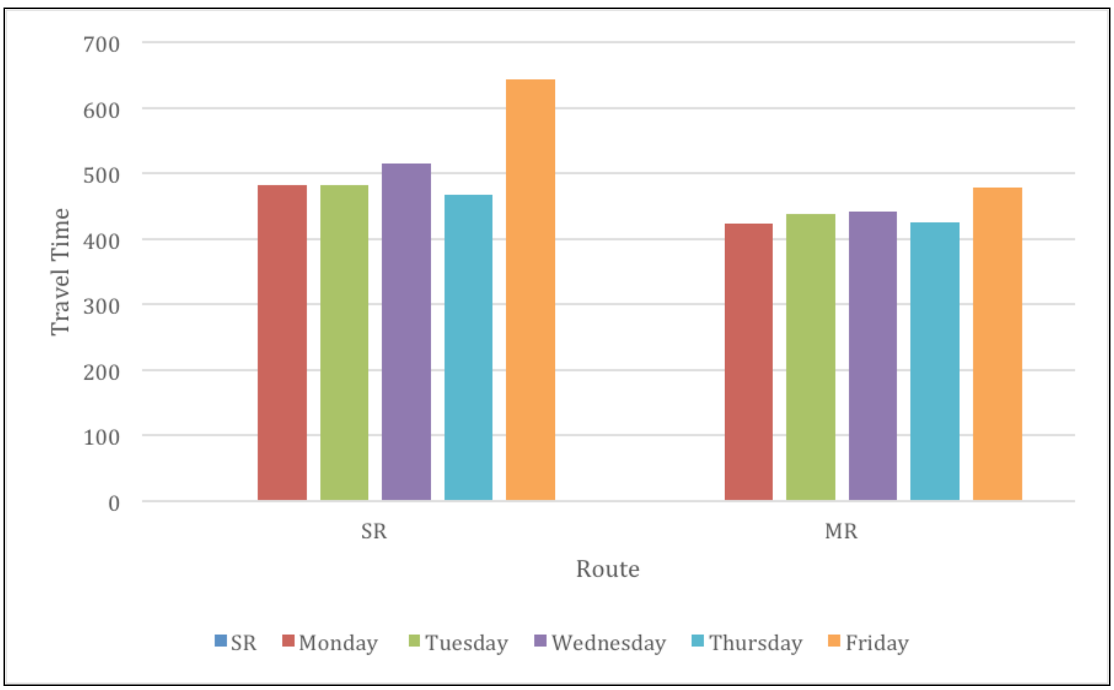


Figure 13. Comparison of travel time during weekdays for the different routes (PM peak)

Average individual weekday travel times were highest for both routes on Friday. This seems to suggest that there is increased vehicular movement during that period on Fridays. Travels times on Friday using the South Road route averaged 547 seconds and 511 seconds on the Marion Road route during the morning peak. Travel times also averaged 643 seconds for the South Road route and 478.3 on the Marion Road route during the Afternoon peak. This may be attributed to the cyclic schedule of events, which culminates in higher traffic on Fridays and was explained in the preceding section as one of the possible causes of traffic congestion. The lowest travel times obtained during the morning peak were obtained on Monday and Tuesday for the South Road route and the Marion road route respectively. These travel times averaged 494 seconds and 447 seconds for the South Road and Marion Road routes respectively. Similarly, lowest traffic times were obtained during the afternoon peak was obtained on Thursday for both routes. These travel times averaged 467 and 425 seconds respectively for the South Road and Marion Road routes respectively.

When compared, it would seem that the morning peak travel times are higher than the afternoon peak. While the cause of this is unknown, it is possible that other factors not considered in this study are responsible for this difference as morning peak travel times are consistently higher or equal for each single day of the week.

4.2 Speed Profiles

Using the gathered data, speed profiles were generated and analyzed. This was analyzed to calculate Proportion stopped time (PST) as well as provide insight into the trip quality for the calculation of congestion indices as well as provide an overview into the nature of the trip. Other uses of speed profiles not however considered in this study include fuel usage as well as emission analysis. The speed-time graph while data-rich is, however, somewhat limited in its immediate information value to the planner or engineer (Lin, Zito, & Taylor, 2005). Speed profiles for both routes during the two periods were plotted in Figures 12 – 15 below.

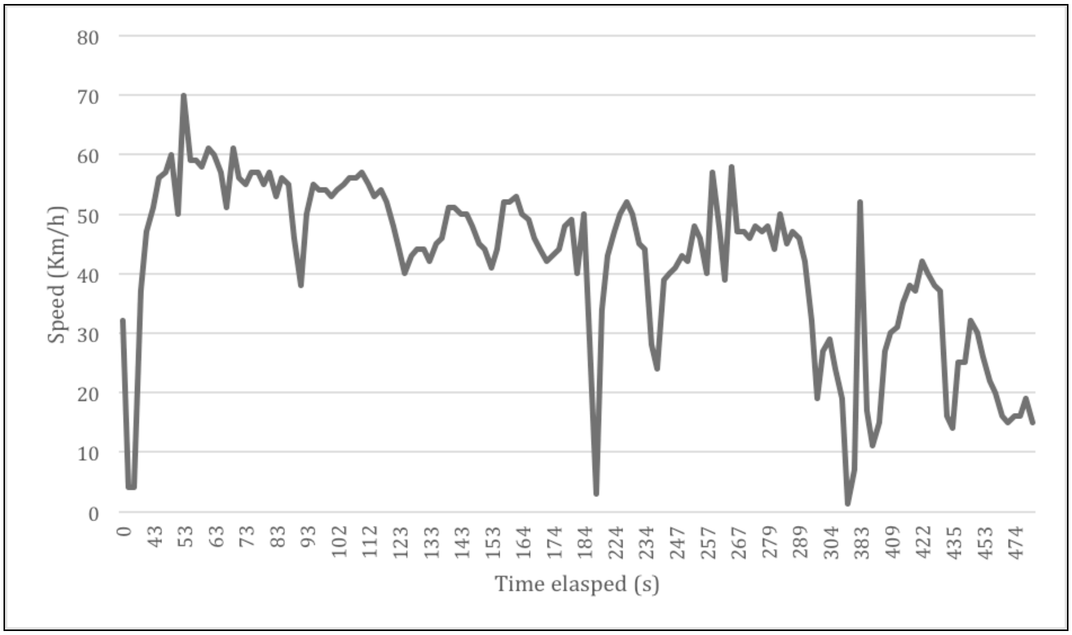


Figure 14. Sample Speed Time Profile for Marion Road Route (AM Peak)

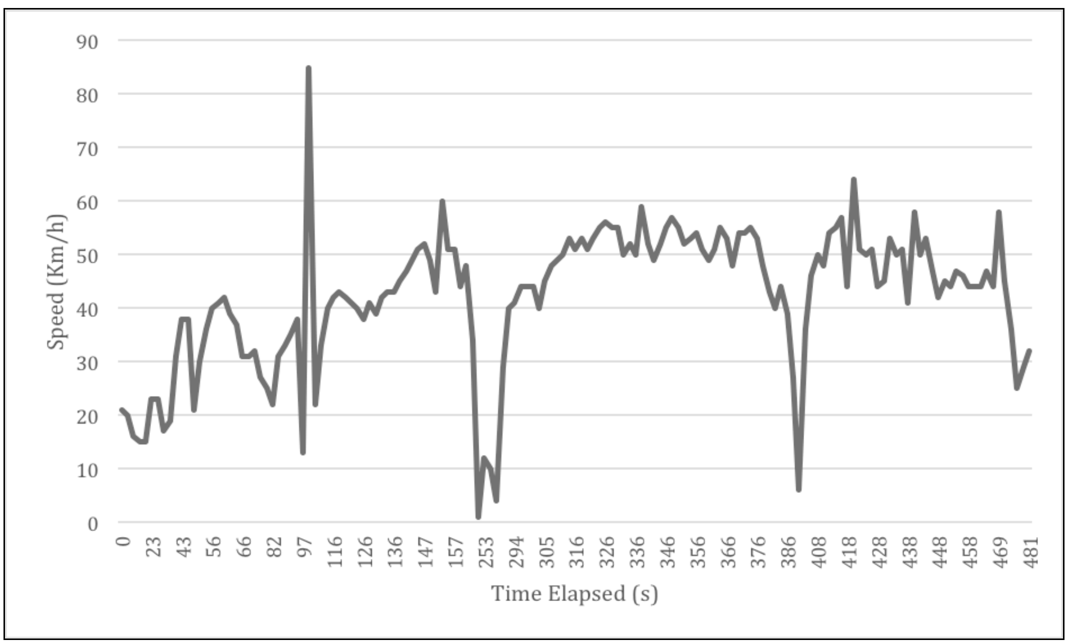


Figure 15. Sample Speed Time Profile for Marion Road Route (PM Peak)

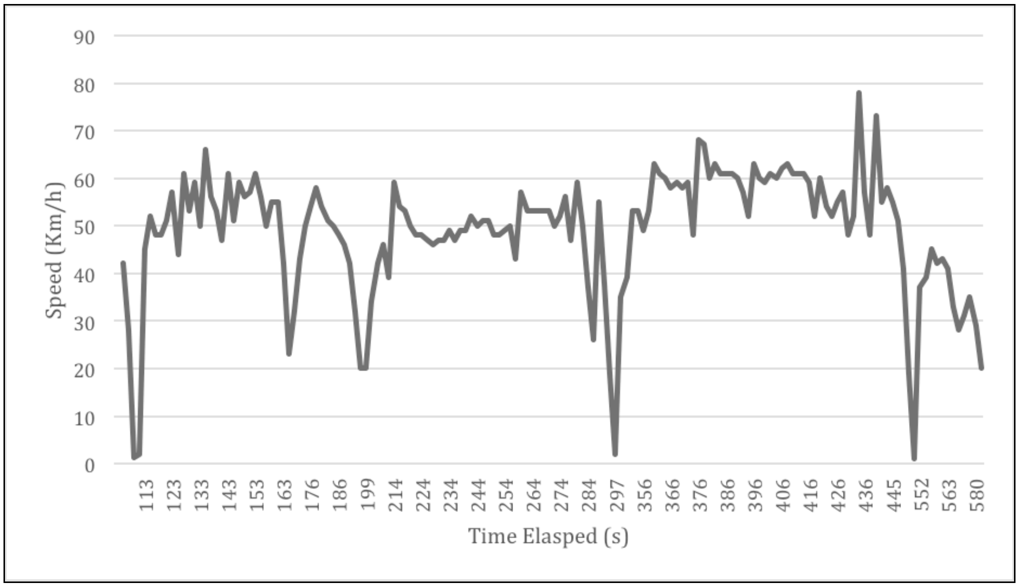


Figure 16. Sample Speed Time Profile for South Road Route (AM Peak)

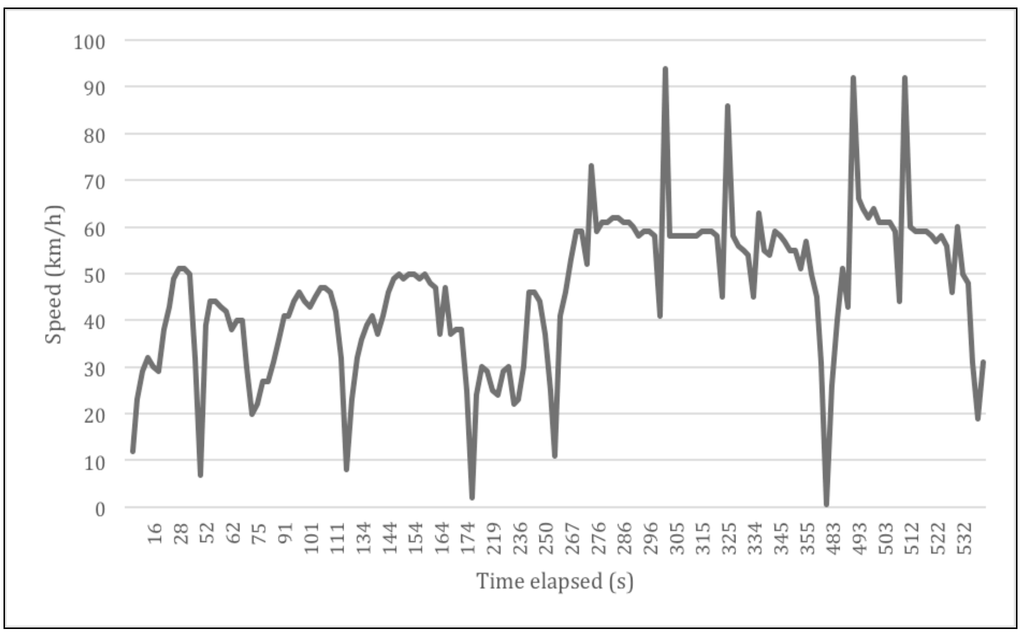


Figure 17. Sample Speed Time Profile for South Road Route (PM Peak)

As can be seen on the plotted speed profile, the PST for any of the trips is zero, as there is no time during which the travel speed is zero or reaches the pre-determined threshold. The speed profile for the Marion Road route during the morning peak reveals that for the first 300 seconds of the trip, the speed is retained below the legal speed limit of 60km/h but above the 40km/h threshold. During the afternoon peak on the same route, the speed of the trip is also held between the 40 – 60 km/h range especially during the last 300 seconds, which corresponds to the first 300 seconds during the morning peak. The speed profile for the South Road route during the morning peak also reveals that the PST for the route during either period of the day is zero.

4.3 Congestion Indices

As earlier discussed, the use of congestion indices allows for trip quality assessment. The mean and standard deviation values of the congestion indices for these routes were calculated as discussed in the preceding section and statically compared. This was done used the t-test assuming unequal variances. This method was chosen in order to compensate for the disparity in the number of the data points used during this study. The calculated congestion parameters of Mean Velocity, Acceleration Noise and Congestion Index are presented in Table 4 below.

Table 3. Statistical differences in mean values of the congestion parameters on the two routes.

Period	Acceleration noise (*AN*)	Mean Velocity (MV)	Congestion Index (CI)
Am peak			
t-statistic	1.191	1.5842	1.877173
t-critical (α= 0.05)	2.012	2.011	2.016
t-critical (α= 0.01)	2.687	2.684	2.695
degrees of freedom	46	47	43
result	!!!	!!!	!!!
Pm peak			
t-statistic	1.246	1.253	0.635
t-critical (α= 0.05)	2.026	2.024	2.068
t-critical (α= 0.01)	2.715	2.711	2.807
degrees of freedom	37	38	23
result	!!!	!!!	!!!

!!! Not significantly different at five per cent level

All am peak and pm peak data were collected in similar time periods.

When compared, the Acceleration Noise (AN) values for the South Road route were lower than that of the Marion road route during the two periods of the day. This is however much more pronounced during the afternoon peak and seems to suggest a higher quality of traffic movement when compared to the Marion road route. Similarly, the South Road allow had lower values of mean velocity as well as congestion index for during all periods of the day.

However when statically compared at both 95% and 99% confidence level, all the congestion indices were found not to be significantly different at both periods of the day. Further checks on the integrity of the test using the "Sample Standard deviation method" proposed by (Quiroga, Quiroga, & Bullock, 1998) puts the expected error given the sample size at 3.2km/h for the 95% confidence limit. This is presented in Table 5 below.

Table 4. Comparison of computed minimum sample sizes required for travel time runs at specified error ε (km/h) and actual sample sizes (95% confidence)

Route	**Standard deviation**	**Minimum sample size for permitted error ε (km/h)**			
		ε = 1.61		**3.22**	**4.83**
MRAM	3.03 ≈ 3	38	*34*	12	7
MRPM	3.27 ≈ 3	38	*34*	12	7
SRAM	2.88 ≈ 3	38	*16*	12	7
SRPM	4.28 ≈ 4	65	*16*	19	11

1. Values in italics are the actual sample sizes (see also Tables 4 and 5).
2. Computed minimum sample sizes are based on the 'sample standard deviation and t distribution method' described by (Quiroga & Bullock, 1998).
3. Tabulated values converted from given mph values.

4.4 Intersections & Road links Analysis

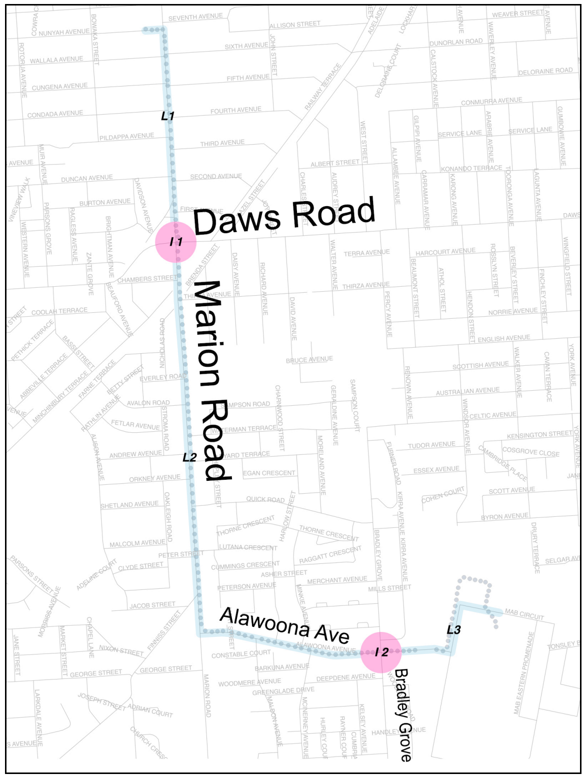


Figure 18. Intersections and Links of Marion Road with Road Names

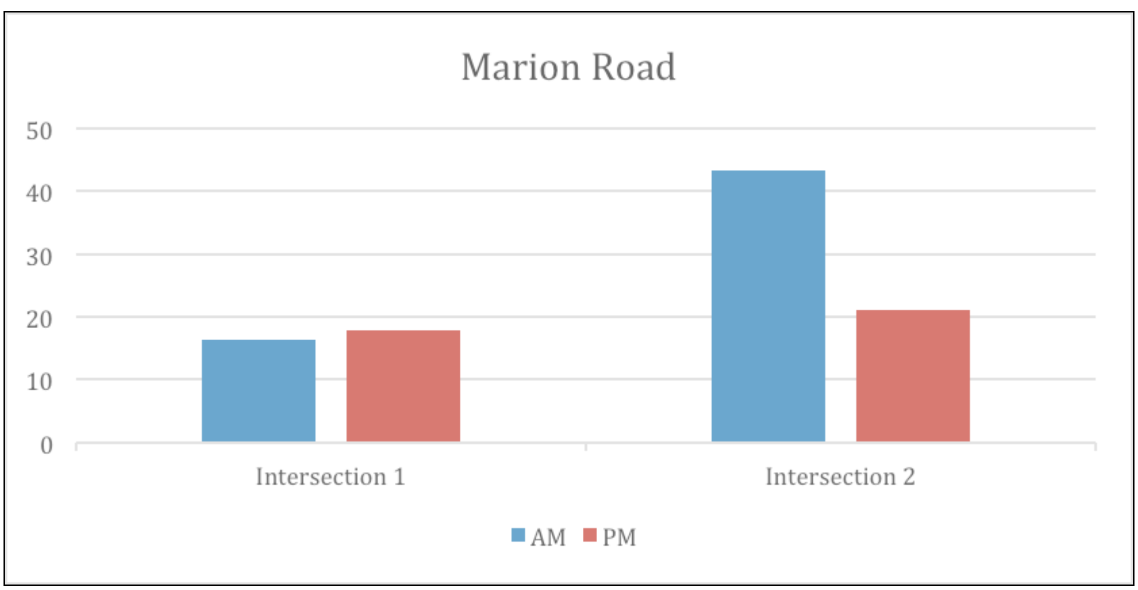


Figure 19. Marion Road Intersections comparison

The Marion road route, which has two intersections as shown in Figure 18 when compared to the South Road route, which has four intersections, shows lesser travel times at spent at the intersection. The highest average time spent at a intersection on the Marion road route is 43 seconds in contrast to 90 seconds on the south road route. On the Marion road route, ‘intersection 2’ features consistently higher travel times than ‘intersection 1’ at all periods of the day.

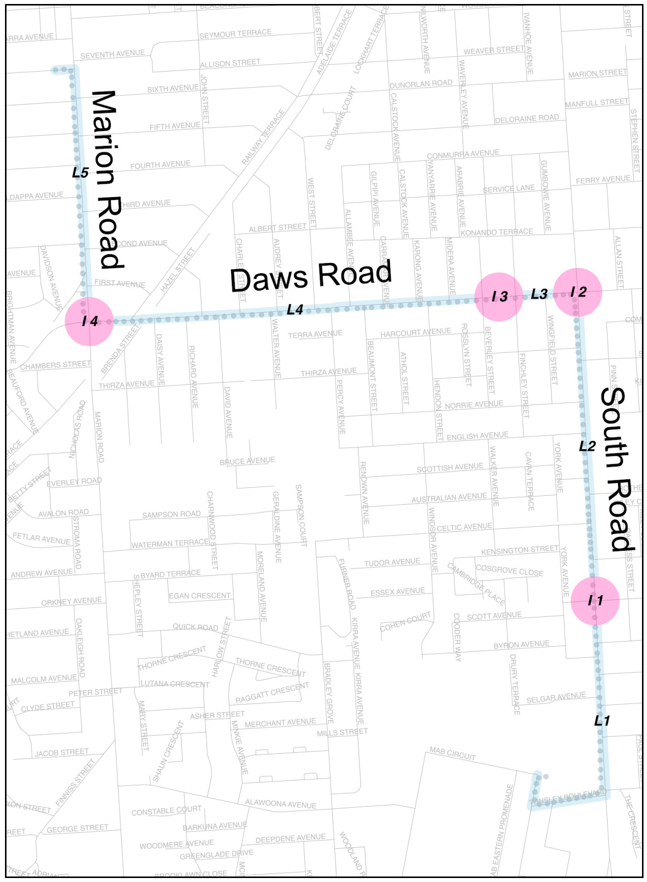


Figure 20. Intersections and Links of South Road with Road Names

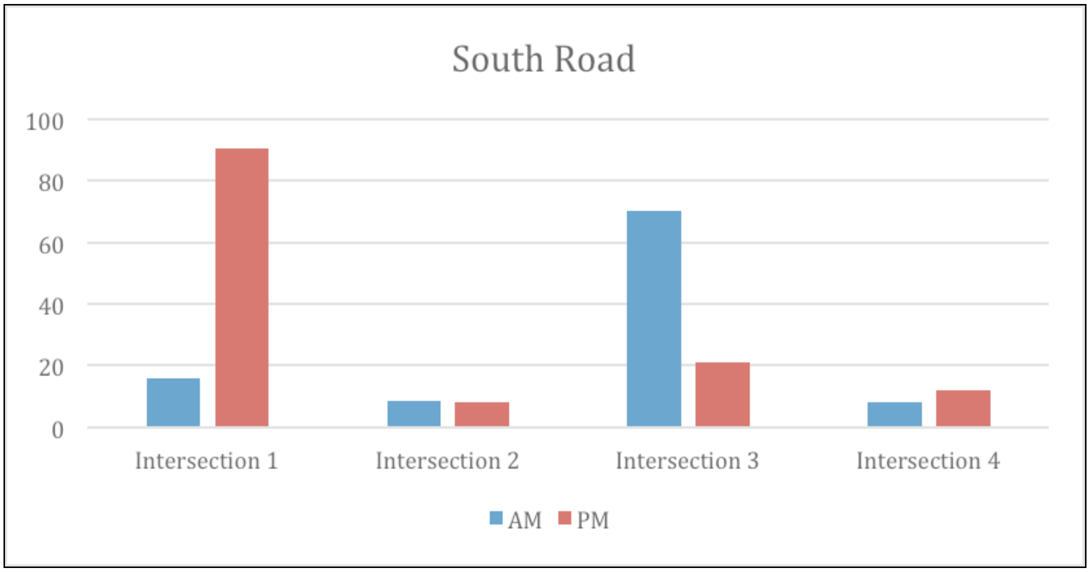


Figure 21. Marion Road Intersections comparison

On the South Road route, 'intersection 1' and 'intersection 3' feature considerably higher travel times than 'intersection 2' and '4'. With 'intersection 1' having higher travel times during the PM peak period and the intersection 3 having higher AM peak periods.

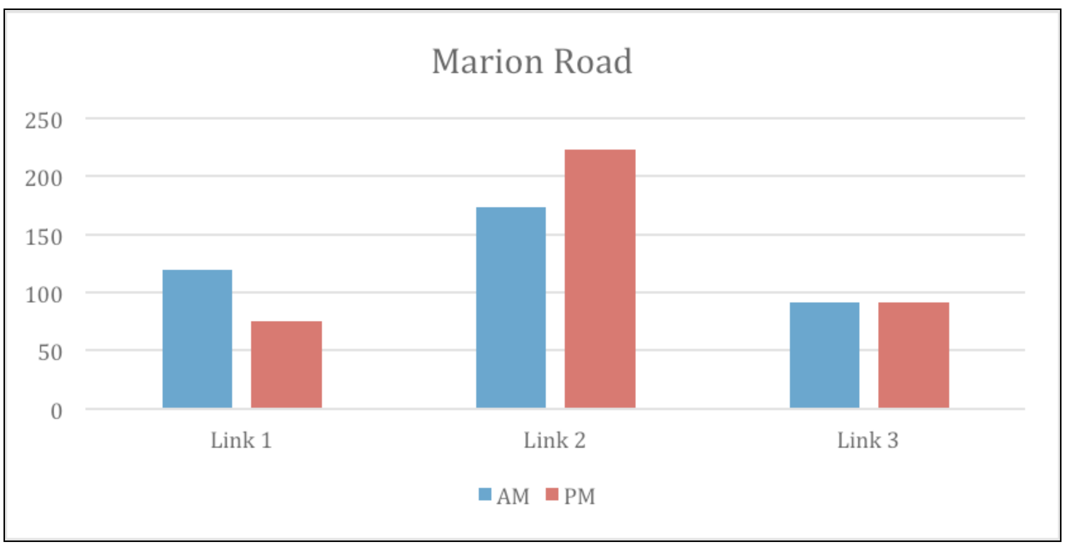


Figure 22. Comparison of Links – Marion Road

The Marion road route also features shorter number of links when compared to the South Road route.

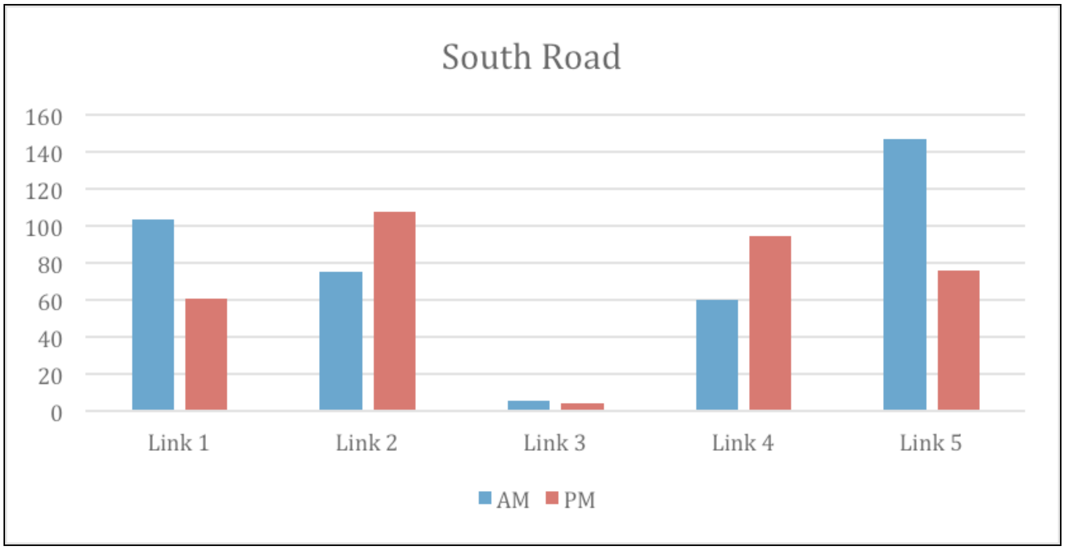


Figure 23. Comparison of Links - South Road

Overall the link with highest travel time is ‘link 2’ on the Marion Road route. This could however attributed to the length of link, as the links on the Marion road route are longer due to the fewer number of links.

CHAPTER V: CONCLUSION

As desired in the study objectives, studies on the estimated travel time of selected routes in Metropolitan Adelaide (Marion Road and South Road) were carried out. This also demonstrates the effectiveness of GPS as a cost effective, accurate source of traffic data. Travel time estimates from the selected routes were also found to be reliable as was indicated by the congestion indices especially the Proportion Stopped Time.

Proportion stopped time (PST) calculated from the speed profiles expressed an overall nature of the trip. The PST for any of the trips is zero, as there is no time during which the travel speed is zero or reaches the pre-determined threshold. Statistical analysis was performed on the congestion indices values using the t-test assuming unequal variances at both 95% and 99% confidence level. All the congestion indices were found not to be significantly different at both periods of the day. Further checks using the Sample Standard deviation method puts the expected error given the sample size at 3.2km/h for the 95% confidence limit.

The average speeds of the two routes when compared were found to differ significantly during the AM peak period. This may be attributed to the difference in traffic volume on these routes, as the South Road route showed higher traffic volumes at the certain sections of the route. The relationship between average speeds and traffic volume is most certainly an important one, as it allows studies of this nature predict the traffic reliability of various routes featuring similar traffic characteristics to the routes in this study within Metropolitan Adelaide. Road and traffic characteristics such as road class, traffic volume, time period and average speed could otherwise serve as indicators of traffic conditions of similar routes. For example, traffic volume and road class information obtained from (DPTI, 2017) revealed slightly higher traffic volumes on the roads for the South Road Route as against lower traffic volume for the Marion road route. It is probable that routes such as Tapleys Hill Road and Green Hill Road will feature similar characteristics to Marion Road given the similarities in Road class and traffic volume. Routes such as Port Road are also expected to feature the same characteristics as South Road given the similarities in Road Class and Traffic Volume.

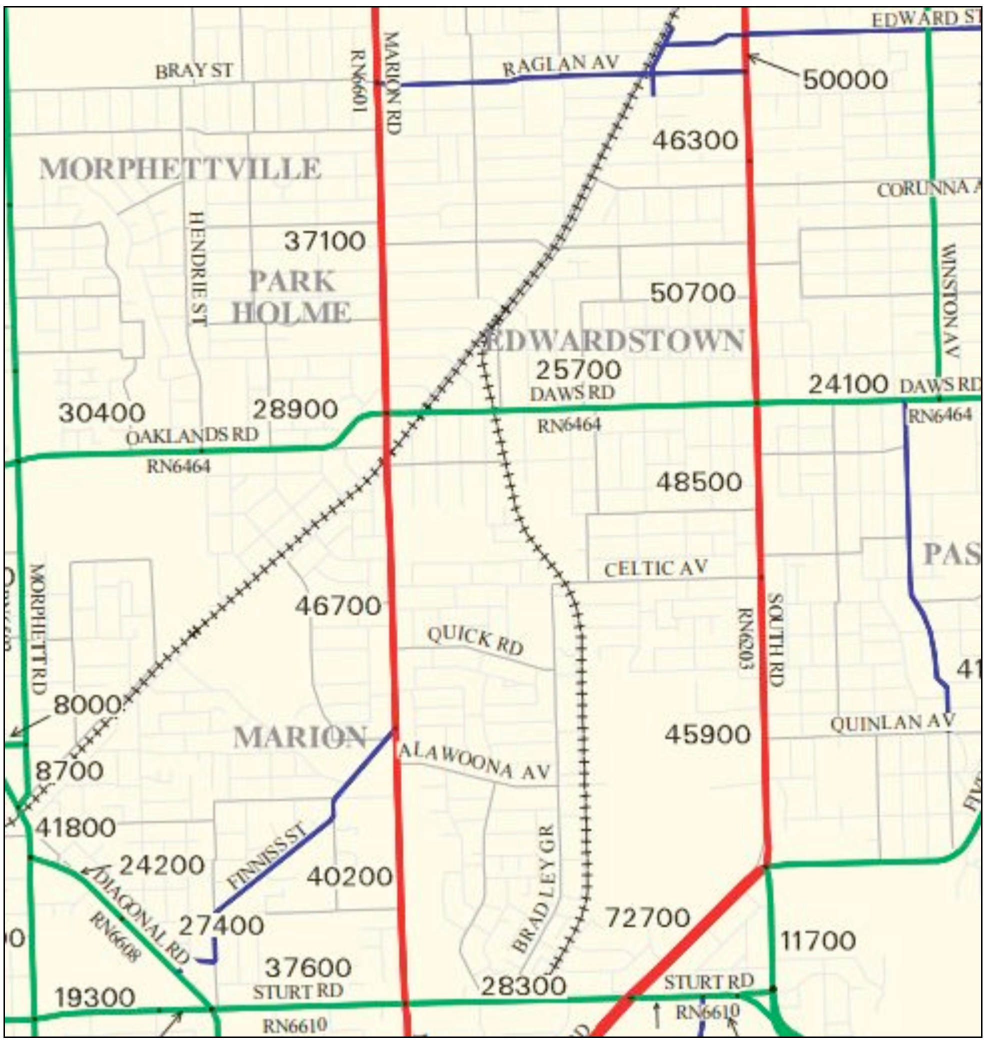


Figure 24. Road class and average traffic volumes of the two routes (DPTI, 2017).

FURTHER RESEARCH

One area that provides an avenue for further research is the integration of emission measurement and control into subsequent studies. As this is unconsidered in this study, it's inclusion into subsequent studies would allow the level of emission of gases such as CO_2 as well as un-combusted fuel products, to be used as an assessment criteria in travel studies.

Also desirable is the integration of fuel consumption in further studies. The integration of fuel consumption as assessment criteria in travel studies is necessary in order to determine fuel-efficient routes as well as transportation patterns. In the face of dwindling energy resources, the need for fuel-efficient transport systems is quite important.

Additional research could also be made to compare and validate congestion and travel data acquired by GPS based techniques used in this study with conventional data collecting techniques. Techniques such as the "floating car" technique described by Wardrop and Charlesworth (1954), Robertson (1994), Taylor, Bonsall and Young (2000). This would involve the parallel collection of data through GPS based methods alongside information on the net overtaking and the number of vehicles met in the opposing flow. This is explained in detail in Cowan and Erikson (1977).

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Appendix A

Python Code for Calculating congestion Indices

Input files:

CSV tracks file – text file containing GPS points along route that need to by analysed.
CSV file should be containing: car GPS position stored in column:
[PID_GPS_LATITUDE], [PID_GPS_LONGITUDE]
current speed stored in column:
[PID_GPS_SPEED] time:
[PID_GPS_DATETIME]

Roads shapefile – shapefile containing geospatial data about street network, each street should contain data about speed regulation. Street network data will be used to identify intersections, links and then to calculate distance of whole trip, each link and each intersection.

Input parameters:

Path to workspace folder – path to folder where all work shape file will be stored.

Path to results folder – path to folder where all report files will be stored.

Path to layers style folder - path to folder where style files are stored, this files are used to create output map in predesigned style.

TrafficCongestionAnalyst – workflow

Step 1: Setting up workspace and results folder

Step 2: Reading route CSV files and creating point shapefile
based on CSV data input: CSV file
OutputroutePoints.shp

Step 3: Creating report templete

Step 4: Projecting all data to one common Coordinate Reference System **WGS 84 Web Mercator [EPSG:3857]**

input: routePoints.shp, roads.shp
output: routePoints3857.shp, roads3857.shp

Step 5: Adding Web Mercator XY coordinates data of each point to points of route points shapefile.

Input:
routePoints3857.sh
p Output:
routePoints3857X
Y.shp

FINDING DRIVE ROUTE – CALCUALTION FOR WHOLE ROUTE

Step 6: Creating buffer around route points

Input:
routePoints3857
XY.shp
Parameter: R=
200 m
Output: routeBuffer.shp

Step 7: Clipping street network within buffers area

Input: routeBuffer.shp,
roads3857.shp
Output: streetNetworkClip.shp

Step 8: Creating python functions for calculating traffic

congestion parameters timeFormat

StoppedTime MeanJournaySpeed DayTime

ProportionalStopdTime AccelerationNoise

MeanVelocityGradient

Step 9: Defining data fields in route

points shapefile Input:

routePoints3857XY.shp

Step 10: Creating list of all route points data

Step 11: Reading data about start time, end time, start point and end point of journey from list created in step 10

Start time is time of first point in CSV file and end time is time of last point in CSV file.
Start point is location of first point in CSV file and end point is location of last point in CSV file.

Step 12: Calculating total drive time

Drive time is calculated as subtraction of end time

and start time Output: total travel time in seconds

Step 13: Finding shortest paths form first route point to last route point along clip street network (In this section I used Graph analysis function from QGIS Network analysis library)

Input: streetNetworkClip.shp, coordinates of start point and end point of route.

Start point is location of first point in CSV file and end point is location of last point in

CSV file. Output: routeLine.shp – line of travel along street networ

Step 14: Finding information of day time

Day time information is based on start point time

Step 15: Finding information about total travel distance

Input: routeLine.shp from Step 13

Output: totalDistance – total travel distance in meters

Step 16: Calculating mean journey speed – (**MeanJournaySpeed** function from Step 8)

Input: travelTime – total travel time in seconds from Step 12
totalDistance – total travel distance in meters from Step 15
Output: MeanJournaySpeed – mean journey speed in kilometers per hour

Step 17: Calculating sum of stop time periods – (**StoppedTime** function from

Step 8)

Input: routeList – list of data form route points from Step 10 idSPEED – index of SPEED field form Step 9
idTIME – index of TIME field form Step 10
output: StoppedTimeResults - sum of stop time periods in seconds

Step 18: Calculating proportion stopped time – (**ProportionalStoppedTime** function from Step 8)

Input: StoppedTimeResults – sum of stop time periods in seconds Step 17 travelTime - total travel time in seconds from Step 12
Output: proportionStoppedTime – proportion stopped time

Step 19: Calculating acceleration noise – (**AccelerationNoise** function from Step 8)

Input: routeList – list of data form route points from Step 10 idSPEED – index of SPEED field form Step 9
idTIME – index of TIME field form Step 10
travelTime – total travel time in seconds form Step 12
StoppedTimeResults – sum of stop time periods in seconds Step 17
output: AN2 - acceleration noise

Step 20: Calculating mean velocity gradient– (**Mean velocity gradient** function from Step 8)

Input: AN2 – AccelerationNoise from Step 19
totalDistance – total travel distance in meters from Step 15 travelTime - total travel time in seconds from Step 12

output: MVG - mean velocity gradien

Step 21: Calculating Congestion index

Step 22: Creating rapport file for whole route Writing CSV rapport file

Step 23: Extracting route nodes

Output: vertexonLine.shp – point shapefile representing all vertices on route line

Step 24: Creating buffers around route nodes

Input: vertexonLine.shp from Step 13
Parameter: R=1 m
Output: vertexBuffers.shp – polygon shape file representing 1 m buffers around all vertices on route line

Step 25: Extracting street network nodes

Input: roadNetworkClip.shp from Step 7
Output: routesVertexes.shp point shapefile representing all vertices on clipped street network

Step 26: Counting number of street connection to

intersection Input: vertexBuffers.shp

from Step 24
routesVertexes.shp from Step 25

output: countVertex.shp – polygon shapefile containing data about number of street ends inside each polygon

Step 27: Choosing only this intersections that have at least 4 streets

connection Input: countVertex.shp from Step 26
Output: selectedBuffers.shp – polygon shapefile representing buffers around intersection
that have at least 4 street ends inside (TRUE INTERSECION)

Step 28: Creating 100 buffer around 'true intersection points'

Input: selectedBuffers.shp from Step 27
Output: trueInterMulti.shp – intersections buffers shapefile that represents true intersections area

There are some additional processing procedures in this step that are made to avoid creating two intersections on dual carriageway crossings.

Step 29: Numbering intersections

Input: routePoints.shp form Step 2
trueInterMulti.shp from Step 28

Output: trueInterMulti.shp polygon shapefile of true intersecions with 'InterNr' attribute updated

Step 30: Extracting route part inside

intersection Input: routeLine.shp form Step 13

output: trueLines.shp – polyline shapefile representing parts of route line inside

intersections Step 31: Extracting route points inside intersections

Input: routePoints.shp form Step 2
trueInter.shp from Step 28

output: routePointInInter.shp – point shapefile representing route points inside intersections

Step 32: Extracting links route parts

Input: routeLine.shp form Step 13
trueInter.shp from Step 28

Output: roadOutInterMulti.shp – polyline shapefile representing parts of route line outside intersections

Step 33: Numbering of links

Input: roadOutInterMulti.shp form Step 2

Output: NumberedLinks.shp – polygon shapefile representing links lines with 'LinkNr' attribute updated
roadLinkBufferTrue.shp – polygon shapefile representing buffer around links with 'LinkNr' attribute updated

Step 35: Extracting route points outside

intersections Input:

routePoints.shp

from Step 2

roadLinkBufferTrue.shp from Step 3

Output: routePointOutInterNumbers.shp - point shapefile representing route points outside intersections.

Appendix B

Table 5. Congestion Parameters for the Marion Road Route (AM Peak)

Trip code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
AM peak - Marion Road, Period (May – June)								
0205MRAM	4681.375	467	0	36.08768706	0	0.761042288	0.021089	0.652642
0305MRAM	4655.747	431	0	38.88791133	0	1.779396031	0.045757	0.531457
0405MRAM	4641.189	478	0	34.95456143	0	1.160401704	0.033197	0.7024
0505MRAM	4696.998	504	0	33.54998903	0	3.361258356	0.100187	0.779178
0605MRAM	4689.441	422	0	40.00470928	0	8.668641607	0.216691	0.491489
0905MRAM	4685.629	471	0	35.81372715	0	0.739922409	0.02066	0.665675
1005MRAM	4697.639	431	0	39.23781759	0	1.722235315	0.043892	0.521326
1105MRAM	4691.638	420	0	40.21404305	0	0.557593823	0.013866	0.483905
1205MRAM	4667.823	449	0	37.42575033	0	1.989983291	0.053172	0.592359
1305MRAM	4666.01	493	0	34.07228188	0	1.72905599	0.050747	0.748906
1605MRAM	4677.281	442	0	38.09550328	0	1.414668276	0.037135	0.565185
1705MRAM	4667.826	422	0	39.82031547	0	4.912440573	0.123365	0.496604
1805MRAM	4674.348	383	0	43.93642571	0	0.963665051	0.021933	0.356888
1905MRAM	4669.871	487	0	34.52060401	0	0.899861625	0.026067	0.726563
2005MRAM	4667.418	691	0	24.31650568	0	1.023575323	0.042094	1.450759
2305MRAM	4708.44	460	0	36.84865841	0	1.430527633	0.038822	0.620924
2405MRAM	4657.323	436	0	38.45495788	0	3.161127578	0.082203	0.548836
2505MRAM	4696.122	452	0	37.40273783	0	0.868359161	0.023216	0.595833
2605MRAM	4642.79	450	0	37.14231709	0	1.652866702	0.044501	0.60227
2705MRAM	4690.817	516	0	32.7266313	0	2.14693365	0.065602	0.82332
3005MRAM	4665.176	401	0	41.8818752	0	0.520261905	0.012422	0.422727

3105MRAM	4685.941	486	0	34.71067634	0	0.571922019	0.016477	0.718637

Trip Code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
0106MRAM	4665.565	444	0	37.82891	0	3.431532	0.090712	0.575191
0206MRAM	4684.349	497	0	33.9309	0	3.756385	0.110707	0.75798
0306MRAM	4671.108	401	0	41.93513	0	1.650833	0.039366	0.421388
0706MRAM	4643.487	415	0	40.28085	0	2.219614	0.055103	0.477484
0806MRAM	4717.023	475	0	35.75007	0	0.319765	0.008944	0.671519
0906MRAM	4654.993	448	0	37.4062	0	0.663563	0.017739	0.592053
1006MRAM	4661.848	540	0	31.07899	0	0.581195	0.018701	0.916904
1506MRAM	4647.618	382	0	43.79954	0	1.956785	0.044676	0.359103
1606MRAM	4675.039	572	0	29.42332	0	0.903797	0.030717	1.026253
1706MRAM	4682.172	780	0	21.61002	0	0.445568	0.020619	1.759953
2006MRAM	4669.782	446	0	37.69331	0	0.805466	0.021369	0.581228
2106MRAM	4674.086	577	0	29.16241	0	1.578535	0.054129	1.044274
Mean	4674.233	475.5	0	36.17663	0	1.774964	0.048408	0.684742
Std. dev	18.37019	81.42	0	4.893765	0	1.625995	0.041384	0.287844

Table 6. Congestion Parameters for the Marion Road Route (PM peak)

Trip Code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
PM peak direction - Marion Road, Period (May – June)								
0205MRPM	4676.933	434	0	38.79483	0	0.899916	0.023197	0.536941
0305MRPM	4647.714	438	0	38.20039	0	0.595345	0.015585	0.55832
0405MRPM	4720.443	473	0	35.92727	0	0.464892	0.01294	0.663585
0505MRPM	4719.344	405	0	41.94972	0	18.57697	0.442839	0.424669
0605MRPM	4696.204	463	0	36.51476	0	0.769582	0.021076	0.634649
0905MRPM	4708.66	381	0	44.49128	0	1.68961	0.037976	0.342501
1005MRPM	4675.389	398	0	42.28995	0	0.823558	0.019474	0.409797
1105MRPM	4711.002	420	0	40.38002	0	1.06449	0.026362	0.479377
1205MRPM	4671.243	390	0	43.11916	0	0.716005	0.016605	0.382368
1305MRPM	4684.502	484	0	34.84341	0	0.84165	0.024155	0.711955
1605MRPM	4716.087	454	0	37.39628	0	1.682642	0.044995	0.597855
1705MRPM	4708.735	364	0	46.56991	0	3.556114	0.076361	0.282585
1805MRPM	4701.022	493	0	34.32795	0	16.76421	0.488354	0.739242
1905MRPM	4682.316	508	0	33.18176	0	0.341174	0.010282	0.797467
2005MRPM	4673.974	457	0	36.81905	0	1.305763	0.035464	0.619151
2305MRPM	4671.532	403	0	41.7308	0	15.28084	0.366176	0.428382
2405MRPM	4682.354	545	0	30.92931	0	1.163791	0.037627	0.928373
2505MRPM	4688.633	481	0	35.09164	0	0.2751	0.007839	0.700232
2605MRPM	4654.744	397	0	42.20926	0	0.751234	0.017798	0.410871
2705MRPM	4654.842	441	0	37.99871	0	0.778378	0.020484	0.567215

Trip Code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
3005MRPM	4715.373	409	0	41.50451	0	0.95673	0.023051	0.439639
3105MRPM	4613.518	503	0	33.01922	0	0.719942	0.021804	0.799371
0106MRPM	4672.804	376	0	44.73961	0	1.978676	0.044226	0.332415
0206MRPM	4725.073	455	0	37.38519	0	1.198991	0.032071	0.599112
0306MRPM	4697.523	452	0	37.4139	0	0.768422	0.020538	0.59548
0706MRPM	4662.336	384	0	43.7094	0	1.22588	0.028046	0.363026
0806MRPM	4672.049	445	0	37.79635	0	0.273675	0.007241	0.577116
0906MRPM	4698.848	396	0	42.7168	0	2.374598	0.055589	0.397518
1006MRPM	4615.022	572	0	29.04559	0	1.004933	0.034598	1.045711
1506MRPM	4656.829	410	0	40.88923	0	1.293973	0.031646	0.456588
1606MRPM	4639.78	590	0	28.31052	0	0.460708	0.016273	1.101761
1706MRPM	4642.298	507	0	32.96306	0	0.473668	0.01437	0.805365
2006MRPM	4708.307	462	0	36.6881	0	0.965992	0.02633	0.628006
2106MRPM	4676.865	712	0	29.16241	0	0.791057	0.033453	1.52146
Mean	4680.656	455.9	0	37.72335	0	2.436132	0.062789	0.614062
Std. dev	29.03464	71.39	0	5.158614	0	4.621744	0.118534	0.255449

Table 7. Congestion Parameters for the South Road Route (AM Peak)

Trip Code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
AM Peak - South Road, Period (August)								
0108SRAM	5672.465	562	0	36.33607	0	2.435081	0.067016	0.676763
0208SRAM	5715.785	450	0	45.72628	0	1.602081	0.035036	0.334885
0308SRAM	5670.868	642	0	31.79926	0	1.23644	0.038883	0.915856
0408SRAM	5627.056	486	0	41.68189	0	0.635152	0.015238	0.458855
0508SRAM	5600.713	611	0	32.99929	0	0.519883	0.015754	0.840586
0808SRAM	5584.574	451	0	44.57753	0	1.840642	0.041291	0.361561
1008SRAM	5601.07	503	0	40.08718	0	0.696642	0.017378	0.515172
1108SRAM	5650.143	523	0	38.892	0	1.521657	0.039125	0.565067
1208SRAM	5596.626	587	0	34.32343	0	0.999428	0.029118	0.769263
1508SRAM	5606.042	434	0	46.50173	0	1.219434	0.026223	0.30645
1708SRAM	5605.17	494	0	40.84739	0	1.586845	0.038848	0.48724
1808SRAM	5609.405	511	0	39.51831	0	2.502402	0.063323	0.537543
1908SRAM	5644.624	443	0	45.87053	0	1.44405	0.031481	0.326649
2208SRAM	5580.52	494	0	40.66776	0	0.750713	0.01846	0.492194
2308SRAM	5598.385	575	0	35.05076	0	1.507473	0.043008	0.732683
2908SRAM	5633.035	531	0	38.19007	0	1.876257	0.049129	0.592655
Mean	5624.78	518.5	0	39.56684	0	1.398386	0.035582	0.557089
Std.Dev	37.38866	62.39	0	4.637661	0	0.594831	0.01558	0.187082

Table 8. Congestion Parameters for the South Road Route (PM Peak)

Trip Code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
PM Peak - South Road, Period (August)								
0108SRPM	5593.293	410	0	49.11183674	0	1.643639	0.033467	0.236327
0208SRPM	5618.931	491	0	41.19786393	0	0.957516	0.023242	0.475473
0308SRPM	5598.633	497	0	40.55348149	0	0.951561	0.023464	0.49759
0408SRPM	5614.487	533	0	37.92148675	0	0.842364	0.022213	0.602642
0508SRPM	5647.907	882	0	23.05268297	0	1.164455	0.050513	1.640158
0808SRPM	5555.852	541	0	36.97054925	0	1.149597	0.031095	0.63963
1008SRPM	5618.931	496	0	40.78256288	0	1.360512	0.03336	0.490499
1108SRPM	5576.555	454	0	44.21937964	0	0.943122	0.021328	0.372104
1208SRPM	5587.737	546	0	36.84222459	0	2.178944	0.059143	0.64766
1508SRPM	5618.931	486	0	41.62171026	0	1.78132	0.042798	0.460448
1708SRPM	5612.265	554	0	36.46959037	0	3.934291	0.107879	0.666284
1808SRPM	5575.431	416	0	48.24892488	0	1.591859	0.032993	0.257449
1908SRPM	5615.325	501	0	40.34963873	0	0.947723	0.023488	0.506254
2208SRPM	5611.154	600	0	33.66692229	0	1.102375	0.032744	0.80491
2308SRPM	5612.965	472	0	42.81075297	0	0.833929	0.019479	0.419516
2908SRPM	5525.52	375	0	53.04499236	0	1.332135	0.025113	0.141221
Mean	5598.995	515.8	0	40.42904	0	1.419709	0.036395	0.553635
Std.dev	29.5393	113.6	0	6.891342	0	0.771114	0.022041	0.337501

Appendix C

The GPX files had the following structure.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<gpx creator="GPS Stone Trip Recorder for iPhone by Obvious Idea"
version="1.1" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns="http://www.topografix.com/GPX/1/1"
xsi:schemaLocation="http://www.topografix.com/GPX/1/1 http://www.topografix.com/GPX/1/1/gpx.xsd">
    <trk>
        <trkseg>
            <trkpt lon="138.570948" lat="-35.007255">
                <ele>55.095276</ele>
                <time>2016-06-01T03:27:04</time>
                <magvar>343.476562</magvar>
                <hdop>5.000000</hdop>
                <vdop>6.000000</vdop>
            </trkpt>
            <trkpt lon="138.570821" lat="-35.007090">
                <ele>58.393475</ele>
                <time>2016-06-01T03:27:10</time>
                <magvar>326.250000</magvar>
                <hdop>5.000000</hdop>
                <vdop>3.000000</vdop>
            </trkpt>
```

The data is stored in the XML file format. The starting tag <gpx> have only metadata, xml schemas and its location etc. The root tag is <trk> which stores the track information.
The track information is stored in the sub tag <trkpt>. <trkpt> has two attributes; lon and lat. The values of these attributes are latitude and longitude in decimal degree format based on WGS84 system. The other sub tags under <trkpt> are <elv> showing the elevation, <time> the time stamp in UTC format, <magvar> magnetic variation with respect to magnetic north direction, <hdop> horizontal dilution of precision in GPS position, <vdop> vertical dilution of precision.

These GPX files were converted into the ASCII Text files using Garmin MapSource software.
The Text files stores the data in following format.

```
Grid    Lat/Lon hddd.ddddd°
Datum   WGS 84

Header  Name    Start Time      Elapsed Time    Length  Average Speed   Link

Track   Track 001       6/1/2016 3:27:04 AM     0:06:16 4.0 km  38 kph

Header  Position        Time    Altitude        Depth   Temperature     Leg Length      Leg Time        Leg Speed       Leg Course

Trackpoint      S35.00725 E138.57095    6/1/2016 3:27:04 AM     55 m
Trackpoint      S35.00709 E138.57082    6/1/2016 3:27:10 AM     58 m                    22 m    0:00:06 13 kph  328° true
Trackpoint      S35.00693 E138.57064    6/1/2016 3:27:16 AM     59 m                    24 m    0:00:06 14 kph  317° true
Trackpoint      S35.00677 E138.57052    6/1/2016 3:27:21 AM     60 m                    21 m    0:00:05 15 kph  328° true
Trackpoint      S35.00656 E138.57044    6/1/2016 3:27:27 AM     59 m                    24 m    0:00:06 14 kph  341° true
Trackpoint      S35.00638 E138.57050    6/1/2016 3:27:31 AM     60 m                    22 m    0:00:04 20 kph  17° true
Trackpoint      S35.00616 E138.57053    6/1/2016 3:27:35 AM     59 m                    24 m    0:00:04 22 kph  6° true
Trackpoint      S35.00595 E138.57057    6/1/2016 3:27:39 AM     57 m                    23 m    0:00:04 21 kph  7° true
Trackpoint      S35.00579 E138.57038    6/1/2016 3:27:44 AM     55 m                    24 m    0:00:05 18 kph  317° true
Trackpoint      S35.00576 E138.57014    6/1/2016 3:27:47 AM     56 m                    22 m    0:00:03 27 kph  278° true
Trackpoint      S35.00572 E138.56983    6/1/2016 3:27:50 AM     55 m                    29 m    0:00:03 34 kph  280° true
Trackpoint      S35.00568 E138.56955    6/1/2016 3:27:53 AM     54 m                    26 m    0:00:03 31 kph  280° true
Trackpoint      S35.00583 E138.56934    6/1/2016 3:27:57 AM     53 m                    26 m    0:00:04 23 kph  229° true
```

the first 10 lines show the datum, Grid units , Start time of the track, length of track, average speed of track, time elapsed etc.

The consequent rows shows the track points in Lat/long format with prefix of S for south latitude and prefix of E for Longitude. The additional information is the altitude, temperature (this is not stored in above GPX files), leg length (calculated as geodesic distance), leg time (time taken between two consecutive points), Leg speed, Leg course (Magnetic north).

There were many files which need to convert in CSV file and the data was required to be in atomic cells in comma delimited file format to export in other software. In order to automate this process, a windows script was written in VB to transform the text files in csv.

The script is shown below:

```
dim fso : set fso = CreateObject("Scripting.FileSystemObject")
dim CurrentDirectory : CurrentDirectory =
fso.GetAbsolutePathName(".")
dim MySource : Set MySource = fso.GetFolder(CurrentDirectory)

For Each file In MySource.Files
If Right(file.Name, 3) = "txt" Then
    ExtractValues file.Name, file.Path, Replace(file.Path,
file.Name, "")

End If
Next

Sub ExtractValues(NewFileName, File1 , NewFilePath )
Dim WrdArray
Dim txtstrm
Dim line
Dim clm
Dim Rw
Dim FSO : Set FSO = CreateObject("Scripting.FileSystemObject")
Set txtstrm = FSO.OpenTextFile(File1)
Rw = 1

Dim isRequiredRow :isRequiredRow = False
Dim newCSVFile :newCSVFile =
"PID_GPS_DATETIME,PID_GPS_LATITUDE,PID_GPS_LONGITUDE,PID_GPS_ALTI
TUDE,PID_GPS_SPEED" & vbNewLine


Do Until txtstrm.AtEndOfStream
```

```
  line = txtstrm.ReadLine

  WrdArray = Split(line, vbTab) 'Change with ; if required
  If (isRequiredRow = False And UBound(WrdArray) > 2) Then
    If (Mid(WrdArray(1), 1, 1) = "S") Then isRequiredRow = True
  End If

  If (isRequiredRow And UBound(WrdArray) > 2) Then
  Dim vDateTime, vPosition, vAltitude, vGpsSpeed
  vDateTime = WrdArray(2)
  vPosition = WrdArray(1)
  vAltitude = WrdArray(3)
  If (UBound(WrdArray) > 8) Then
   vGpsSpeed = WrdArray(8)
  Else
   vGpsSpeed = ""
  End If
    Dim tmpDateTime, tmpLat, tmpLong, tmpAltitude, tmpGPSSpeed
   tmpDateTime =  FormatDateTime(vDateTime, vbLongTime)
   vPosition = Replace(vPosition, "S", "-")
   vPosition = Replace(vPosition, "E", "")
   Dim arrPos:   arrPos = Split(vPosition, " ")
   tmpLat = arrPos(0)
   tmpLong = arrPos(1)
   tmpAltitude = Extract_Number_from_Text(CStr(vAltitude))
    tmpGPSSpeed = ""
   if(vGpsSpeed <> "")then
    tmpGPSSpeed = Extract_Number_from_Text(CStr(vGpsSpeed))
   end if

   newCSVFile = newCSVFile & tmpDateTime & "," & tmpLat & "," &
tmpLong & "," &    tmpAltitude & "," & tmpGPSSpeed & vbNewLine
  End If


  Rw = Rw + 1
Loop
txtstrm.Close

 Set a = FSO.CreateTextFile(NewFilePath & "\" &
Replace(NewFileName, ".txt", ".csv"), True)
  Dim arrLines : arrLines = Split(newCSVFile, vbNewLine)
    For Each line1 In arrLines
    a.WriteLine (line1)
    Next
    a.Close
```

```
end sub



Function Extract_Number_from_Text(Phrase )
Dim Length_of_String
Dim Current_Pos
Dim Temp
Length_of_String = Len(Phrase)
Temp = ""
For Current_Pos = 1 To Length_of_String
If (Mid(Phrase, Current_Pos, 1) = "-") Then
  Temp = Temp & Mid(Phrase, Current_Pos, 1)
End If
If (Mid(Phrase, Current_Pos, 1) = ".") Then
 Temp = Temp & Mid(Phrase, Current_Pos, 1)
End If
If (IsNumeric(Mid(Phrase, Current_Pos, 1))) = True Then
    Temp = Temp & Mid(Phrase, Current_Pos, 1)
 End If
Next
If Len(Temp) = 0 Then
    Extract_Number_from_Text = 0
Else
    Extract_Number_from_Text = CDbl(Temp)
End If
End Function
```

After executing the above script, the files for AM and PM for each day from the folder were transformed and loaded in an output folder.