Assessing the major causes of travel time reliability on urban freeways

Ahmad Tavassoli Hojati[1], Luis Ferreira[2], Phil Charles[3]

[1] PhD Researcher, The University of Queensland, Brisbane QLD 4072 Australia
[2] Professor, School of Engineering, The University of Queensland, Brisbane QLD 4072 Australia
[3]Director, Centre for Transport Strategy, The University of Queensland, Brisbane Qld 4072 Australia

ABSTRACT-Travel time reliability (TTR) has become one of the most important indicators of transportation performance. From a user's perspective, the reliability of arrival times often ranks as the most important attribute, ahead of total trip travel time. This paper summarises the early findings of a study aimed at quantifying reliability causes so that improved predictive reliability models can be put forward.

After dealing with the definition of reliability from different viewpoints, the paper summarises the latest findings related to the causes of travel time variability (TTV) and uncertainty on urban freeways. Both recurrent and non-recurrent congestion are dealt with separately. The causes of TTV are categorized in seven major groups. The relative importance of each of these factors is discussed together with the data collection and analysis methods needed to build TTR predictive models.

The paper provides some preliminary findings from the analysis of TTV data for a section of an urban freeway in Brisbane. On the basis of that analysis, some general conclusions are drawn related to the type and the amount of data which must be collected to enable predictive reliability models to be built.

Key words: travel time; travel time reliability; Traffic Incidents; recurrent and non-recurrent congestion

1. INTRODUCTION

Travel time is one of the most important aspects of transportation. It can be considered as an effective factor to measure transportation network performance. It reflects the efficiency of the road network and has an easily understood meaning for most travellers. Travel time varies over time. This variability in travel time from one day to another is due to the very unsteady and variable characteristic of the key conditions that are the direct sources of congestion. Recurrent congestion relates to everyday peak period traffic flow when demand exceeds capacity. Travellers are used to this sort of congestion and they plan for it. The worse kind of congestion happens due to unsteady and unpredictable changes from time to time or day to day and also due to the unexpected occurrences. These situations are referred to as non-recurring congestion.

Acknowledging the effects of congestion on travel time variability, many studies have attempted to measure the travel time uncertainty in order to present average conditions and indications of how often and/or how much travel time varies over time (Lomax et al. 2003).

Kaparias et al. (2008) found that, in spite of the fact that travel time is considered an important factor for route choice decisions, travel time variability can be even of more significance.

There is an increasing awareness of the importance of travel time reliability (TTR), notably for commuters and industries that rely heavily on specific travel times for the delivery of goods. From a user's perspective, the reliability of arrival times often ranks as the most important attribute, ahead of total trip travel time. Much research has been undertaken on the importance of travel time reliability including attempts to model it (Cambridge Systematics Inc. & Texas Transportation Institute 2005; Elefteriadou, Lily, Xu & Xie 2008; Lyman & Bertini 2008)

The aim of the current work is to deal with the definition and the measurement of reliability from different viewpoints and reviewing the latest findings related to the causes of travel time variability (TTV) and uncertainty on urban freeways. Both recurrent and non-recurrent congestion are dealt with separately. After categorizing the causes of TTV, the relative importance of each of these factors is discussed together with the data collection and analysis methods needed to build TTR predictive models.

Some preliminary findings from the analysis of TTV data for a section of an urban freeway in Brisbane are set out and their results are presented.

2. DEFINING TRAVEL TIME RELIABILITY

There have been many attempts at defining travel time reliability. In a study by Ebeling (1997) reliability is defined as "the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions. It is the probability of non-failure over time." Also, reliability is defined as the impact of non-recurrent congestion on the transportation system (Lomax et al. 1997). In other definitions, reliability is a measure of variability of travel time (Cambridge Systematics Inc. 1998), a measure of the amount of congestion users of the transportation system experience at a given time (Lomax et al. (2003), the level of variability between the expected travel time (based on scheduled or average travel time) and the actual travel time experienced (Elefteriadou, Lily & Cui 2007).

In the last definition, while the expected travel time is based on pre-planned or average travel time, the actual travel time is affected directly by non-recurrent congestion. The expected travel time is clearly defined as the mean travel time during a particular period of time. However, in this definition there is no clear reliable/failure limit is presented. Besides, the expected travel time and the actual travel time in the facilities congested for long periods of time are both high and the small difference between those values may mislead us to consider the facility as reliable, while it is continuously congested (Elefteriadou, L & Xu 2007).

In a more recent study, travel time reliability is defined as the consistency or dependability of a particular trip's travel time measured from day to day and/or across different times of the day (Lyman & Bertini 2008).

According to all definitions, two different TTR measures can be presented, mainly: a) an appropriate measure for agencies to monitor the reliability of different facilities, and b) a suitable measure for travellers to estimate certain trips' travel times more accurately.

3. MEASURES OF RELIABILITY

Many different characteristics of travel time distribution have been studied in order to build appropriate measures for quantifying the TTR. These measures imply the amount of congestion that might be faced on a given link.

According to Polus (1979), reliability was quantified as the inverse of the standard deviation of the link's travel time distribution. Also in (Lomax et al. 2003), travel time window was defined as a new measure of reliability as follows:

Travel Time Window = Average Travel Time ± Standard Deviation

Subsequently, this was measured as the difference between the 95th percentile and the median of the travel time distribution, that is called the Buffer Time (Dandy & McBean 1984; Lam & Small 2001). By adding this time to the average travel time, the traveller will arrive at his/her destination 95% on time.

In these definitions measures are not dimensionless. To overcome this disadvantage reliability measures have been developed by using both the width of travel time and skewness. Lomax et al. (2003) has introduced three main categories of measures, namely: statistical range measures, buffer measures and tardy trip indicators. Due to its statistical nature, the first group of measures is not used generally and is limited to agencies and statisticians, while the second group presents comprehensible, handy measures usable for the travellers. These measures help travellers to calculate the extra time needed to be allocated in particular trips to arrive on time. The third group indicates the unreliability impacts regarding the number of the late trips. Here are the most popular measures of each category[1]:

$$\text{Percent Variation (PV)} = \frac{\text{Standard Deviation}}{\text{Average Travel time}} \times 100$$

$$\text{Buffer Time Index (BTI)} = \frac{\text{95\% Travel rate} - \text{Average Travel Rate}}{\text{Average Travel Rate}}$$

$$\text{Misery Index (MI)} = \frac{\text{Average Travel Rate for Worst 20\% Trip} - \text{Average Travel Rate}}{\text{Average Travel Rate}}$$

4. FACTORS AFFECTING RELIABILITY

Travel time on freeways varies over time due to changes in congestion. These changes lead to changes in TTR. According to Elefteriadou and Xu (2007) and Cambridge Systematics Inc. & Texas Transportation Institute (2005), there are seven major sources of congestion including traffic incidents, work zones, weather, traffic control devices, special events, fluctuation in normal traffic and physical capacity. Figure 1 presents these factors and the relationship between them.

Traffic Incidents are any events creating a temporary reduction in freeway capacity and degrading safety. Events such as vehicular crashes, breakdowns, spilled cargo, and debris in travel lanes are the most common form of incidents. These may include not only the physical blockings of travel lanes, but also the events on the shoulder or roadside, which affect traffic flow by drawing drivers' attention, creating changes in drivers' behaviour and, finally, defecting the traffic flow quality. In evaluating the effects of traffic incidents, duration of incident and number of closure lanes are the two important factors to be considered.

[1] "Travel Rate" represents travel time per distance unit.

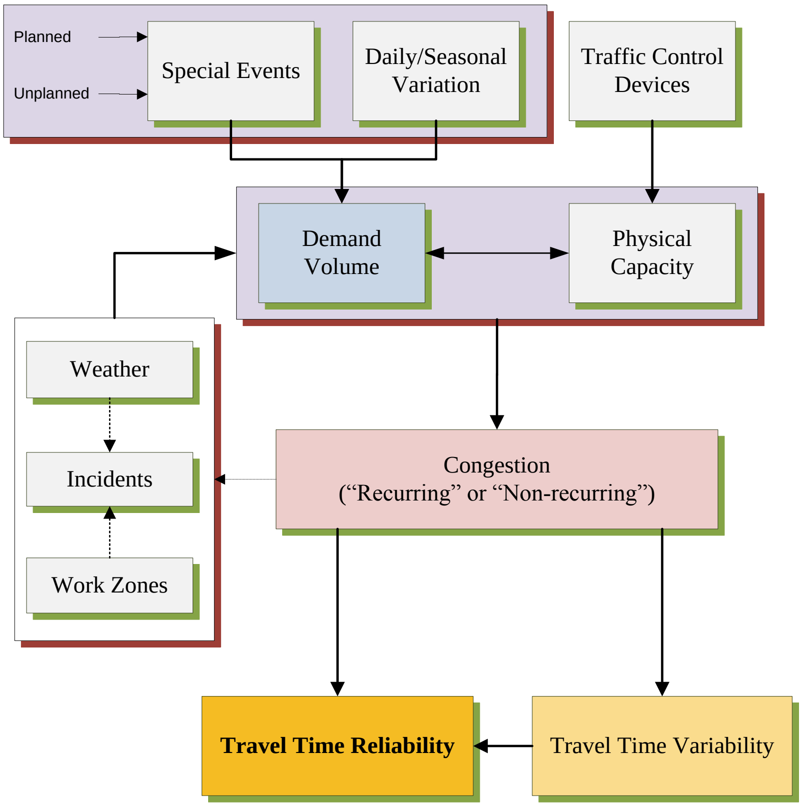


Figure 1- Sources of congestion and their relationship with TTR

Work Zones refer to construction activities on the roadway that may lead to temporary lane or complete road closure.

Weather refers to environmental conditions that can affect driver behaviour and therefore, affect traffic flow. In a study by Koetse and Rietveld (2009) it is claimed that temperature and wind have almost no effects on traffic speed. Also rain has no substantial effect on free-flow speed, while rain and snow have considerable impacts on traffic speed in already congested roads and also during peak hours of day.

Traffic Control Devices refers to the irregular disruption of traffic flow caused by poor performance of control devices such as railroad grade crossings and poorly timed signals.

Special Events are special cases that cause changes in demand fluctuations and make the traffic flow in its vicinity completely different from "typical" patterns. Special events may cause "surges" in traffic demand that overwhelm the system. Special events might be planned and predictable events such as Christmas Day, or emergency and unexpected events such as fire.

Fluctuations in Normal Traffic – Based day-to-day variability in demand, some days have higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also leads to variable (i.e., unreliable) travel times.

Physical Capacity ("Bottlenecks") – Capacity is the maximum possible amount of traffic to be handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves).

In order to make accurate estimations of TTR, it is necessary to collect sufficient data about the sources of congestion shown in Figure 1. Loop detectors and other modern technologies such as cameras that recognize plate numbers and GPS are among the most helpful and efficient means of collecting precise data.

5. PILOT CASE STUDY

In order to empirically illustrate the TTR measures using traffic flow distributions, we conducted a pilot study using data from a specific section of the major urban freeway in Brisbane to calculate the relation between TTR and vehicle flows. The following sections show the data collection, analysis procedures and the results obtained.

5.1. TRAFFIC DATA

In this study, we selected an area in Pacific Motorway (M1), a major freeway in Brisbane, between Marshal Road and Lewisham Street in both directions. A recent survey has been done on this region for a five-day period from 11:30am, 9th to 8:00am, 13th of March 2009, and has collected data continuously via three cameras recognizing license plate numbers in each direction on the left lane of the motorway. The data consist of date, time, plate number and the location of the vehicles. Figure 2 highlights the corridor. This study section covers 2.4 kilometres containing two segments; one from Marshal Road to Esher Street (0.78 km), the other from Esher Street to Lewisham Street (1.66 km).

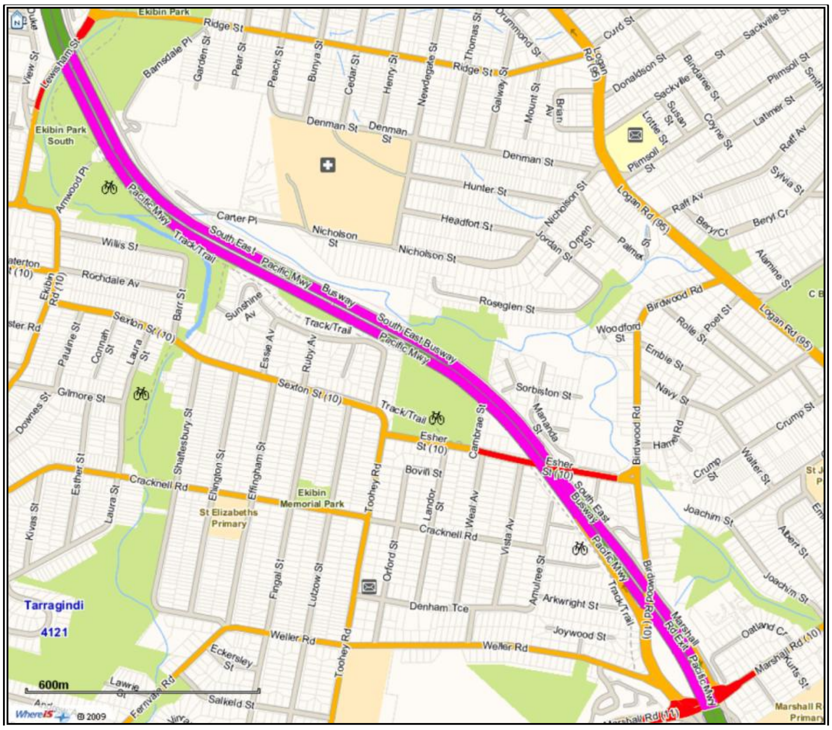


Figure 2- Pacific Motorway Study Segment

5.2. PRELIMINARY DATA ANALYSIS

In this study, a program was written to match the plate number in each direction and each segment, and to calculate travel times. Those direct travel time measurements present us with travel time distribution data. Figure 3 shows the travel time distribution and number of vehicles during the survey period. The TTR measures described in section 3 were calculated in both directions and segments, for each day separately and for the whole period of the survey. Tables 1 and 2 present the results in detail. As shown in Figure 3, travel time in most times of the day is near to free flow travel time. In some cases, there is a lag between travel time and number of vehicles; for example, in the northbound direction segment 1, there is a peak traffic period around 6:00am, but the peak travel time occurs between 7:00 to 8:00 a.m. (which is expected to be the a.m. peak period). This is because of the fact that the survey is only limited to the left lane. The high traffic volume on the left lane at around 6:00 a.m. might be the result of other factors, such as work zones or incidents in any of the other lanes. Figure 4 presents the travel time distribution and the number of vehicles. Base on that, all graphs in Figure 4 show the log-normal distribution with skewness. Most vehicles are moving at or close to the free flow time.

Figure 5 shows the relation between the traffic volumes and different TTR measures. As can be seen in Figure 5, the different TTR tend to follow the same trend with increasing traffic volume.

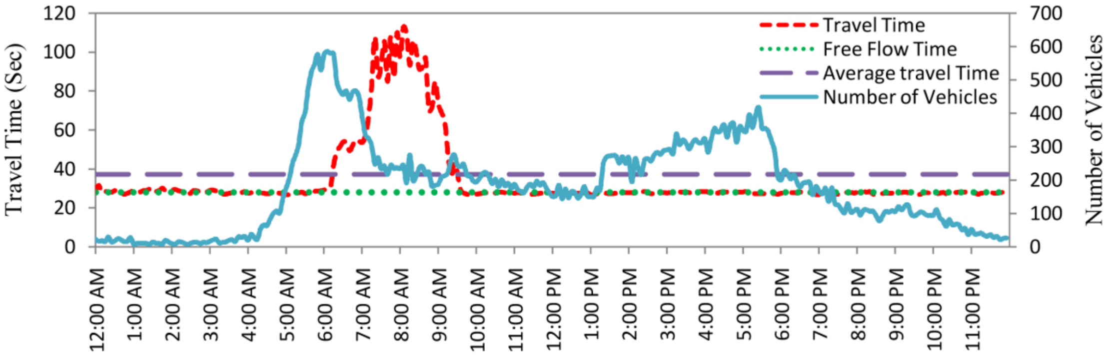
Table 1– TTR measures in segment 1

Segment 1	Northbound (Sec)							Southbound (Sec)						
	Av. TT	95% TT	Av. TT worse 20%	STD	PV[1]	BTI[2]	MI[3]	Av. TT	95% TT	Av. TT worse 20%	STD	PV	BTI	MI
9-Mar	28.2	32.8	31.9	1.6	5.5	0.2	0.1	30.3	56.0	67.2	5.4	17.9	0.8	1.2
10-Mar	36.6	133.0	128.2	25.1	68.5	2.6	2.5	28.7	49.7	57.3	4.3	15.1	0.7	1.0
11-Mar	42.7	171.7	185.2	32.1	75.1	3.0	3.3	28.8	45.6	33.4	2.6	9.0	0.6	0.2
12-Mar	37.5	124.7	124.8	24.3	64.8	2.3	2.3	29.0	37.9	37.5	2.7	9.4	0.3	0.3
13-Mar	38.5	71.6	69.3	15.7	40.7	0.9	0.8	29.7	37.2	36.7	3.5	11.9	0.3	0.2
Total	37.2	157.5	149.9	24.9	67.0	3.2	3.0	29.1	55.9	62.4	3.8	13.2	0.9	1.1

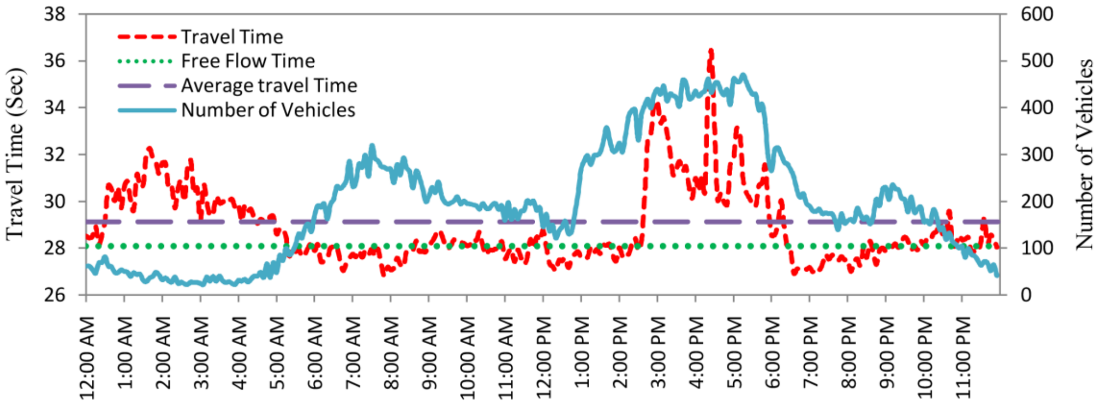
Table 2– TTR measures in segment 2

Segment 2	Northbound (Sec)							Southbound (Sec)						
	Av. TT	95% TT	Av. TT worse 20%	STD	PV	BTI	MI	Av. TT	95% TT	Av. TT worse 20%	STD	PV	BTI	MI
9-Mar	60.7	67.6	66.3	3.0	4.9	0.1	0.1	75.7	159.9	179.9	27.3	36.1	1.1	1.4
10-Mar	90.0	280.8	270.1	63.8	70.9	2.1	2.0	66.7	88.6	91.4	8.2	12.3	0.3	0.4
11-Mar	93.6	294.8	286.1	62.5	66.8	2.2	2.1	67.9	86.6	84.5	6.4	9.4	0.3	0.2
12-Mar	80.4	252.9	240.6	52.3	65.1	2.1	2.0	69.9	94.4	97.2	9.1	12.9	0.3	0.4
13-Mar	67.2	100.1	98.3	13.8	20.5	0.5	0.5	67.7	83.3	83.6	5.7	8.3	0.2	0.2
Total	83.1	280.8	264.5	54.8	66.0	2.4	2.2	69.5	145.4	176.0	14.0	20.1	1.1	1.5

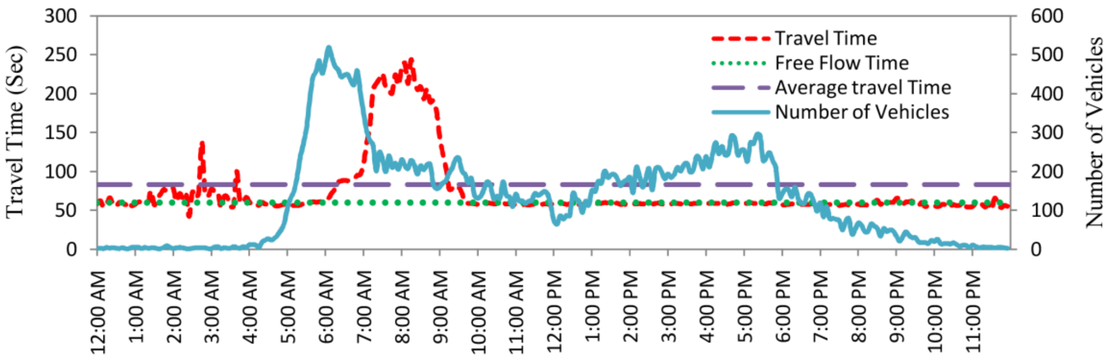
[1] Percent Variation (PV)
[2] Buffer Time Index (BTI)
[3] Misery Index (MI)



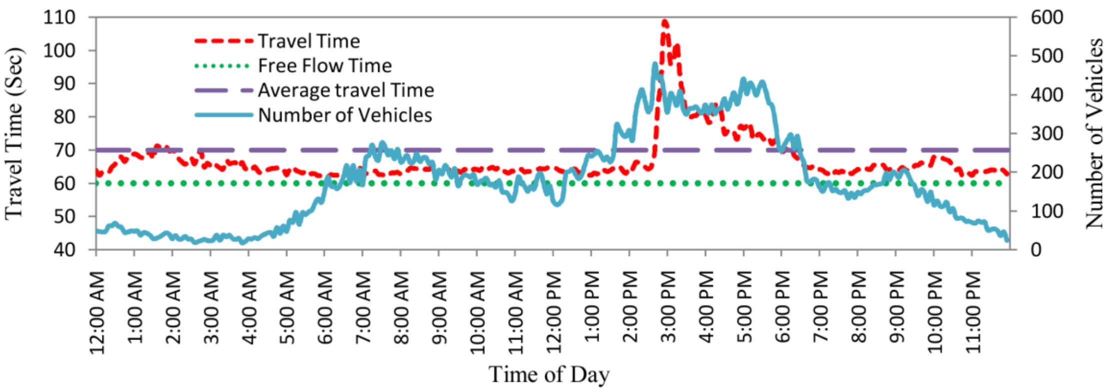
Segment 1- Marshal road to Esher St. (Northbound)



Segment 1- Marshal road to Esher St. (Southbound)

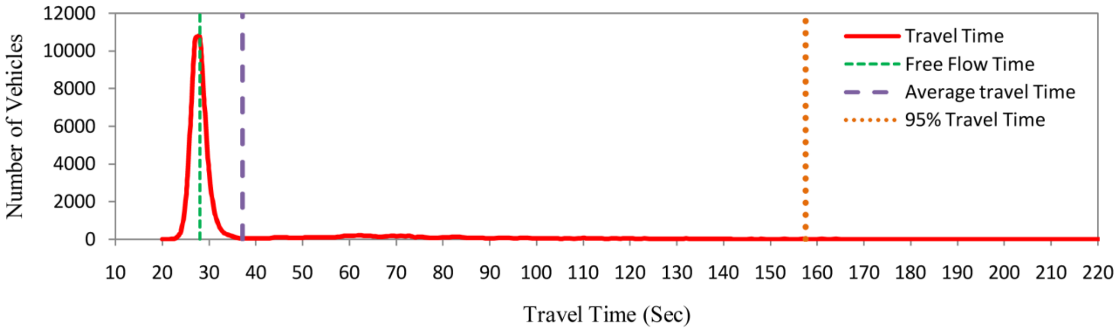


Segment 2- Esher St. to Lewisham St. (Northbound)

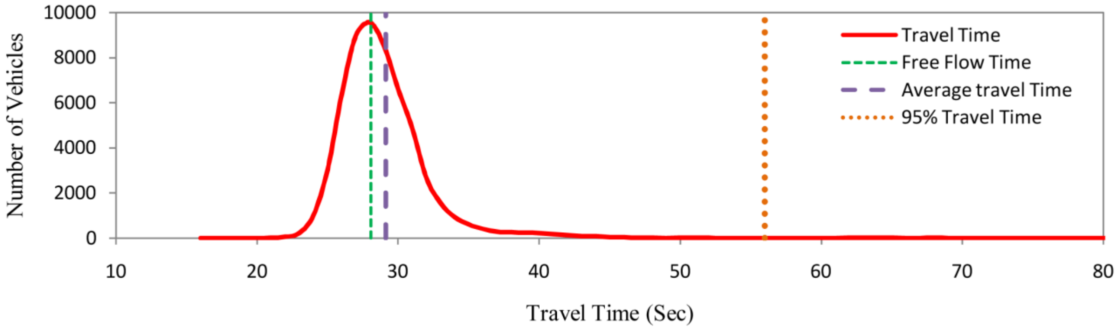


Segment 2- Esher St. to Lewisham St. (Southbound)

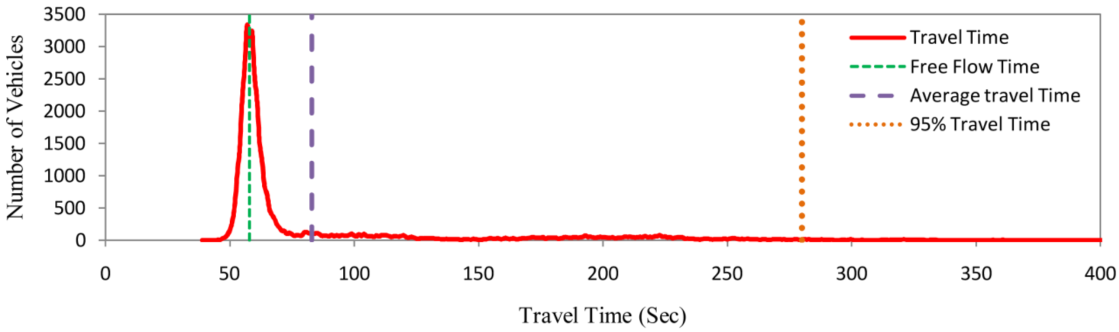
Figure 3- Distributions of travel time and traffic volumes



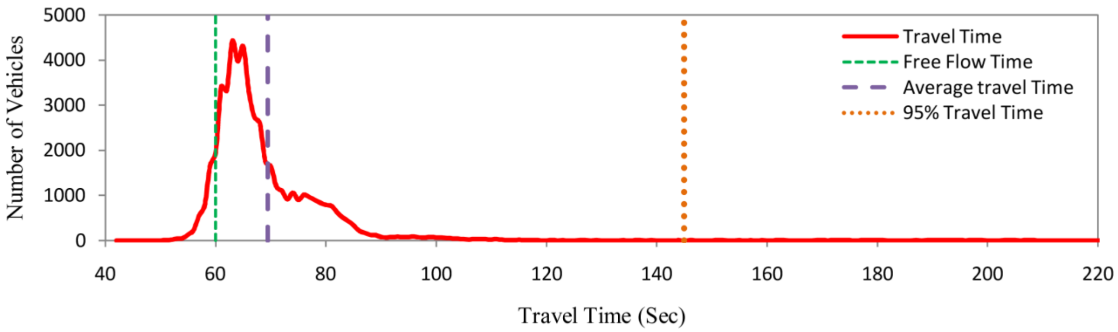
Segment 1- Marshal road to Esher St. (Northbound)



Segment 1- Marshal road to Esher St. (Southbound)

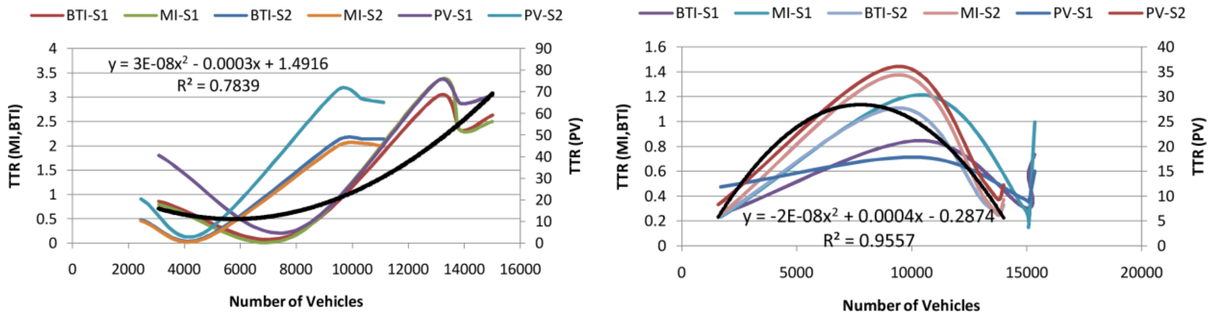


Segment 2- Esher St. to Lewisham St. (Northbound)



Segment 2- Esher St. to Lewisham St. (Southbound)

Figure 4- Traffic volumes and travel time relationship



a)northbound b)southbound

Figure 5- TTR measures[1] and Traffic volumes

6. CONCLUSION

This paper presented the results of a pilot study on the relation between TTR and traffic flow distribution. Different definitions and measures of TTR are presented, and the factors affecting TTR are expressed. Preliminary findings from the analysis of TTV data for a section of an urban freeway in Brisbane are provided. The study indicates that different TTR measures follow a similar trend with increasing traffic volumes. In addition, traffic volume is directly related to TTR measures. It can be concluded that the number of vehicles can be considered as an effective factor in modelling TTR. However, the different trends in northbound and southbound directions, as shown in Figure 5, point to other factors, such as work zones, being major determinants of TTR.

However, to provide accurate TTR measures for the studied segment, a more comprehensive data collection exercise would be necessary. Data collected from a single lane in a surveyed segment may be insufficient. In addition, data for other factors, such as work zones, incidents and weather, should be collected and considered in TTR studies.

This study covers mainly the effects of one factor, namely traffic demand, on TTR. The effects of other factors and their combinations will be the subject for further research.

Acknowledgment

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[1] PV (Percent Variation)- BTI (Buffer Time Index)- MI (Misery Index)- S1(Segment 1)- S2(Segment 2)

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