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

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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 PT 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 PT fares and underlying affordability and equity issues in the cities.

There is growing tension that transport planners have to face between meeting the increased demand for quality 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. It also can lead to low productivity and decreased employment participation especially for low income or part-time workers who spend a large per cent of their income on commuting. It can generate loss of revenue from increasing fare evaders which also threatens 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 transport 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 on a realistic measure household's expenditure on their regular travel activities. This study will advance current transport vulnerability analysis by using advanced spatial analysis of commuting patterns and household's spending on their private vehicle fuel 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 for private vehicle users and PT riders?; 2) what transport relationships can be observed between the two different modes?; and 3) where are the areas that are vulnerable from high fuel vehicle cost that also face high PT fares?

The paper is structured as follows: the next section provides the study area description. The third section describes the data used in this study. Section four explains the methods and techniques used in the travel cost modeling and social vulnerability analysis. The results are discussed in the fifth section and the last section contains a conclution of the research, limitations, and recommendations for future research.

2. Study area

Brisbane is one of the fastest growing cities in Australia. During the last two decades, the city has experienced sprawling low density urban development with a dispersed distribution of population and highly centralized employment clustered in the major economic centers including Brisbane's CBD. Due to its dispersed urban structure, Brisbane has developed high levels of transport demand which is heavily dominated by the car. In 2006, 78.1% of all trips in Brisbane used a private motor 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 to reduce the rate of private car trips from 78.1% to 56% by 2031 (Office of Urban Management, 2006).

In 2008, Brisbane City Council's Transport Plan 2008–2026 outlined a number of strategies to achieve its transport mode share targets, including new investments in light rail and new Bus Rapid Transit (BRT) systems to improve PT infrastructure and services . In addition, a new PT ticketing '*go* card' was implemented that allows passengers to travel on all TransLink bus, train and ferry services in South East Queensland. In 2012, more than 80 percent of Brisbane's PT passengers used the *go* card (Queensland Government, 2012). Since 2012, the *go* card fare increased 15% to support the funding for multiple PT improvements including new services and facilities. Although the Brisbane City Council is committed to providing affordable, easily accessible, reliable and safe public transport for all residents however, finding ways of ensuring service quality and keeping fares affordable remain a public policy challenge.

3. Data

To analyse household transport cost for private vehicle travel and PT travel, three data sets were used.

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 costs. 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. 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 resource is desired to model and compare the household transport costs by different travel modes.

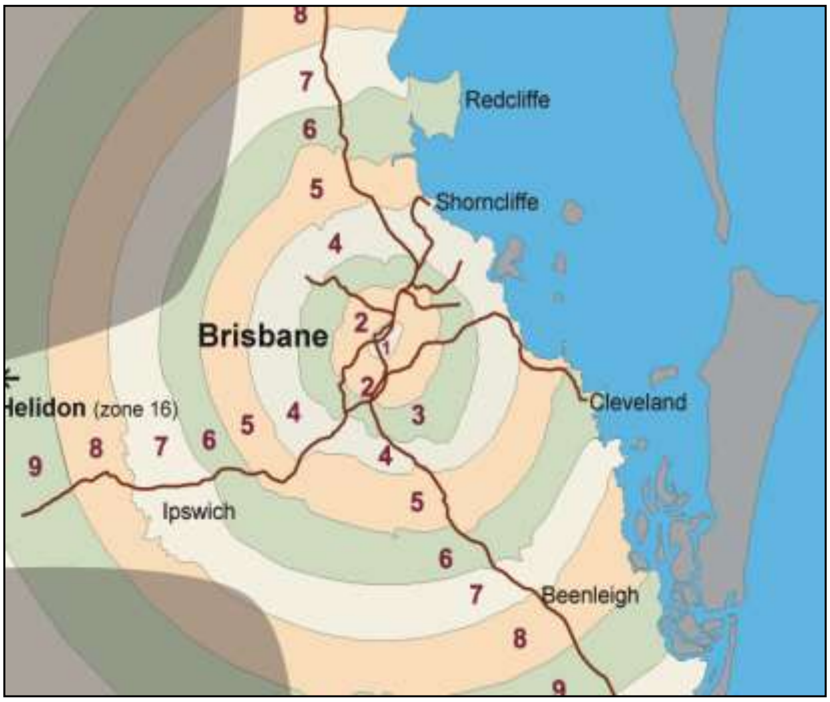
3.2 Queensland Motor Vehicle Registration Data and Australian Government Green Vehicle Data

The fuel efficiency (VFE) of private vehicles that commuters drive is considered as a key variable to determine levels of fuel energy cost. To account for fuel consumption of all private vehicle travels, the complete dataset for registered motor vehicles for Brisbane is used. The Australian Government Green Vehicle data provides the standard fuel consumption rate (litres/100km) for vehicle make and models in the registration data. The fuel standard consumption rate was used for the vehicle energy efficiency analysis because 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 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 metropolitan Brisbane (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 private vehicle trip distance, fuel consumption and the price of vehicle fuel. The advantage of the approach is that it uses the entire private vehicle fleets and the standard vehicle fuel efficiency ratings for each individual vehicle, which provides a richer depiction of standard fuel consumption of that fleet under current household travel demand. The average monetary cost for private vehicle trip was calculated following three steps:

Firstly, average private vehicle travel distance (VKT) was computed for each suburb of residence using number of car commuting travels between that suburb (origin) and all destinations and the Queensland road network data to determine the vehicle travel distance (shortest road network distance) between each origin and destination of travel.

Secondly, the standard vehicle fuel consumption rate (litres of fuel per 100km travelled) was calculated for private vehicle fleet in each suburb. The fuel consumption rate by specific make and model (provided by the 'Green Vehicle' data) was allocated to each individual vehicle (by make and model) in the vehicle registration. Once all fuel efficiency rates were allocated to the matched vehicles, 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 of private vehicle fleet for each suburb were multiplied with the average trip distance to calculate average litres of fuel consumed by the private vehicle for each trip. 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 sub-datasets for all JTW trips 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 starts 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 PT 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 applied. To calculate the fair for suburban trips that pass through the city centre, the PT 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 the Brisbane CBD (includes those trips that end or do not end at the CBD), 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 PT fares for these trips were 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 trips in Brisbane (< 1%). Once the PT fares were calculated for all PT trips in a suburb, the average PT fare per single trip was then calculated for that suburb based on the total number of (departing) PT trips in the suburb.

5. Results and Discussion

In this section, the geographical patterns of trips by private vehicle and PT in Brisbane are evaluated. The respective household expenditure on PT and private vehicle travels are evaluated and compared. Finally, 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 along the transport links between some industry-based suburbs. For example, trips 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 trips by private vehicle

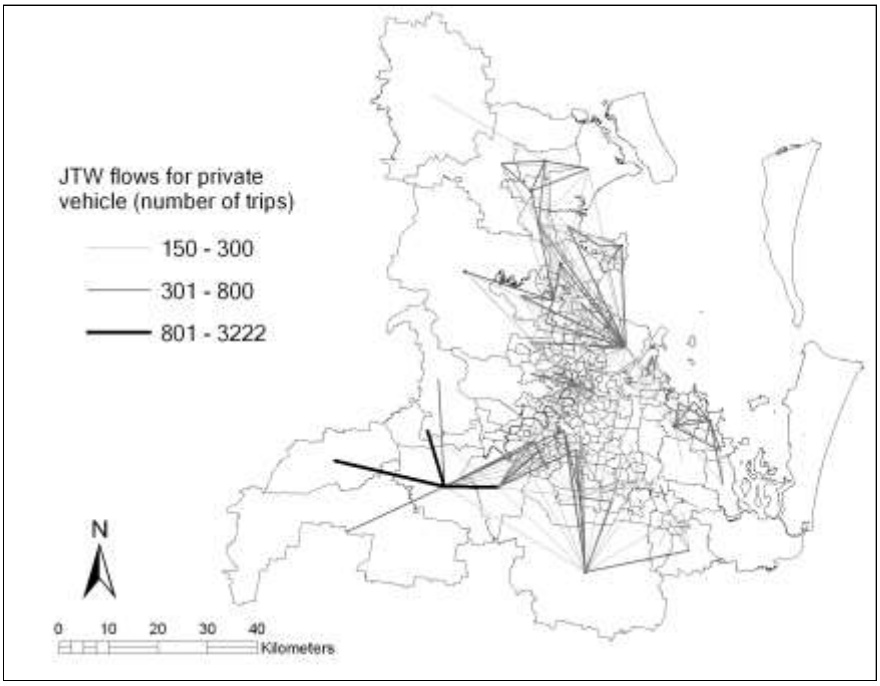
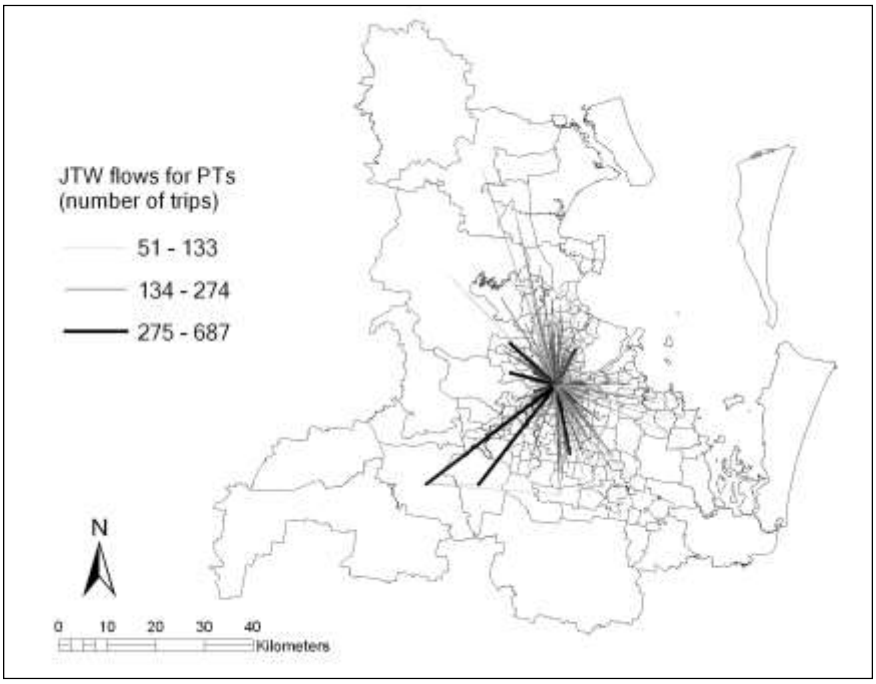


Figure 3. JTW trips by public transport

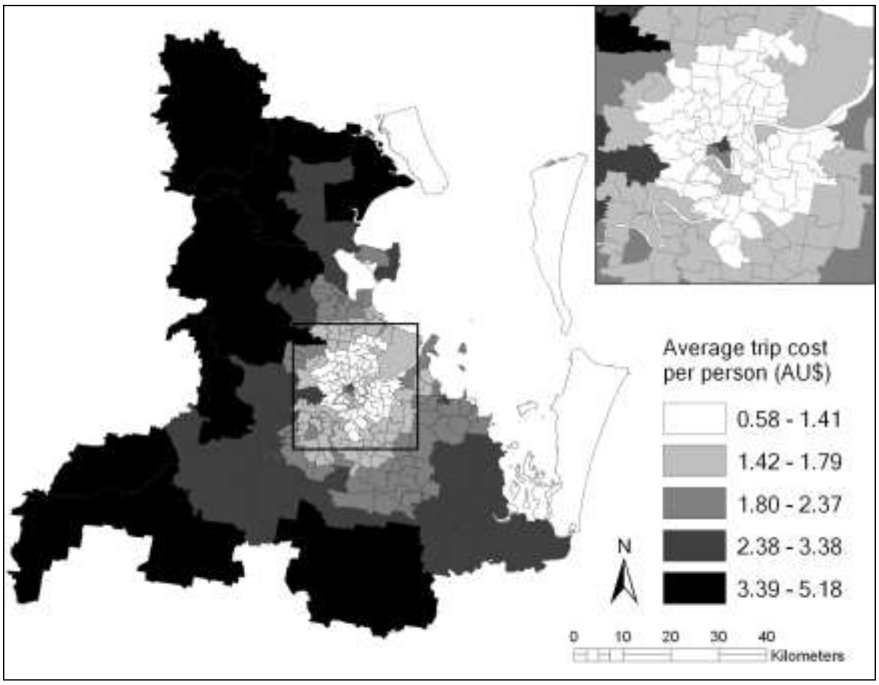


In contrast to private vehicle trips, Figure 3 shows the JTW trips using PT exhibit a very mono-centric pattern in Brisbane. There were 78.7 percent of PT commuters in Brisbane traveling toward Brisbane City, including those trips that end or do not end at the Brisbane CBD. Although the Brisbane CBD contains 20 percent of all employment, it accounts for 69 percent of all PT travel. In contrast 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 as one moves away from the CBD. The limited suburb-to-suburb trips by PT reflect that the PT route configuration and services in Brisbane is radial and CBD-orientated, and does not support well residents traveling to work at middle-outer suburbs. Improved PT services in the outer suburbs (e.g. especially orbital services) are needed to provide residents with better access to suburban employment.

5.2 Trip Cost

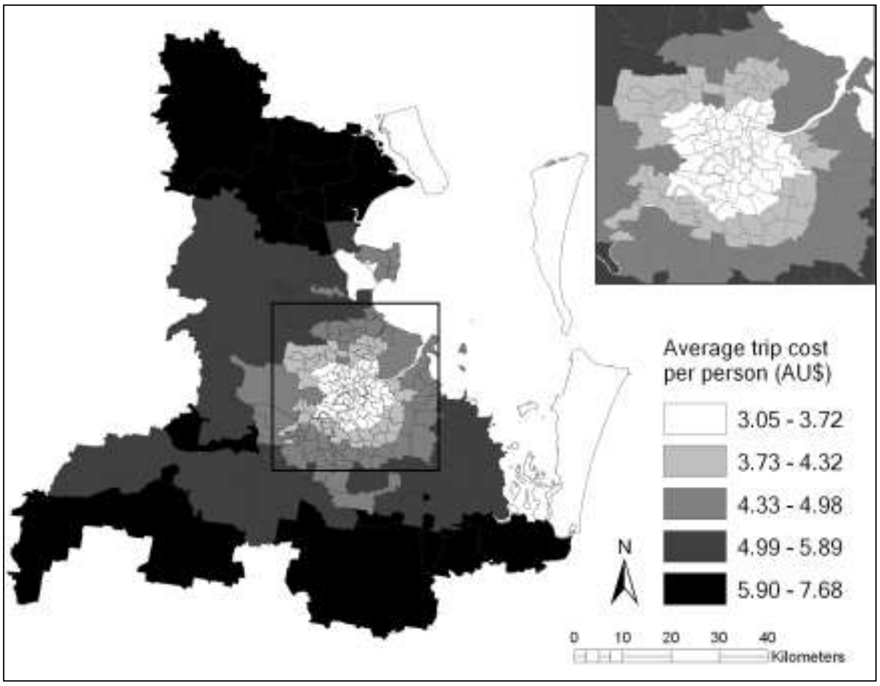
The average travel costs for private vehicle and PT trips in Brisbane are shown in Figure 4 and Figure 5. Figure 4 shows that the average trip cost measured by the dollar values of the amount fuel consumed by private vehicle tends to be lower for households living closer to the CBD, whilst those living further from the CBD have higher vehicle fuel expenditure. The average private vehicle trip cost tends to increase as household moves away from the CBD. The average vehicle trip cost in outer suburban area is higher because people living in those areas have more dispersed commuting patterns. An additional hypothesis is that the higher vehicle fuel consumption in the middle and outer suburbs can be aggravated by low proportion of fuel efficient vehicles used these areas. The inset map in Figure 3 highlights that the average vehicle trip cost for car commuters from the Brisbane CBD appears 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 the Brisbane CBD (e.g. toward the Gold Coast) and relatively small total number of car-based travels in the City.

Figure 4. Average cost per private vehicle trip in the Brisbane Urban Area



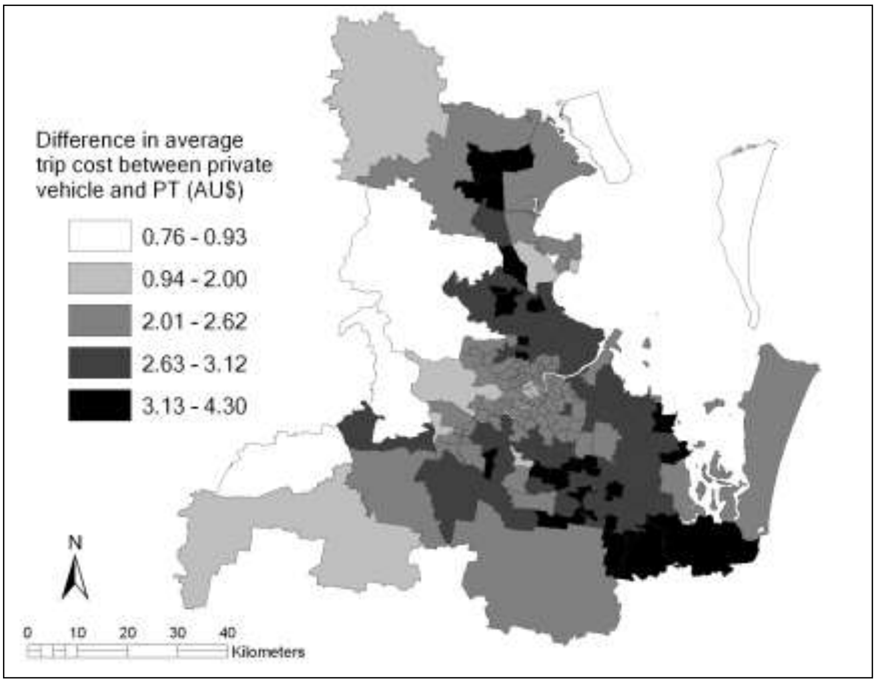
The average fare cost (dollars charged for PT fares per trip) of PT trips for Brisbane suburbs is shown in Figure 5. This includes commuting travels using PT including train, bus and ferry. In general, the average travel cost distribution is similar to that of private vehicle trip in Figure 4, except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

Figure 5. Average cost per PT trip in the Brisbane Urban Area



The difference in average travel costs between private vehicle travels and PT travels is compared in Figure 6. 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 trip to work than those local car commuters who can drive relatively shorter distance to work.

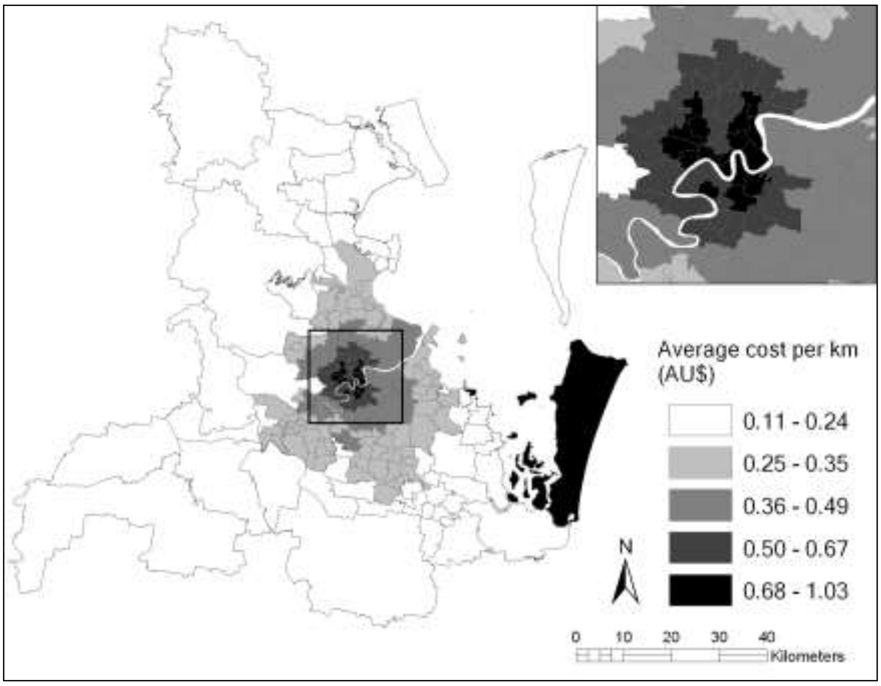
Figure 6. Difference in average cost per trip between PT and private vehicles



Whilst Figure 6 illustrated the distinct trip costs between two transport modes, it does not show the relative cost intensity (dollars spent for every kilometer travelled) of two transport modes 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 trips is firstly calculated for Brisbane. Figure 7 illustrates that PT fare on a per kilometer basis, tend to be lower on suburban PT systems than central city systems. This means that although the capital spending for PT fares is higher for suburban residents, they pay relatively lower PT 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 lower fare rate was promoted for outer suburbs than inner suburbs in Brisbane in order to attract and retain discretionary commuters and stimulate PT ridership in suburbs.

The cost intensity of private vehicle travels reflects the distribution of fuel efficiency of private vehicle fleet in Brisbane (Figure 8). 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. The outer suburbs present higher cost intensity can be caused by the higher proportion of large/high performance and lower vehicle efficiency vehicles (e.g. SUVs) used in those areas. This finding supports the VFE hypothesis stated in the Section 5.2. In addition, some high income suburbs or industry-based suburbs also present higher vehicle fuel cost intensity.

Figure 7. PT average cost/km



Next, the difference in cost intensity between PT and private vehicle travels is compared in Figure 9. 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 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.

Figure 8. Private vehicle average cost/km

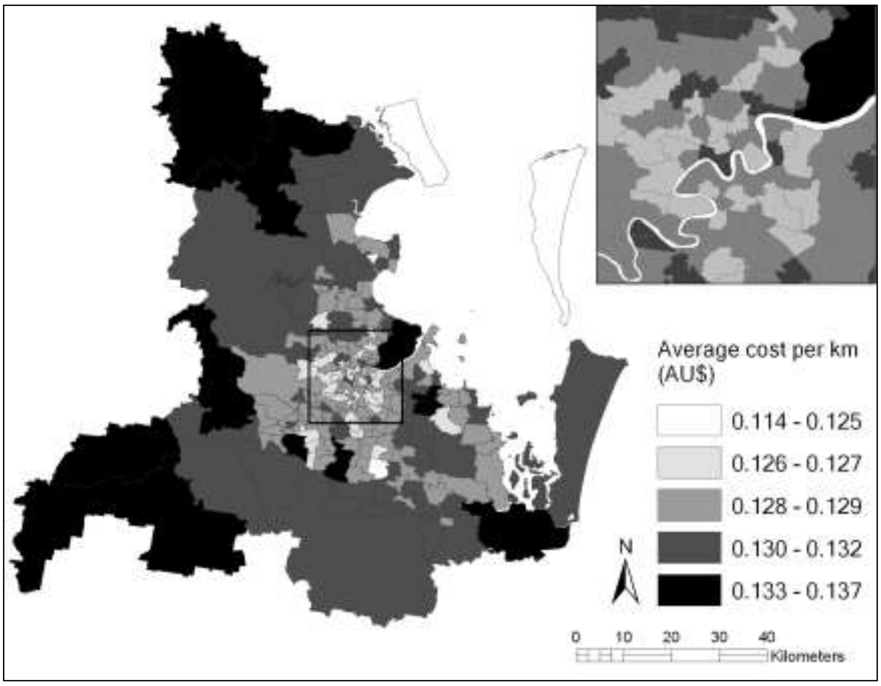
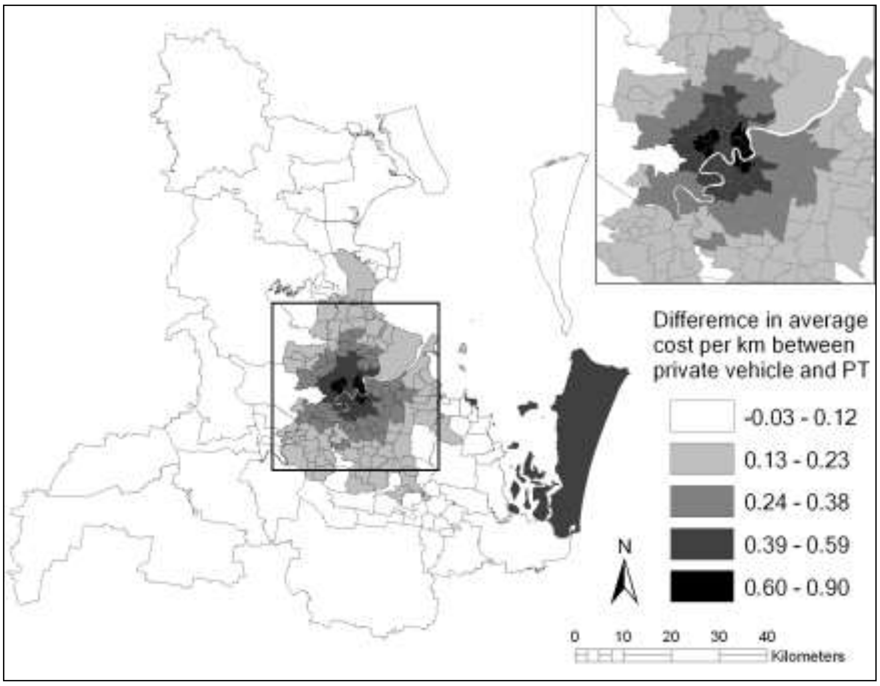


Figure 9. Difference in average cost/km between private vehicle and PT



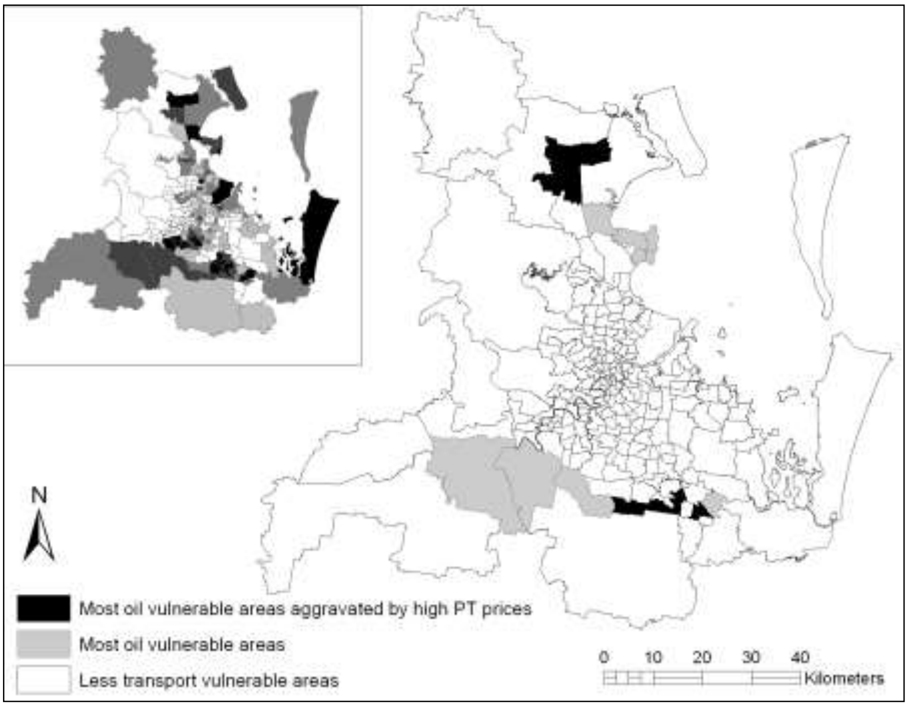
5.3 Travel Costs at Disadvantaged Suburbs

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 current policies have shown 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.

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 cost 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 10 shows the distribution of the most disadvantaged suburbs that are coupled with the highest household transport cost in Brisbane. 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 PT 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 insufficient PT services but also higher riding cost.

Figure 10. Oil vulnerable suburbs aggravated by high PT prices
(Inset map shows the SEIFA index)



6. Conclusion

Public transport is increasing in importance in Australian cities. The rising PT fares is creating a problem because it puts PT as a competitive disadvantage against the private car. This could threaten future PT demand. This paper sought to gain insights into transport vulnerability by exploring spatial patterns of household expenditure on PT compared to vehicle fuel in the Brisbane urban area.

Through a spatial analysis of travel patterns derived from JTW data and transport cost intensity associated with the PT fares and private vehicles, the result showed distinct geographical patterns of travel between private vehicle and PT travel groups. It also identified household trip costs 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 vehicles and PT. By comparing vehicle fuel cost and fare cost on a per kilometre basis, we gained further 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 private vehicles. However, unlike suburban residents, inner urban residents constrained by transport alternatives and parking conditions tend to be less sensitive to higher fares. This finding is consistent to the exiting transport fare elasticity literature (Cervero, 1990; Moore, 2002; Crowther, 2011). The paper then compared the combined household trip costs with patterns of suburban socio-economic disadvantage in Brisbane and demonstrated that 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 literature by incorporating advanced spatial analysis of multi-modal transport cost. However there remains a number of methodological limitations that will form the basis of future research. First, the generalized operational costs of private vehicle should include registration, vehicle maintenance, parking and congestion in the analysis of household private vehicle expenditure. 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 patterns in Brisbane. The approach is not considered widely applicable to other cities with a different spatial structure (such as Beijing where passengers travel on polycentric and dispersed PT networks). In extending this research it will be important to do more analysis to explore the household transport expenditure from all travel activities -- not only for the JTW. Finally, while this paper examined spatial patterns of household transport expenditures for Brisbane, further work should be done to see how the findings compare with other Australian urban areas.

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