Australasian Transport Research Forum 2017 Proceedings
27 – 29 November 2017, Auckland, New Zealand
Publication website: http://www.atrf.info

Estimating the net traffic congestion impact associated with urban public transport – A Melbourne, Australia Case Study

Duy Q. Nguyen-Phuoc[1*], Graham Currie[1], Chris De Gruyter[1], William Young[2]

[1]Public Transport Research Group, Monash Institute of Transport Studies, Monash University Victoria, Australia 3800
[2]Department of Civil Engineering, Monash University, Monash University Victoria, Australia 3800

Email for correspondence: nguyen.duy@monash.edu

"This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author(s)."

Abstract

This paper aims to explore the net congestion impact associated with the entire PT system (including train, tram and bus) using a case study of Melbourne. The methodology used in this study is to contrast the level of congestion in two scenarios, ‘with PT’ and ‘without PT’, using a transport network model. In the ‘with PT’ scenario, the negative effects of PT on creating traffic congestion are taken into account. In the ‘without PT’ scenario, mode shift from PT to car is adopted to represent the positive effects of PT on relieving congestion. Findings show that Melbourne’s PT operations reduce the number of severely congested road links by over 60%. In addition, vehicle time travelled and total delay on the road network reduce by around 48%. The net congestion effect of PT is highest in inner areas where congestion is more severe particularly in peak hours. This study provides important insights into the congestion effects associated with PT in urban areas.

1. Introduction

Traffic congestion is a major issue in the daily lives of commuters, especially those living in large cities. As vehicles on the road network in metropolitan areas grow, congestion has an increasing direct effect on commuters. In order to reduce the effect of traffic congestion, public transport (PT) offers a method of increasing person throughput. Its use has been encouraged and applied in all cities around the world. PT provides an alternative mode of travel, resulting in changes of trip making by automobile to PT, affects land-use activity and leads to direct and indirect employment (Litman, 2015). On the other hand, there are also negative impacts that PT itself can have on traffic such as the congestion effects of at-grade rail crossings, tram/bus stop operations and the take up of road space for priority tram/bus lanes (Nguyen-Phuoc et al., 2017c, Nguyen-Phuoc et al., 2017b). Thus, there is a need to estimate the net congestion effect associated with PT.

2. Literature review

Though PT is recognised to be an effective measure to reduce traffic congestion, studies on PT congestion impacts are rare. To the best of our knowledge, there have been three major approaches used to investigate the congestion impacts associated with PT. The first approach is to observe and compare traffic conditions before and during a PT strike. The second approach examining the congestion effects of PT adopts analytical models of the transportation system. The third approach is to use transport network modelling to contrast the level of congestion in two scenarios: ‘with PT’ and ‘without PT’.

To our knowledge, there has been no study exploring the net network-wide congestion impact associated with the entire PT system. This paper will address this topic, using a case study of Melbourne, Australia.

3. Research context

This section firstly describes the Melbourne’s PT system which is used as the focus for this study. The Victorian Integrated Transport Model (VITM) is then outlined in the next section.

3.1. The Melbourne’s PT system

The research reported here focused on the PT system in Melbourne, Australia. Melbourne consists of 31 Local Government Areas (LGAs) which are grouped into three categories (inner, middle and outer) (VicRoads, 2005) and accommodates 4.53 million people over nearly 2,000 square kilometers (ABS, 2016). Melbourne has an integrated PT system including trains, trams and buses that extends from the city center in all directions with offering comprehensive PT services. PT captures only 9% mode share of all trips within the metropolitan area, or 11% when expressed in terms of passenger kilometers (Currie and Burke, 2013). However, in the CBD and few parts of inner Melbourne, PT is used widely. Between 52% and 65% of work trips to these areas were made by PT.

3.2. The Victorian Integrated Transport Model

The Victorian Integrated Transport Model (VITM), a conventional four-step model, is created to estimate travel demand in Victoria, Australia. The model is implemented in Cube Voyager. In VITM, a set of links (66,848 links) and (28,499) nodes present the road network that is considered as the input of this model.

4. Study methodology

The methodology involved three major parts. The share of mode shift from PT to car for each LGA is firstly estimated with the use of data from a field survey as well as secondary data. In the second part, microsimulation is used to model the impact of PT operations on generating congestion. Finally, the mode shift and results from microsimulation models are used in a macrosimulation model (VITM) to estimate the net congestion impact associated with PT.

4.1. Prediction of the share of mode shift from PT to car

In order to estimate the positive impacts of PT on reducing traffic congestion, it is needed to investigate a decrease in the number of car trips due to PT operations. In this study, the number of PT users shifting to car in the case of PT removal are assumed to represent the number of car users attracted by PT operations. There are a series of studies exploring mode shift from PT to car in the event of PT removal (Nguyen-Phuoc et al., 2016, Nguyen-Phuoc et al., 2017d, Nguyen-Phuoc et al., 2017a). Nguyen-Phuoc et al. (2017a) developed methods to estimate mode shift to car for difference areas when PT ceases. Firstly, a field survey was conducted from 648 PT users in Melbourne. In this survey, PT users were asked to choose an alternative transport mode if PT was not available for their last PT trips in the AM peak hours (7h-9h). The survey also collected information about the traffic characteristics of PT users. A linear regression equation showing the relationship between the share of mode shift and traffic characteristics of PT users was then developed. Finally, the equation was applied for the Victorian Integrated Survey of Travel and Activity (VISTA) database, which comprises the detailed travel information and individual information of Melbourne's travelers using PT in the AM peak hours, to predict mode shift to car and explore its spatial distribution for LGAs in Melbourne.

4.2. Modelling of the impact of PT operations on generating traffic congestion – Microsimulation approach

In this paper, the impact of at-grade rail crossings, the impact of bus stop operations and the impact of tram stop operations on traffic congestion are considered as the negative impacts of PT operations. Vissim, a microscopic multi-modal traffic flow simulation software package, was used to simulate the operation of PT and identify the impact of individual PT modes (train, tram and bus) on general traffic flow. For each PT mode, two scenarios 'with PT' and 'without PT' were developed and run to obtain the average travel time on a road link. The simulations were run with a range of inputs such as traffic volumes and PT frequencies. Finally, the travel time between two scenarios, 'with PT' and 'without PT', are compared to define the relationship between the percentage change in travel time and a range of traffic characteristics (Equation 1).

$$\text{Increase in travel time} = f\,(\text{Traffic characteristics}) \qquad (1)$$

4.3. Modelling of net traffic congestion impact associated with PT – Macrosimulation approach

A modelling procedure adopts an assumption regarding PT user diversion to private car, the negative effects of PT on a road link (from microsimuation) and a transport network model to assess the net impact of PT on traffic congestion. The modelling analysis was carried out for an average weekday morning peak (7am-9am) as the highest level of congestion is expected in this period. Hence, the highest congestion impact of PT can be quantified.

The modelling procedure comprises three major steps:

- In the scenario 'with PT', the impacts of PT on creating traffic congestion (impacts caused by frequent stopping of PT) are modelled by incorporating the results of the microsimulation models into VITM. The vehicle travel time on links with at-grade rail crossings, non-exclusive tram rights-of way[1] and bus operations is added with an increase in travel time obtained from the microsimulations. The level of congestion on the entire road network is then predicted.
- In the scenario 'without PT', the congestion relief impact is modelled by adding the current car trip matrix with a modified PT trip matrix (PT trip matrix is multiplied with mode shift to car which varies for LGAs) to obtain a modified car trip matrix. This matrix is then assigned into the road network to explore the level of congestion in the case of PT withdrawal with the use of VITM.

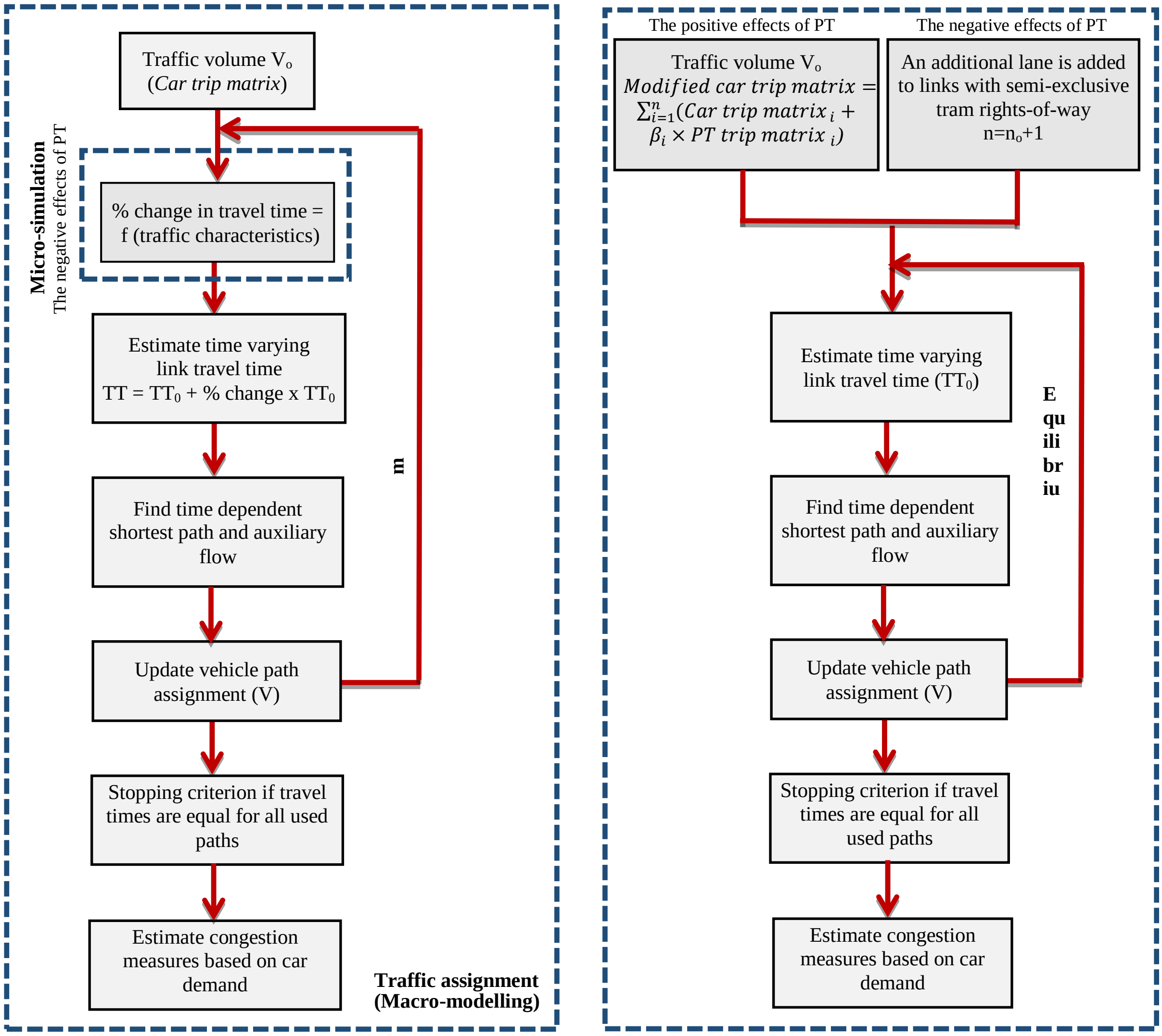
  In this step, road links with a priority PT lane (such as semi-exclusive tram rights-of-way[1]) is added one more traffic lane to model the effect of the occupation of priority PT lanes which reduce the capacity of the roads.
- The levels of congestion in two scenarios 'with PT' and 'without PT' are contrasted to investigate the net congestion effect of the entire PT system on the road network.

---

[1] Melbourne's tram system operates on three types of right-of-way: non-exclusive, semi-exclusive and exclusive right-of-way (Nguyen-Phuoc et al. (2017c))

Figure 1 illustrates the modelling procedure for assessing the level of congestion in two scenarios: ‘with PT’ and ‘without PT’.

Figure 1: Process of estimating the travel demand with traffic assignment in two scenarios



(a) With PT (b) Without PT

Where
V_0: traffic volume
V: updated traffic volume
TT_0: travel time without PT effects
TT: travel time with PT effects
β : mode shift to private car (%)
n_0: number of traffic lanes on link with semi-exclusive tram rights-of-way
n: number of traffic lanes on link with semi-exclusive tram rights when tram is removed

5. Results

The results are presented in three major subsections. The first subsection presents the spatial distribution of mode shift to car when PT is unavailable. In the second subsection, the impact of individual PT modes on generating congestion on a road link is shown. The third subsection reports the results of the net congestion impact associated with PT.

5.1. Mode shift from PT to car

After undertaking regression analysis for primary data obtained from the field survey, four parameters were found to be significant (P value < 0.05) including share of PT users with a driver's license (P1), share of PT users with more than one car in their household (P2), share of PT users with long PT trip distance (more than 5 km) (P3) and share of PT users with trip destinations in the CBD (P4). Equation 2 shows the relationship between the share of mode shift to car and these four traffic characteristics P1, P2, P3 and P4 (Nguyen-Phuoc et al., 2017a). It can be seen that a PT user with a driver's license and more than one car in their household, and who has a long distance trip and to the CBD is more likely to mode shift to car.

$$\text{Share of mode shift to car (\%)} = -42.834 + 0.377 \cdot P1 + 0.501 \cdot P2 + 0.382 \cdot P3 + 0.285 \cdot P4 \quad (2)$$

Applying secondary data (VISTA database) for Equation 2, mode shift from PT to car for each Local Government Area (LGA) can be estimated (as shown in Table 1). These figures will be adopted into VITM to represent the positive effects of PT on traffic congestion.

Table 1: Distribution share of car mode shift for Melbourne's LGAs

	LGA	Share of mode shift to car (%)	Average (%)
Inner	City of Melbourne	38.2	48.0
	City of Port Phillip	46.4	
	City of Stonnington	60.9	
	City of Yarra	46.6	
Middle	City of Banyule	68.3	63.2
	City of Bayside	69.2	
	City of Boroondara	58.1	
	City of Brimbank	68.9	
	City of Darebin	55.5	
	City of Glen Eira	65.6	
	City of Hobsons Bay	58.1	
	City of Kingston	66.4	
	City of Manningham	75.8	
	City of Maribyrnong	55.0	
	City of Monash	67.8	
	City of Moonee Valley	64.1	
	City of Moreland	52.1	
	City of Whitehorse	59.9	
Outer	City of Cardinia	76.2	66.9
	City of Casey	65.9	
	City of Frankston	72.3	
	City of Greater Dandenong	49.5	
	City of Hume	64.1	
	City of Knox	72.8	
	City of Maroondah	64.8	
	City of Melton	74.7	
	City of Mornington Peninsula	61.2	
	City of Nillumbik	68.5	
	City of Whittlesea	64.7	
	City of Wyndham	69.2	
	City of Yarra Ranges	66.3	

5.2. Negative impact of PT operations on traffic

5.2.1. Impact of train operations on creating congestion

Table 2 shows the polynomial function of the relationship between vehicle volume and percentage change in travel time for various train frequency levels (Nguyen-Phuoc et al., 2017b). These equations are used to adjust the travel time on road links with at-grade rail crossings in VITM. The impact of at-grade rail crossings can be then modelled precisely under alternative traffic movement volumes.

Table 2: The relationship between traffic volume and the percentage change in travel time as a result of at-grade rail crossings

Frequency (trains/hour)	Function	R^2
50	$y = 0.0002x^2 - 0.0406x + 58.188$ (V<400) $y = 0.0071x^2 - 5.5661x + 1166.3$ (V>=400)	1.00 1.00
40	$y = 0.00002x^2 + 0.0498x + 38.287$ (V<700) $y = 0.0033x^2 - 4.7226x + 1734.9$ (V>=700)	0.98 1.00
35	$y = 0.00002x^2 + 0.0105x + 32.255$ (V<800) $y = 0.0011x^2 - 1.5702x + 631.59$ (V>=800)	0.92 1.00
30	$y = 0.00004x^2 - 0.0239x + 27.552$	0.88
25	$y = 0.00003x^2 - 0.0165x + 22.809$	0.92
20	$y = 0.00002x^2 - 0.0109x + 18.62$	0.87
15	$y = 0.00002x^2 - 0.0127x + 14.412$	0.82
10	$y = 0.00002x^2 - 0.0169x + 11.292$	0.94
5	$y = 0.00001x^2 - 0.0065x + 5.6295$	0.93

Source: Nguyen-Phuoc et al. (2017b)

Where:

y: Increase in travel time (%)

x: Traffic volume (vehicle/lane/hour)

5.2.2. Impact of tram operations on creating congestion

Table 3 manifests the polynomial functions of the relationship between vehicle volume and the percentage change in travel time for various tram service frequencies on a one-lane and two-lane road link respectively (Nguyen-Phuoc et al., 2017c). These equations are used to adjust the travel time on road links with non-exclusive tram rights-of-way in VITM. This allows the impact of a non-exclusive tram right-of-way to be modelled more precisely in VITM.

Table 3: The relationship between traffic volume and the percentage change in travel time on a road link with a non-exclusive tram right-of-way

Frequency (trams/hour)	Type of road link	Function	R^2
35	Two-lane road link	$y = 0.00009x^2 + 0.0147x + 40.569$	0.97
30	Two-lane road link	$y = 0.0001x^2 - 0.0032x + 39.098$	0.97
25	Two-lane road link	$y = 0.0001x^2 - 0.0419x + 38.544$	0.97
22	Two-lane road link	$y = 0.0001x^2 - 0.0297x + 34.688$	0.99
20	One-lane road link	$y = 0.00009x^2 - 0.0005x + 86.605$	0.98
	Two-lane road link	$y = 0.0001x^2 - 0.0339x + 33.162$	0.99
17	One-lane road link	$y = 0.0001x^2 - 0.0421x + 82.277$	0.98
	Two-lane road link	$y = 0.00009x^2 - 0.023x + 27.3$	0.99
15	One-lane road link	$y = 0.0002x^2 - 0.078x + 76.639$	0.97

	Two-lane road link	$y = 0.00008x^2 - 0.0251x + 23.964$	0.99
13	One-lane road link	$y = 0.0001x^2 - 0.0323x + 54.084$	0.98
	Two-lane road link	$y = 0.00009x^2 - 0.0397x + 22.531$	0.95
10	One-lane road link	$y = 0.0001x^2 - 0.0463x + 50.636$	0.96
	Two-lane road link	$y = 0.00007x^2 - 0.031x + 17.543$	0.98
8	One-lane road link	$y = 0.00008x^2 - 0.0317x + 37.519$	0.91
	Two-lane road link	$y = 0.00004x^2 - 0.0085x + 11.183$	0.99
5	One-lane road link	$y = 0.00008x^2 - 0.0428x + 27.479$	0.89
	Two-lane road link	$y = 0.00003x^2 - 0.0093x + 8.4764$	0.97

Source: Nguyen-Phuoc et al. (2017c)

Where:
y: Increase in travel time (%)
x: Traffic volume (vehicle/lane/hour)

5.2.3. Impact of bus operations on creating congestion

From the results of microsimulation models, six non-linear regression models are developed to predict the percentage change in travel time resulting from bus operations for different road link types (as shown in Table 4). Four parameters including traffic volume (V), dwell time (D), speed limit (S) and bus arrival frequency (F) have a significant impact on the increase in travel time in these regression models (Nguyen-Phuoc et al., 2017e).

Table 4: Functions for estimating travel time increases caused by bus stop operations

	Type of road link	Regression functions
Curbside bus stop	One-lane road link	$y = e^{0.000003*V^2-0.0029*V+0.0256*D+0.0160*S+0.0751*F+0.3337}$
	Two-lane road link	$y = e^{0.000005*V^2-0.0048*V-0.0109*D+0.0197*S+0.0705*F-0.2124}$
	Three-lane road link	$y = e^{0.000005*V^2-0.0050*V-0.01118*D+0.0183*S+0.0680*F-0.4102}$
Bus bay	One-lane road link	$y = e^{0.000005*V^2-0.0055*V-0.0149*D+0.0026*S+0.0687*F+1.8971}$
	Two-lane road link	$y = e^{0.000005*V^2-0.0055*V-0.0160*D+0.0089*S+0.0699*F+0.7111}$
	Three-lane road link	$y = e^{0.000005*V^2-0.0055*V-0.0131*D+0.0106*S+0.0687*F+0.1618}$

Source: Nguyen-Phuoc et al. (2017e)

Where:
y: Increase in travel time (%)
V: Traffic volume (vehicles/lane/hour)
D: Dwell time (second)
S: Speed limit (km/h)
F: Bus arrival frequency (buses/hour)

5.3. Net impact of PT on traffic congestion

Table 5 presents the net congestion effect associated with the entire Melbourne PT system on the road network. The results in Table 5 indicate that:

- The operation of PT contributes to reduce the number of severely congested links and moderately congested links by more than 60% and 7% respectively (as shown in Figure 4).
- Vehicle time travelled and total delay on the road network reduce by around 48%.

- Average travel speed increases from 37.22 km/h to 47.53 km/h (an increase of 27.7%) whilst actual travel time per km reduces by approximately 43%.

Table 5: Net congestion impact of PT on Melbourne's road network in AM peak hours (7h-9h)

Measure	With PT	Without PT	Absolute change	Change (%)
Number of severely congested links	2,198	5,591	3,393	60.7
Number of moderately congested links	1,983	2,142	159	7.4
Vehicle distance travelled (million veh-km)	15.06	17.58	2.52	14.4
Vehicle time travelled (million veh-hr)	0.41	0.80	0.39	48.5
Total delay on road network (million veh-hr)	24.62	48.00	23.38	48.7
Average travel speed (km/h)	47.53	37.22	-10.31	-27.7
Actual travel time per km (min)	1.98	3.49	1.50	43.1

Notes: Severely congested links are road links which have a volume to capacity (V/C) ratio equal to or greater than 0.9. Moderately congested links are road links which have a V/C ratio equal to or greater than 0.8 and lower than 0.9 (Semcog, 2011).

The comparison of PT congestion impact on the road network in different parts of Melbourne is detailed in Table 6. The results show that Melbourne's PT system in has the highest effect in inner areas and lowest impact in outer areas. Table 6 shows that:

Table 6: Net congestion impact of the entire PT system on Melbourne's road network in inner, middle and outer areas

Measure	Inner			Middle			Outer		
	With PT	Without PT	Change (%)	With PT	Without PT	Change (%)	With PT	Without PT	Change (%)
Number of severely congested links	464	1473	**68.5**	1,175	2,901	**59.5**	559	1,217	**54.1**
Number of moderately congested links	268	347	**22.8**	973	1,132	**14.0**	663	742	**10.6**
Vehicle distance travelled (million veh-km)	1.61	2.17	**25.8**	6.17	7.37	**16.3**	7.27	8.04	**9.6**
Vehicle time travelled (million veh-hr)	0.07	0.20	**65.0**	0.19	0.40	**52.5**	0.15	0.21	**28.6**
Total delay on road network (million veh-hr)	3.89	11.94	**67.4**	11.53	23.71	**51.4**	9.20	12.35	**25.5**
Average travel speed (km/h)	42.43	24.90	**-70.4**	43.68	33.25	**-31.4**	54.56	49.49	**-10.2**
Actual travel time per km (min)	2.51	5.95	**57.8**	2.14	3.64	**41.2**	1.54	1.87	**17.6**

6. Discussion and conclusion

This paper explores the net traffic congestion effect of Melbourne's PT system including rail, tram and bus services on the road network. This research is the extension of a previous research that explores only the positive effects of PT on relieving traffic congestion. The results show that the net effect of PT is still positive. Melbourne's PT operations were found to contribute to reduce the number of severely congested links and moderately congested links by more than 60% and 7% respectively. Vehicle time travelled and total delay on the road network also reduces by around 48%. The net congestion effect of PT is assessed in the AM peak hours (7h-9h) when the level of traffic congestion on the road network is expected to be highest. Hence, the findings show that PT operations significantly contribute to alleviate vehicle traffic congestion. These congestion effects estimated in this study are much higher than the results of Aftabuzzaman et al. (2010b) even the negative effects of PT are subtracted. The main reason is that this study adopts a higher mode shift to car that explored from a real world data (38.2%-76.2% compared to 32.4%).

Overall the method described in this paper is considered to be an improvement to methodological approaches for assessing one of PT's most significant impacts on Australian cities; acting to reduce urban traffic congestion. It is clear these impacts are growing as Australian urban population rise. This method can be applied to estimate the net congestion effect of PT for other cities. The future research would be to explore the long term effects of PT on traffic congestion.

References

ABS 2016. *Regional Population Growth, Australia, 2014-15*. Australian Bureau of Statistics, Australia.

Aftabuzzaman, M., Currie, G. & Sarvi, M. 2010a. Evaluating the congestion relief impacts of public transport in monetary terms. *Journal of Public Transportation,* 13(1), 1-23.

Aftabuzzaman, M., Currie, G. & Sarvi, M. 2010b. Modeling the spatial impacts of public transport on traffic congestion relief in Melbourne, Australia. *Transportation Research Record: Journal of the Transportation Research Board,* 2144(1), 1-10.

Anderson, M. L. 2013. Subways, strikes, and slowdowns: The impacts of public transit on traffic congestion. *NBER Working paper series,* United States.

Arasan, V. T. & Vedagiri, P. 2010. Microsimulation Study of the Effect of Exclusive Bus Lanes on Heterogeneous Traffic Flow. *Journal of Urban Planning and Development,* 136(1), 50-58.

Chand, S., Chandra, S. & Dhamaniya, A. 2014. Capacity drop of urban arterial due to a curbside bus stop. *International Conference on Sustainable Civil Infrastructure.* Civil Engineering Department IIT Hyderabad, India.

Currie, G. & Burke, M. 2013. Light Rail in Australia – Performance and Prospects. *Australasian Transport Research Forum*, Brisbane, Australia.

DOT 2014. *2013-14 Annual Report*. Department Of Transport, Planning And Local Infrastructure., Melbourne, Australia.

Garnaut, R. 2012. Transforming Transport. *The Garnaut climate change review.* Australia.

Litman, T. 2015. *Evaluating public transit benefits and costs*. Victoria Transport Policy Institute, Victoria, British Columbia, Canada.

Lo, S. C. & Hall, R. W. 2006. Effects of the Los Angeles transit strike on highway congestion. *Transportation Research Part A,* 40(10), 903–917.

Nguyen-Phuoc, D. Q., Currie, G., De-Gruyter, C. & Young, W. 2016. Understanding public transport user behavior adjustment if public transport ceases - A qualitative study. *Australasian Transport Research Forum (ATRF)*, Melbourne, Australia.

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C. & Young, W. 2017a. Congestion relief and public transport: An enhanced method using disaggregate mode shift evidence. *Transport Policy,* Under review.

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C. & Young, W. 2017b. Local and system-wide traffic effects of urban road-rail level crossings: A new estimation technique. *Journal of Transport Geography,* 60(89-97).

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C. & Young, W. 2017c. Net Impacts of Streetcar Operations on Traffic Congestion in Melbourne, Australia. *Transportation Research Record: Journal of the Transportation Research Board,* 2648(1), 1-9.

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C. & Young, W. 2017d. Transit User Reactions to Major Service Withdrawal-A Behavioral Study. *Transportation Research Board 96th Annual MeetingTransportation Research Board*, Washington DC, United States.

Nguyen-Phuoc, D. Q., Currie, G., Gruyter, C. D. & Young, W. 2017e. Net impact of bus operations on traffic congestion in Melbourne. *Transport Research Part A: Policy and Practice,* Under review.

Parry, I. W. H. & Small, K. A. 2009. Should Urban Transit Subsidies Be Reduced? *American*

Economic Review 99, 3(700–724).
Public Transport Victoria 2016. *Annual Report 2015-16*. Public Transport Victoria, Melbourne, Australia.
Schrank, D., Eisele, B. & Lomax, T. 2012. *TTI's 2012 Urban mobility report*. Texas A&M Transportation Institute, United States.
Semcog 2011. Congestion Management Process (CMP). Michigan: Southeast Michigan Council of Governments, United States.
VicRoads 2005. Austroads Metropolitan Network Performance Database. Melbourne, Australia.