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An empirical study of railway station access mode choice

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Abstract

This paper discusses residents' preferences regarding train travel with a focus on mode choice behaviour for railway station access modes of car, bus, bicycle and walk. Train transit is perceived as a stable and punctual service, yet in low density and car oriented cities, train services are ignored by travelers. The general issue is that train stations are often too difficult to access. This paper utilizes stated preference data to help identify significant factors in train access mode choices on a case study of a rail corridor. The findings uncover that walking distance, bus access, waiting time for bus, car access and car park availability are statistically significant. When considering the choice heterogeneity, time of day is related to the walk mode, and it also impacts the choice between car and bus access modes to the station. Sociodemographic factors of age, income and gender also influence mode choice and should always be considered in policy strategy. Further policy recommendations in this paper include to provide sheltered walkways and shaded cycling paths, improve feeder bus services to railway stations and increase station services to create a safer environment that can attract more train users. This study also indicates that transit nodes adjacent to urban precinct developments that provide a shorter accessing distance would help to reduce car usage and should be a continuous focus in urban planning.

Key words: rail travel, railway station precinct design, transit connection, feeder bus, park and ride

1. Introduction

Transportation makes a substantial contribution to energy consumption. Vehicle emissions are recognised as a major source of air pollution making up 15 per cent of total household emissions (Lenzen & Dey 2002) and 15.3 per cent of Australia's greenhouse gas emissions in 2010 (DCCEE 2012). Policy tools that focus on the built environment and transit service improvement have become increasingly important in reducing emissions, such as transit-oriented development (TOD) in transit corridors (Meng, Taylor & Scrafton 2016) or the enhancement of transport network city structure via land use and transport integrated development (LUTI) (Curtis 2006). Often rail corridors are perceived as having the lowest traffic congestion and the most reliable transit services. In 2009-10, 634.1 million heavy rail and 184.4 light rail passenger journeys occurred in Australia's urban areas but these two modes only made up 15.7 per cent of total passenger kilometres across all modes. In Adelaide, there were about 11.8 million heavy rail and 3 million light rail trips in 2009-10, which only account for 1.5 per cent of passenger kilometres out of the total motorised passenger tasks (BITRE 2014). These statistics demonstrate that there are some barriers existing in train use, particularly in Adelaide.

Distinct barriers to rail use do not impact travelers individually, rather as a combination of factors (Blainey, Hickford & Preston 2012) which can make it difficult to identify which barriers are most significant. Brons, Givoni and Rietveld (2009) suggested that satisfaction with the quality and level of accessibility is an important element in explaining rail use. Various other factors have been intensively discussed in previous research work, such as in Hoogendoorn, Hauser and Rodrigues (2004), the authors investigated how gates could be configured to assist pedestrian flows. While Wen, Wang and Fu (2012) looked at cost and time of access, they stressed that rail travellers are cost sensitive. Applying a different methodology, Polydoropoulou and Ben-Akiva (2001) used joint revealed preference (RP)[1] /stated preference (SP) data[2] to include attitude factors, such as feeling of comfort in their analysis. They identified that the number of multi-model mode transfers was most important, followed by mode of transport and the probability of having a seat while waiting for the train. With a growing impact on planning policy, station access (feeding) mode choice and behaviour are important issues to investigate.

Rail station access mode choice is influenced by complex factors (or barriers) including urban form, transport system supply, car park availability, railway station safety, feeder bus system quality, and broader issues across the economy and environment (Bhat & Guo 2007; Cervero 2002; Handy & Niemeier 1997). In low density cities such as those in Australia, access mode choice behaviour is more heterogeneous and often not adequately emphasized. There is a lack of indication of which barriers prevent or deter people from taking a train to work and how to promote increased train use by satisfying travelers' needs. This study reports a behaviour choice approach that analyses the perceptions of travelers' train station access modes and therefore informs on how to improve the identified factors to encourage train use. This empirical work embraces the concepts of transit-oriented development (TOD) in a local rail corridor, Adelaide's Northern Rail Corridor (ANRC) in Australia. The stated preference choice design includes walking, cycling, (feeder) bus, and car ('kiss and ride' and 'park and ride') access modes.

This paper includes a review of recent studies on barriers to railway station access in Section 2. It then describes methodologies for using discrete choice models and stated preference design in Section 3. Section 4 presents observation and survey results, and describes the estimations developed from discrete choice models and the results obtained for the case study area. Section 5 provides policy relevance and discussion, and finally Section 6 summarises and concludes the research.

Literature review

Rail, light rail (LRT) or a rapid bus transport corridor have become increasingly important in transit studies. A long distance from a railway station makes it difficult for travellers to reach. For some travelers, a multi-model network consisting of rail and connected station access modes make an attractive service (Zemp et al. 2011) to link rail line precinct suburbs and beyond. A well-designed network shortens transfer distances and times which will promote non-motorised travel (Breheny 1995; Dittmar, Zelzer & Autler 2004). As part of the transit network, high-speed rail lines could reduce journey times and therefore increase rail's relative attractiveness (Preston 2009). When considering the total travel time and waiting time in the rail trip chain, the modes for accessing train stations have been taken account in computing and adjusting train timetables (Niu, Zhou & Gao 2015; Vansteenwegen & Van Oudheusden 2007). An individual's mode choice preference and responsiveness to station accessibility affects her/his travel mode choice for a work trip (Bhat 2000) which largely relates to transit connection services, socio-demographic backgrounds, personal characteristics and extra travel needs (Loutzenheiser 1997).

TOD rail (and other transit) corridors are aiming to shorten the distance from home to stations by bringing a higher density development to transit nodes to encourage residents to use public

[1] Revealed preference (RP) data are derived from real markets but selected by the decision maker's perceptions of the real market.
[2] Stated preference (SP) data are collected by asking respondents to make choices from hypothetical choice scenarios sets which are composed by the experiment design.

transport (Dittmar & Poticha 2004). Researchers claim that walking paths and cycling routes directly influence people's travel mode choice and make a transit node area a more desirable residential location (Givoni & Rietveld 2007; TRB 2008). They are also 'the only completely sustainable forms of travel' (e.g. Mees 2009). When there is only a short distance of travel from home to railway stations, walking or cycling are preferred (TRB 2004). Givoni and Rietveld (2007) used a Dutch railway survey and found that 43% of rail passengers in the Netherlands would like to choose bicycle, walking and public transport, while car availability did not affect mode choice to a railway station. Debrezion, Pels & Rietveld (2009) claimed with the existence of a negative distance effect on station access by walking and cycling, offering parking and bicycle stands can have a positive effect for car and bicycle modes. Improving the quality of walkways and bicycle routes also depends on the preferences of local residents, local culture and weather conditions, e.g. in Adelaide, Australia, providing shaded (by trees or other cover) walking and cycling routes or short cuts (Meng, Taylor & Scrafton 2016).

The provision of car access (park and ride) to a rail station would promote ridership (TRB 2009). However it may also encourage car use to access the station rather than other sustainable modes, such as taking a bus, cycling or walking. Parking supply at railway stations has historically been a subject of academic controversy. Some argue that parking has been over supplied in the past and its availability encourages people to drive their cars, particularly if it is free (Banfield 1997; Shoup 2005). Others argue that providing parking at public transit stations as 'park and ride' in low density cities must be treated differently from parking in high density cities as parking can promote train patronage, and parking supplied near public transport stations can work as an effective feeder service for rail corridors (Bos et al. 2004; Curtis 2008; Mees 2000; Willson 2005). Another issue related to car parking is whether a fee should be charged on parking bays. Some researchers believe price restrictive policy might lead to a better public transit choice (Access Economics Pty Limited 2005; Marsden 2006; Marsden & May 2006; Willson 2005) and a parking levy could be used to improve the public transportation system (Access Economics Pty Limited 2005; Longworth 2006; Shoup 2005; Willett 2005). Parking fees are always likely to be politically controversial and need to be defined according to local conditions and economic development. Bos et al. (2004) studied the choices for 'park and ride', and claimed that the quality of connecting public transport, relative travel times by transport modes, and social safety are key attributes to the success of 'park and ride' facilities management. Studies have also found that station access behaviour may be demand-focused, e.g. bicycle riders do not care about whether there are parking facilities at a station or not (Givoni & Rietveld 2007). Free parking may promote car use, and price needs to be adjusted according to local variables and should also be altered over time. The apparent lack of a statistically significant relationship between supply and mode choice is of interest to planning regulation and development practices (Willson 2005).

Social safety has become one of the most important issues for train and public transport users. The perception of an unsafe railway station is a significant handicap for train patronage. Kim, Ulfarsson and Todd Hennessy (2007) analysed how individual, built environment and crime characteristics influence railway station accessibility. Their results showed that crime at stations has an impact on station access mode choice. Some factors that would help people to feel safer are a well-designed station platform, sufficient lighting, CCTV cameras, graffiti removal, the existence of a neighbourhood community patrol and informant hotlines (White & Sutton 1995). Another study found a lack of safety on public transport can be a major deterrent to attracting ridership, however, the feeling of security on the train accessing and departing the train station receives less attention (Loukaitou-Sideris, Taylor & Fink 2006). In particular, crime and personal security made female travellers more likely to be picked-up/dropped-off at the station or drive a car for trips at night (Kim, Ulfarsson & Todd Hennessy 2007). Better social interactivity can help people to cultivate a feeling of safety, for instance community programmes for travel planning could reduce the likelihood of personal assault accidents. Personal security concerns also impact on people's choice of using public transport, and must be taken into account in station design (Loukaitou-Sideris, Taylor & Fink 2006).

The weather may form a hurdle to rail use and also could aggravate other issues of station access making the waiting experience more unpleasant than what would be otherwise, particularly if access is by bike or on foot or if no sheltered waiting areas are available (Blainey, Hickford & Preston 2012). Kalkstein et al. (2009) investigated the impact of the weather on daily Bay Area Rapid Transit ridership in Chicago. Their findings showed a significant impact with usage typically increasing on dry, comfortable days, and decreasing on moist, cool ones, particularly on weekends. Although the comfort of a particular weather varies throughout the year, seasonality is not a significant factor with respect to the weather–ridership relationship. However, Kalkstein et al. (2009) found that transit ridership increases during periods of bad weather in Brussels, Belgium as people perceive cycling and walking would be difficult. Changnon (1996) suggested that summer rain days with storms would lead to decreased ridership on public transportation systems. Kalkstein et al. (2009) further suggested that there is a need to focus on weather forecast/ridership relationships.

Methodology

Discrete choice modelling

Discrete choice models analyse individual behaviour under hypothetical choices with variable attributes. The basic discrete choice model, the Multinomial Logit (MNL) model, is confined by the Independence of Irrelevant Alternatives (IIA) (Luce, cited in McFadden, 1972), and the residuals are independent distributions referred to as Independent and Identically Distributed (IID) (Louviere, Hensher and Swait, 2000). This allows the MNL model to simplify econometric estimations and forecasting. In practice, the IIA assumption is often violated during a choice making process which requires advanced specifications in simulation and analysis. Various specifications of advanced discrete choice models, such as Mixed Multinomial Logit model (MMNL), Latent Class model (LCM), Nested model (NL), Random Parameter model (RPM), Error Component model (ECM), Willingness to Pay (WIP), and Generalised Multinomial Logit model (GMNL) have been developed in recent years to assist in solving more complex transport problems (e.g. Bhat, 1995; Greene and Hensher, 2003; McFadden and Train, 2000; Rose et al., 2013; Walker, 2002; Wen et al., 2012).

The starting point for consideration of the appropriate discrete choice model is the basic MNL model, defined as

$$P_{jn,s} = \frac{\exp(U_{jn,s})}{\sum_j \exp(U_{jn,s})}, j = 1, \dots, J_{ns}, s = 1, \dots S_n \tag{1}$$

where $P_{jn,s}$ is the probability that individual n will select alternative j from a set of alternative scenarios s. The value of each alternative to n is given by its utility function $U_{jn,s}$:

$$U_{jn,s} = V_{jn,s} + \varepsilon_{jn,s},\ j = 1, \dots J, n = 1, \dots n \tag{2}$$

where $\boldsymbol{V_{jn,s}}$ represents a function of the observed attributes, and $\varepsilon_{jn,s}$ represents unobserved attributes. $\boldsymbol{V_{jn,s}}$ may be defined as a linear weighted sum of attribute values, written as $\boldsymbol{V_{jn,s}} = \boldsymbol{\beta X_{jn,s}}$ where $\boldsymbol{\beta}$ is a vector set of fixed coefficients and $\boldsymbol{X_{jn,s}}$ is the set of attribute values. As discussed above, the MNL is subject to the IIA and the IID extreme value assumptions.

The MMNL model structure relaxes some of MNL assumptions, which assists in accounting for a degree of correlation between alternatives and enables the model to provide a flexible and computationally practical approach (McFadden and Train, 2000; Walker, 2002).

The RPM is a MMNL model that provides greater flexibility in estimation, for example, as discussed in Ben-Akiva, Bolduc and Walker (2001) and Hensher and Greene (2003). RPM provides the flexibility to accommodate general characteristics as well as differences across individuals presented in the variables (Bhat, 2001), with utility function

$$U_{jn,s} = \beta_1' X_{jn,s} + \beta_2' X_{jn,s} + \varepsilon_{jn,s} \tag{3}$$

where $\boldsymbol{X_{jn,s}}$ presents a vector of attribute values for individual *n* considering alternative *j* in a scenario *s*. $\boldsymbol{\beta_1'}$ is a vector of non-random (fixed) coefficients while $\boldsymbol{\beta_2'}$ is a vector of random coefficients that is unobservable and may vary across individuals. $\boldsymbol{\varepsilon_{jn,s}}$ represents a random term and a relaxed IID extreme value. Therefore the unobserved portion $\boldsymbol{\beta_2'X_{jn,s}} + \boldsymbol{\varepsilon_{jn,s}}$ is correlated over alternatives made by each respondent (Train, 1998) and $\boldsymbol{\beta_2'}$ represents the unobserved heterogeneity, as described in Ortúzar and Willumsen (2002) and McFadden and Train (2000). The RPM specification suggests additional random effects that present the unobserved heterogeneity existing both within and between individuals and are across all the alternatives.

The choice probability $P_n\ (\theta^*)$ that individual *n* will select alternative *j* from a set of alternative scenarios *s* can then be written as:

$$P_{nj}\ (\theta^*) = \int_{-\infty}^{\infty} \prod_s \frac{\exp(\beta_1' X_{jn,s} + \beta_2' X_{jn,s})}{\sum_j \exp(\beta_1' X_{jn,s} + \beta_2' X_{jn,s})}\ f(\beta|\theta^*) d\beta \tag{4}$$

where $\prod_s \frac{\exp(\beta_1' X_{jn,s} + \beta_2' X_{jn,s})}{\sum_j \exp(\beta_1' X_{jn,s} + \beta_2' X_{jn,s})}$ represents the unconditional choice probability for individual *n*, $f(\boldsymbol{\beta}|\theta^*)$ is the density of taste variations in the population, and θ^* represents the mean and standard deviation of tastes in the population of individuals (Ortúzar and Willumsen, 2002; Train, 2003).

The utility function $\boldsymbol{U_{jn,s}}$ for the RPM combines the factors of alternative-specific variables, person-specific variables and built environment specific variables, and choice probability then depends on the covariance density *f(**β**)* based on ***β*** which is distributed normally as $\boldsymbol{\beta \sim N\ (\mu, \sigma^2)}$ (or with another distribution if required, as described in Train (2003)).

The ECM is based on alternative definitions of the error component, as described in Greene and Hensher (2007). When the MMNL model ignores random-coefficients, then error components create correlations among alternatives in a modified utility function of the form:

$$U_{jn,s} = \alpha_n' X_{jn,s} + \mu_n' Z_{jn,s} + \varepsilon_{jn,s} \tag{5}$$

where $\boldsymbol{\mu_n' Z_{jn,s}} + \varepsilon_{jn,s}$ represents error components as a random portion of the utility which depends on the attribute vector $\boldsymbol{Z_{jn,s}}$. $\boldsymbol{Z_{jn,s}}$ may share some attributes with $\boldsymbol{X_{jn,s}}$, as well as including some additional attributes. For a standard MMNL such as RPM, $\boldsymbol{Z_{jn,s} = 0}$, which means there is no correlation in utility over alternatives. When $\boldsymbol{Z_{jn,s}}$ is non-zero – which identifies the difference between a RPM and an ECM – there is unobserved heteroscedasticity and correlation over alternatives in the utility (Brownstone and Train, 1999; Train, 2003). The ECM thus focuses on the decomposed unobservable component of utility, as discussed by Train (2003) and Greene and Hensher (2007).

Stated preference design

In discrete choice modelling development, stated preference data have become increasingly popular in recent decades. Stated preference data allow researchers and decision-makers to consider choices within a set of mutually exclusive alternatives (Hensher et al., 2005; Louviere et al., 2000), especially for choice situations involving unfamiliar or novel alternatives. Efficient design assumes parameters for standard error and approximates the Asymptotic Variance Covariance (AVC) matrix without the need to conduct a full survey. The AVC matrix is equal to the negative inverse of the Fisher information matrix, which defines the expected values of the second derivative of the maximum likelihood function:

$$\frac{\partial^2 LL(X|\beta)}{\partial\beta_{k1}\partial\beta_{k2}} = \sum_{n=1}^{N}\sum_{s=1}^{S}\sum_{j=1}^{J} X_{jk_1n,s} P_{jn,s}(X|\beta)\left(X_{jk_2n,s} - \sum_{i=1}^{J} X_{jk_2n,s} P_{jn,s}(X|\beta)\right) \tag{6}$$

where, $p_{jn,s}$ represents the probability that individual *n* will select alternative *j* from each set alternative scenario *s* (*s* = 1, …, *S*), the value of each alternative to *n* (*n* represents respondent *n* = 1, …, *N*), is given by its utility function, *j* represents alternative (*j* = 1, …, *J*), *k* represents attribute ($k = 1, \ldots, K$), design *X* consisting of attribute levels $X_{jksn,}$ β is parameters to be estimated.

These equations are stated in detail in Bliemer and Rose (2009). The design criteria can be D-error (the deterant of the AVC matrix), A-error (the trace of the AVC matrix) and S-estimates (for sample size), more description can be found in Bliemer and Rose.

Elasticity

The relationship between the percentage change for some attributes and the percentage change in the quantity demanded can be estimated by using demand elasticities. Choice elasticity is a positive differentiable function expressed by the relative change in the probability of a choice. There are two types of elasticity in general: direct-point elasticity and cross-point elasticity. Direct-point elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in an attribute of that same alternative. Cross-point elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in a competing alternative (Ortúzar and Willumsen, 2002).

If z_{nj} is an attribute of alternative *j* and the choice probability is P_{nj}, then the direct point choice elasticity is:

$$E_{jZ_{nj}} = \frac{\partial V_{nj}}{\partial Z_{nj}} Z_{nj}(1 - P_{nj}) \tag{7}$$

Alternatively, the cross-point elasticity of P_{nj} with respect to a variable entering alternative *j* is given by:

$$E_{jZ_{nj}} = -\frac{\partial V_{nj}}{\partial Z_{nj}} z_{nj} P_{nj} \tag{8}$$

Detailed explanations can be found in Ortúzar & Willumsen (2002), Train (2003), and Hensher, Rose and Greene (2005).

Case study

This study investigates the potential for railway use and station precinct transit-oriented development (TOD) in Adelaide. Adelaide is populated by 1.2 million residents and has six metropolitan railway lines (with over 80 railway stations), plus the Glenelg-Adelaide-Hindmarsh light rail transit tram route (with 28 tram stops). The case study area covered the northern part of an Adelaide corridor (the Gawler line, or Adelaide Northern Rail Corridor (ANRC)), from Mawson Lakes to Gawler. The line links the Adelaide CBD and regional areas with service frequencies of around six trains per hour in peak periods, four per hour off peak, and two per hour on weekends.

This study collected revealed preference (RP) data and stated preference (SP) data. RP data includes:

- overview of the rail corridor: obtaining a general understanding of overall social and built environments of the defined corridor and identifying the impact on local public transport by analysing history, economy, culture and residential travel habits in the local area
- analysis of census data: mapping socio-demographic information at spatial locations and analysing travel behaviour by using journey to work data by mode and residential dwelling type
- observations at rail interchanges: providing train patronage data at major interchanges including travel flow, access mode choices and car park occupation patterns by train users

- results from focus groups: providing an in-depth discussion of local issues to assist in understanding local travel mode choice preferences and their impacts on residential area development
- responses to general questions in a household survey.

SP data are a set of hypothetic choice scenarios derived from the understanding of local rail travel observation (RP data) then developed by efficient experiment designs.

Overview of rail corridor

Northern Adelaide has a well-connected road network that incorporates Main North Road, Salisbury Expressway and the newly built Northern Expressway. The Gawler railway line is fed by several bus routes at interchange stations. Expressways, feeder buses and 'park and ride' facilities around railway stations can increase the quality of rail transport (Curtis 2006; Mees 2000). One of the greatest advantages is that the Northern railway line has been upgraded to a rapid electrical railway, with a significantly shortened travel time and the potential to become the major mode of transport in Northern Adelaide.

Analysis of census data on work trip by train

Travel to work generates the majority of travel activities and is usually a focus of travel behaviour studies. Figure 1 indicates methods of travel to work by main mode from census data collected in 2006 (Australian Bureau of Statistics 2006). The figure illustrates the

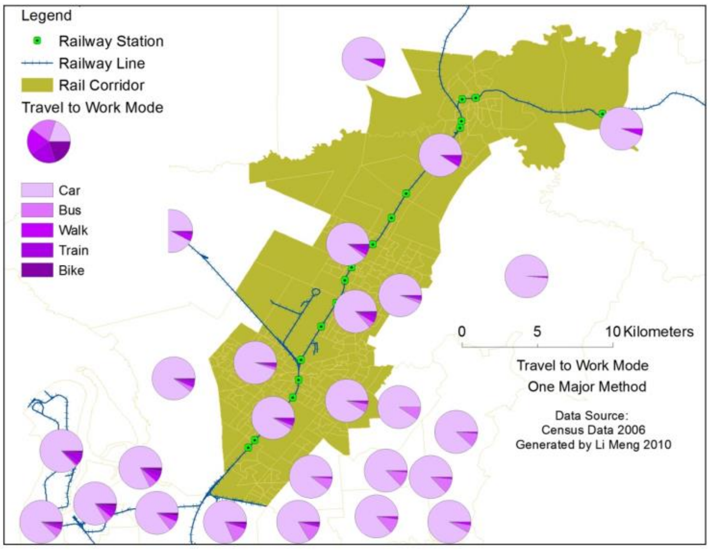

Figure 1: ANRC main mode of travel to work

allocation of the working population in the rail corridor and their travel to work by main mode. It reflects the dominance, in all cases, of car travel. The train mode is slightly more acceptable for people who live closer to the rail corridor than for those who do not. The majority of people drive a car to their work, even many of those who live near a railway line.

Travel to work by train by access modes

Census data also provides information on the methods that train users use to access railway stations (Australian Bureau of Statistics 2006). Figure 2 provides this breakdown by mode along the corridor and beyond. Walking was the dominant mode to access the train station if they live close by. People who live further from a railway station are more likely to use bus or car to access the railway station. Bicycle access to train stations was not specifically recorded.

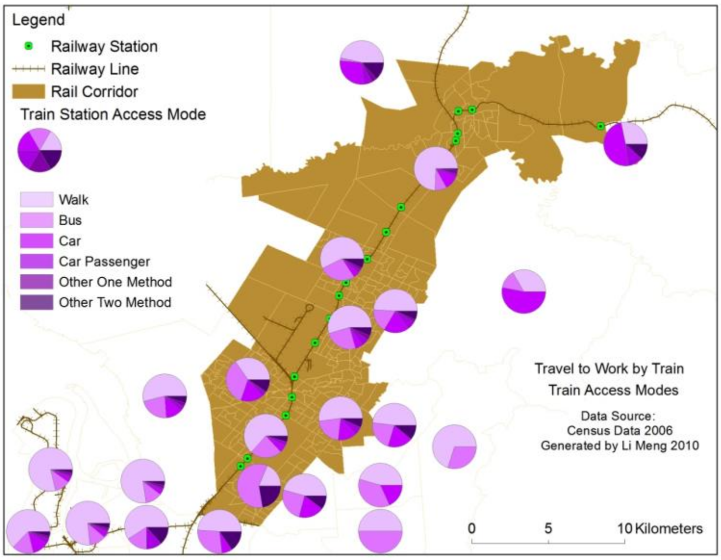

Figure 2: ANRC train user access mode to railway stations

Railway station observations

The census provides data on travel to work and residential dwelling type at the time of the census collection period in 2006. For this train corridor study, up-to-date rail passenger travel information was needed to better understand travel behaviour. A railway station observation survey was designed to cover all the station access points and to record the passengers' arrival and departure modes to and from the railway station in 2010. The observations took place between 6 am and 7 pm on a weekday and were recorded at 5 minute intervals at Mawson Lakes, Elizabeth and Gawler interchanges. Access modes were recorded including walking, bicycle riding, bus, 'park and ride' and 'kiss and ride'. These data provide useful information to describe the travel patterns of train users.

Mawson Interchange

The results of the rail interchange survey at Mawson Interchange undertaken by the project team in 2010 showed the level of daily rail patronage. The station was busy at peak times, around 7:30 am and 4:30 pm. In total, 1602 passengers used the station to depart, arriving at the station either by bus, car, cycling or walking, see Figure **3**.

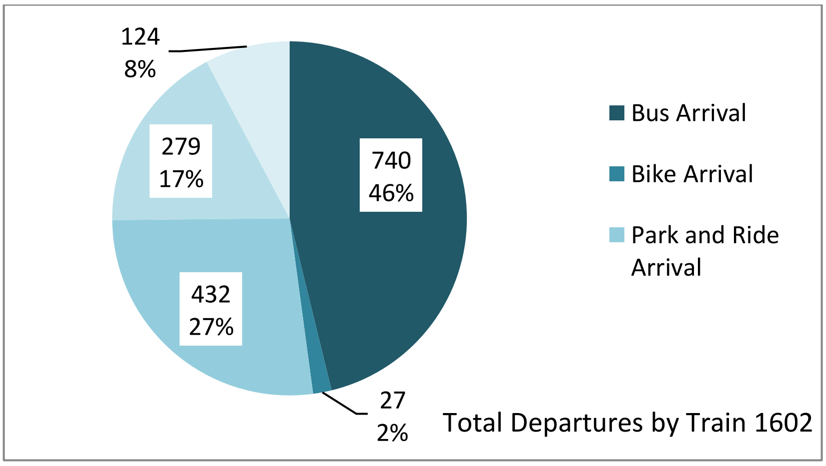

Figure 3: Arrival methods at Mawson Interchange

Nine feeder bus routes brought in 740 train passengers per day. Walk and cycle arrivals only accounted for 10 per cent of total train users while 17 per cent of users arrived using 'kiss and ride', plus 432 passengers utilised 'park and ride' facilities. Security patrols around the station enhanced the feeling of safety for train users, which supported Mawson Interchange as a more attractive station to get on and off the train, especially in the hours of darkness.

From the same interchange survey, data showed (in Figure **4**) the majority of train users left Mawson Lakes to the city in the morning peak time and in the evening peak time they returned from the city to Mawson Lakes. The largest number of passengers in a five minute interval was 250. As expected, passengers are travelling from their home to work in the morning period, while in the evening travellers arrived at the interchange from the city after work. This reflects the problem of a lack of employment development in Mawson Lakes: fewer companies than expected have so far established businesses in the area.

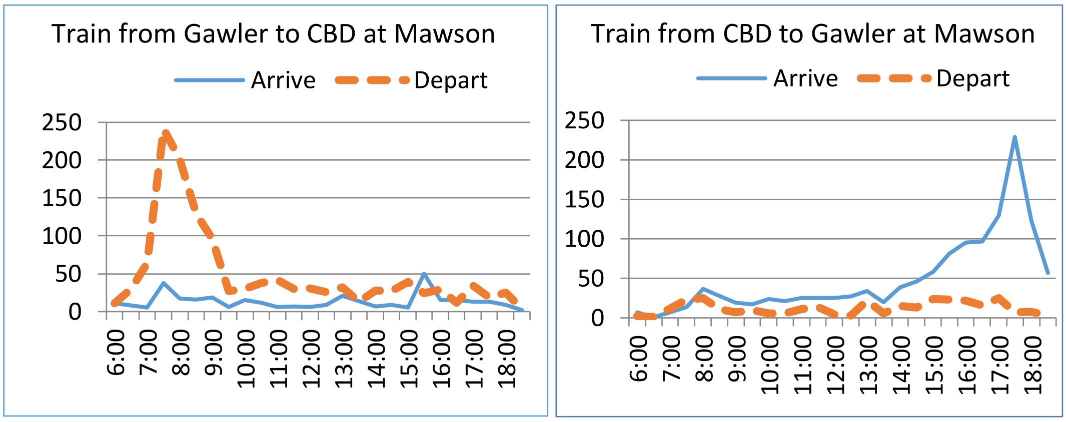

Figure 4: Daily profile of train patronage at Mawson Interchange

Figure **5** shows the number of cars that were parked at the Mawson Lakes railway station throughout the observation day. 'Park and ride' users occupied 75 per cent (total of 418 available car parks) for most of the day. 399 cars used the car park, which included some users who parked in the car park to pick up 'kiss and ride' passengers.

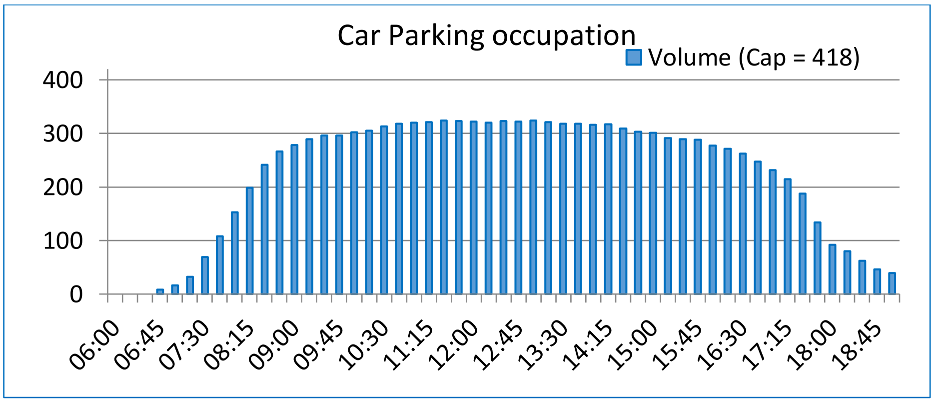

Figure 5: Car parking occupation at Mawson Interchange

Elizabeth Interchange

The results of the interchange survey in Elizabeth (in Figure 6) showed some slightly different results from those of Mawson Lakes. 1290 passengers arrived at Elizabeth interchange on the day of the survey, 37 per cent of which arrived on foot, only seven per cent by 'kiss and ride' and 11 per cent by 'park and ride'. A possible explanation for the increased number of walk arrivals may be that many of the walkers parked their car in the nearby shopping centre car park for security reasons or were dropped off nearby.

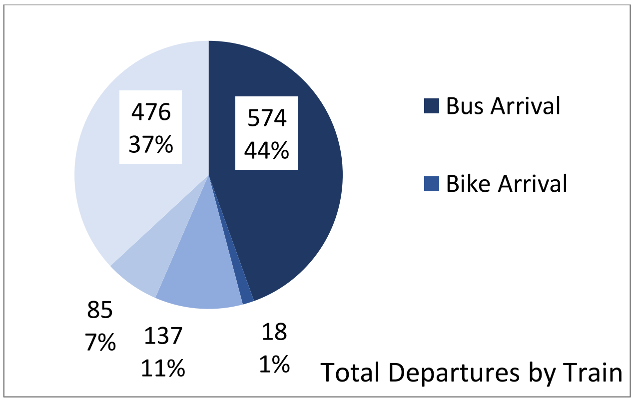

Figure 6: Arrival methods at Elizabeth Interchange

Figure **7** shows that arrivals at Elizabeth Interchange formed a travel trend and peak hour period similar to that at Mawson Interchange. The main difference is that the number of passengers at peak time at Elizabeth Interchange was only half of that at Mawson Lakes.

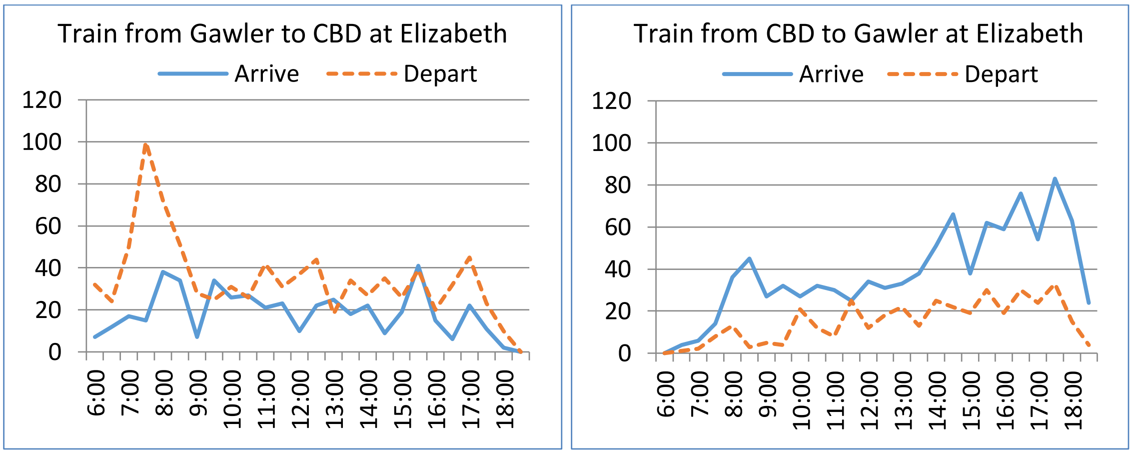

Figure 7 : Daily profile of train patronage at Elizabeth Interchange

Only 168 cars utilised the car park at Elizabeth interchange with half hourly observations. This data may not represent the true ‘park and ride’ picture though as other evidence suggests that some passengers may have parked their car in the nearby shopping centre.

Gawler station

There are three stations in the Town of Gawler being Gawler, Gawler Oval and Gawler Central. The Gawler station observation was conducted at the Gawler station. The survey results show that there were only 665 train passengers on the day, of whom only 3 per cent of train users (see Figure 8) arrived at the station by bus as there was only one regional bus service in the area in 2010 which ran on an occasional call basis. A higher proportion of walkers (43 per cent) arrived at Gawler station than at the other stations. Around 15 per cent of people used ‘kiss and ride’ which indicates that a drop-off bay is important for Gawler train users.

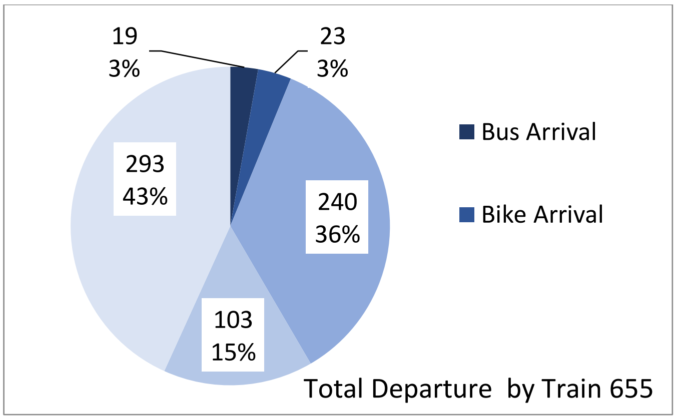

Figure 8: Arrival method at Gawler

The travel trend at the Gawler station forms a morning and afternoon peak shown in Figure 9. It is not surprising that the morning peak was earlier and afternoon peak was later than those at Elizabeth, as Gawler is further away from Adelaide. A small peak formed around 14:30 to 15:00 which could be contributed by the industrial workers in the Northern area as shifts mostly start at 6:20 and finish at 14:20.

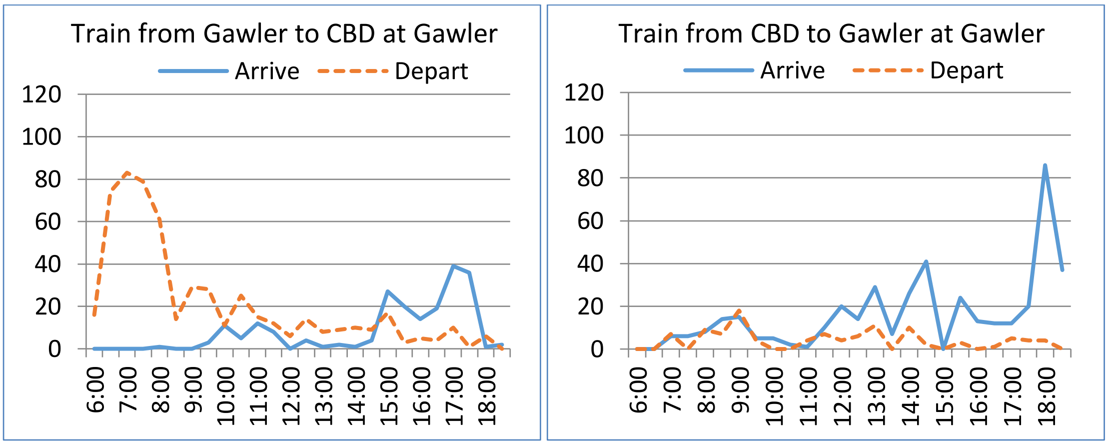

Figure 9: Daily profile of train patronage at Gawler

Car parking occupation was low compared with parking capacity. The maximum occupancy rate was only around one third of the capacity with a total of 196 cars on the day, with the most at any time being 100 at around noon.

Focus group results

The six groups comprised one each from residents living in Mawson Lakes, Elizabeth, Gawler, one from suburbs in the corridor excluding the aforementioned three suburbs, frequent rail users, and students at the University of South Australia's Mawson Lakes campus. The outcomes of the focus groups were as follows:

- Public transport infrastructure was an important topic discussed in the focus groups. The most frequently mentioned issue in regards to public transport was anti-social behaviour, security and crime on train carriages or at train stations. Graffiti and scratches on public transport or station made people feel unsafe as well.
- Public transport accessibility was another highlighted issue mentioned during the focus group sessions. For example, the newly established Mawson Interchange only provides easy access from the eastern side. On the west, the railway lines themselves can only be traversed by a grade-separated road, which adds inconvenience to the trip and restricts walking access from the northern side. Some stations have reasonably easy access, but the surrounding environment does not appeal to train passengers.
- Poor public transport availability and connection is another transit infrastructure issue, especially on weekends and after work hours. Some participants said that their children would love to use public transport for weekend trips but unfortunately, it took 30 minutes to one hour to wait for the next transfer. Some of the participants travelled to work by train or bus, but they chose to drive a car for non-work activities when the service is less frequent, especially on weekends. The majority of students in the Mawson Lakes study group owned a car that was only used for visiting their friends or going shopping on weekends.
- Urban land use patterns affect local residents' lifestyle and travel patterns. Participants who lived near the rail corridor and mixed land developed areas tended to use public transport more than a car for the journey to work. In Mawson Lakes, a TOD-like area, a walkable distance to local services and public transport acts an important element to attract residents to move in. However, other services are still not available as some participants complained that there is no post office, so they have to drive several minutes to another area for the service. Another issue relates to residential housing preference, as the higher density apartment types prevalent in Mawson Lakes may not be acceptable to some local residents who show a 'not-in-my-back-yard' (NIMBY) attitude towards apartments and claim that they damage the local amenity.
- Road infrastructure provision, such as walkways and bicycle lanes, heavily impact upon the quality of living areas. In the Mawson Lakes town centre, residents could walk or ride a bicycle alongside a scenic lake to Mawson Lakes Boulevard which has restaurants, core retail outlets and education facilities. However, this convenience does not appear elsewhere in this development, such as the areas around the Mawson Lakes railway interchange itself. The provision of roads in the town of Gawler was designed differently to Mawson Lakes and Elizabeth. Being a historic town, established in 1839, Gawler encounters difficulties in coping with redesign of its narrow streets while retaining heritage sites. The conflict between transport constraints and population growth causes traffic congestion at rush hour.

Other general issues such as limited recreation facilities, insufficient ancillary services and house affordability are of high concern in the ANRC corridor.

Stated preference questionnaire design

Stated preference (SP) data was also collected to develop a discrete choice model. Using the combined results from the literature review, station observations and focus groups, the stated preference experiments were designed to include a set of choices of ‘car’ (denoting ‘park and ride’), bus, walk and bike, and factors relating to train station access mode, as below for station access mode experiments:

- travel distance to station
- quality of walking route to station
- quality of bicycle route to station
- waiting time for access bus to station
- availability of car parking at station
- frequency of train service
- station design and personal security
- time of day and personal security
- weather conditions
- social interaction, concerned with travelling alone or with companions.

A questionnaire that combined revealed preference and stated preference questions was sent to local residents via mail either in paper form or by notification to online access. Stated preference questions were included to explore local issues. Sets of 12 station access mode choice scenarios were designed by applying Bayesian prior parameters with efficient Bayesian design criteria of D-error at 0.126, A-error at 1.571 and S-estimates at 42 (see an example in Figure 10). The survey design and data analysis are described in Meng et al. (2012).

When choosing please consider that:

- The train station is an environment where you do not feel safe
- It is daytime
- The weather is wet
- You are travelling alone
- Interval between trains is 10 minutes.

	Car	Bus	Walk	Bicycle
Travel distance to the train station	1 km	1.5 km	0.5 km	2.5 km
Parking availability at the train station	$2/day parking			
Waiting time for bus to train station		10 mins		
Quality of walking route			Good	
Quality of bicycle route				Good
Which of the mode alternatives would you choose for your journey to the train station?	☐	☐	☐	☐

Figure 10: Sample of stated choice scenarios

Household survey results

The questionnaires were distributed via paper and internet surveys in the defined corridor area, comprising about 15,000 households. With a four per cent response rate, there were 697 respondents. Comparing the socio-demographic characteristics of respondents to the entire population, respondents older than 30 were over represented while those younger than 30 were under represented. The highest variance was for the 45-49 year age group who were represented by 13 per cent of respondents but only 7 per cent of the population. Based on the income level, people who have higher incomes appeared more likely to answer survey forms than those with lower incomes. From all the survey respondents, in considering the working population presented some special characteristics, 356 respondents whose major daily activity was described as work (whether full time, part time or casual) formed a working population model. Missing data items were handled by using the methods of miss at random or missing at completely random, for which a more detailed description can be found in Schafer and Graham (2002).

Revealed Preference data

Revealed preference survey questions include age, gender, income and occupation and some important rail travel information. Figure 11 shows survey respondents' actual train use frequency, it suggests the majority of the respondents use a train less than weekly, while a big large proportion of respondents never use a train. Only around 30 respondents used a train every day, around 40 used a train twice a week and 45 of them used a train weekly.

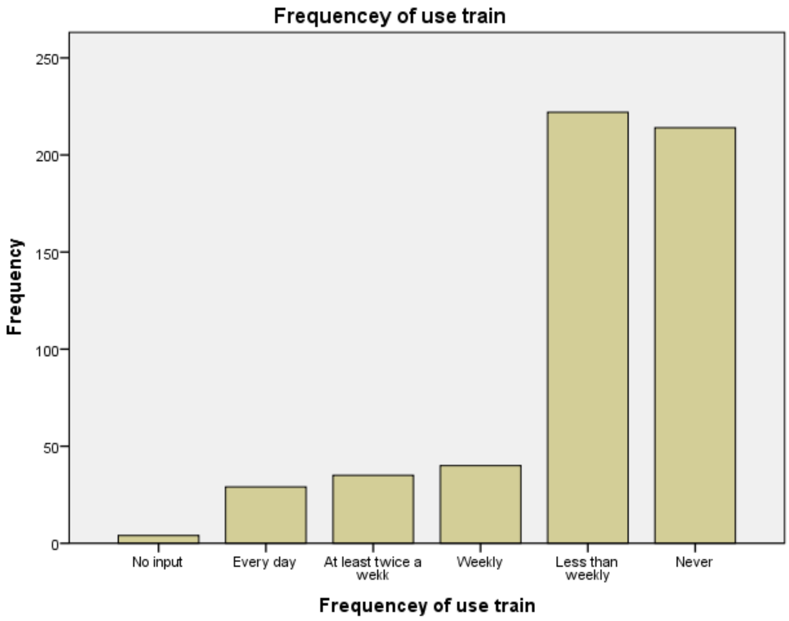

Figure 11: Respondents' frequency of use train

Figure 12 shows the actual train access modes. There was a large number of respondents who used a free car park. The second largest group was those who accessed the train by walking, while a small number of people used feeder buses by frequencies varying from 10 min to 30 min. A considerable number of respondents used drop off (kiss and ride). The no input number matches with the number of respondents who 'never' use a train.

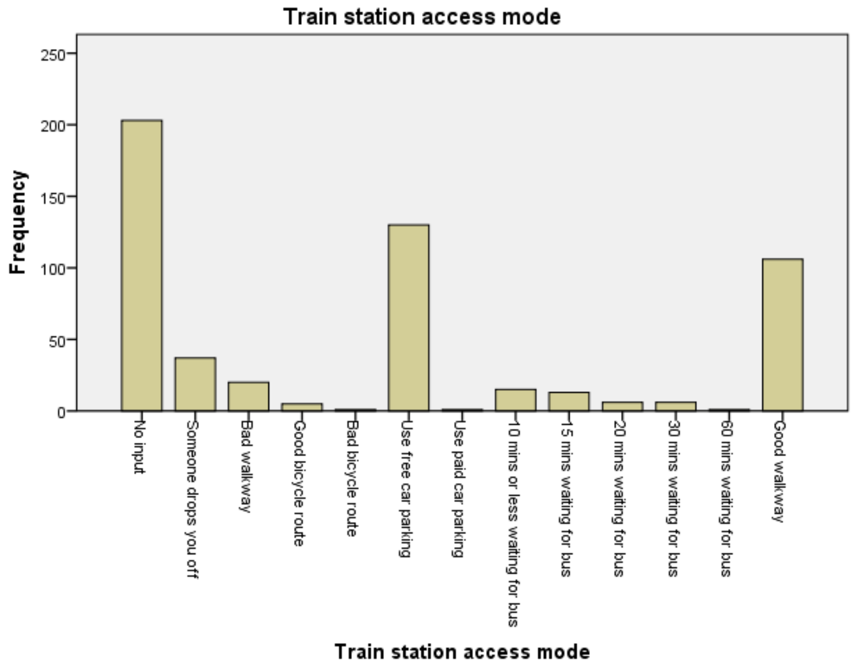

Figure 12: Respondents' train station access modes

Stated Preference data and discrete choice modelling results

The 4,272 choice variables in the stated preference data were selected for input into a RPM and an ECM. In applying a Random Parameter Model (RPM) and an Error Components Model (ECM), this study used 1,500 Halton draws to test the interactive coefficient of the variables and provide best fit model results. The model fitting results are shown in

Table **1**[3] which the Which the presents the mode availability shares, mode choice shares, and the descriptive statistics for the level-of-service measures in the work population sample. The maximum likelihood method was applied to estimate parameters to have smaller asymptotic standard errors (or variation around the mean). These error terms are useful for representing the influence of a particular attribute associated to utility. The likelihood ratio test is used to compare the fit of the MNL model and RPM (or ECM). For RPM, the obtained likelihood value of -1667 (starting value -1,754) and a p-value of 0.049 proved to be a better fit than the original MNL model. The Pseudo R^2 index is 0.246, which indicates the estimated model is progressively improved for an overall goodness of fit. The Chi-square related ρ-value report of 0.000 is statistically significant at the 95 per cent confidence interval. Based on a systematic process of eliminating variables found to be statistically insignificant in the aforementioned specifications, the final variable specification will be explained for the overall performance of the model with the individual parameter estimation, t-statistics and p-value. A number of variables associated with individual socio-demographics and trip characteristics were considered for accommodating observed taste heterogeneity.

[3] Notes: *** significant *p*-value ≤ 0.001; ** significant *p*-value ≤ 0.01; * significant *p*-value ≤ 0.05; Parentheses indicate t-ration.

Table 1: Station access mode choice models Random parameter Model (RPM) and Error Component Model (ECM) [coefficient (t-statistics)]

Variable	**RPM**		**P.**	**ECM**		**P.**
Walk distance	-1.29(-7.2)		***	-1.0(-6.3)		***
Age	0.08(3.44)		**	0.1(3.78)		**
Bike distance	0.02(0.32)			0.05(0.78)		
Bike route	0.14(1.88)			0.12(1.43)		
Bus	2.28(2.84)		**	3.04(2.3)		*
Bus distance	0.12(3.82)		**	0.09(2.68)		**
Car	5.43(5.35)		***	6.58(4.57)		***
Car distance	-0.01(-0.5)			-0.01(-0.56)		
Distance from home to train station				0.09(4.12)		***
Distance from home to bus stop				0.15(2.38)		*
Driving licence	0(0.03)			-0.08(-1.76)		
Family relationship	0.02(0.9)			-0.1(-1.92)		
Frequency of use train	0.15(3.29)		**	0.19(3.92)		**
Gender	-1.43(-4.34)		***	-1.19(-2.55)		*
Income	0.03(2.13)		*	0.04(2.3)		*
Occupation	-0.02(-1.02)			0.01(0.59)		
Parking availability	0.14(3.83)		**	0.11(2.71)		**
Residential car park type	-0.11(-2.87)		**			
Registered vehicles	-0.39(-5.21)		***	-0.18(-1.01)		
Social	0.08(0.84)			0.06(0.57)		
Station safety	-0.01(-0.19)			-0.01(-0.14)		
Time of day	-0.03(-1.43)			-0.04(-1.28)		
Train frequency	-0.08(-1.73)			0.02(0.31)		
Train station access modes	-0.12(-2.7)		**	-0.13(-2.64)		**
Travel to work distance	0.21(6.01)		***	0.1(1.44)		
Travel to work time	-0.18(-5.19)		***			
Usual station access mode				-0.15(-2.39)		*
Waiting time for bus	1.12(1.23)			-0.27(-0.21)		
Walk	0.03(1)			0.04(1.12)		
Walk way	0.83(5.94)		***	0.73(4.73)		***
Weather	0.15(4.77)		***	0.17(4.6)		***
Waiting time for bus	0.08(3.44)		**	0.1(3.78)		**
Heterogeneity in mean, Parameter Variable: walk vs train frequency	-0.09(-3.71)		***	-0.09(-3.71)		**
Derived standard deviations of Parameter distributions: Walk distance	1.19(7.12)		***	0.53(4.11)		***
Heterogeneity in mean, Parameter Variable: Walk distance/Time of day	0.08(5.15)		*			
Heteroscedasticity in Random parameters: Walk distance/Residential car park type	-0.12(-2.51)					
Standard deviations of latent Random effects: Error component on car and bus				2.32(4.36)		***
Heterogeneity in variance of latent Random effects: Error component/ Occupation				-0.13(-1.97)		*
Heterogeneity in variance of latent Random effects: Error component/ Time of day				0.11(3.87)		**
Log likelihood function	-1754	-1667		-1452	-1380	
Info. Criterion: AIC	2.235	2.31		2.225	2.125	
Finite Sample: AIC	2.235	2.132		2.342	2.127	
McFadden Pseudo R-squared		0.246			0.252	
Chi squared (degree of freedom in parentheses)	293(26)	1089(33)		267(27)	932(35)	
Prob [ChiSqd > value]		0.000			0.000	
At start values -1369.792		0.049	*		0.049	*

For the RPM, the tested parameters show that walking distance, car mode, gender, registered vehicle at home, train station access mode availability, travel to work distance, weather and waiting time for a bus with a p-value smaller than 0.001 are statistically significant important variables. While, age, bus availability, bus travel distance to train station, frequency of train use, car park availability at the station and at residential and train frequency are statistically significant with a higher p-value ranging between 0.001 and 0.01. Income was also statistically significant but slightly less, with a p-value smaller than 0.05. Walk to train station choice is strongly related to train frequency which suggests if train frequency is high, people don't mind to walk to the train station, otherwise walking may possibly cause travellers to miss a train and lead to a long wait. Walking distance to the train station is a statistically significant random parameter. In addition, the relationship of walking to the train station and time of day presents the significant heterogeneity across each individual: some people wouldn't mind walking during the night time while others do. Walking and residential parking availability at living area presents the heterogeneity across each individual too, but slightly less significant, as residential parking availability may restrict car ownership and therefore influence the choice of whether to walk to the train station. If a semi-detached house or unit provides enough parking, these types of house may be accepted more easily by people who work. It is surprising that station safety is not a significant factor in the RPM estimation, but time of day is importantly influencing choices on car or bus. This might be explained as people will perceive the station to be non-safe when it is night time.

The ECM enables the car and bus alternatives to be nested in one group and compares the heterogeneities between them. The results of the ECM, see

Table **1**, presented a better fit than the MNL model, with statistically significant tests in likelihood function of -1,380 (started at -1452), and p-value (0.049) to demonstrate a better model than MNL model. ECM has a Pseudo R^2 index of 0.252, which indicates an improved parameters estimate with an overall goodness of fit. The Chi-square related ρ-value report of 0.000, is statistically significant at the 95 per cent confidence interval. The identified influential factors that contribute to a statistically significant overall model fit can be evaluated over by coefficients, t-statistics and p-value.

In the ECM, walking distance from home to the train station, car mode, travel distance from home to the bus station, travel distance to work, weather and waiting time for bus are statistically significant variables with a p-value of smaller than 0.001. While the variables of age, bus travel distance to train station, frequency of train usage, car park availability and train frequency are statistically significant too with a slightly higher p-value between 0.001 and 0.01. While, bus choice, distance from home to train station, gender, income and travel to work time are statistically significant but less so with a p-value under 0.05. Achieving a similar estimation, walking distance to a train station is a statistically significant random parameter. The walk to train station choice is strongly related to train frequency. Applying the special advantage of ECM to estimate the unobserved heteroscedasticity and correlation over ‘car’ and ‘bus’, time of day is statistically significant heterogeneity in making a choice to access the train station by car mode and bus mode in the error component. While, occupation makes a big difference in the choice to use a car or bus mode to access the train station. Again station safety and time of day do not obtain a high number of t-ratio in the estimation. But time of day does effect the choice of car or bus. Occupation is another significant factor, which might be related to Holden night shift workers, who work at either a morning shift starting at 6:20 am or an afternoon shift finishing at 11:20pm.

The cross-elasticity test results are provided in **Error! Not a valid bookmark self-reference.**. In the RPM, when the train frequency changes 1 per cent, the choice of car access mode will reduce 0.2967 per cent, the choice of bus will increase correspondently with 0.2953 per cent, and walk and bike will all increase. When the weather improves one percent, the car mode will drop 0.4345 per cent. For the ECM, when travel to work distance reduces 1 per cent, car mode will drop 0.5291 per cent, bus will increase 0.5175 per cent, bike mode will increase 0.2947 per cent and walk will increase 0.5305 per cent. The car choice would be able to reduce via increasing train frequency, shortening travel to work distance and improving bus stop shelter.

Table 2: Estimated elasticities

Model	RPM		ECM
Changing attribute	Train frequency change in Choice CAR	Weather change in Choice BUS	Travel to work distance in Choice CAR
Choice of CAR	-0.2967	-0.4345	-0.5291
Choice of BUS	0.2953	0.9548	0.5175
Choice of WALK	0.1521	-0.2103	0.2947
Choice of BIKE	0.2115	-0.3782	0.5305

Policy relevance and discussion

The estimation results from both the RPM and ECM show that walking distance to the train station is a very important factor to encourage travelers to use rail transit, which proves that the TOD concept of bringing higher density residential development would promote rail transit. In addition, especially in low density rail corridors, car access to railway station (often mentioned as 'park and ride', 'kiss and ride') are important modes for promoting rail use, which indicates pick up curbs and car park provision is essential. Using free parking shows the highest access mode for train use from respondents' actual usage survey information (revealed preference data). Therefore, free parking still plays a positive role in promoting train use and TOD development in Adelaide. Parking price should be utilized as a levy according to space occupants over time. The statistically significant indicators of bus mode, waiting time for bus, and home distance to bus station (only in ECM) demonstrate that it is essential to have feeder buses servicing the railway station, and the feeder bus time table should be synchronized with the train time table. Providing more buses to feed train stations is vital to improving transit connections and in turn to reducing private car travel to work. This will improve the current situations for suburban work locations that could not be reached by public transit. In a practical world, there are some impediments to policy implementation. Common problems include the availability of funds and public acceptance. Feeder buses to rail (or rapid bus) corridor should be promoted as an efficient tool to enhance the transit network and to connect outer suburbs, especially for the home to work journey.

Train frequency is not a significant factor in the parameter estimation, but it is statistically significant in the heterogeneity of walk mode choice, the higher train frequency will encourage walking more. The cross-elasticity test also shows that if train frequency is higher, people will reduce car access choice but use more walking, cycling and bus. Another interesting finding is related to safety, which has been identified as one of the most important factors in the focus group, however, it is not statistically significant in the parameter estimation. When looking in to heterogeneity tests, time of day impacted on walking distance to access to the railway station. Time of day also affects the choice of car or bus. This implies that in the daytime, at most but not all stations, travellers feel safer and more comfortable to use rail. At night time, preferences are either restricted by station pick up or conditions of whether cars can be parked at a safely accessed spot. Safety at night time around transit stations is a typical handicap for rail patronage, and in recent years, strategic policy initiatives have been implemented to increase station services, such as coffee shops, or providing safety patrols (for example, at Mawson Lakes Interchange).

It is not a surprise that travellers' age, income and gender are statistically significant in station access mode choice behavior. These factors should be utilised to assist in deriving specific transport policy strategies. Age group, for example, can be an important socio-economic category that provides a good indicator, such as for a transport behavior change program. Sometimes, transport policies attempt to solve too many problems at once and lose the power to achieve an effective return. Introducing socio demographic factors in policy making can be a powerful tool to improve implementation efficiency. In another study, Meng et al. (2016) suggested that policy should be aimed at a portion of the population, such as those aged 34 and under who are more willing to use train, to achieve an efficient outcome. While, policies also need to consider the older generation and their mobility which would require a specific study to make recommendations for this age group’s mobility.

Another influential factor for travellers is weather. To cope with the typical weather, for example, in Adelaide, it is very hot in summer and wet in winter, it is important to keep waiting areas dry (or air-conditioned if possible), and trees can be planted around waiting areas providing shade in summer. Paths linking different modes are often overlooked but should be protected from weather conditions where possible. Elasticity tests show that if the weather is good, bus or bicycle access modes would be improved considerably. There are ways to improve the impacts of bad weather, such as, tree canopies to provide shade for cyclists, and more user friendly innovations for people who wait in hot or cold weather need to be explored.

Travel distance to work is a statistically significant factor in the estimations. The elasticity test also shows that if travel distance to work is reduced, people would like to use less car, but use more walking, cycling and bus. This reflects that TOD developments, mixing residential and employment urban development would help to reduce private car use.

Conclusion

This study applied discrete choice models (hypothetical choice data) and observed data (actual data) to identify what are the preference of rail travellers to access train stations and suggested what can be done to improve train usage. The results show that walking distance to railway station, bus mode, waiting time for bus, and car parking availability are all essential factors to be improved in enhancing train transit attraction. Socio-demographic variables of age, income and gender make a difference in access mode choice, and should be applied in targeted strategic policy making. Train frequency and weather are some additional indicators that can be manipulated in promoting train patronage. Safety is an important issue for travelers at night time, in addition an improvement in the perception of safety can make a difference to future transit use.

For TOD development policy, the strong concerns of walking distance from home to the railway station indicated that creating higher density around railway stations with mixed land use would be welcomed by local residents. These findings can serve as evidence based planning indicators to promote sustainable land use and transport infrastructure development. Discrete choice models of Random Parameter model and Error Component model are advanced tools in analyzing transport related choices and behavior. In relation to future transport and land use development studies, a panel model might be useful to observe a sample of the same respondents over multiple time periods (Baltagi 2009; Train 2003), to investigate the development of a TOD over time and to adjust prior parameters in stated preference design.

Improved station access modes will improve the multi-model trip chain. Benefits will not only be limited to increased train usage, but also to contribute to urban planning, infrastructure provision, and even improving the social and economic environments and beyond.

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