Using multi-modal travel and cost analysis to re-evaluate transport disadvantage for the Brisbane metropolitan area

Tiebei LI [a], Jago DODSON [b], Neil SIPE [c]

[a,b,c] *Urban Research Program, Griffith University, Brisbane 4111, QLD, Australia*
[a] *E-mail: t.li@griffith.edu.au*
[b] *E-mail: j.dodson@griffith.edu.au*
[c] *E-mail: n.sipe@griffith.edu.au*

Abstract: Public transport (PT) has become importance in the travel task in Australian cities. Raising PT fares create a competitive disadvantage against private motor vehicle that are threatening the PT ridership. This paper seeks to gain further insights into transport vulnerability by exploring spatial patterns of household expenditure on PT fares and vehicle fuel in Brisbane metropolitan area. Through an analysis of household travel patterns and transport costs associated with the PT fares and private vehicles, this paper identified household commuting expenditures. The results show that across all suburbs, PT was not a cost-effective means of transport for households compared with private motor vehicle. The paper then compares the combined household trip costs with patterns of suburban socio-economic disadvantage in Brisbane, we demonstrate that the high PT fares exacerbates household exposure to higher transport costs, and compounds other forms of transport disadvantage and vulnerability.

Keywords: Transport Disadvantage, Public Transport Fare, Vehicle Fuel Efficiency, Journey to Work, Spatial Analysis

1. INTRODUCTION

Australian government's national policy has incorporated development of low carbon cities supported by sustainable transport systems, in seeking to reduce high transport cost and negative social and environmental impacts imposed by private car travels (Australian Government, 2010; Gipps *et al*., 1997; Weisbrod *et al*., 2003; Dodson and Sipe, 2007; Mees *et al*., 2008). Developing high quality public transport (PT) systems has been a key planning priority in many governments' strategic plans, which seeks to attract more private car users onto bus and rail systems, and contribute towards reduced private vehicle use in urban travels (Office of Urban Management, 2006; Brisbane City Council, 2008; Australian Government, 2010).

Because of their dispersed urban structure and low density development, providing high quality PT systems in Australian cities often entails expensive public investments in building rail and bus service. This tends to raise the overall cost of PT services, which has led to increased pressure for transport fares. In Brisbane, the average PT fares have increased 15% by 2012 to support multiple service and facility improvements. A recent public transport user survey reports that now only 12% Brisbane passengers consider taking PT is a cheap transport option (TransLink, 2010). In other Australian cities, PT may also not be seen as a cost-effective means of transportation compared with private vehicle travels. Although transit operators have offered substantial subsidies and incentives to uplift the current low PT ridership especially in the suburban areas, but the subsidy allocations were often based on fixed conditions such as population density and existing services. No recent regional and metropolitan transport plans have sufficiently addressed the rising transit fares and underlying affordability and equity issues in the cities except promising high quality services in the future.

There is growing tension transport planners face between meeting the increased demand for new and better PT services, and ensuring those services are socially affordable and equitable. Whilst there has been large body of research paid significant attention to PT supply, network efficiency, and social disadvantage access (Hine and Mitchell, 2003; Yigitcanlar *et al*., 2009; Currie *et al*., 2009; Currie, 2010; Dodson *et al*., 2011), very few research has examined the cost effectiveness of PT services and underlying transport disadvantage and vulnerability from the high fare cost in Australian cities which have shown strong implications for transport affordability, social equity, and future PT ridership efficiency. The high fare price may raise a new dimension of competitive disadvantage of PT that may force more people seeking to choose car travel as a cheap transport mode (forced car ownership). It also can lead to low productivity and decreased employment participation especially for low income or part-time workers (who spend large percent of their weekly income on expensive transport for commuting). It can generate huge lost of revenue from increasing fare evaders cost which is also threatening the regulated social behavior and attractiveness of the city as a whole.

In the domain of transport vulnerability research, many Australian studies have focused on analysis of household transport pressure from their private vehicle use (e.g. Dodson *et al*., 2010; Li *et al.*, 2012), but seldom from realistic travel cost from other transport modes. Given the increasing importance of public transport in the travel task in Australian cities, this paper will gain further insights by exploring how transport disadvantage can be further refined by incorporating a more comprehensive analytical framework that will permit PT travel can be included as a key element in the modelling of transport disadvantage and social vulnerability. In addition, previous studies evaluate household's transport pressure based on the assumptions about the household's mobility (e.g. vehicle ownership) and transport demand, not a more realistic measure of exact costs of household's expenditure on their regular travel. This study will advance current transport vulnerability analysis by using advanced spatial analysis of patterns of commuting travel and household's spending on their private vehicle and PT fares. Specifically, this paper incorporates the standard vehicle fuel efficiency and standard rate of PT fares into travel analysis and model these cost factors in a monetary term, by which both households' spending on private vehicle fuel and PT fare can be explicitly evaluated and compared. By adding such important qualitative and quantitative dimensions, we aim to investigate three key questions: 1) What are geographical patterns of travel cost distribution for private vehicle users and PT riders? 2) What transport relationships can be observed between the two different modes? 3) Where are the areas that are vulnerable from high fuel vehicle cost but also facing cost challenge of PT fares?

The reminding paper is structured as follows: the next section briefs the context of study area. The third section details the data used in this study. Section four describes the methods and techniques used in the travel cost modeling and social vulnerability analysis. Then the results are discussed in the fifth section. In the last section, the paper concludes with a discussion of the limitation of the research and outline of avenue forward.

2. STUDY AREA

Brisbane is one of the fastest growing cities in Australia. During the last two decades, the city has experienced a sprawling low density urban development that has a dispersed distribution of population and highly centralized employment clustered in the major economic centers including the Brisbane CBD. Due to its dispersed urban structure, Brisbane has developed high level of transport demand and the transport is heavily dominated by car travels. By year 2006, 78.1% of all trips in Brisbane use private vehicle (Department of Transport and Main Road, 2011). This has placed increased pressure on transport infrastructure, household vehicle energy cost and greenhouse gas emissions. As a part of the Queensland government's strategy for sustainable growth, a target has been set for Brisbane to shift to a more sustainable transport mode, this includes reducing the rate of private car trips from its current 78.1% to 56% by 2031 (Office of Urban Management, 2006).

In 2008, the Brisbane City Council passed legislation of a Transport Plan for Brisbane 2008–2026. The plan outlines a number of strategies to achieve its transport mode share targets, include new investments on light rail project and new Bus Rapid Transit (BRT) systems to improve the PT services and infrastructure needed to support new demand of increased suburban travels. Fares policy and pricing is now a Queensland Government responsibility under TransLink. Since 2010, an integrated ticketing '*go* card' was implemented in the public transport system that allows passengers to travel on all TransLink bus, train and ferry services in Brisbane. It quickly replaced previous legacy paper tickets because of its broad benefits for both operators and users such as cheaper ticket price, faster boarding times and lower operating cost. In 2012, there are more than 80 percent of passengers in Brisbane travelling using a *go* card (Queensland Government, 2012). Since 2012, the *go* card fare increased 15% on all fares to support the funding for multiple improvements, with new services and facilities on the network. Although the Brisbane City Council is committed to addressing transport disadvantaged and mobility needs such as access to affordable, easily accessible, reliable and safe transport is vital to quality of life for all residents, finding ways of ensuring quality services and keeping fares affordable remain a public policy challenge.

3. DATA

To analyse household transport cost for their private vehicle travels and PT travels, three databases were used in the study:

3.1 Journey to Work (JTW) Data

The JTW datasets collected by the Australian Bureau of Statistics (ABS) for the 2006 Census were used to calculate the household travel patterns for private vehicle and PT trips. The reason of using JTW data is that commuting travel constitutes a typical daily activity for most population, placing most significant demands on the transportation systems, and is linked to the major household transport cost (Horner, 2004). The JTW datasets contain information on the trip origins (usual residence of employed persons) and their trip destinations (workplaces) and the JTW origin-destination matrix referencing the number of commuting trips between each origin and destination. There were two sub-sets of JTW data used in this study: The first comprises all private vehicle trips and the second contains all trips using PT (include bus, train, and ferry) between 300 origin zones and 300 destination zones for the South East Queensland region including Brisbane, the Gold Coast, and the Sunshine Coast. The standard spatial units used to represent these zones of origins and destinations are suburbs. It is acknowledged that the *TransLink go* card transaction record data is also available that provides more details on PT passenger behaviour. However, the data was not used to analyse fare cost in this research, because the JTW data is considered sufficient to model aggregate travel patterns, and a consistent data resources is desired to model and compare the household transport costs by different travel modes.

3.2 Queensland Motor Vehicle Registration Data and Australian Government Green Vehicle Guide

The fuel efficiency (VFE) of private vehicles that commuters drive is considered as an key variable to determine levels of fuel energy and monetary cost. To account for VFE on fuel consumption of all private vehicle travels, the complete dataset for registered motor vehicles for Queensland is used in this study. Motor vehicle registration data are collected by the Queensland government comprising 441,930 private motor vehicle records (2008) containing the make, model, year, body shape, number of cylinders, suburb and postcode location.

The Australian Government Green Vehicle data provides information on the environmental performance for 14,996 vehicle types (makes and model) that were sold in Australia between 1986 and 2003, and manufactured in 2005 and 2009. The Green Vehicle data provides air pollution rate, CO2 emissions, noise, and standard vehicle fuel consumption, and vehicle make/model. For this study, the fuel consumption rate (litres/100km) was extracted and used for the vehicle energy efficiency analysis as it provides accurate information on vehicle fuel consumption in urban driving.

3.3 TransLink *Go* Card Pricing Scheme

The TransLink *go* card pricing scheme is used to calculate the fare cost of all PT trips in Brisbane. TransLink operates services across 23 zones in Brisbane metropolitan areas. As displayed in Figure 1, the TransLink zone system works in a concentric pattern, with zone 1 starting in Brisbane CBD which is surrounded by zone 2 and zone 3 covering major inner suburban and works a similar way north to the Sunshine Coast and south to the Gold Coast and west out to Ipswich. The *go* card fare charging is based on the total number of TransLink zones a trip travel through during each journey (TransLink, 2012). A single price is charged for every count of TransLink zones travelled regardless the length and number of transfers of the travel (e.g., $3.06 is charged for a single zone fare, and $4.17 for a two zone fare).

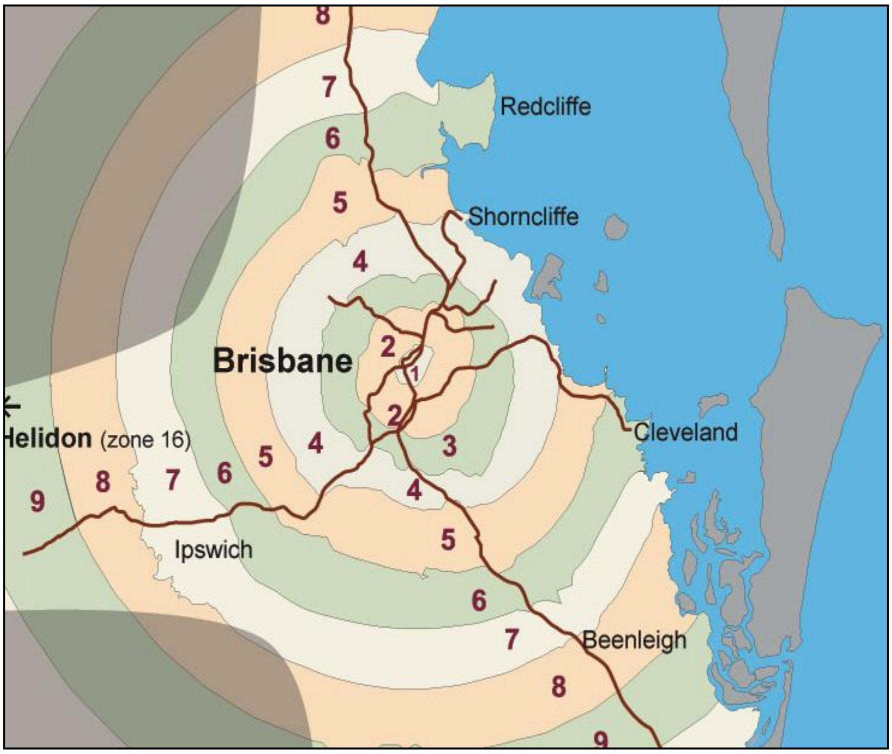

Figure 1. *TransLink* zones for the Brisbane metropolitan areas (TransLink, 2012)

4. METHOD

4.1 Calculating Private Vehicle Travel Cost

In this paper, average household expenditure on private vehicle trips was calculated based on household vehicle trip distance, fuel consumption and the price of vehicle fuel. The advantage of the approach is that it links current vehicle fleets and standard vehicle fuel efficiency ratings to the individual vehicle level, which provides a richer depiction of household vehicle travel cost, not only of the car ownership and urban vehicle fleet, but also of the relative levels of fuel consumption of that fleet under current household travel demand. The average monetary cost for private vehicle trip was calculated following three steps:

Firstly, the average fuel consumption for private vehicle trip was primarily based on the average distance of private vehicle travel (VKT) in a suburb. The average VKT was computed for each suburb of residence using number of car commuting travels between that suburb (origin) and all destinations (from the JTW data) and the Queensland road network data to determine the vehicle travel distance (shortest road network distance) between each origin and destination of travel.

Secondly, we assume the variation in VFE of Brisbane vehicle fleet will influence on fuel consumptions for the distance travels. In order to calculate standard vehicle fuel consumption rate (litres of fuel per 100km travelled) for Brisbane private vehicle fleet, the

VFE for each suburb was modelled through a combination of motor vehicle registration data and the 'Green Vehicle' fuel efficiency data. The fuel consumption rate by specific make and model (provided by the 'Green Vehicle' data) was allocated to each individual vehicle in the vehicle registration database. Once the fuel efficiency rate was allocated, all vehicle registration records containing a VFE value were then aggregated at the suburb level and the average VFE were calculated based on the total number of private vehicles in a suburb.

Thirdly, the average VFE level of private vehicle fleet for each suburb were then multiplied with the average trip distance to calculate fuel consumption from private vehicle travel (the litres of fuel consumed by the private vehicle). Finally, a uniform fuel price (taking an average value AU$ 1.4 per litre of fuel in 2012) was applied to generate the average monetary cost of fuel (in Australian dollars) consumed for every private vehicle trip in a suburb.

4.2 Calculating PT Travel Cost

The JTW sub-datasets for all travels using public transport were used to calculate the average PT trip costs. The PT fare for each trip was calculated based on the number of TransLink zones travelled through between trip origin and destination and the standard rate of *go* card charge (for peak hours) for the number of zones travelled. For example, if one trip stars from a location in zone 7 and ends at a location in zone 1, the total number of TransLink zones travelled between origin and destination is 7 zones. The transit fare for that trip is charged at a seven zone fare (AU$6.62). If one trip starts from a location in zone 8 and ends at a location in zone 5, a four zone fare (AU$4.77) was allocated because that trip travelled though 4 TransLink zones. To calculate the fair for suburban trips that pass through the city centre, the transit fare is determined based on the number of zones travelled through between zone 1 and the highest zone (either origin or destination). For example, if one cross-city trip starts from zone 5 in the north and ends at zone 3 in the south, the *go* card fare is charged at 5 zone fare.

Because there were 78.7 percent of PT commuters in the Brisbane traveling toward Brisbane City (includes those trips that end or do not end at the city centre), it is possible to capture the number of zones travelled for most trips by overlapping those origin-destination trips (using straight lines) with the concentric TransLink zones using spatial analysis. For those PT commuters who do not travel toward the Brisbane City (e.g. orbital or cross suburban travels that do not well intersect with TransLink zone boundaries), the cost of trips for specific origin-destination were identified using the TransLink online query system '*Journey Planner*'. For some origin-destination trips that were not found in '*Journey Planner*', the *go* card rate for these trips was determined by the distance of travel. The distance was compared with the travel distance of the closest possible origin-destination pairs with their rate are available from '*Journey Planner*'. Although this process may potentially introduce some errors into the analysis, it was deemed acceptable given that they only represent a small number of the total PT travels in Brisbane (< 1%). Once the transit fares were calculated for all PT trips in a suburb, the average transit fare for PT travels were then calculated for that suburb based on the total number of (departing) PT trips in the suburb.

5. RESULTS AND DISCUSSIONS

In this section, the geographical characteristics of trips by private vehicle and PT are first evaluated. The respective household expenditure on PT and private vehicle travels are examined and compared. Finally, then the results were combined with socio-economic disadvantage distribution in Brisbane to re-evaluate transport vulnerability from both PT and private vehicle travels.

5.1 JTW Flows

The JTW flows by PT and private vehicle are shown in Figure 2 and Figure 3, using desire lines representing the total number of trips between every origin and destination. Figure 2 shows that the private vehicle travel in Brisbane presents a dispersed and polycentric structure. The number of private vehicle travels appears to be very high between major suburban employment centers and their surrounding suburbs. The most self-contained trip connections are observed between Capalaba and Cleveland in the east, Strathpine in the north, and trips within Ipswich Shire in the west. In addition, there were a great number of private vehicle trips occur at the transport links between some industry-based suburbs. For example, travels between Brisbane Port and northern suburbs, and trips between Rocklea and Ipswich in the west. This suggests that the occupation and industry sector of local residents may strongly affect the rate of private vehicle use and travel patterns. A moderate level of private vehicle trips were also found at the Brisbane CBD, showing that the Brisbane City as a key employment centre and a destination of many high-profiled workers still attracts a moderate level of car travels from inner suburbs.

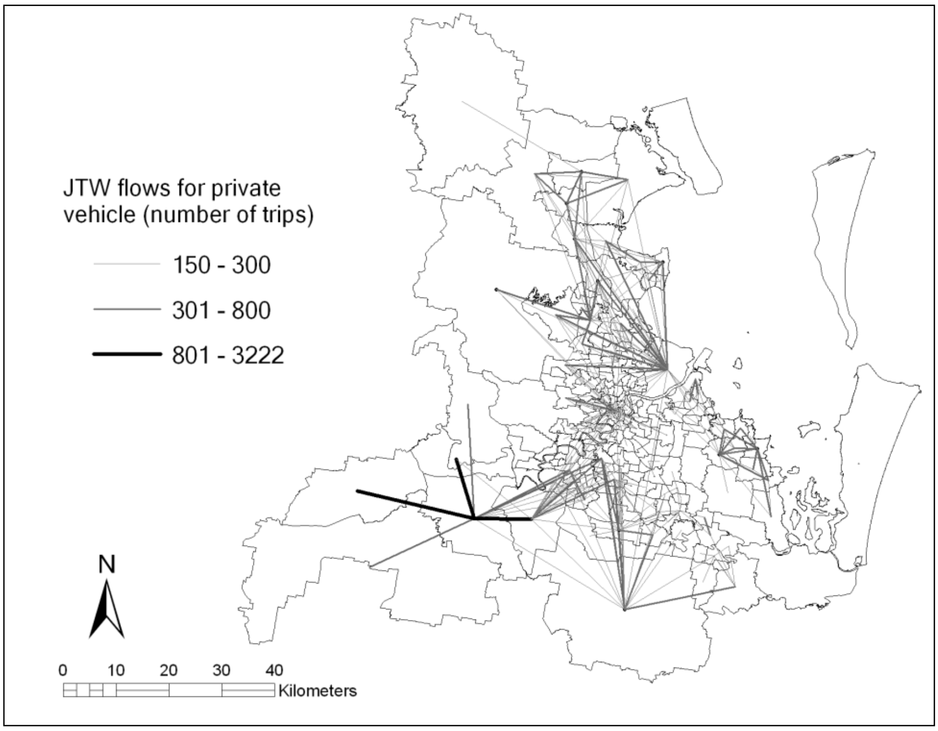

Figure 2. JTW flows by private vehicle (number of trips)

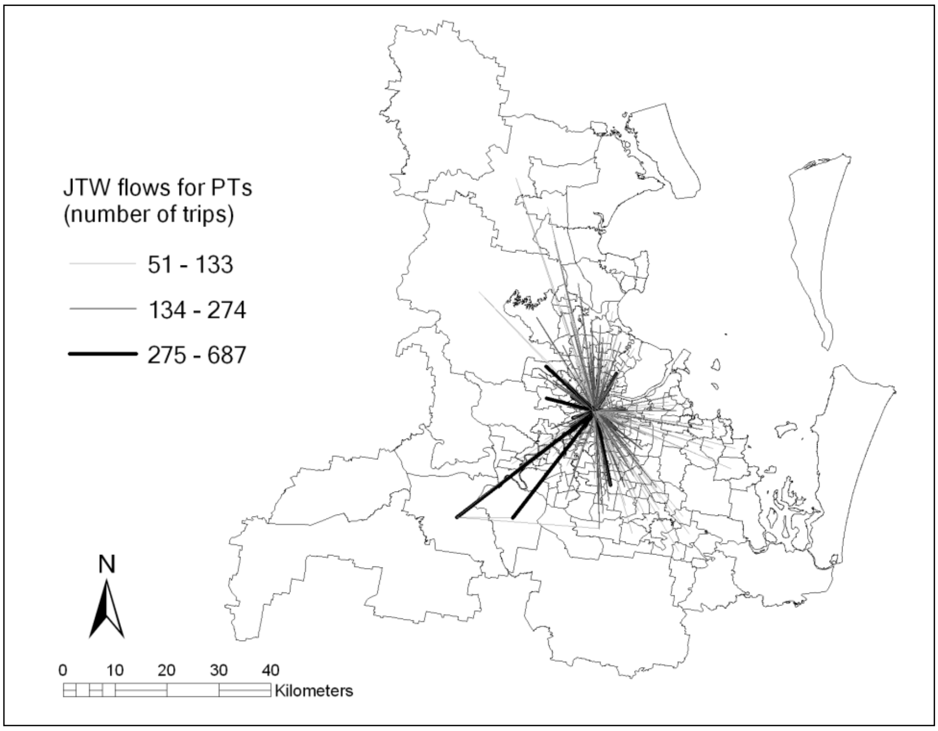

Figure 3. JTW flows by public transport (number of trips)

In contrast to private vehicle trips, Figure 3 shows the JTW trips using PT exhibit a very mono-centric pattern in Brisbane. There were 78.7 percent of PT commuters in Brisbane traveling toward Brisbane City, including those trips that end or do not end at the Brisbane CBD. Although the CBD contains 20 percent of all employment, they account for 69 percent of all PT travels in Brisbane. Comparisons to the CBD, suburbs have half of Brisbane jobs but attract only 29 percent of total PT trips, and the number of PT trips tends to decrease with the longer distance to the Brisbane CBD. The limited suburb-to-suburb trips by PT reflect that the PT route configuration and services in Brisbane is rather radial and CBD orientated, that may not well support residents traveling to work at suburbs. Planning improved services at outer suburbs (e.g. especially orbital services) are needed to provide suburban residents better access to suburban employment, especially in connecting dispersed suburban residents to suburban employment sites.

5.2 Travel Cost

The average travel costs expressed in monetary terms for private vehicle and PT trips in Brisbane are shown in Figure 4 and Figure 5. Figure 4 shows that the average fuel cost (dollars paid for the amount of fuel consumed) of private vehicle trip tends to be lower for households living closer to the CBD, whilst those living further from the CBD have higher vehicle fuel expenditure. The average private vehicle trip cost tends to increase as household moves away from the city centre. The average vehicle trip cost in outer suburban area is higher because people living in those areas have more dispersed commuting patterns with many commuting across suburbs. In addition, the higher vehicle fuel consumption in the middle and outer suburbs can also be driven by low proportion of fuel efficient vehicles in the local fleet. Those living in outer urban area households tend to travel longer distances for work, and use less fuel efficient vehicles which increases vehicle fuel consumption in these areas. The inset map in Figure 3 highlights that the average vehicle trip cost for car commuters from inner city areas (e.g. Brisbane CBD) appear to be higher than those in the surrounding inner suburbs. The higher average vehicle trip cost for reverse commuting is driven by a number of long distance vehicle trips from inner city Brisbane (e.g. toward the Gold Coast) and relatively small total number of car-based travels in the inner Brisbane City.

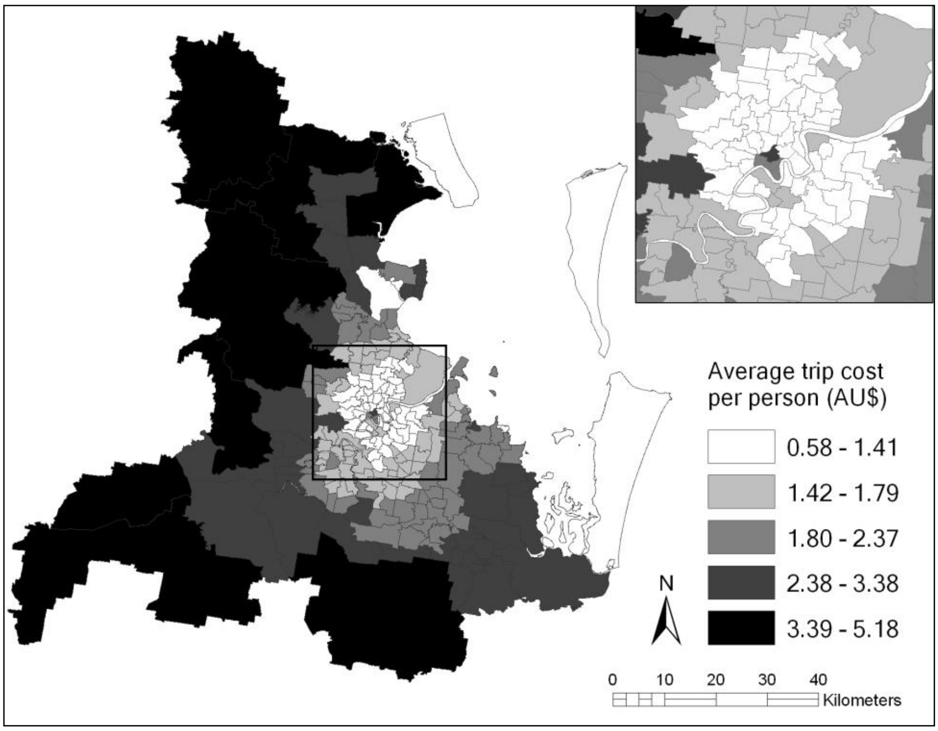

Figure 4. Average travel costs by private vehicle for Brisbane suburbs (dollars per trip)

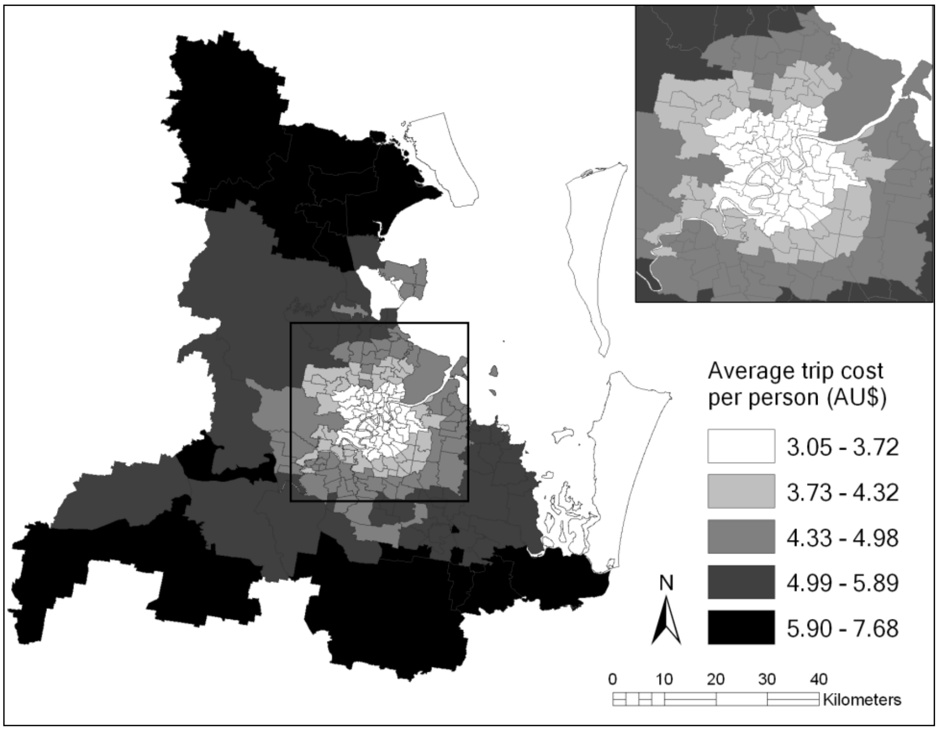

Figure 5. Average travel costs by PT for Brisbane suburbs (dollars per trip)

The average fare cost (dollars charged for PT fares per trip) of PT trips for Brisbane suburbs is shown in Figure 5. This includes commuting travels using trains and buses. In general, the average travel cost distribution is similar to that of private vehicle trip in Figure 4, except some local variations in some suburbs that can be explained by the differences in travel patterns. The average fare cost per trip for households in the suburbs in the far north and far south is higher may be primarily driven by their longer commuting distance (i.e. greater number of TransLink zones traveled) to the work destination. Households in the inner urban areas exhibit relatively lower PT fare expenditures, reflecting their closer proximity to employment and better access to PT services.

The difference in average travel costs between private vehicle travels and PT travels is compared in Figure 4. Overall, the average cost per trip for PT trips is higher than the private vehicle trips across the Brisbane suburbs, ranging from 0.76 to 4.30 dollars per trip. The highest difference can be observed at outer suburbs along the main transport corridors (e.g. northern and southern rail line of Brisbane) and some high density coastal suburbs (e.g. Cleveland, and Redland Bay). The higher PT travel cost in those areas can be associated with their longer trip distances compared with local private vehicle travels. This may reflect diverse employment commitment of working residents in those areas. For the outer suburban residents who are highly reliant on the CBD jobs, they pay significantly higher price for longer trip to work than those local car commuters who can drive relatively shorter distance to work.

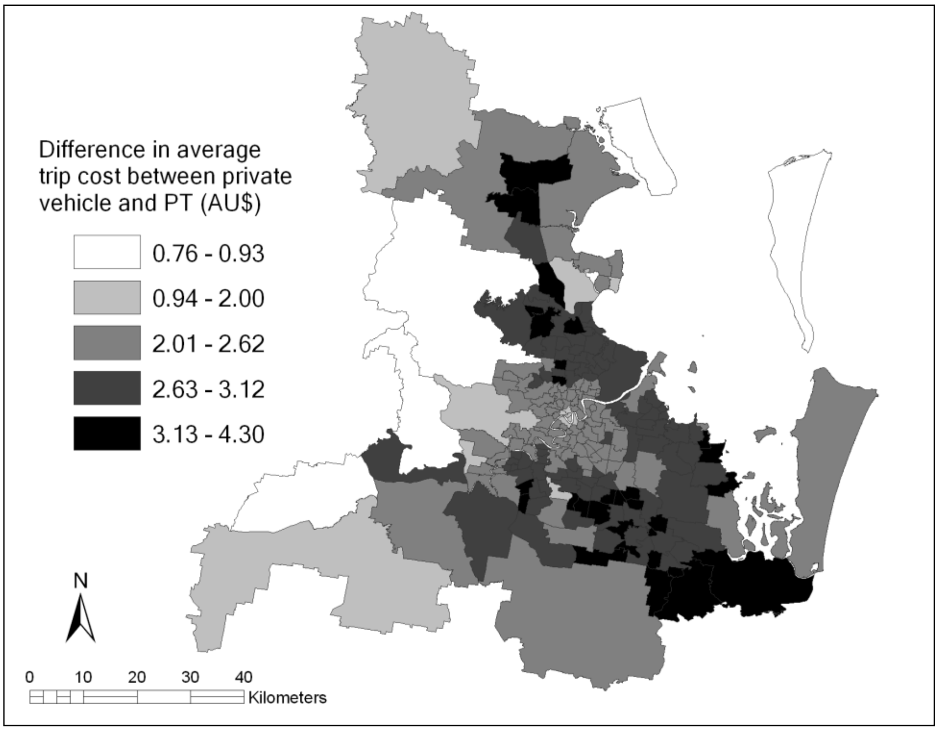

Figure 4. Absolute difference in average travel costs between PT travel and private vehicle travels for Brisbane suburbs (dollars per trip)

Whilst Figure 4 illustrated the distinct levels of trip costs between two travel groups using different travel modes, it does not show the relative cost intensity (dollars spent for every kilometer travelled) faced by two travel groups in Brisbane. The relative cost intensity is a key variable for understanding the cost effectiveness and affordability of transport systems. The cost intensity for PT travels is firstly calculated for Brisbane. Figure 6 illustrates that PT fare on a per kilometer basis, tend to be lower on suburban transit systems than central city systems. This means that although the capital spending for PT fares is higher for suburban residents, they pay relatively lower transit fare for every kilometers travelled than the inner suburb people. The average cost intensity for PT rider in the inner city is AU$0.85/km, compared to AU$0.30/km on the middle suburban and AU$0.18/km on the outer suburban riders. This spatially varied fare structure means the higher subsidies were promoted for outer suburbs than inner suburbs in Brisbane in order to attract and retain discretionary commuters and stimulate PT ridership in suburbs.

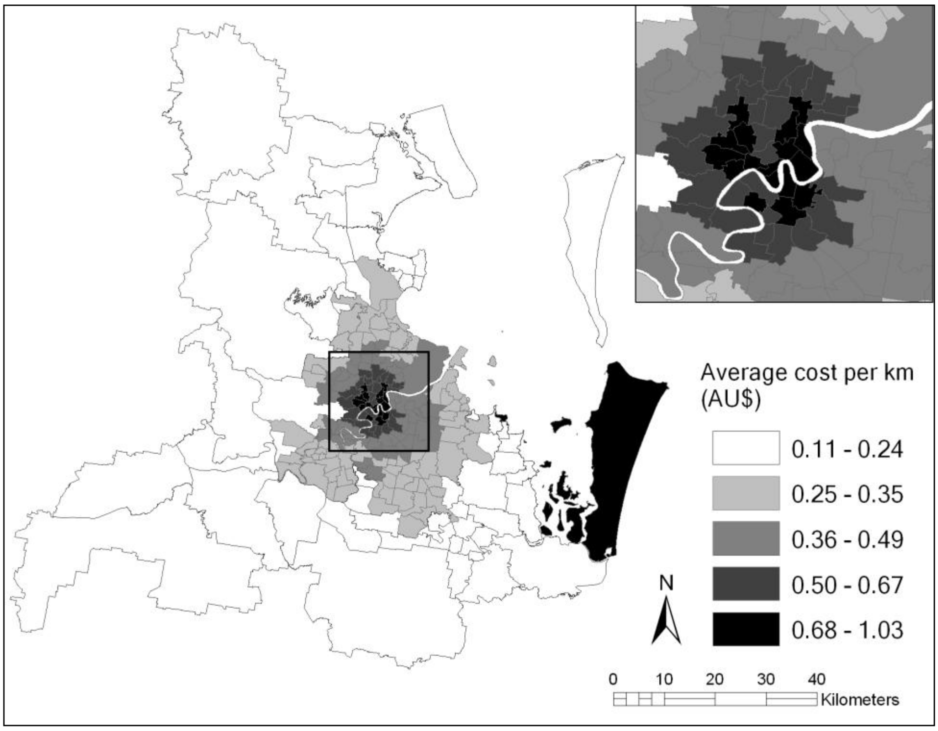

Figure 6. Cost intensity for PT travels

The cost intensity of private vehicle travels reflects the distribution of fuel efficiency of private vehicle fleet in Brisbane. In general, the cost intensity distribution of private vehicle travels presents an opposite structure to PT fare intensity, with the cost intensity tends to be lower with increasing distance from the city centre (inner urban areas tends to be higher VFE). This finding supports the VFE hypothesis stated in the Section 5.2. There is greater number of inner suburbs with lower level of cost intensity. Some suburbs present high cost intensity can be caused by the higher proportion of large/high performance and lower vehicle efficiency vehicles (e.g. SUVs) used in some high income suburbs or some industry-based suburbs that reduced overall energy efficiency.

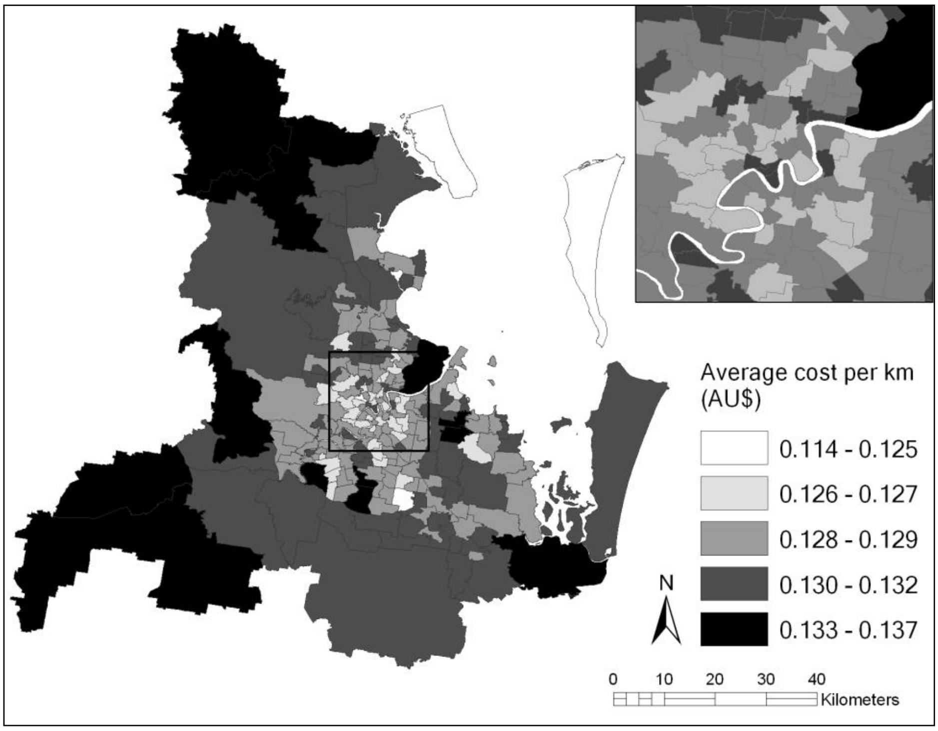

Figure 7. Cost intensity for private vehicle travels

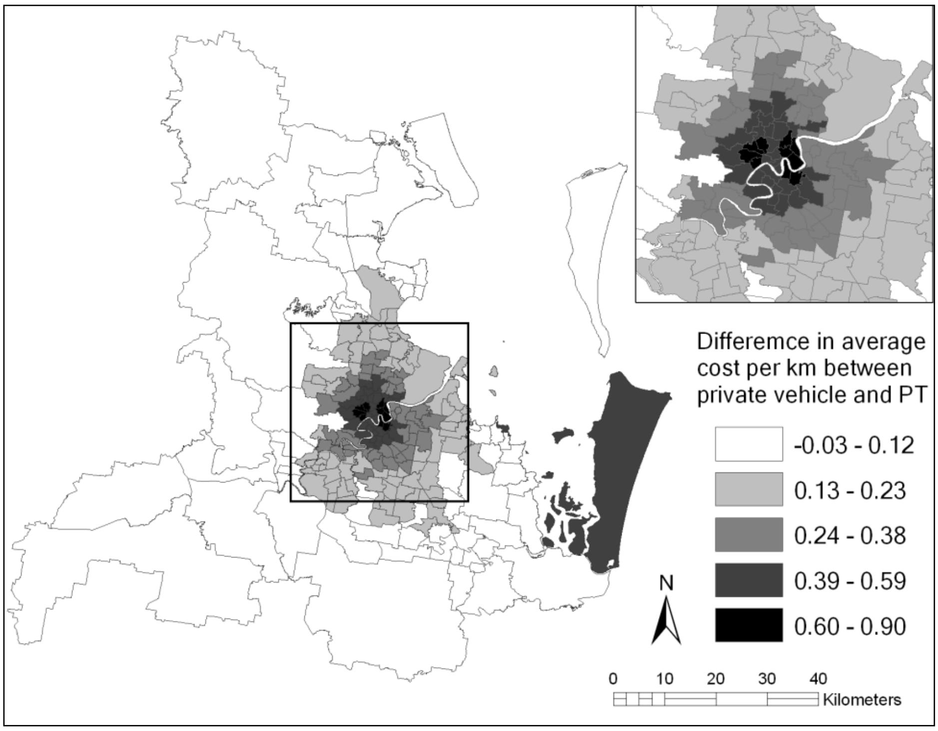

Figure 8. Difference in cost intensity between private vehicle and PT (dollars per km)

Next, the difference in cost intensity between PT and private vehicle travels is compared in Figure 8. We found that the fare cost intensity is clearly higher than the VFE on per kilometer basis. The significant higher cost intensity of PT fare are concentrated at the Brisbane CBD and inner suburbs. This spatial pattern is contrast to the known distribution of PT ridership in Brisbane as PT currently carries 45% of travel to the CBD and inner suburbs compared with 13% in the outer suburbs. The higher PT cost intensity at inner urban areas did not show a strong fare elasticity, which indicates that those inner urban PT riders are less sensitive to higher cost than the outer suburban PT riders who can often choose to drive rather than pay higher fares. Although the *TransLink* fare promote lower rates (cost intensity) for outer suburbs, the fare elasticity has not resulted in an increased number of inbound PT travels from outer suburbs. Suburban residents are unwilling to travel using PT, or do not use PT in the entire trip. For example, many outer suburban residents choose drive long distance to the inner suburbs, then park and ride at the inner city PT nodes to complete their trip to workplaces at the CBD.

5.3 Travel Costs at Disadvantaged Suburbs

In this section, we compare the household travel cost with their socio-economic status in an effort to re-evaluate transport vulnerability across the Brisbane. It is expected that transport agencies would target more resources to improving PT services on both efficiency and equity grounds, but they have show more concern with attracting riders out of private vehicle than with serving the needs of those who with low income, less transport options and most depend on PT.

To evaluate the total household expenditure on transport, including those who use PT and private vehicles, a composite value of travel cost was calculated by combining the average costs of private vehicle travels and PT travels. The cost of travel from each mode was weighted by its proportion of total travels within a suburb. For example, if a small portion of people in a suburb use PT, their impact on a total travel cost for that suburb will be less important (compared with high proportion of private vehicle travels).

A benchmark should be set to evaluate household affordability on the transport expenditure. For example, Armstrong-Wright (1996) defined a benchmark for appropriate levels of transport disadvantage is that more than 10 percent of households spend more than 15 percent of household income on JTW. Because the data for numeric value of household income and expenditure are not available, we compare the total transport cost with household socio-economic status to assess social transport vulnerability. The ABS Socio Economic Index for Areas (SEIFA) for 2006 was used as our measure of socio-economic disadvantage in Brisbane. SEIFA index is constructed by a number of socio-economic factors such as income, house ownership, and level of education to measure relative household disadvantage. Those socio-economic disadvantaged households, as indicated by low SEIFA values, have less ability to afford higher transport cost than households with higher SEIFA values. In assessing vulnerability was to overlay the suburbs with the highest transport cost with the most socio-economic disadvantaged suburbs to identify 'hotspots' of transport impact and vulnerability. The suburbs with the highest transport expending were classified as those suburbs with transport cost values greater than one standard deviation from the mean (AU$1.72/trip). The most socio-economic disadvantaged suburbs were those with SEIFA scores in the lowest decile class.

Figure 9 shows most disadvantaged suburbs in Brisbane that are coupled with the highest household transport cost. Households in these areas are facing highest social and economic hardships but also deemed highly vulnerable to the high transport expenditure. The most transport vulnerable areas are mainly concentrated at Brisbane's outer suburbs, especially Ipswich in the west, and Redcliff and Caboolture in the north, and the Ipswich-Logan corridor in the south. In addition, the results show that some most vulnerable suburbs to high vehicle fuel cost are also aggravated by high PT cost. Households in those suburbs were not only deemed as highly oil vulnerable but also facing the high expenditure on PT fares. These results yield some implications that although go card fare was designed with varied rates to attract outer suburban commuters (with an aim of reducing private vehicle use and road congestions and emissions), the rate of PT fare is still less affordable to low income, disadvantaged communities especially in the outer suburbs. As a result, the potential mode shift of commuters from private vehicle to PT is seemed less likely to happen not only because of its connectivity limitation but also higher riding cost.

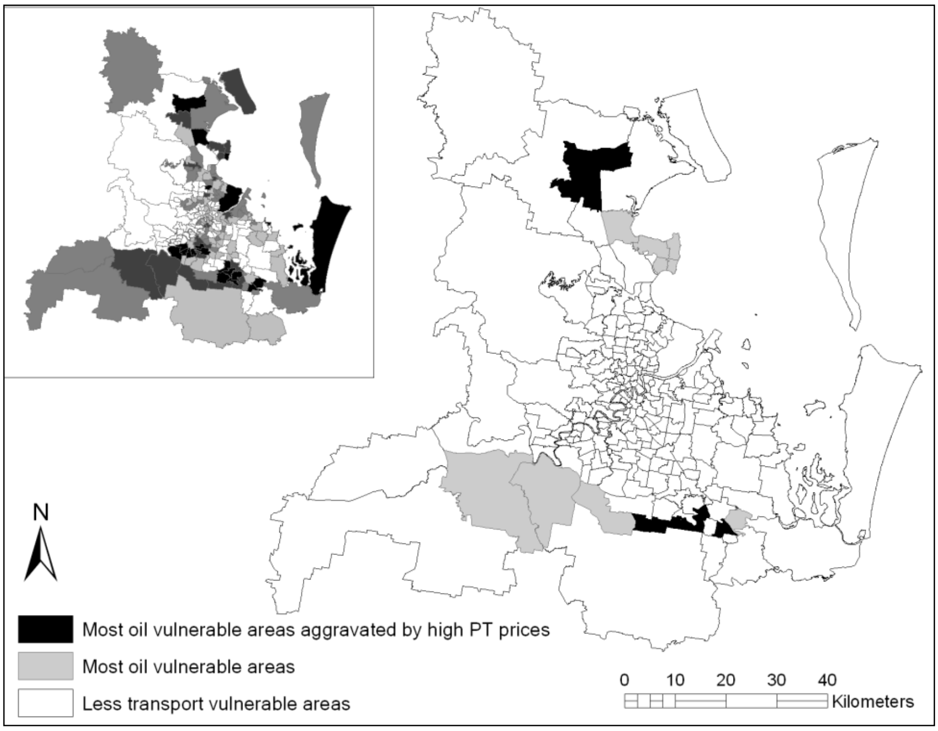

Figure 9. Oil vulnerable suburbs aggravated by high PT prices
(the inset map shows the distribution of SEIFA score)

6. CONCLUSION

Public transport has shown increasing importance in the travel task in Australian cities. The raising fare cost of PT perceives problem of competitive disadvantage against private car travels that is threatening the PT demand patterns and future ridership. This paper seeks to gain further insights of transport vulnerability by exploring spatial patterns of household expenditure on PT fares and compared with vehicle fuel in Brisbane metropolitan area.

Through a spatial analysis of travel patterns derived from JTW data and transport cost intensity associated with the PT fares and private-owned vehicles, the result showed distinct geographical patterns of travel between private vehicle and PT travel groups. It also identified the household trip costs (in monetary term) associated with vehicle fuel and PT fares, showing the average trip cost for both mode tends to increase as one moves away from the CBD. Further spatial analysis was done to compare the transport cost intensity of private vehicle and PT travels. By comparing vehicle fuel cost and fare cost on a per kilometre basis, we gain broader insights into multi-modal transport relationships. The results show that across all suburbs, PT was not seen as a cost-effective means of transport for households compared with their private vehicle travels. However, as constrained by transport alternatives and parking conditions, inner urban residents tend to be less sensitive to higher rate of fare cost. In the contrary, suburban residents are unwilling to use PT because of the significant lower overall travel costs of private vehicle. This finding is consistent to the exiting transport fare elasticity literature (Cervero, 1990; Moore, 2002; Crowther, 2011). The paper then compares the combined household trip costs for the two travel groups with patterns of suburban socio-economic disadvantage in Brisbane, we demonstrate that the high PT fares exacerbates household exposure to higher transport costs, and compounds other forms of transport disadvantage and vulnerability.

This paper contributes to existing transport vulnerability analysis by involving advanced spatial analysis of multi-modal travels and household trip cost. While, there remain a number of methodological limitations that will form the basis of future research. First, the general cost of vehicle ownership such as registration and service, parking cost and congestion cost should be included in analysing household expenditure on using private vehicles. Second, although the method presented is applicable to model the fare cost of PT trips, it is designed solely based on the *TransLink* zone structure and PT flow pattern in Brisbane. The approach is not considered widely applicable to other cities with a different spatial structure (such as in the city of Beijing, passengers travel on a more complex, polycentric and dispersed PT networks). In addition, in extending this research it will be important to do more analysis to explore the household transport expenditure from travel activities for all trip purposes -- not only the commuting travels. Finally, while this paper examined spatial patterns of household transport expenditure for a single city – Brisbane; further work should be done to see how the findings for Brisbane compare with other Australian metropolitan areas.

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