LOW CARBON LIVING CRC

Greening Urban and Suburban Travel

Final Report

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

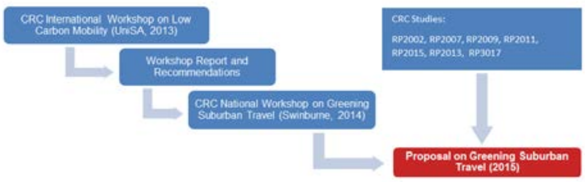
and provided constructive feedback which was considered and addressed by the author(s).

Executive Summary

This document presents the final report for Project RP2021: Greening Urban and Suburban Travel, which was supported by the CRC for Low Carbon Living.

This project was a delivered as result of an extensive collaboration which involved CRC research providers and key end users, stakeholders and partners. The project included a collaborative engagement between researchers and students from Swinburne University of Technology, University of South Australia, University of Melbourne and CSIRO, who worked together with a key industry partner, the Government of South Australia, to deliver the project outcomes.

The project was initiated through extensive stakeholder consultation starting with an international workshop held in Adelaide in October 2013, followed by a national workshop held in Melbourne in November 2014. The project was informed by a number of CRC studies including RP-2002, RP-2007, RP-2009, RP-2011, RP-2015 and RP-2013, as well as RP-3017 (Adelaide Living Lab). In doing so, the project addressed a number of CRC milestones in Program 2 including R2.2.3, R2.3.4, R2.4.5, U2.2.2, U2.3.2, and U2.4.5



The overarching objective of this research was to reduce greenhouse gas emissions from passenger car usage in urban and suburban areas. Transport activity is one of the major sources of emissions related to the combustion of fossil fuels in Australia. In 2010, transport contributed 83.2 Mt CO2 or 15.3% of Australia's net emissions with road transport accounting for 71.5 Mt CO2 or 86% of national transport emissions. Passenger car usage in urban areas was the largest transport source, contributing 8.5% of Australia's net emissions and accounting for around 39.7 Mt CO2.

This research was fundamentally an investigation into new methods to provide urban and suburban public transport and active travel options that offer efficient, affordable and flexible trips while reducing reliance on private vehicle use. There were several components to this project which enabled a national team to investigate interesting questions that are of immediate practical importance. These include development of a number of tools for estimating the carbon emissions benefits from proposed intervention measures. Specifically, the research comprised three complementary work packages which included investigations of travel demand; investigations of travel supply and transport planning studies focusing on pathways to increasing customer usage of alternative modes of transport; and development and application of a framework for supporting effective investment decisions that increase the uptake of the high priority low carbon transport interventions.

This document is divided into three complementary reports that address the different aspects of the project described above.

The first report presents results from investigations of travel demand and determinants of shifts in travel behaviour from private vehicles to public transport and active transport in the context of travel surveys and analysis for six suburbs in Adelaide.

The second report includes modelling of transport mode choices in the context of a case study for the Monash National Employment and Innovation Cluster (MNEIC) in Melbourne.

The third report is a summary of travel supply analysis also in the context of the MNEIC case study.

This document should be read in conjunction with a number of interim deliverables that looked into identifying best practices and emerging trends, in addition to other deliverables that looked into travel demand analysis.

One of the key contributions of this work is the identification of a framework for supporting effective investment decisions that increase the uptake of low carbon transport interventions. This has been achieved with a combination of the tools and the research streams as detailed in an accompanying final report that detailed the tools that have been developed in this research.

Another key contribution of the work is the establishment of a research agenda that can guide future effort in this area. This agenda will provide a unique opportunity to enhance support for Australian research and innovation by building on existing transport research and intellectual capital.

This research not only represented a major investment in the future of low carbon mobility and sustainable transport in Australia, it also provided a distinctive training ground for students, staff and industry practitioners who worked together on problems and identified solutions of immediate impact.

LOW CARBON LIVING CRC

RP 2021 Greening Suburban Travel

Investigations of travel demand and determinants of shifts in travel behaviour from private vehicles to public transport and active transport

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Mr.Andrew Bishop – Revenue SA
Mr.Pete McKenna –DPTI
Mr.Michael Cushway- DPTI

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Executive Summary

The overarching aim of this study is to reduce greenhouse gas emissions derived from passenger car usage in suburban areas. Currently 86% of Australians live in suburbs, concentrating car use and the associated carbon emissions in these areas. Apart from outlining current trends on suburban travel, the key aim of this project is to report the analysis of the stated preferences and household surveys, carried out to determine current mode choices and transport priorities of suburban residents and to explore other sustainable travel options available to them. This report also includes the analysis of the demand for public travel, using smartcard data.

This study surveyed residents in six suburbs across the greater Adelaide region to determine travel preferences. The survey was conducted across three inner suburbs within five kilometres of the city (Bowden, Brooklyn Park and Tusmore), and three more at least ten kilometres from the city centre (Aberfoyle Park, Campbelltown and Parafield Gardens). Participants were asked about their habits and preferences regarding various travel modes: privately-owned cars, shared vehicles including public transport, cars used by share schemes or for carpooling, and the active modes of walking and cycling. Questions for the distant suburbs focused more on motorised transport. This survey consisted of two types of question: current travel choices, and future choices under hypothetical conditions. From the hypothetical choices, this study found that total travel time is the most important attribute when users are choosing a transport mode, with cost coming a close second. When respondents were asked about options for accessing public transport services, they reported a strong preference towards driving a car to an interchange rather than walking to a nearby stop; many demanded an expansion of existing parking areas. This demand is at odds with the current policy direction of exploiting the increased value of land around public transport stops. A significant number of respondents, i.e. 40% of the surveyed population of the three more distant suburbs, were willing to use public transport at interchanges if they were well connected by shuttle services, and even willing to pay an additional $2.50 to get a shuttle to high-quality service. This puts the onus on public transport providers to incorporate both cars and push bikes as fast modes of access to their networks, at no extra charge to users.

An accurate estimation of public transport origin and destination (OD) will be a significant help to public agencies involved in route rationalisation and lead to higher patronage of public transport. This research presents an overview of ridership patterns in Adelaide, using one-month MetroCard data. Analysis of on-time performance of bus services shows less variability in lateness on weekends, although a lower percentage of prepaid tickets are used at this time.

This report is divided into five chapters. The first chapter introduces the topic and outlines the current trend relating to suburban travel. The second and third chapters review and synthesise earlier published work relating to travel preferences and discusses details of the surveys, including the stated preference and household surveys, conducted in Adelaide for this study. The third chapter explains the analysis of the stated preference and household surveys, and the fourth deals with smartcard data analysis. This report concludes with a chapter of discussion and recommendations. Analysis for this report was done with the help of specialised software including Geographic Information Systems (GIS) Ngene and Nlogit. Appendices one to three present the survey questionnaires and scripts written for this study.

Introduction

Australia's fastest growing emissions source is transport (Climate Council 2016). As the vast majority of Australians live in suburbs, it is important to understand their choices of transport modes and develop strategies influencing them to use those that are sustainable. A suburban setting is on the threshold of population density sufficient to justify the provision of public services and public transport is an energy-efficient method of moving large groups of people.

The current public transport network in Adelaide was conceived in the 19th century and refined throughout the early 20th. In the later 20th century, after World War II, the advent of the motor car caused the network to fall into decline. At first glance, cars certainly seem more efficient than public transport. First, by eliminating the walking time needed to access public transport and the continual need to stop to serve other passengers, cars provide a quicker end to end travel. Second, because they are not shared, cars provide privacy and are ready to go whenever demanded. Finally, drivers have a sense of control over their travel, a powerful psychological benefit (Taylor 2017). As cars allowed the population to become accustomed to these attributes, public transport suffered; it could not compete. A strong dislike for walking spawned the first and last mile problem. Recently cars have been re-imaged as space inefficient, creating congestion and pollution when moving en mass: they are no longer considered the ideal future transport. The problem now is how to improve public transport and make it relevant again.

Walking is a transport mode that is available to the majority of the public, and a vast network of footpaths is available to facilitate the movement of pedestrians. However, because of the slow speed of walking (Roislien et al. 2009), it is unsuitable as an end-to-end mode for the majority of journeys although it remains an important secondary mode as it links a person's origin or destination to the primary transport mode. Walking is the most common method used to access and alight from public transport vehicles (Sleep, Somenahalli & Mosallanejad 2013). For journeys where there is no car parking available immediately outside the destination, walking is required.

Bicycles provide the flexibility of a car, taking riders from where they are to where they want to be, and are much quicker than walking an average 18 kilometres per hour is easily achievable on a bike. However, there are significant downsides as well: even on flat terrain, with good tyres and adjustable gear ratios, maintaining speed requires much energy and causes the rider to sweat. Australia very hot weather (and its sometimes-wet weather), is not conducive to arriving into work bandbox-fresh. Any canopy installed to combat these issues would make the bicycle too heavy for use (other cities have investigated installing canopies over whole corridors) (Finger 2017). Finally, there are safety concerns: cyclists use the same roads and interact with much larger vehicles with their sometimes inconsiderate drivers. This is not to say the bicycle is a thing of the past: as people have begun to feel safer cycling, there has been a resurgence of interest in this transport mode.

Since the end of World War II, the use of public transport in Australian cities has declined as the automobile industry has grown. Car ownership has increased rapidly since this time, and the car has evolved beyond being a means of transportation into a subject of interest and a cherished lifestyle among many people in the world (Bureau of Infrastructure Transport and Regional Economics 2013). In Australia, the car population is growing faster than the human population, and more than 90% of Australians live in a household with access to a car.

Traffic congestion is a major problem for urban Australia. Figure 1 shows that congestion levels are increasing by 2 to 4% annually. This congestion forces private vehicle users to spend more time on roads. Bus patronage is generally weak around the country, to some extent because of the growing levels of congestion. Efforts to shift at least a few percentage points of car trip users to public transport will help reverse this problem. However, while public transport patronage remains low it is difficult to justify spending money on improvements to service, and government agencies have tended to respond by reducing supply, with the effect of increasing the general shift to driving as public transport becomes less and less convenient or, indeed, available. Recent efforts have been made to stop this cycle as the negative social and environmental ramifications of cars and their contribution to air pollution have become increasingly evident. Moves are now being undertaken to make people less automobile-dependent and more fit and active by undertaking, for instance, regular walking.

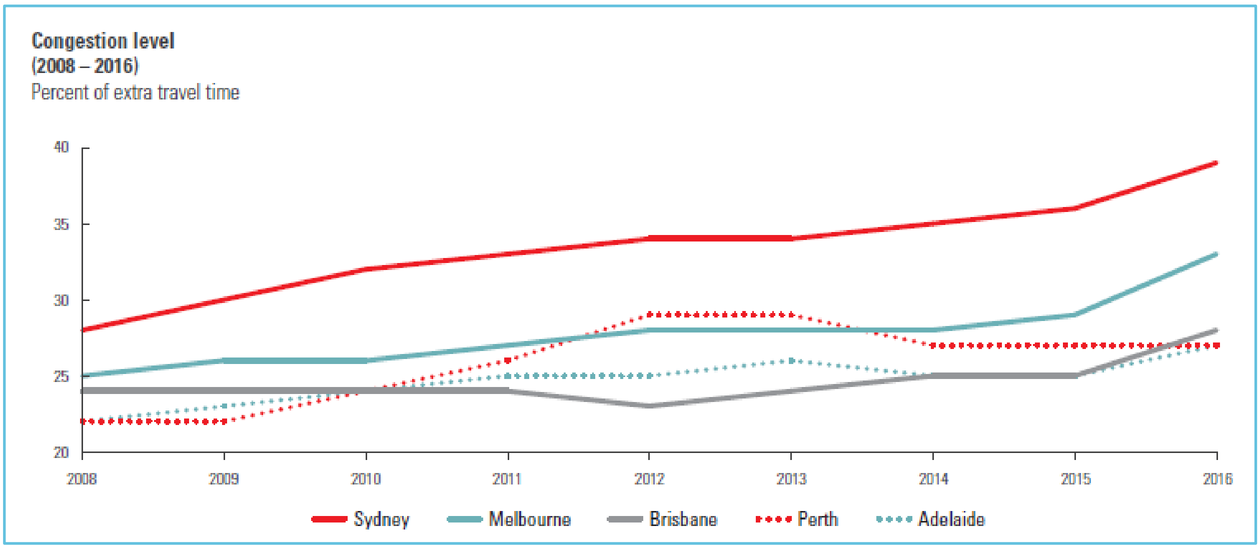


Figure 1: Congestion Levels in Key Australian Metropolitan Cities. TTF & LEK Consulting, 2018

The majority of Australians believe that we should be doing more to reduce our environmental impact. However, 72.4% of all kilometres driven in the 12 months to October 2014 were in privately owned passenger vehicles (ABS 2015), with an average fuel efficiency of 10.7 L/100km. With an average bus fuel efficiency of 28.8L/100 km, there is a net fuel saving even if only three people ride the bus instead of driving. Rail vehicles (trains and trams) are faster than buses and even more efficient, due to the low friction of steel wheels on steel rails. Transport for NSW (2017) reported that greenhouse gas emissions per passenger kilometre for rail transport is as much as five times less than those from cars. Walking and cycling are even better for the environment as they require a much narrower paved surface and require no fuel.

Why do only about 12% of people choose to commute by public transport or active transport (walking or cycling)? The answer is that our beliefs do not necessarily determine our actions (Heberlein 2012). If informing people is not the answer, how can people's behaviour be influenced? Several methods have been tried, ranging from large network changes like those in Portland in the United States, with a high-frequency grid for bus routes (Walker, 2012), to small temporary changes like giving habitual drivers in Kyoto (Japan) a free one-month bus pass to try and instil a new habit (Fujii & Kitamura 2003). In both cases, some success was noted but only to a small degree. Can we reduce people's car dependence by making driving more difficult or expensive? In isolation this is not possible, given the political or economic repercussions it might cause, but combining it with improved public transport may offer a significant gain in public transport patronage (Wegener 1996). For instance, in Stockholm, Sweden, a congestion charge was introduced along with public transport service improvements (Heberlein 2012). While there was an initial reluctance to change, this was overcome because the improved public transport services could replicate the same trips previously undertaken in cars.

The cities of different countries are vastly different, with different physical forms and collective attitudes. These attitudes have to be directed before change can take place. In Australia, passengers find that needing to transfer to complete a journey is a significant deterrent, especially for commuters. In Adelaide very few trips on public transport (29%) require a transfer, but they still have only 10% of the share of work trips. In London, by comparison, 44% of all underground journeys require a transfer (Guo & Wilson 2011). Often this difference is considered to be a matter of density: London has a much higher density then Adelaide (and other Australian cities). Yet while density may well have an impact, it does not seem to be the governing factor in other cities across the world that share similar sizes and densities as Melbourne but have significantly higher public transport shares; the reason for this is considered to be a matter of the quality of the services. For instance, In Vancouver the strategy prioritised public transport and other service improvements early on, recognising that changes in urban density and form are slow processes.

Earlier research (Heberlein 2012) suggests that complementary changes have a much greater effect than individual ones. Various methods have been suggested to improve public transport ridership and reduce CO_2 emissions from a mobile population. As might be expected, these work best when they are applied together. It is not enough to simply provide a better public transport service; nor will charging drivers more lead to systematic change.

Unlike Stockholm, Adelaide has a very low suburban density, and many people consider this to account for the low utilisation of public transport within the suburban region (Mannix 2013). To date, attempts to increase usage of public transport have not been successful. In this case, public transport options were added only after the housing developments were complete: it is much harder to change a resident's behaviour once a habit has been formed. Conversely, as noted by the Melbourne Public Transport Users Association, Vancouver is providing public transport services before housing developments actually begin (PTUA 2016). This allows new residents to factor in this option before moving in.

While it may be tempting to build a way out of transportation problems, there is some evidence that this is not the way forward (Mees 2014). In Victoria, the recent Regional Rail Link project and the upcoming Melbourne Metro are huge construction projects in dollar terms but focusing on transport to the central business district (CBD) will not provide systematic behaviour changes. Instead, better use needs to be made of existing infrastructure. Large-scale solutions such as increasing urban density or constructing new transport corridors are also slow to implement. Improving access to existing facilities and upgrading these facilities might be a more effective way to achieve sustainability goals in the shortest timeframe. For the new services that are required, Bus Rapid Transit is well balanced for a city the size of those in Australia. This mode has medium to high capacity, reasonable route flexibility, and good speed. Where it has been implemented already, in Brisbane and Adelaide, the results have been very encouraging. In Adelaide it was noted that there was a very firm boundary outside which bus use was low. The O-Bahn busway services expanded this boundary to the north-east, from its otherwise generally circular form. The O-Bahn Busway is a guided busway that is part of the bus rapid transit system servicing the north-eastern suburbs of Adelaide, South Australia.

Much research has been published on public transport accessibility (Malekzadeh 2015; McIntosh, Trubka & Newman 2014) although only a very few papers focus on transit as a provider of accessibility rather than as a service to be accessed (Yigitcanlar et al. 2007). Of those papers that address network patterns, the grid network layout (Chien and Schonfeld 1997; Walker 2012) is a popular choice as it provides the highest access to all neighbouring nodes with a minimum number of transfers. Even so, this layout still requires transfers to get passengers from a point of origin to a destination. There is a great deal of research into passenger preference, and the case study by Guo and Wilson (2011) suggests that a better understanding of transfer behaviour and improvements to the transfer experience could significantly benefit public transport systems. This research suggests that some sections of the travelling public are more deterred by transfers than others, particularly those commuting to work or school. Transfer waiting time is such a deterrent that it was modelled at twice the time cost of travel time in Brisbane (Yigitcanlar et al. 2007). In addition, potential users can have conflicting aims, such as the desire to get anywhere (accessibility) and the desire to do so in one vehicle (convenience). A grid network may help resolve accessibility issues regarding minimum transfers, but how many transfers is too many? One study carried out in the Brisbane area found that passengers had a strong high reluctance to choose trips requiring even one transfer (Malekzadeh 2015). A study in Brisbane (Buys & Miller 2011) found that a combination of physical and psychological factors was required to describe convenience, although the study found it impossible to quantify how much impact individual factors had on people's choices.

Perception of public transport options is of great importance, but what drives it? Transit maps play a large part in selling a network to new users; it is known that these maps are distorted for simplicity. A drawback of this effect was discovered only recently: passengers in London were observed taking sub-optimal trips because they looked optimal on the schematic map (Guo 2011). In all Australian cities attempts have been made to develop high-quality schematic maps, but currently available schematic maps are designed by modes instead of route. This is predominantly because the suburban area is so vast that fitting it on a schematic is a significant challenge. Other studies have indicated that reliability and punctuality have a significant impact (Adelaide Metro, 2012; Nankervis 2016).

Often a small deviation from perfection in an urban public transport service attracts an angry response, suggesting that day-to-day variability in travel time has a great impact on people's perception of the service. In this case, all transit modes were operating above 91% punctuality. It seems people put great faith in printed material in general with the transit maps and timetables held up as public transport gospel.

In contrast, providing travel time information to drivers is a much newer concept, with Google Maps giving estimates and a system called 'Addinsight' providing Adelaide drivers with information on their phones and via roadside signs at strategic locations. AddInsight is a traffic intelligence system centered on a network of low-cost receivers that can provide network-wide performance indicators in real time. This information is fairly variable, so drivers are not as likely to have a strong attachment to an exactly estimated time of arrival.

In the context of a car or public transport mode choice, some overseas research from the Netherlands (Van Excel & Rietveld 2010) suggests that if a public transit trip has a total door-to-door travel time of 1.5 times that of driving, it begins to seem competitive to potential passengers. Is this applicable in the Australian context? What happens if you get below a unity ratio, i.e., public transport is actually quicker? In Perth the results have been astounding: the southern rail corridor with trains travelling at 130km/h has vastly exceeded all expectations (McIntosh, Newman & Glazebrook 2013).

Currently, Australia has the highest cost of congestion in the world (Arup 2016). Given the suburban nature of our cities, this is a difficult but hugely important issue to address. The literature often fails to address improvements to the suburban form, instead implying that the suburbs are the enemy and need to become denser. While walking and cycling play a huge role in reducing congestion in the world's most successful cities (for example, Paris has a 48% walking mode share (Arup 2016), which contributes to its appeal both as a tourist destination and as a place to live), in the Australian suburban context, walking and cycling alone are not the structural fixes they are in denser cities. The low density in Australia results in longer trip distances, and it is unreasonable to assume that these trips can be undertaken by the slower modes of walking and cycling. These modes are currently being used as complementary; however, as suggested by Krygsman, Dijst and Arentze (2004), other, faster modes could be used for the access and egress legs of a public transport journey, enlarging the catchment areas around transport nodes. In this way, it seems existing nodes and their surrounding suburban developments could be geared towards achieving goals of sustainability and social inclusion as Transit Oriented Developments. Given the Australian context, it is important to address this issue. Our suburbs are not going to disappear: far from it: even as younger generations express less desire to be car-dependent (Arup 2016), they are moving into fringe suburbs.

More research into the decision-making process is needed among the Adelaide population. Following the work of David Hensher (Hensher & Button 2007) it was decided that a stated choice experiment is an appropriate tool to address this issue of mod choice.

One of the important objectives of this research is to address the question of how to encourage people from Australian suburbs to use sustainable, low carbon transport modes of mass transit, cycling and walking. Since the transport modes people habitually take may not be the best for the environment, it is important to understand their travel choices and estimate the utility functions for alternative sustainable modes. This research employs Revealed Preference (RP) and Stated Preference (SP) surveys to understand this issue for the case study of Adelaide. It also analyses public transport smart card data to investigate the issue of reliability, a key component that will influence their usage. Finally, this analysis suggests measures to encourage people to favour public and active transport modes.

Stated Preference and Revealed Preference Surveys

Ninety-six people from the three selected inner suburbs of Adelaide, and 169 from the three outer suburbs, took part in this survey. They were able to volunteer information such as specific origins and destinations and information relating to their travel. Where information was provided, it was often specific to a mode of travel such as driving or public transport. The information gathered from the surveys helped the team to understand current behaviours and made it possible to create a model that could predict future mode shifts under various conditions. This model took the 'logit' form, and point elasticities were determined to indicate the public's sensitivity to various aspects of transport such as cost or time.

Information was also obtained about those currently using Adelaide's public transport network, in the form of boarding records. This data was used to check the insights gained from the surveys and reduce any bias. Some respondents may overestimate their desire to shift to another mode of transport, and the boarding dataset does not contain such biases, so we can see which services are most attractive and quantify this against the service attributes in the survey.

Data collection for this project included undertaking two surveys in the designated suburbs of Adelaide. The surveys were split into three sections, with two sections collecting RP information, relating to respondents' current behaviour and opinions, and the other collecting SP information, which is concerned with people's choices under controlled hypothetical conditions. The two RP sections differed in their focus and geographic reach, with one, a household survey, asking questions about the travel of persons in households in the suburbs within five kilometres of Adelaide CBD where active transport modes such as cycling and walking are available; the other concerned people travelling from the middle to outer suburbs, with the focus on public transport options. The respondents in the outer suburbs also received the SP survey about choices of transport mode in different scenarios. The questions involved providing the respondent with a hypothetical task, in this case a journey, and various options (modes) by which it might be achieved. These options had different attributes such as speed and comfort, and changes in these attributes could be investigated across a series of tasks. While RP questions are important in revealing decisions made under real conditions, SP questions serve to generate utility functions, indicating the expected response of the public to future scenarios.

The three inner suburbs received a simple RP survey, with many of the same questions as in the major survey, and a few more targeting the use of active transport modes such as walking and cycling. Tusmore, Bowden and Brooklyn Park were selected because they represented low use of active transport, i.e. walking and cycling in going to work, as documented in the 2011 census. The three outer suburbs were selected after examination of the GIS maps of the 2011 census data revealed they had low rates of catching public transport to work. 'Ngene' software was used to develop various SP scenario options, while 'Nlogit' software was employed to derive utility functions and elasticities.

Ethics approval

Once the survey questionnaire was finalised, it was sent for ethics approval. The Ethics Committee of the University of South Australia made a few recommendations, the most important being that we provide potential participants with enough information that they could make an informed decision about participating. An information sheet about the project was developed to achieve this objective. The SP survey was carried out in the form of interviews, so a flyer was designed by which respondents could signal that they were opting out of the study. Although the methodology changed from interviews to postal surveys during the survey process, there was no update required for this as we had already received approval to undertake a postal survey.

As part of this procedure reimbursement was considered. It was decided that 24 gift cards from Coles would be distributed to participants once the survey was completed, 12 for each survey. However, the longer SP survey proved onerous, so a further 24 cards were obtained to compensate respondents for their efforts. This extra incentive was most effective in Parafield Gardens, leading to a noticeable increase in responses.

Sample size

Using the random sampling equation from *Survey Methods for Transport Planning* (Richardson, Meyburg & Ampt 1995), achieving a 95% confidence interval across the three suburbs required a minimum 100 responses. For the postal RP survey of the inner suburbs this target was achieved, but five months of surveying returned a total sample of 160 for the longer survey of the outer suburbs. This was at least 50 replies in each suburb, reaching a minimum confidence interval of 92% in all three cases.

For the postal survey of the inner suburbs, cluster sampling was employed: small groups of addresses were selected to receive surveys in the mail. Each cluster included the same number of addresses, and given the grid layout of all three suburbs, these clusters were located around intersections for simplicity. These clusters were likely to be similar, given the locational characteristics, so it was assumed that each cluster would represent one sample for error calculation; the number of these clusters was such that errors were less than 11%. For the newly developed inner suburbs with smaller populations, every household was mailed; the mailing list was provided by Renewal SA. These surveys were much shorter than the SP variant and allowed up to six responses from each household on each form. This resulted in a much larger response rate than what was required, and with these plus the household samples we exceeded the minimum values for a representative sample with 90% certainty.

Stated preference survey attributes

The four choices given in the SP survey were divided into two categories: a public transport category encompassing bus and rail options (including O-Bahn services) and a drive category including options for driving alone or in a carpool with people known to the participants. Commuting by bicycle was omitted from the options in the RP component of the survey because the average commute in Australia (on average 15.6 kilometres) is above a distance considered cyclable (Bureau of Infrastructure Transport and Regional Economics 2015). As well, the attributes for a bicycle journey differ significantly from those of motorised modes, with greater importance placed on safety and fitness levels. Comparing cycling to modes with a monetary cost is also quite difficult.

With labelled choice options selected, three attributes for investigation were defined: monetary, time, and flexibility costs. The dollar costs used as attributes are only visible to the decision-maker. They are particularly difficult to estimate because they can be separate from the act of driving: some people might include fuel, maintenance, depreciation, registration and insurance in their calculations, but costs like insurance and registration are not clearly tied to the act of driving. Even fuel costs are problematic: when people fill up at the service station, they cover the cost of all the driving done in the period since the last fuel purchase, without thinking about how much their commute cost is compared with other trips, for example, for a social outing. Our scenarios asked about respondents' choice if all modes were available: i.e. they had access to a car.

Cost variables

Four attribute levels for cost were included:, extra low, low, medium and high. For public transport options this was easy enough, with different fare structures available; in some cases one dollar was added to account for a driving component, to the station or interchange. The fare products were as follows: the extra-low value of $4 represented an adult concession fare; for the low option the 28-day pass was assumed to be used, and its cost divided by two lots of 20 working days with a free access mode such as walking or cycling; the medium option assumed that standard Metrocard fares applied; and the high option assumed that day tickets (paper) were purchased.

Car-based trips were more difficult to distinguish as the associated costs are much less visible. Costs associated with owning a vehicle, insurance and registration, for example, were excluded from the questionnaire since the focus of this study is a reduction in total kilometres driven, not car ownership. Maintenance costs were also excluded as earlier research shows that the impact of this is small per kilometre and is often discounted by members of the public (Gardner & Abraham 2007) leaving fuel and parking costs. The easiest cost to deal with is parking, and the daily parking costs at commercial carparks in the Adelaide CBD were collected. Low, medium and high values were found, and a free ($0) value was added to this range to account for free parking on the street or provided by the workplace. Although the most obvious driving expense is fuel, getting realistic values for this cost is quite difficult.

A number of assumptions were made to calculate these values. First, a trip length needed to be assumed, and so 20 kilometres was chosen. This is the distance to the Adelaide CBD from the centre of Aberfoyle Park or the northern part of Parafield Gardens. These trips both take about 30 minutes, so this was taken as the base travel time. The Australian Bureau of Statistics) estimates the average efficiency for light vehicles in Australia is 11.5 litres per 100 kilometres (L/100 km). Given this average a lower value was chosen, based on measurements from a 2.4L engine driven gently between Adelaide and Mawson Lakes and using 7.7L/100 km. A higher value of 15.4L/100 kilometres was used to represent a larger car. The team had no access to a larger car and assumed a standard distribution of fuel efficiencies around the average. Finally, the volume of fuel used in a 20-kilometre journey was calculated. With this done the challenge of fuel price was broached, with huge variability over very short periods (the current price cycle produces a 27% change over each month from $1.10 to $1.40 a litre). An average monthly price for March 2017 was found on the RAA website, and $as used to generate costs. The pricing remained consistent during the design and conduct of the survey, and there was no reason to predict any significant change in the imminent future.

Four parking cost and three fuel cost options permit a huge number of potential combinations. For this reason, fuel and parking costs were provided separately and then summarised for respondents to consider. The cost of fuel was separated from the task of driving and aggregated across all trips between visits to the service station. This separation may have resulted in reducing the impact of this variable on decisions in real situations; it is far from the pay per trip model of public transport.

Travel times

Car travel is the simplest case, providing a baseline with limited variability. Public transport travel time ratios were generated based on trials using the Google Maps trip planning software. Trips above two and below 0.9 travel time ratios were excluded, the upper bound time ratio of 2 was chosen because such travel time was uncommon and deemed to be so undesirable. The lower bound of 0.9 was chosen as few of the trips trialled on the software generated a value this low, and as the public perception of public transport in AdelaideWhere carpooling is concerned, the extra travel time is due to making stops and detours to pick up or drop off passengers. These ratios were multiplied by 30 and presented to the participants as travel time. Thirty minutes was chosen as it is neither insignificantly short or overly long and is considered a reasonable time to travel from the outer suburbs to the CBD under the free-flowing conditions experienced in Adelaide; The travel time values were fed into the Ngene software so that choice combinations could be selected, as while representing the same information, they provided a higher resolution; that is to say, there is numerically a larger separation between 27 and 60 minutes than between 0.9 and 2. Ngene uses these numbers to evaluate the efficiency of the design without knowing what the units are or what they mean to the respondent. This is particularly critical for coded values where the numbers do not represent a continuous variable that people would normally assign to a number. An example of this is the facility variable below, with discrete values of 0, 1, 2, 3 or 4.

Access/egress time breakdowns

For time breakdowns, access and egress were expressed in five-minute intervals.This resolution provides enough difference to be noticeable while maintaining the properties of a small change. The maximum access/egress intervals were capped at 15 minutes, the assumed upper limit of attractive walking to or from public transport. This assumption applied to captive public transport users rather than choice riders. After some trials, however, it was decided to reduce access walk times to increments of four minutes because 15 minutes was having an abnormally large effect on choice.

Where rail modes (including the O-Bahn) were considered, the access/egress distance was driven rather than walked in all but one option.

Attributes specific to public transport modes

Like the access and egress times, frequencies are given in five-minute intervals as this is a common interval. The values of 5, 10 and 15 cover the full range of current peak hour headways, generally 15 or 7.5 minutes, when investigating whether potential passengers would require significant improvement before this mode was accepted. These are the timetabled values and assume perfect reliability. Due to the already complex nature of the survey, no attempt was made to account for the effect of perceived reliability.

To reduce the number of attribute levels, the interchange facilities were accumulated into four ranks based on the current situation. They are coded from 0 to 4 (for café). The cumulative nature means that a higher ranked facility offers all the services available in a lower ranked facility, plus additional services. For instance, a café provides morning coffee and evening refreshments in addition to the security, transport information, and toilets offered by the transit interchange.

Although travel time reliability is an important consideration when people plan a trip (Coulombel and de Palma 2012), this attribute was not considered in this survey. It was primarily ruled out because no measure could be devised that was sufficiently simple to comprehend and convey enough information to the respondent. A statistical approach was trialled to estimate the probability of 'on time' arrival, but proved too taxing to evaluate. Another approach is to provide a range of travel times for each scenario, but this would make it difficult to evaluate what the respondent is assessing. So many attributes were already being provided that it was felt that no more should be added. Table 1 lists all the SP attributes and their levels.

Table 1 Stated Preference Attributes and Their Levels

Attribute	Public Transport	Drive	Carpool/share
Cost (fuel/fare) + $1 for Park and Ride options	Extra Low: $4 Low: $6 Medium: $8 High: $11	$4.60 $6.90 $9.20	(½ drive) $2.30 $3.50 $4.60
Cost of parking	—	Free $8* $16 $24	Free $5 $10 $15
Travel time	15 minutes (train only) 20 minutes (train only) 25 minutes (train only) 30 minutes (train only) 35 minutes 40 minutes (bus only) 45 minutes (Bus Only)	25 minutes 30 minutes 35 minutes	30 mins 35 mins 40 mins
Peak hour frequency	High: timetabled every 5 mins Medium :every 10 mins Low: Every 15 mins	-	-
Distance to bus stop (basic facilities)	4 minutes' walk 8 minutes' walk 12 minutes' walk	-	-
Distance to interchange/station	Walk, as above, 5 minutes' drive 10 minutes' drive	-	-
Egress distance (distance to work)	Low; 5 minutes' walk Medium: 10 minutes' walk High: 15 minutes' walk	Low: No walk needed Medium: 5 minutes' walk High: 10 minutes' walk	Same as a drive option
Stop/interchange facilities (all operation hours)	0: Bus stop No Shelter 1: Shelter (basic interchange) 2: Toilet 3: Passenger office: public transport information 4: Café: food/drink		

Postal RP surveys

The RP survey of the inner suburbs was conducted by post as physical addresses were available, making it possible to target the selected suburbs. Furthermore, postal delivery meant that potential participants had the survey in hand rather than having to make contact or request an online form. Of the 1171 surveys sent out, 98 were returned: very close to the sample target of 100. The sample rate of 8.37 is reasonable for this method of delivery.

While designed to be similar, there were differences in the information recorded in each survey. The RP postal survey of the inner suburbs was designed to capture responses from several members of a household. While this approach was also planned for the interview surveys, it took too long and exceeded the patience of most respondents, so a single representative was sought from each household. The question concerning the most regular destination differed significantly, but like the survey of the inner suburbs it had two spaces for destinations: one for work/study and one for other destinations if applicable. In the interview survey only the most common destination was recorded. Participants in the postal survey were expected to answer only the most relevant question, but many people chose to answer both destination related question. These differences mean that the number of destinations per household does not correlate across surveys and great care must be taken when analysing this information. Figure 2 below shows one typical sampling cluster surveyed in the outer suburb of Tusmore.

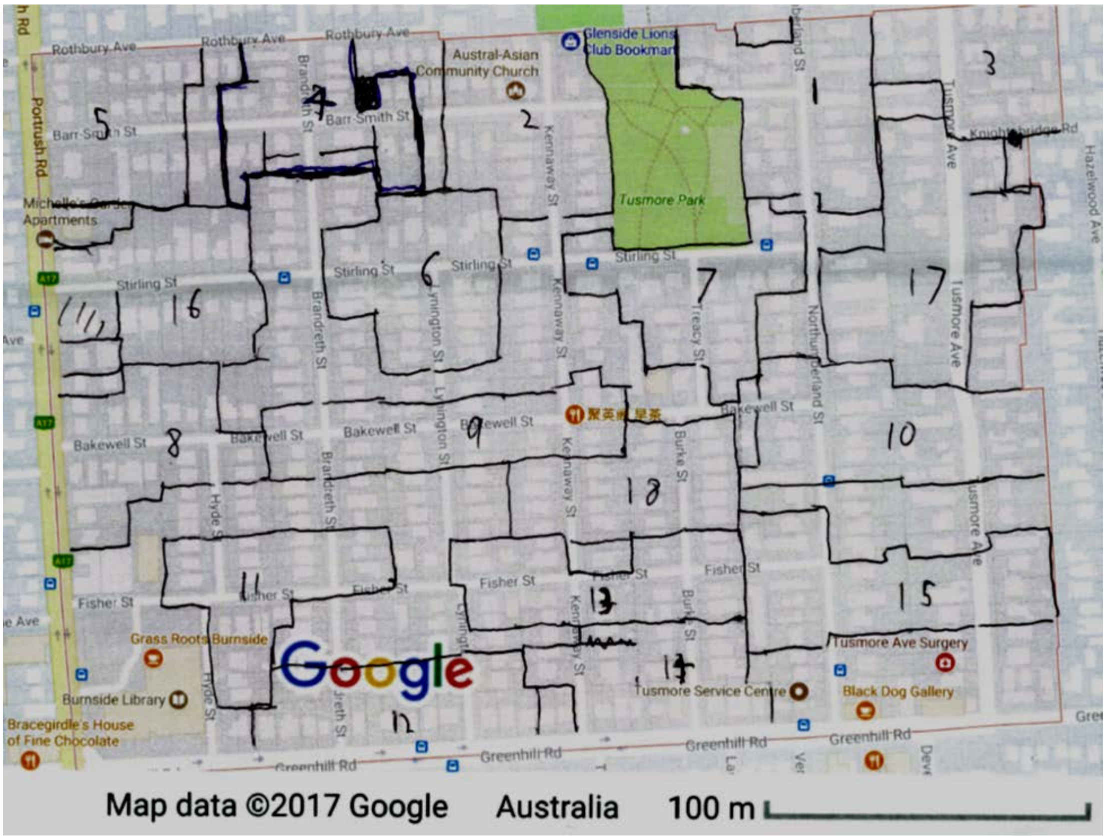


Figure 2 Inner Suburb (Tusmore) Sampling Cluster Map

Combined RP & SP surveys

It became evident that different suburbs respond differently to different methods. For example, the people of Parafield Gardens had the lowest response to surveys delivered in person but the highest response to the postal survey with the increased incentive, suggesting that they value privacy and are financially driven. Aberfoyle Park had a much lower response rate to the postal survey with increased incentive format. Campbelltown response rates to both survey formats were similar and it possibly the case that people here are more neutral.

To give potential respondents warning of the arrival of surveyors and an opportunity to opt out, a flyer was distributed before the door-knocking. This meant every survey location had to be visited twice, and it also reduced the sample size because residents with 'no junk mail' signs on their letterboxes could not be contacted. The time between delivering the flyer and the survey was critical, but difficult to optimise. Delivering flyers 24 hours ahead of the survey was tried first, but proved too short as people did not check their mail every day. The survey process was much slower along a road, and on a number of occasions flyers were dropped off far ahead of where the surveyors finished their day. It was decided not to try these houses later as the flyers said that contact would be made within 24 hours.

This process was not a total waste of time as a few interviews were arranged with people who used the contact details on the flyers. Learning from this, it was decided to deliver a whole month's flyers in a single session. This had its own problems, and a number of phone calls indicating dissatisfaction with the opt-out method were received. People were instructed to put the flyer by their letterbox if they were not interested, and the calls related to people not wanting to have the flyer out all month. It also became apparent that people were not aware they would have to fix the flyer in place. The surveyors assumed this to be common sense, but on a number of occasions people answered the door and stated they put the flyer outside, but it was nowhere to be seen.

Face-to-face interview surveys

Initially a route was traced through Parafield Gardens with the plan of moving along this path day by day dropping off flyers, then returning to knock on doors and do the surveying. One street (roughly 300m) was chosen to test this methodology and it was found to work nicely—although only one response was received. This method soon proved to be overly ambitious: it took a few hours to go 2.8 km through the suburb and distribute the flyers. The intent was to follow this path for one week, and the flyers provided the date range of the expected surveys. Due to clashes between the availability of surveyors and when people were at home, only a kilometre was covered; the rest of this route was abandoned. It was decided after this to broaden the date range and include contact details on flyers. This met with some success, with three of the best responses coming from surveys arranged in this way.

As the survey of the outer suburbs was more time-consuming (taking about 30 mins to fill), it was decided to approach participants in person and interview them. It was decided a flyer would be dropped off letting people know of our intent to survey and allow them to opt out with a simple sign by the letterbox. This flyer was delivered to people's letterboxes but not to those where a 'no junk mail' sign or something similar. The follow-up door knocking further excluded houses, where a 'do not knock' sign was evident.

The interview method obtained the best quality of response as we were on hand to answer any questions. The majority of people did not answer their doors, and only a small fraction of those who did had time for a survey. If somebody opened their door but did not have time to answer, we left the survey with them to return at the end of our survey session and return to collect them. There was a good success with this, as about a third of these responses were collected.

Figure 3 below shows one typical sampling cluster surveyed in one of the outer suburbs (Aberfoyle Park) where red represents selected streets where face-to-face interviews were conducted.

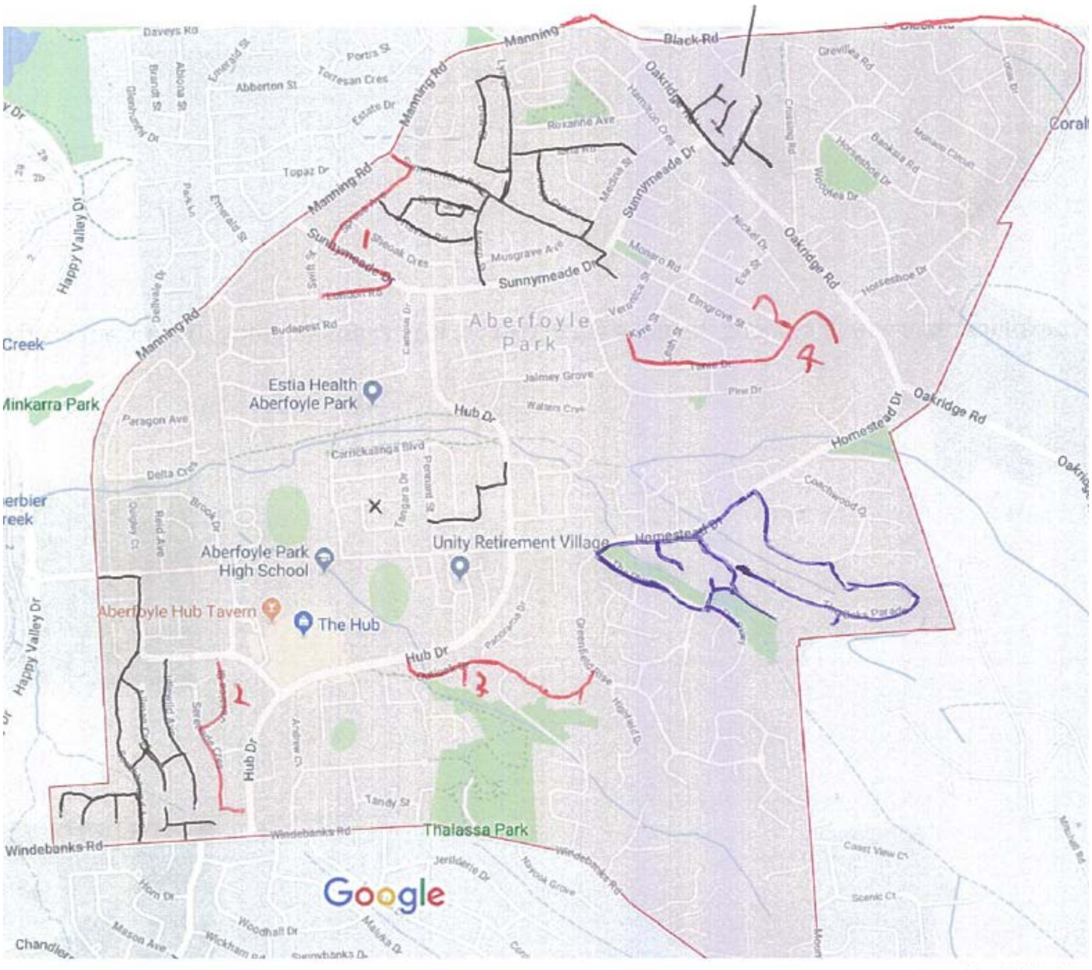


Figure 3: Outer Suburb (Aberfoyle) Sampling Cluster Map

Postal interview surveys

As staffing became difficult and potential respondents were absent during a holiday break, it was decided to deliver survey forms to letterboxes; this had the bonus of covering houses that either had a ‘do not knock’ sign or where no one was home when we called. Inserting surveys into envelopes took about a minute each; our best time was 300 surveys packaged in one day. In one week 900 survey forms were printed, processed and hand delivered across the three study suburbs.

Processing surveys involve taking printed A4 sheets and folding them before adding a reply envelope and putting the whole packet in an envelope for delivery. The flexibility of deciding and implementing flexible delivery times was critical to success. Surveys were delivered to letterboxes and only those with ‘No Junk Mail’ or ‘Authorised Australia post mail only’ were excluded as the survey was not advertising material or a circular.

In the end, we received 40 posted surveys primarily due to vacant blocks being selected from a map. Once this postal method was decided upon we saved $2000 in postage and ensured all the surveys reached an inhabited property.

Validation

Journey to work data from the 2016 census was investigated for all six suburbs. While great differences were observed there were also similarities, which was to be expected as the respondents were reporting their most common journey rather than their commute.

The income estimates we developed from the survey results are reasonably consistent with those recorded by the Australian Bureau of Statistics (2016). Our estimate for Aberfoyle Park was 3.14% greater than the median value produced by the ABS, and our value for Brooklyn Park was 3.2% lower. We found Bowden to be 7.9% higher than the ABS median; this could be because this survey did not include the single-storey housing in the suburb’s north. The estimates for Parafield Gardens and Tusmore were both significantly below the ABS median, by 12.3% and 13%. Finally, Campbelltown reported having incomes 30% higher than the ABS value. These estimates are only rough guides for a number of reasons: the respondents were given the opportunity to opt out of the survey as a whole or out of this question individually; and these are self-reported values, so there may be some bias.

Analysis of Stated Preference and Household Surveys

A number of analytical methods were utilised in this study. Many of our resources went into the creation of an econometric model that placed values on the importance of different attributes when people were choosing a mode of travel. However, the question of where people were travelling was best answered by a GIS map analysis. Likewise, the question of preferred public transport services was best answered with a statistical analysis of Metrocard data. The questions about mode choice related to people's perceptions, and here the text responses provided an opportunity to capture information that was difficult to investigate numerically.

Gender differences

It was noted that across both the inner and outer suburb surveys, women were more likely to respond than men, at a ratio of 60:40. There were significant differences in priorities between genders. Men were more interested in combining cycling with a public transport journey, with 40% of those surveyed either cycling already or considering cycling if more facilities were provided. This compared to only 26% of the women. Women were more conscious of safety, reporting that they felt unsafe walking to and from public transport stops, particularly at night. Given this, it is surprising to see that the majority of public transport users are female. Walking at night is more acceptable to people, particularly women, when there were many people around, particularly of people known to them or in an active street presence of pedestrians, café staff or traders.

Econometric modelling

Utility functions were developed to help explain people's mode choice behaviours numerically, and these are presented below. This study reveals that speed or a reduction in travel time is by far the most important factor in people's decision-making, with a coefficient an order of magnitude larger than the next most important factor, parking costs**.** This output also validates our assumption that fuel costs and fares are considered equivalents by people. This may explain the small value of the coefficients here, as all costs included either fuel or fare costs of a similar magnitude. The services available at a public transport stop had very little impact on the decision.

U (Train) = -0.06581*Fare – 0.06581*FuelCost - 6.6706*TravelTime – 0.00852*Headway

– 0.03373*DriveAccess - 0.05129*Egress + 0.00704*Facilities

+ 0.00048*HHIncome+0.08220*Gender

U (Bus) = -0.06581*Fare - 6.6706*TravelTime – 0.00852*Headway –0.05877*WalkAccess

- 0.05129*Egress + 0.00704*Facilities + 0.00048*HHIncome + 0.08220*Gender

U (Drive) = -0.06912*FuelCost – 0.12477*CostParking 5.35096*TravelTime

-0.05129*Egress + 0.01097*Age

U(CarPool) = -0.06912*FuelCost – 0.12477*CostParking - 6.6706*TravelTime - 0.05129*Egress – 0.10956*PoolPersons + 0.01097*Age

Elasticities

Elasticities measure the rate of change in a decision being made when there has been a change in a particular attribute. They are estimated by comparing the responses across the attribute range presented. As a simple example, if fuel cost $1 per litre many more people would drive, but if it rose to $2 per litre, then the reality lies somewhere in the middle A linear relationship can be generated, resulting in a slope or rate of change with price, and this is called elasticity. This elasticity gives us an idea of how much people are motivated by each attribute individually. In order to answer questions (for example, does reducing the price or increasing service quality result in a higher mode shift towards public transport?), a standard representation of these elasticities is needed. Elasticities are calculated for the standard representation of 'change of 1%'. Because the effect of a change may not be linear, these values are only applicable at the current point on the curve and using them to estimate the decision change resulting from a large attribute change, one outside the attribute range used in the model is not advised.

From this survey, it emerged that a 1% increase in travel time for train services (18 seconds) would cause a 0.2% shift towards driving among the participants of the SP survey, shown in Table 2. The opposite is also true: a 1% reduction in travel time will see 0.2% of people shift from cars to the train. Expanding this to the whole population, it means that a 23% increase in train speed will encourage 5% of the population in surrounding suburbs not to use their cars, as shown in Table 3. This is quite achievable when, as was done with the Seaford line in Adelaide, the Gawler railway sees an increase to a maximum speed of 110 kilometres per hour when electrified. Likewise, the fare was indicated as people's most important attribute, and the recent 20% reduction in fares with the 28-day pass should see patronage increase by 6%, according to the elasticities generated from the model. Similarly, Tables 4 and 5 show the results of elasticities relating to parking and fuel costs respectively. More details relating to Ngene and Nlogit coding in RP and SP studies and the survey questionnaire are listed in Appendices 1 to 4.

Table 2 Results of a 1% Increase in Travel Time

Time	Bus	Train	Drive	Pool
Bus	-.4951	.1712	.1612	.1378
Train	.2151	-.4773	.2062	.2117
Pool	.0731	.0893	.0783	-.3641

Table 3 Results of a 1% Increase in Fare

Fare	Bus	Train	Drive	Pool
Bus	.-3130	.1144	.0900	.0944
Train	.1438	-.3094	.1199	.1517

Table 4 Results of a 1% Increase in Parking Costs

Park	Bus	Train	Drive	Pool
Drive	.2564	.2163	-.5815	.1491
Pool	.0952	.0952	.0323	-.3357

Table 5 Results of a 1% Increase in Fuel Costs

Fuel	Bus	Train	Drive	Pool
Train	.0155	-.0279	.0119	.0087
Drive	.1195	.1411	-.3376	.0998
Pool	.0749	.0942	.0577	-.3433

Influence of frequency on patronage

When the influence of service was investigated, it was found that a frequency increase translated into patronage growth. The rates of public transport patronage growth were approximately twice the frequency increase; in other words, stations with twice the frequency saw use quadruple. Similarly, bus patronage to the CBD is high for many reasons. including better service frequency. It is observed that more than 60% boardings are for trips involving the CBD both on weekdays and weekends. Moreover, apart from high frequency, the directness of a route influences people's perceptions of public transport. For example, the most utilised bus routes are the M44 and the G10, both cross-town services with a high frequency; headways of five and ten minutes are common in peak periods, which is well above the 15 minutes required to be classified as a Go Zone. A Go Zone is not a route but a zone that offers convenient services approximately every 15 minutes between 7.30am and 6.30pm Monday to Friday

Role of public transport interchanges on patronage

Across the whole network, the boardings at interchanges are as high as 18.1% during weekends and 17.3% on weekdays,. These results show a significant desire to access the public transport network at locations where a wide variety of services and high service frequency are available. Over 30% of boardings take place at interchanges. Another one-third of boardings take place in the CBD, and about a third at suburban roadside stops which comprise over three-quarters of the potential boarding locations. This also highlights the demand for cross-suburban travel, as a third of passengers are not travelling to or from the Adelaide CBD. Another important observation is that as much as 59% of interchange boarding (that is, 18.1% of total boardings) occurs at the three O-Bahn interchanges, with 7.72% of total boardings at Paradise, making it the most attractive location t access point outside the CBD.

These findings indicate that providing better facilities is unlikely to be a driving factor in a mode shift towards public transport, as respondents value flexibility more. This flexibility is significantly higher at interchanges where services intersect and there is an increased possibility of trip chaining or using an alternative route if one is missed. In addition, increased speed and frequency play a part, with the three interchanges located along the O-Bahn track recording the highest passenger counts of any bus interchange. This is comparable to Adelaide's rail corridors, offering fast, direct services at a frequency unmatched across the Adelaide public transport network. As with bus services, the majority of rail boardings occur at interchange locations.

Destination hotspots

From the survey data collected across all six sample suburbs, destination hotspots are the Adelaide CBD (as expected), the airport, and Norwood, highlighted in red in Figure 4 below. Some areas were less popular destinations than expected (cold spots, in shades of blue). Four of these regions stood out in terms of size: Port Adelaide, Smithfield, the region between Modbury and Main North Road, and in the south the area between Noarlunga and Old Reynella. While Campbelltown and Parafield Gardens generated destinations in all directions, residents of Aberfoyle Park showed a distinct tendency to go north rather than east or south. If this was limited to public transport travel, this could make sense.

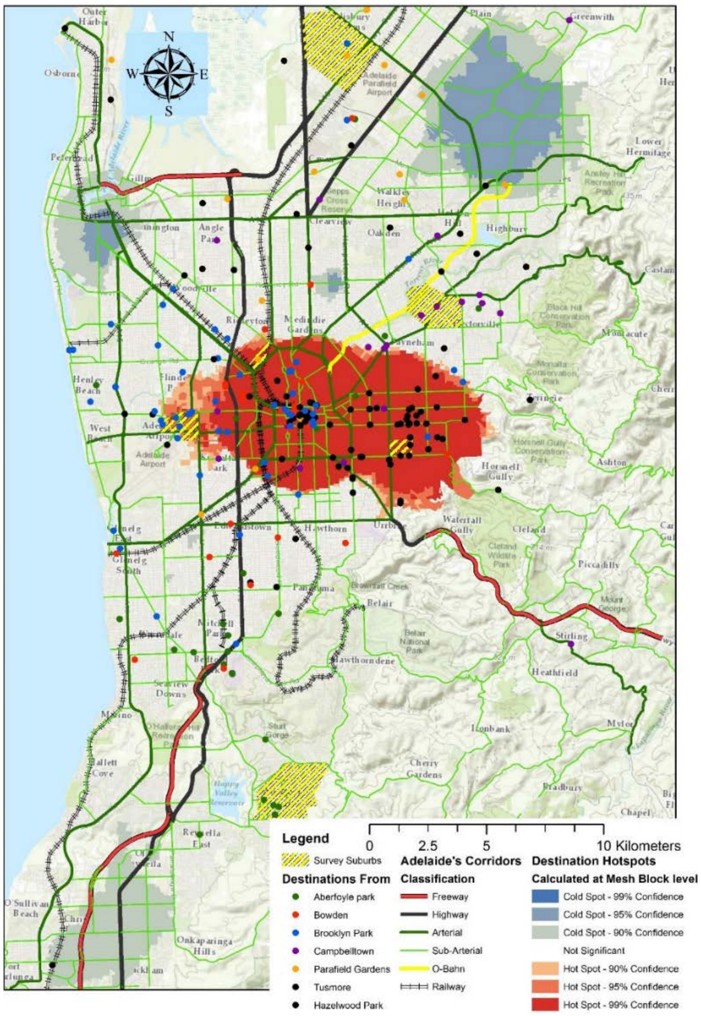


Figure 4 Destination hotspots

First and last mile connectivity issues

This survey found that people were walking 15 to 30 minutes to public transport services, particularly rail. However, these journeys were often made out of necessity rather than a choice, by those captive to public transport. People are keen to use high-frequency public transport (PT) and are willing to pay an additional amount ($2.5) to reach those nearby PT interchanges (Figure 5).

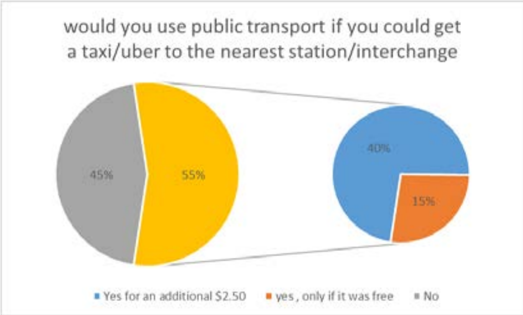


Figure 5 People who are willing to pay an additional amount to reach nearest high-frequency PT interchange

Weather and travel choice

Our respondents said that they avoided both cycling and walking in hot or rainy weather. As these are the most common access and egress methods, the result is that they avoid public transport, preferring to drive. The weather has less impact on those who park-and-ride, so increasing these facilities may keep public transport ridership high through periods of uncomfortable weather. This solution, however, has disadvantages to public health as it promotes sedentary behaviour, and traditional active modes should still be encouraged.

Car sharing

Some companies allow cars to be shared among a population, offering short-term rentals of cars parked on the side of the road. Goget is such a company, with cars currently based in Adelaide City and Bowden. Bowden residents' surveys contained questions relating to their knowledge and use of such car-sharing initiatives. Interestingly, while they showed high knowledge about Goget, due to local pushes by Renewal SA, their usage was still low.Renewal SA, provides an integrated approach to urban development on behalf of the government of South Australia. Use of Uber was also investigated, and no correlation was found between those using Goget and those using Uber, although the target populations are the same. Perhaps this reflects how people see the services: both aim to reduce private vehicle ownership, but Uber offers a cheaper a variant of the existing taxi service (a cheaper taxi) while Goget represents something different.

Electric vehicles

Shifting to electrical power is often seen as a way to move towards sustainability; and so it can be as long as the source is sustainable and there is enough power to go around. The question is storage: how can we store the electricity required to drive? Today's large-scale vehicles do not; trains, trams and trolleybuses use a transmission system to use electricity generated live, which curtails flexibility as they must remain connected to their supply cables, usually overhead. Not only is this a concern for route flexibility and infrastructure provision: it creates other issues, including visual pollution and energy security. During a state-wide blackout in 2016 s well as other instances of power failure (The Advertiser 2016), the Seaford trains ground to a halt very quickly while the diesel units on other lines continued to provide a service. .

Autonomous vehicles

Autonomous vehicles are the talk of the industry right now. It is generally considered that they will use renewable energy technologies and not contribute to pollution as their hydrocarbon ancestors do. However, there is some dispute over who will own such vehicles, and what impact they will have on the network. In one extreme scenario, the nation's vehicles will be owned by a transport agency (not necessarily the government) and shared by the population, maximising carpooling for parallel trips and reducing the number of vehicles on the road. At the other extreme, if they are owned by individuals as today's cars are, the increased ease of travel will encourage many more trips and increase traffic congestion dramatically. The reality is likely to be somewhere between these extremes.

Smartcard Data Analysis

As public transport agencies increasingly adopt automatic data collection systems, a significant amount of boarding data becomes available, providing an excellent opportunity for transit planners to access spatial-temporal data (Rahbar, Hickman & Tavassoli 2017; Tao 2018) which can be used for a better understanding of human mobility and the performance of a transit system (Mahrsi et al. 2017). Smart card data can be used to examine a whole network regularly, and to make practical estimates of OD patterns, and is a great asset in understanding issues of public transport reliability. Knowledge of demand for public transport that is reliable will facilitate the design of appropriate routes and increase efficiency, which will in turn enhance patronage. The data used in this research was provided by the Department of Planning Transport and Infrastructure (DPTI) in Adelaide for the month of May 2017. A methodology was developed using SQL software and based on the trip chain model to create an OD matrix for Adelaide's bus users, and from it to estimate demand for the system. Adelaide was chosen for this study because it is unique in having commuters scan their smart card on boarding but not on alighting. This allows the algorithm to be generic and therefore applicable elsewhere.

Data structure

The primary function of the smart card is to collect a fare, but it can also be used to find passengers' travel patterns. Usually, smart card data does not directly provide the information required for planners (Kurauchi & Schmöcker 2016) as the flat fare policy, and some zonal fare policies, require commuters to tap once after boarding, recording only a single transaction. In some cities an exit reader is available as well if the fare is based on distance or zones. In such a system, each trip generates records for both boarding and for alighting (Kurauchi & Schmöcker 2016). In Adelaide, where a flat fare policy operates, commuters validate their cards when they board but not when they alight. Three modes of transport are available: bus, train and tram. The information for each smart card transaction contains card identification, time, date, transport mode used, fare type, stop code, stop label, route code and validation type (see Table 6). When passengers swipe their card and pay an initial transaction, the fare is valid for two hours, and passengers can use any public transport within this time at a single cost.

Table 6. Individual MetroCard information

Media code	Fare type	Transport mode	Date & time	Stop code	Latitude	Longitude	Route code	Direction
807*CB**	SV	4	2017-05-01 09:49:35	8089	-34.979759	138.525912	Tram	1
94E*FB**	TICKETS	1	2017-05-01 10:39:15	3351	-34.924343	138.598468	251	1
11C*89**	28DAY	1	2017-05-05 10:46:32	3285	-34.920343	138.607313	271	1
707*27**	OTHER	1	2017-05-01 11:04:05	2072	-34.870071	138.638452	H22	1
584*97**	SV	5	2017-05-08 11:06:36	1852	-34.860916	138.650472	GWC	1

Note: Transport mode: 1 = Bus, 3 = Station, 4 = Tram, 5 = Train

There are some deviations from the one-swipe rule: railway stations in Adelaide operate under a closed system and swiping is required for both boarding and alighting; and various systemic and user issues mean that transfers between the train and other modes cannot be estimated directly from the MetroCard. In addition, there is a free tram zone in the city where passengers do not need to swipe their cards; this means that the tram boarding point is not available. Given these limitations, this study focuses on bus users.

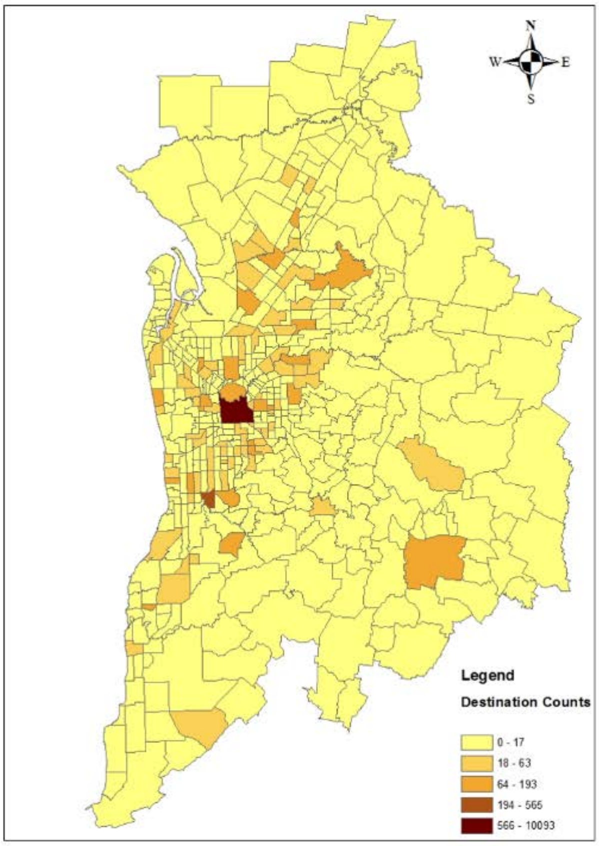
Estimation of origin and destination matrices

Knowledge of transit demand plays a decisive role in plans to improve the performance of a public transport system. A common method for estimating the destination is the trip chain model. As mentioned previously, each smart card can provide the boarding location and time of each bus trip but not the alighting location, so the trip chain model assumes the alighting stop is located within acceptable walking distance of the next stop. Some assumptions considered in this algorithm are:

- The initial boarding location of a trip leg is the 'origin'.
- A passenger's alighting point is assumed to be within walking distance of the next boarding stop.
- Passengers return to the place where they first boarded that day, or to some other nearby station.
- Commuters take the first available service after arriving at a boarding place.
- Each smart card is used by a single commuter and not by multiple passengers.
- Commuters who use the public transport system do not use any other mode of transport that day.

Origin and destination analysis

One of the critical considerations when planning transit services is estimating the demand for each route, to determine the frequency and capacity of the vehicles (Tamblay, Muñoz & Ortúzar 2018). An OD matrix provides critical information for transit planners by estimating the number of journeys between different zones, information which can be used in planning, design and management. After analysing the data based on the trip chain model, bus users' origins and destination counts during the morning peak were derived for each suburb (Figure 6). Most trips originated from the suburbs of Paradise, Modbury, Adelaide CBD, and Klemzig; Adelaide, Bedford and Modbury were the destinations of most journeys during the day. Suburbs with the highest origins and destinations were shortlisted and analysed, and the data validated using other sources from the Department of Transport and a limited survey.



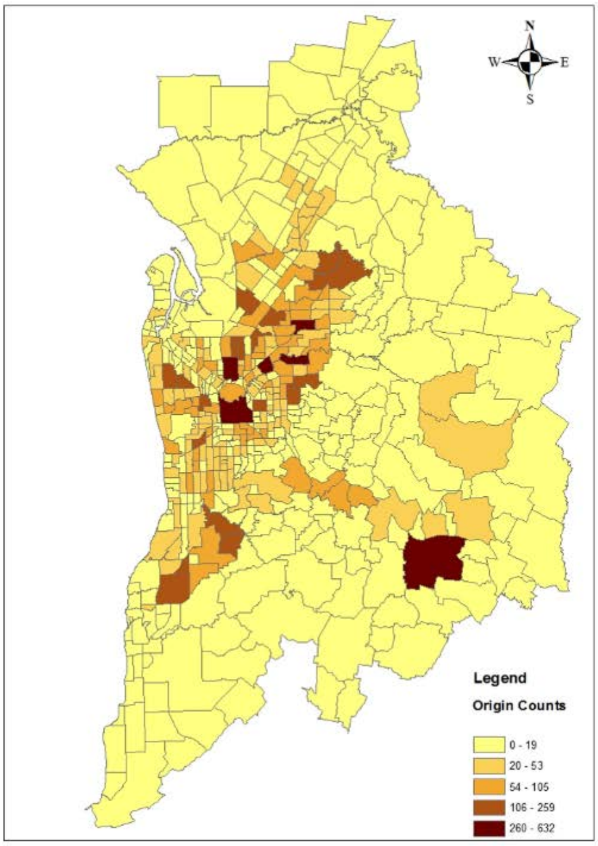


Figure 6 Origin and Destination Counts for Each Suburb (Bus Users)

The OD analysis showed that bus movements were radial, and that most trips during the morning peak ended in the CBD. These movements were further explored to rationalise the existing routes. The information from an OD analysis was used to identify new bus routes that would optimise existing routes and reduce congestion within the CBD of Adelaide. Examples of suggested new routes are given below:

Modbury–Bedford Park: the OD analysis showed high demand from Modbury to Flinders University during the morning peak, but just one route (G40) runs between the suburbs, passing through the CBD. The results indicate that providing direct routes from Modbury interchange to Bedford Park will reduce overall travel time to passengers and also reduce congestion in the Adelaide CBD.

Paradise–Bedford Park: there are two bus routes between these two suburbs and both pass through the CBD. It is worth exploring the option of a direct route from Paradise to Flinders University that avoids congested city links.

Modbury–North Adelaide: bus routes between these two suburbs run through the CBD. As before, introducing direct routes between these two suburbs will reduce congestion in the city centre.

The OD analysis helped us understand the mode transfers and the role played by the key interchanges. The results indicate that all the transfer points are the same for both weekdays and weekends, although destinations may change. Most transfers on weekdays occurred in Adelaide CBD, Paradise, and Modbury; and as expected, most passengers travelled to

Adelaide during the morning peak to start a daily activity (see Figure 7). Modbury and Paradise are identified as the busiest interchanges, and it is evident that most commuters use these locations for transfer.

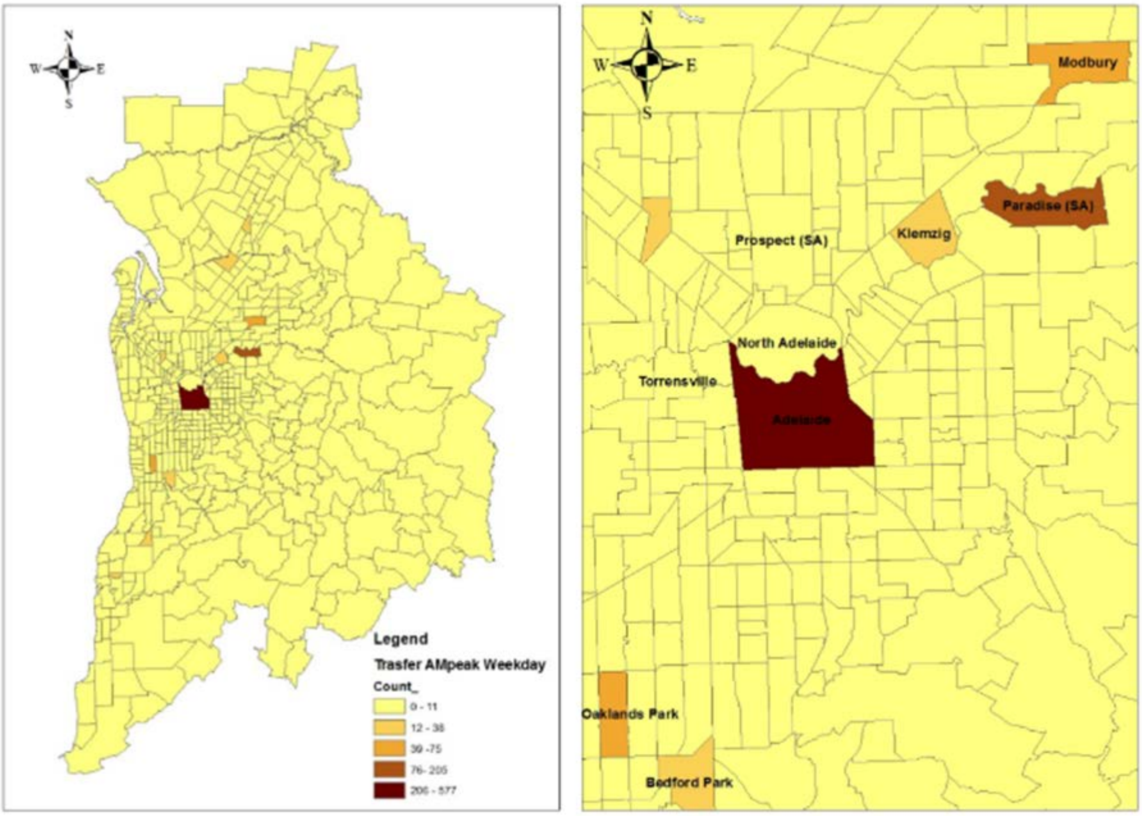


Figure 7 Suburbs with a High Number of Transfers (Weekday Morning Peak)

As presented in Figure 8 the comparison of weekday and weekends illustrates that bus-to-bus and train-to-train transfers are most popular. On the weekend most, commuters transferred from bus to bus (51%), but on weekdays this decreased to 39.76%, which means that the number of passengers who transfer from train to train on weekdays is higher than on the weekend. This can be related to the reliability of trains in comparison with buses, given traffic congestion and travel time, so people prefer to use the more reliable system on weekdays to access their destination. Travel patterns using bus-to-train transfers and vice versa is the same on weekdays and weekends.

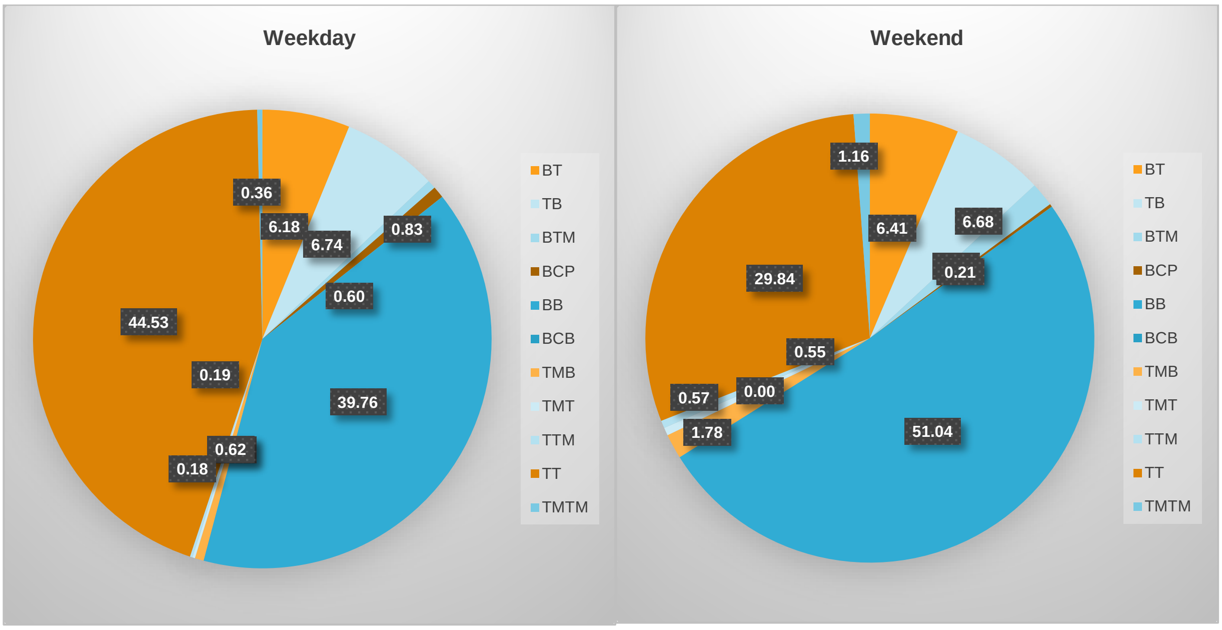


Figure 8 Transfer Type during Weekends and Weekdays.

(B = bus, T = train, TM = tram, CP = car park)

On-time performance of bus services using smartcard data

Throughout the world the reliability of public transport systems is constantly under review. In recent years the widespread prevalence of privately-owned motor vehicles and the quickening pace of life has increased the importance of having a reliable public transport service that delivers passengers on time. This presents a problem, as buses share road space with a growing number of other vehicles. In Adelaide, the capital city of South Australia, the public transport system has been plagued by complaints of unreliable services (Kelton 2012a). The South Australian community is encouraged by the government to use public transport, especially for regular trips such as the daily commute; but many commuters avoid this, reducing the number of commuters using public transport (Kelton 2012b). South Australia's initial boardings for the metropolitan public transport rose each year incrementally between 2000 and 2009, reaching 52.4 million in the 2009–2010 financial year (DPTI, 2011). However, DPTI's annual report for 2010–2011 states that in 2010–2011, initial boardings reduced by 2.2% to 51.25 million. One reason for this reduction is the perceived unreliability of services (Nankervis 2016). Often buses do not meet advertised service times, and many services run a quarter or even half an hour late—or, in some cases, do not arrive at all (Kelton 2012a). South Australia's public transport system is operating well below its potential. According to the Australian Bureau of Statistics (2009), 14.4% of adults across Australia were using public transport for their trip to work or study in 2006, while in Adelaide this figure was less than 10%. The use of public transport between 1996 and 2006 increased by only 18% in Adelaide, dwarfed by increases of 35% in Melbourne and 22% in Brisbane (Australian Bureau of Statistics 2009). According to the Adelaide Metro website (2012), the quality of South Australian public transport needs minor improvement. DPTI monitors the performance of bus contractors to make sure that the quality of service (on-time running and reliability) meets community needs and demands. DPTI considers service 'on-time' and 'reliable' if the vehicle departs no more than

59 seconds before and no more than 4 minutes 59 seconds after the time published in the timetable (Adelaide Metro 2012). Not all stops appear on these timetables; and at these locations estimated times are provided to the travelling public. Even with this six minutes' flexibility, a large proportion of services fail to meet targets; and this lack of reliability is a significant concern. In the past, several attempts have been made to improve the reliability of bus services in Adelaide, including fining contractors when they fail to meet targets (Bray & Wallis 2008); continually changing and reviewing timetables to suit changing road conditions; fitting buses with global positioning devices; and auditing buses to determine which routes require attention. Automated vehicle location systems help public transport agencies everywhere to improve performance, but there is a difference between performance at vehicle level and what passengers experience, often at the bus stop level (Chen et al. 2009), so it is important to collect and interpret data with this in mind. This study seeks to investigate travel time reliability as seen by passengers, using automatically collected data.

Assessing bus arrival time reliability

Using boarding data to assess travel time has the advantage that these records directly relate to passenger experiences. In Adelaide, boarding data is recorded at stops, as is timetable data, eliminating the need to process and compare the datasets geographically. We separated bus services from other route services offered by Adelaide Metro for analysis primarily because they form the bulk of the network and are most affected by variable travel times. In the Adelaide network, the bus driver is also the ticket salesperson, and must wait until no further passengers need to buy a ticket before driving on. In comparison, the rail services offer onboard vending machines that can collect fares while a train is in transit. Time spent selling bus tickets is generally taken as dwell time, and this shaped our approach: that the last recorded passenger boarding also indicated bus departure time. An expected, the similarity was observed when our estimations of departure time and boarding data were compared to those obtained from automatic vehicle location records.

Data processing

Each bus's true departure time was estimated from the last validation at a particular stop. This was deemed valid for assessing lateness as there is only one boarding door at the front of the bus and the driver's presence helps enforce fare payment. For example, the records in Table 7 below are those showing the progress of bus 1125 along route 503. Those records highlighted in the darkest grey will be retained for further processing. The raw data shown in Table 7 has three distinct sections of information: identifying information specific to each record in the form of an ID and a timestamp; geographical information identifying the boarding location; and service information relating to the vehicle's operation.

Table 7 Initial Boarding Data Structure

1	VALIDATION_ID	VALIDATION Time	STOP_CODE	STOP_LABEL	STOP_LATITUDE	STOP_LONGITUDE	ROUTE_CODE	TRIP_DIRECTION	Vehicle_NUMBER
196028	1609919983	8:26:36	6931	Zone A Klemzig Interchange	-34.886524	138.639269	C1	2	1125
196029	1609919985	8:26:50	6931	Zone A Klemzig Interchange	-34.886524	138.639269	C1	2	1125
196030	1609920004	9:13:02	1217	Zone A Tea Tree Plaza Intercha	-34.831325	138.694308	503	2	1125
196031	1609920006	9:13:05	1217	Zone A Tea Tree Plaza Intercha	-34.831325	138.694308	503	2	1125
196032	1609920027	9:29:05	1656	34D Valiant Rd	-34.85004	138.67158	503	2	1125
196033	1609920029	9:29:08	1656	34D Valiant Rd	-34.85004	138.67158	503	2	1125
196034	1609920031	9:29:10	1656	34D Valiant Rd	-34.85004	138.67158	503	2	1125
196035	1609920034	9:30:01	1706	34C Valiant Rd	-34.853742	138.671835	503	2	1125
196036	1609920039	9:31:46	1762	34 Lyons Rd	-34.857462	138.667326	503	2	1125
196037	1609920041	9:31:48	1762	34 Lyons Rd	-34.857462	138.667326	503	2	1125
196038	1609920047	9:34:09	1869	29B Sudholz Rd	-34.861157	138.661002	503	2	1125
196039	1610698084	15:33:03	7735	School Urrbrae College Cross R	-34.964703	138.625472	990	1	1125
196040	1610698086	15:33:05	7735	School Urrbrae College Cross R	-34.964703	138.625472	990	1	1125

Analysis of bus arrival time reliability

The data was first aggregated by route, and while there was some inconsistency in average lateness across the three days individually, there is a clear trend towards consistency across days. On a scatter plot all the routes and their average likenesses were plotted for each day separately. Each route was treated equally spaced one unit apart along the X-axis. Regardless of the order of the routes presented the trend lines for the two days are in high agreement, showing little to no variance (Figure 9). Statistically, the routes on Wednesday and Thursday have an almost standard distribution of lateness with mean and median values within 20 seconds. Their average lateness was within 21 seconds, although the variance as measured by standard deviation was almost 40 seconds higher on Thursday. As might be expected bus services showed less variability on Saturday, with average lateness of 55 seconds and a standard deviation of fewer than two minutes (Table 8). Figure 10 depicts this difference between route lateness distributions on a weekday vs a weekend. Because there were no routes in every time category, a moving average has been used to smooth the distribution curve.

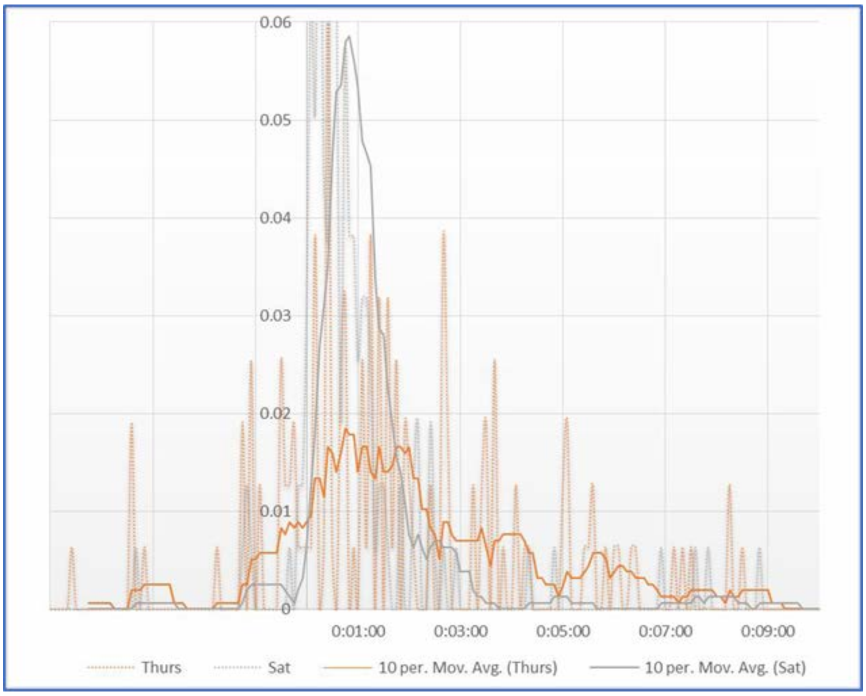


Figure 9 Comparison of Weekday and Weekend Route Lateness Frequency Distribution.

Table 8 Descriptive Statistics of Route Groupings

	Wed (Time: hh:mm:ss)	Thurs (Time: hh:mm:ss)	Sat (Time: hh:mm:ss)
Average	0:01:40	0:01:22	0:00:55
St dev	0:02:27	0:03:05	0:01:53
Median	0:01:21	0:01:10	0:00:30

The average observed lateness was calculated as well as the percentage of boarding locations where the service exceeded the five-minute tolerance for lateness. Route 747 stood out as being, on average, 7.5 to 9.25 minutes late across both days. Buses at 17% of boarding locations were reported as late by the Adelaide metro i.e. standard of arrival 5 minutes or more after the published time. Route 747 is a feeder service linking the Seaford and Noarlunga interchanges in Adelaide's far south, in a clockwise loop. Interestingly, the 745 route which follows the same streets but in an anticlockwise direction showed much more variability with average lateness, approaching 12 minutes on Wednesday but only 3.5 minutes on Thursday. Perhaps this is due to a disproportionate number of unsignalled right turns required across traffic for the 745 services.

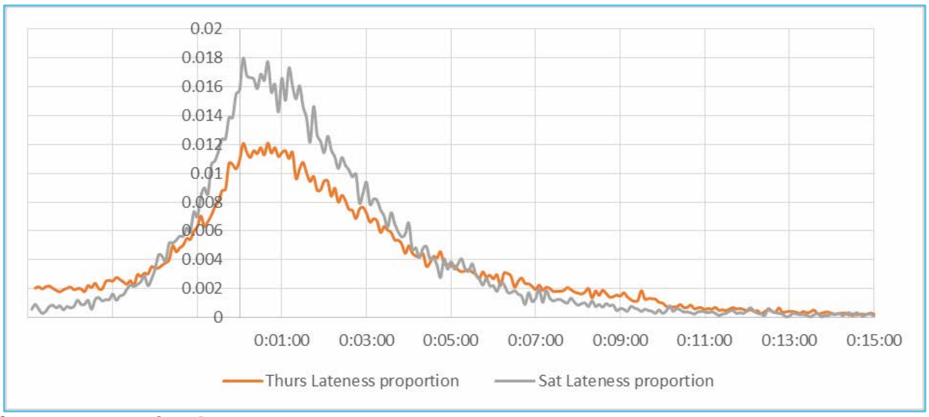


Figure 10 The Distribution of Lateness at Boarding Stops

Table 9 Statistics for Passenger Observation Data

	THURSDAY	SATURDAY
AVERAGE HR:MIN:SEC	0:00:36	0:02:13
MEDIAN HR:MIN:SEC	0:01:03	0:01:12
ST DEV HR:MIN:SEC	0:13:03	0:08:26
% ONTIME	56.332%	75.451%

The services on Thursday performed considerably poorly with a standard deviation of 13 minutes (Table 9). This higher spread means the buses were within the acceptable limits of +1 and -5 minutes for only 56% of observations, compared with 75.5% of those on Saturday. Where there were multiple boardings of bus service at the same stop, the time between boardings could be found. A Metrocard, boarding took place on average 12 seconds after the previous boarding, whereas boarding with a magnetic ticket (an individual ticket bought from the drive took twice as long as 24 seconds. It was also found that magnetic ticket boardings were over-represented in the database of final boardings at each stop. Across a typical week, single-trip tickets makeup 8% of all boardings, and are the final boarding at a stop 17% of the time. This confirms the assumption that sales and validation prolong the time that buses stand at some stops. When this effect was investigated at a network level, no relationship was found between the percentage of departures where the last recorded boarding was with a paper ticket and how late the buses became, indicating that the sale of tickets is at most a minor cause of travel time unreliability. The presence of extra time taken by paper ticket purchase having no effect on reliability indicates that the distribution of such events, either spatially or temporarily, is captured in the timetable. This implies that there are travel time savings, if not reliability, improvements to be gained through off-board ticket sales or prepaid-only services such as those used in Sydney (Byatt, Oscuro & Rookes 2008).

Discussion and Recommendations

The increased time taken to travel on public services compared to car options is a significant barrier to shifting large proportions of travellers to public modes. Travel time, however, is not the most significant barrier, because flexibility and perceived cost have a larger impact. The personal car is very flexible, offering on-demand departure and options to re-route to avoid congestion. The biggest motivation to use this mode, however, is the hidden nature of its costs: fuel is the most obvious cost of driving, and in the public mind represents the total cost of a journey, equivalent to a public transport fare.

From the hypothetical choices offered to respondents in this study, total travel time was found to be the most important attribute when users were choosing a transport mode, with cost coming a close second.

Overall, public transport coverage is good in Adelaide's metropolitan area. As well as good frequency, it also offers services to passengers' most common destinations, including strong cross-suburban linkages, public transport service span (hours of operation in a day) and first/last mile connectivity. Adelaide Metro trialled initiatives termed 'roam zones' where evening buses dropped passengers off at their door rather than at a bus stop. This was not, however, successful because of the increased travel times incurred by the circuitous routes generated. Nonetheless, there is much more that could be done: for instance, there is an app (Metromate) that tracks a bus, and perhaps this could be made more interactive so that a user could request a ride to a local hub from the nearest bus, like the service Uber provides. This would allow multi-modal trips to be made without requiring car parking facilities. Over half of our respondents said they would be happy making multi-model trips and 40% said they would use PT if they could be driven to the station/interchange with a taxi/Uber for under $2.50; an additional 15% said they would use such a service if it was free (for instance, included as a transfer on their MetroCard/ticket).

Earlier studies have shown that smart mobility and the proper use of transport infrastructure contribute to a more accessible city. Interchanges constitute an important element of urban public transport and play a vital role offered connections. Well-planned interchanges facilitate the integration of different modes of transport, allow passengers to shorten their travelling time, and reduce the effort required to change their means of transport. These lead to the public transport system being used more. The biggest hurdle to improving patronage at public transport interchanges is the poor connections to adjoining suburbs, as transport authorities have little or no knowledge of the influence or catchment areas around public transport interchanges. One measure to increase patronage at interchanges is to connect them with adjoining suburbs using high quality and high-frequency feeder services. Here an on-demand bus stem could be trialled.

Hotspot analysis of the inner suburbs' preferred destinations produced significant cold spots in the outer suburbs, particularly in the north. People in the inner suburbs travel shorter distances and tend not to visit outer suburbs. For example, we found that people living in Aberfoyle Park have two distinct destination hotspots: the centre of Adelaide and a region covering Marion Shopping Centre plus the Tonsley and Bedford Park campuses of Flinders University. For significant respondents from Aberfoyle Park, suburb itself emerged as a destination, indicating an expected tendency to travel locally.

This survey found that people were walking further than the expected 15 minutes, up to 30 minutes, to public transport services, particularly rail. However, these journeys were often made out of necessity rather than a choice by those captives to public transport.

Another measure to improve public transport use at the interchanges is a more effective implementation of the park and ride system currently in place at the Tea Tree Plaza carpark. Here drivers pay a nominal fee ($2.00) to park to catch public transport.

If bicycles are to be used in conjunction with public transport, then cycling conditions need to be generally improved. The most popular facility is the quiet back street alternative route instead of arterial roads, as cyclists find it challenging to negotiate intersections on major routes. Recreational cycling needs to be promoted to encourage this mode's use for day-to-day transport tasks.

Cars are not the solution to the whole transport problem, although if they can be integrated into the realm of public transport, they could be the solution to the first and last mile problem they created. The idea of sharing a car is not new, but there is some resistance to sharing space with strangers. It is expected that the concept of mobility as a service will become popular, offering travellers mobility solutions based on individual travel needs. Public transport providers are well positioned to become part of this, rather than lagging behind as they did in the automobile era.

The public transport OD matrix is a useful prerequisite for planners to optimise public transport systems. The reliability of the system is an important criterion to encourage people to leave their vehicles at home and take public transport instead. An accurate estimation of public transport OD will be a significant help to public agencies involved in route rationalisation, which will lead to higher public transport patronage Adelaide's bus services and show less variability of lateness on the weekends although there is a lower percentage of prepaid tickets used. Ticket sales within the bus are increasing the travel time of Adelaide's public transport bus services although they do not contribute to travel time unreliability. Removing cash ticket sales from the bus network will not improve reliability, but savings in travel time could be achieved.

Our research found that safety was a key current and future concern for passengers. A bus that is too crowded or too empty is deemed unsafe. Further research is needed to determine the ideal number of passengers to enhance the sense of security and comfort. Where train services are concerned, it was found women feel unsafe due to only a limited presence of available staff during both day and night hours.

Adelaide offers an excellent opportunity to consider environmental issues within the context of improving public transport and making it attractive and practical for a large number of its inhabitants. Such matters as providing many options for combined-mode travel, reliable service, minimal transfer times, and solutions for first and last-mile problems will give Adelaide a system that caters for all people in all suburbs in all weathers and offer a model that can be emulated by other cities to reduce GHG reduction in urban transport.

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Appendix 1 NGene code for Stated preference survey design.

Ngene

```
Design

;alts = Drive,Cpool,Bus,Train

;rows = 12

;eff = (mnl,s)


;cond:

if(Drive.CostP = 0,CPool.CostPp = 0),

if(Drive.CostP = 8,CPool.CostPp = [0,5]),

if(Train.DriveA=0, Train.TFare = Bus.fare),

if(Train.DriveA>0, Train.TFare = 1+Bus.fare)


? 0 drive acccess for train options given to respondent as 12 mins walk.


;model:

U(Drive) =  CostD[-0.56657]*CostF[9.2,6.9,4.6]+CostD*CostP[0,8,16,24]+EGR[-
0.101]*Egress[0,5,10,15]+ TT[-0.10]*IVTC[25,30,35]/

U(CPool) =  PPool[-0.77557]*Persons[2,3,4]+ CostP[-
0.25901]*CostPp[0,5,10,15]+CostP*CostFp[4.6,3.5,2.3]+EGR*Egress+TT*IVTP[30,35,40]/

U(Bus)= CostT[-0.33608]*Fare[4,6,7.25,11]+EGR*Egress+TT*IVTB[35,40,45]+HW[-
0.03473]*HeadW[5,10,15,20]+ACSW[-0.11]*WalkA[4,8,12] +Fac[0.48243]*FacB[0,1]/

U(Train)=
CostT*TFare[4,6,7.25,11,5,7,8.25,12]+EGR*Egress+TT*IVTT[15,20,25,30,35]+HW*HeadW+A
CSD[-0.1]*DriveA[0,5,10]+Fac*FacI[1,2,3,4]


? train fare 8 options, 4 bus fare options 4 bus fare +1


;formatTitle = 'Scenario <scenarionumber>'

;formatTableDimensions = 5, 10

;formatTable:

1,1 = '' /

1,2 = 'persons' /
```

```
1,3 = 'cost 1' /

1,4 = 'cost 2' /

1,5 = 'One way Door to door travel time' /

1,6 = 'Flexibility of Departure time' /

1,7 = 'Access to your primary transport mode' /

1,8 = 'Transit facilities

(available all hours ) ' /

1,9 = 'egress  distance

(Distance from main mode to destination)' /

1,10 = 'Choice question&:' /

2,1 = 'bus' /

2,2 = 'any members of the public' /

2,3 = '<bus.fare>' /

2,4 = '' /

2,5 = '<bus.ivtb> minutes' /

2,6 = '<bus.headw> minutes between scheduled services' /

2,7 = '<bus.walka> minutes walk to a bus stop ' /

2,8 = '<bus.facb>' /

2,9 = '<bus.egress> minute walk' /

2,10 = '' /

3,1 = 'train' /

3,2 = 'any members of the public' /

3,3 = '<train.tfare>' /

3,4 = '' /

3,5 = '<train.ivtt> minutes' /

3,6 = '<train.headw> minutes between scheduled services' /

3,7 = '<train.drivea> minutes Drive to an interchange or station' /

3,8 = '<train.faci>' /

3,9 = '<train.egress> minute walk' /

3,10 = '' /

4,1 = 'drive' /

4,2 = 'Just You ' /

4,3 = '<drive.costf>' /
```

```
4,4 = '<drive.costp>' /
4,5 = '<drive.ivtc> minutes'/
4,6 = 'you choose time of departure' /
4,7 = 'Your car is parked at home' /
4,8 = 'N&/A' /
4,9 = '<drive.egress> minute walk' /
4,10 = '' /
5,1 = 'cpool' /
5,2 = '<cpool.persons> including yourself' /
5,3 = '<cpool.costfp>' /
5,4 = '<cpool.costpp>' /
5,5 = '<cpool.ivtp> minutes' /
5,6 = 'Pre-arranged semi flexible meeting time' /
5,7 = 'You will leave from  your house' /
5,8 = 'N&/A' /
5,9 = '<cpool.egress> minutes walk' /
5,10 = ''
;formatTableStyle:
1,1 = 'default' /
1,2 = 'headingattribute' /
1,3 = 'headingattribute' /
1,4 = 'headingattribute' /
1,5 = 'headingattribute' /
1,6 = 'headingattribute' /
1,7 = 'headingattribute' /
1,8 = 'headingattribute' /
1,9 = 'headingattribute' /
1,10 = 'headingattribute' /
2,1 = 'heading1' /
2,2 = 'body1' /
2,3 = 'body1' /
2,4 = 'body1' /
2,5 = 'body1' /
```

```
2,6 = 'body1' /
2,7 = 'body1' /
2,8 = 'body1' /
2,9 = 'body1' /
2,10 = 'choice1' /
3,1 = 'heading2' /
3,2 = 'body2' /
3,3 = 'body2' /
3,4 = 'body2' /
3,5 = 'body2' /
3,6 = 'body2' /
3,7 = 'body2' /
3,8 = 'body2' /
3,9 = 'body2' /
3,10 = 'choice2' /
4,1 = 'heading3' /
4,2 = 'body3' /
4,3 = 'body3' /
4,4 = 'body3' /
4,5 = 'body3' /
4,6 = 'body3' /
4,7 = 'body3' /
4,8 = 'body3' /
4,9 = 'body3' /
4,10 = 'choice3' /
5,1 = 'heading4' /
5,2 = 'body4' /
5,3 = 'body4' /
5,4 = 'body4' /
5,5 = 'body4' /
5,6 = 'body4' /
5,7 = 'body4' /
5,8 = 'body4' /
```

```
5,9 = 'body4' /

5,10 = 'choice4'

;formatStyleSheet = Red hot.css

;formatAttributes:

drive.costf(9.2=#.##, 6.9=#.##, 4.6=#.##) /

drive.costp(0=#.##, 10=#.##, 20=#.##, 30=#.##) /

drive.egress(0=#, 5=#, 10=#, 15=#) /

cpool.persons(2=#, 3=#, 4=#) /

cpool.costpp(0=#.##, 5=#.##, 10=#.##, 15=#.##) /

cpool.costfp(4.6=#.##, 3.5=#.##, 2.3=#.##) /

cpool.egress(0=#, 5=#, 10=#, 15=#) /

cpool.cprat(33=#, 39=#, 45=#) /

bus.fare(4=#.##, 6=#.##, 7.25=#.##, 11=#.##) /

bus.egress(0=#, 5=#, 10=#, 15=#) /

bus.brat(39=#, 45=#, 51=#, 60=#) /

bus.headw(5=#, 10=#, 15=#, 20=#) /

bus.walka(4=#, 8=#, 12=#) /

bus.facb(0=#, 1=#) /

train.tfare(4=#.##, 6=#.##, 7.25=#.##, 11=#.##, 5=#.##, 7=#.##, 8.25=#.##,
12=#.##) /

train.egress(0=#, 5=#, 10=#, 15=#) /

train.trat(27=#, 33=#, 39=#, 45=#) /

train.headw(5=#, 10=#, 15=#, 20=#) /

train.drivea(0=#, 5=#, 10=#) /

train.faci(1=#, 2=#, 3=#, 4=#)

$
```

Appendix 2: Nlogit code & output for SP analysis

```
NLogit
  ;lhs=choice
  ;Choices = Bus, Train, Drive, Pool
  ;effects:CostFar(*)/costpar(*)/costfue(*)/TTime(*)/Egress(*)/Headway(*)
  ;pwt
  ;Model:
    U(Bus) = CostB*CostFar + TTB*TTime + HWAYB*Headway + ACSWB*AccessW + FACILB*Amenitie + Egr*Egress + IncB*HHINC + GendB*Gender/
    U(Train) = CostT*CostFar + CostF*CostFue + TTT*TTime + HWAY*Headway + ACSD*AccessD + FACIL*Amenitie + Egr*Egress + IncT*HHINC + GendT*Gender/
    U(Drive) = CostF*CostFue + CostP*CostPar + Egr*Egress + YearsD*Age + TTD*TTime/
    U(Pool) = CostF*CostFue + CostP*CostPar + TTP*TTime + PPool*Persons + Egr*Egress + Years*Age
  ;Tree = public T(Bus, Train), Car(Drive,Pool)
  $
```

```
+------------------------------------------------------+
|WARNING: Bad observations were found in the sample.|
|Found 704 bad observations among 2022 individuals.|
|You can use ;CheckData to get a list of these points.|
+------------------------------------------------------+

Hessian is not definite at current values.
Switching to BFGS (gradient based) method.
(Not a failure. Just looking for a better algorithm.)
Iterative procedure has converged
Normal exit: 26 iterations. Status=0, F= .1582292D+04

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable             Choice
Log likelihood function    -1582.29222
Estimation based on N =   1318, K =  22
```

```
Inf.Cr.AIC = 3208.6 AIC/N = 2.434
--------------------------------------
        Log likelihood R-sqrd R2Adj
Constants only -1800.3507 .1211 .1158
Note: R-sqrd = 1 - logL/Logl(constants)
Warning: Model does not contain a full
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
--------------------------------------
Response data is given as ind. choices
Number of obs.= 2022, skipped 704 obs
--------+------------------------------------------------------------------
        |           Standard         Prob.    95% Confidence
  CHOICE| Coefficient   Error    z  |z|>Z*      Interval
--------+------------------------------------------------------------------
   COSTB|  -.18611***   .02768  -6.72  .0000   -.24036  -.13186
     TTB| -1.94520   .....(Fixed Parameter).....
  HWAYB|   .05679***   .00602   9.44  .0000    .04500   .06858
  ACSWB|  -.10051***   .01147  -8.77  .0000   -.12299  -.07804
 FACILB|   .65706***   .01086  60.52  .0000    .63578   .67833
     EGR|  -.03473***   .00090 -38.79  .0000   -.03649  -.03298
    INCB|   .00037      .00669    .06  .9559   -.01274   .01348
   GENDB|   .14419***   .01082  13.33  .0000    .12299   .16539
   COSTT|  -.02054   .....(Fixed Parameter).....
   COSTF|  -.10145***   .00782 -12.97  .0000   -.11677  -.08612
     TTT| -2.20547***   .06033 -36.56  .0000  -2.32372 -2.08722
    HWAY|  -.00455   .....(Fixed Parameter).....
    ACSD|  -.00837   .....(Fixed Parameter).....
   FACIL|  -.02538   .....(Fixed Parameter).....
    INCT|   .00053   .....(Fixed Parameter).....
   GENDT|   .02974   .....(Fixed Parameter).....
   COSTP|  -.08422   .....(Fixed Parameter).....
```

```
 YEARSD|   .07988    .....(Fixed Parameter).....
   TTD| -1.74549     57.70702    -.03  .9759 -114.84917 111.35818
   TTP| -1.92226     97.00192    -.02  .9842 -192.04253 188.19801
  PPOOL|  -.04720    .....(Fixed Parameter).....
  YEARS|  -.06885     23.18814     .00  .9976  -45.51676  45.37906
--------+--------------------------------------------------------------------
***, **, * ==> Significance at 1%, 5%, 10% level.
Fixed parameter ... is constrained to equal the value or
had a nonpositive st.error because of an earlier problem.
Model was estimated on Jun 12, 2018 at 04:34:30 PM
-----------------------------------------------------------------------------


Iterative procedure has converged
Normal exit: 51 iterations. Status=0, F=    .1578399D+04


-----------------------------------------------------------------------------
FIML Nested Multinomial Logit Model
Dependent variable              CHOICE
Log likelihood function      -1578.39922
Restricted log likelihood    -1827.13597
Chi squared [24](P= .000)     497.47349
Significance level              .00000
McFadden Pseudo R-squared       .1361348
Estimation based on N =   1318, K =  24
Inf.Cr.AIC  =   3204.8 AIC/N =    2.432
---------------------------------------
          Log likelihood R-sqrd R2Adj
No coefficients -1827.1360  .1361 .1309
Constants only  -1800.3507  .1233 .1179
At start values -1582.2922  .0025-.0036
Note: R-sqrd = 1 - logL/Logl(constants)
Warning: Model does not contain a full
```

```
set of ASCs. R-sqrd is problematic. Use
model setup with ;RHS=one to get LogL0.
---------------------------------------
Response data is given as ind. choices
BHHH estimator used for asymp. variance
The model has 2 levels. Model form: RU1
Number of obs.= 2022, skipped 704 obs
--------+--------------------------------------------------------------------
        |              Standard            Prob.      95% Confidence
  CHOICE| Coefficient    Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
        |Attributes in the Utility Functions (beta)..........................
   COSTB|  -.13262***    .01989   -6.67  .0000    -.17161   -.09363
     TTB| -1.28600     327674.6     .00 1.0000 *********** ***********
   HWAYB|   .04809***    .01321    3.64  .0003     .02220    .07397
   ACSWB|  -.07754***    .01710   -4.53  .0000    -.11105   -.04402
  FACILB|   .67789***    .18043    3.76  .0002     .32425   1.03153
     EGR|  -.03210***    .00494   -6.50  .0000    -.04178   -.02242
    INCB| .62866D-04     .00012     .52  .6032 -.17415D-03  .29988D-03
   GENDB|   .10567       .09996    1.06  .2904    -.09024    .30158
   COSTT|   .00866       .01014     .85  .3929    -.01121    .02853
   COSTF|  -.04570       .04020   -1.14  .2557    -.12450    .03310
     TTT| -1.50169     327674.6     .00 1.0000 *********** ***********
    HWAY|   .00897       .00843    1.06  .2873    -.00755    .02550
    ACSD|  -.00376       .01163    -.32  .7463    -.02656    .01904
   FACIL|  -.02897       .03788    -.76  .4444    -.10321    .04527
    INCT|   .00023**   .9023D-04   2.55  .0108     .00005    .00041
   GENDT|  -.02739       .07427    -.37  .7123    -.17295    .11818
   COSTP|  -.08459***    .01194   -7.08  .0000    -.10800   -.06118
  YEARSD|   .10718***    .03886    2.76  .0058     .03102    .18334
     TTD| -4.80411      .1237D+07    .00 1.0000 *********** ***********
     TTP| -4.98271      .1237D+07    .00 1.0000 *********** ***********
```

```
  PPOOL|   .03720      .06943     .54  .5921    -.09888   .17327
  YEARS|  -.05512      .03911    -1.41  .1587   -.13176   .02153
      |IV parameters (RU1), tau(b|l,r),sigma(l|r),phi(r)..................
 PUBLICT|  2.53849***    .56962    4.46  .0000    1.42206  3.65492
    CAR|   .67252***    .17057    3.94  .0001     .33821  1.00684
--------+--------------------------------------------------------------------
nnnnn.D-xx or D+xx => multiply by 10 to -xx or +xx.
***, **, * ==> Significance at 1%, 5%, 10% level.
Model was estimated on Jun 12, 2018 at 04:34:49 PM
Nested logit random utility normalization .................................
No normalization was imposed a priori. (Default form is RU1)
IV parameters for RU1 model are Tau(Br|Lmb), Sigma(Lmb|Trnk)
Prob(alt=j|br=B,lmb=L,trnk=T) = exp[bX_j|BLT]/Sum     (MNL)
Prob(br=b |lmb=L,trnk=T)      = exp[aY_b|LT+taub|LR*IVB|LT)]/Sum
-----------------------------------------------------------------------------


Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
COSTFAR |   BUS   TRAIN   DRIVE    POOL
--------+-----------------------------------
    BUS| -.7792   .0058   .3980   .4098
  TRAIN| -.0005   .0703  -.0450  -.0579


Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
COSTPAR |   BUS   TRAIN   DRIVE    POOL
--------+-----------------------------------
  DRIVE|  .1630   .1437  -.5514   .3411
   POOL|  .0490   .0417   .0619  -.2268
```

```
Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
COSTFUE |  BUS   TRAIN   DRIVE   POOL
--------+-----------------------------------
  TRAIN| .0021  -.0304   .0219   .0189
  DRIVE| .0428   .0513  -.1712   .1040
   POOL| .0159   .0195   .0342  -.1045
```

```
Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
TTIME   |  BUS   TRAIN   DRIVE   POOL
--------+-----------------------------------
    BUS|-2.3355  -.0261  1.3089  1.1359
  TRAIN| -.0418 -2.7689  1.9690  2.0703
  DRIVE| 1.4712  1.3784 -5.3306  3.4497
   POOL|  .9083  1.0312  2.4544 -6.5638
```

```
Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
EGRESS  |  BUS   TRAIN   DRIVE   POOL
--------+-----------------------------------
    BUS| -.1641  -.0088   .0884   .0973
  TRAIN|  .0211  -.2134   .1322   .1568
  DRIVE|  .0267   .0309  -.1059   .0657
   POOL|  .0179   .0195   .0433  -.1205
```

```
Elasticity wrt change of X in row choice on Prob[column choice]
--------+-----------------------------------
```

```
HEADWAY |   BUS   TRAIN   DRIVE   POOL
--------+------------------------------------
    BUS |  .5378  -.0193  -.2836  -.2429
  TRAIN | -.0024   .1191  -.0796  -.0910
```

Individual form
If you need another please contact Callum at:
Callum.Sleep@unisa.edu.au
Or on: 8302 5163 during office hours

Respondent # _______

Please note that these are individual questions

What is your

1. region of birth
   - ☐ Australia or NZ
   - ☐ Europe includes Russia & UK
   - ☐ China, Japan, Korea
   - ☐ South East Asia OR Indian Subcontinent
   - ☐ Middle East
   - ☐ Africa
   - ☐ USA and Canada
   - ☐ South America including Mexico
   - ☐ Other country _______________

2. Which gender do you identify with

   ☐ Male ☐ Female ☐ Other

3. Please indicate which of these age brackets you fit within

18-24	25 29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65 +
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. From the following Please choose the option which best describes your status

Conventional employment	Shift work	Casual/part time work or study	Full time study	Unemployed or Retired
For example Mon-Fri 9-5	8 hr work blocks scheduled at any time day night or weekend	Predominately day time activity of shorter duration, may involve working weekends	For example you attend campus 3-5 times a week for at least 3 hr sessions	
☐	☐	☐	☐	☐

☐ Other work arrangements For example a FIFO (fly in fly out) work schedule

____

5. Is your most transport requirement for employment (paid or volunteer), education purposes or for another reason

☐ Employment ☐ Education ☐ Other ___________

6. Name of your most regular destination, eg workplace or campus___________________________
OR
Suburb ________________________ Street Name ________________________________

☐ No fixed destination

7. Please select all of the transport modes used in your most common regular journey

Walk	**Cycle**	**Car**	**Bus (on street)**	**Train/Tram/O-Bahn**
☐	☐	☐	☐	☐

How long does this most common Journey take (Door to door) ___________________________?

8. Do you have a Drivers licence?	**No skip to 14**	**Yes (Car class C)**	**Yes Other**______________________
	☐	☐	☐

9. How often do you drive a road vehicle

Every Day	5-6 days a week	3-4 days a week	2-3 days a week	1 day a week or less
☐	☐	☐	☐	☐

10. Roughly how much do you spend a week on fuel?

$20 or less	**$20-30**	**$30-40**	**$40-50**	**$50-60**	**$60-70**	**$70-80**	**80+**
☐	☐	☐	☐	☐	☐	☐	☐

11. How much does parking cost at or near your most regular destination

$0 (Free)	**Max hrs**	**OR**	**$/hr**	**Max hrs**	**OR**	**$ Daily**
☐	_________		________	_________		_________

Cars of the Future

12. Would you be comfortable sharing a driverless car with other people?

☐ **Yes** **I am happy to share my ride with others** ☐ **Yes**

As long as I was alone for my trip. (Afterwards, the car can pick up other passengers)

☐ **No**
I want to own my own vehicle

13. Alternative fuels

a. Where available do you purchase use Biofuel blends when you buy fuel

☐ Yes, E85 (85% Ethanol)

☐ Yes E10 (94 octane 10% Ethanol)

☐ No,

b. If you were to buy a new car today, would you consider buying an electric or hydrogen fuelled vehicle? (Given your chosen type, sedan 4WD etc, is available at the same price as a conventionally fuelled vehicle.)

☐ Electric ☐ Hydrogen ☐ Neither

i. If you didn't select a particular car type please give a brief reason why

☐ Range concerns (distance between charges)

☐ Fuel availability

☐ Fuel storage concern

☐ Battery life

☐ Other ________________

☐ Other ________________

"Now we have some questions about your public transport use"

14. Which type of public transport stop(s) would you consider there are within a comfortable walking distance of this address

☐ Bus stop ☐ Station/Interchange ☐ None

15. Please define your comfortable walking distance ____________ minutes OR _________ metres

16. Do you own a MetroCard (registered or otherwise)

☐ Yes full fare ☐ Yes 2 Section ☐ Yes seniors/ concession ☐ No

a. Do you ever take advantage of day trip tickets or 28 day passes (you may select more than one option if needed)

☐ Yes, Day tickets ☐ Yes, 28day pass ☐ No

17. How often do you catch public transport

6-7 days a week (go to 19)	**4-5 days a week (go to 19)**	**Weekly**	**Monthly**	**Never**
☐	☐	☐	☐	☐

18. If you don't catch public transport for a regular journey, what is the reason

Increased travel time	**Unreliability of transfers**	**Requirement to make stops on route eg to drop a child at school**
☐	☐	☐

☐ Other____

19. Please rank the following changes from 1 - 10 where 1 would most entice you to catch public transport more often and 10 would make little to difference

☐	**Frequency improvements**
☐	Improved safety
☐	Reduced Fares
☐	Cleaner/more attractive vehicles and stops
☐	Stops closer to your home or destination
☐	Shorter travel time

☐	Improved reliability of travel time
☐	increased parking costs at destination
☐	A reduction/elimination of required transfers
☐	Other________________________________

20. During Daylight hours:

a. Do you feel safe accessing public transport stops (walking around your neighbourhood)?

☐ Yes
☐ No, Why? ______________________ ______________________________

b. Do you feel safe at public transport stops?

☐ Yes
☐ No, Why? ______________________ ______________________________

c. Do you feel safe on public transport vehicles?

☐ Yes
☐ No, Why? ______________________ ______________________________

21. During the night

a. Do you feel safe accessing public transport stops (walking around your neighbourhood)?

☐ Yes
☐ No, Why? ______________________ ______________________________

b. Do you feel safe at public transport stops?

☐ Yes
☐ No, Why? ______________________ ______________________________

c. Do you feel safe on public transport vehicles?

☐ Yes
☐ No, Why? ______________________ ______________________________

22. Would you consider combining cycling with a Public transport trip:

a. If secure bicycle parking was provided at your local station/interchange

☐ Yes ☐ No

a. If your local bus could carry your bicycle to your destination for use

☐ No ☐ Yes

23. Would you use public transport if you could get a taxi/Uber to/from the local interchange or train station?

b. If that meant paying a small surcharge (for example $2.50)?

☐ Yes ☐ No

c. If this short taxi trip was included as a transfer in the MetroCard fare?

☐ Yes

☐ No

Part 2: Please chose a preferred transport mode for the 12 scenarios presented

NOTES;
**Carpooling is sharing a driven journey with at least 1 member of your family, friends or colleagues.

***All options are to be considered
for example, where driving to the interchange is given as an option it is assumed this is practical. Either there is access to a carpark for your car or you can be dropped off by someone else.

Please make a choice for each of the 12 scenarios

These scenarios roughly represent hypothetical travel from this suburb to the Adelaide CBD, the conditions are as shown regardless of what you may have experienced.

Assumptions:

- 40 kilometres daily travel
- CBD parking costs
- 50c for fuel to drive to a station/interchange

Example Question

please select one of the following mode choices for your regular commute (your regular travel to work or education) given the hypothetical conditions below

Attribute	Public Transport		Drive	Carpool
Persons	members of the public		1	2
Cost	$7.00	$8.00	$9.20 $30.00	$3.50 $15.00
One way Door to door travel time	39 minutes	30 minutes	30 minutes	36 minutes

For example if it regularly takes 30 minutes for you to drive to work/study then in this scenario there are public transport options available that would take the same time or 6 minutes longer while it would take 36 minutes to carpool with another person.
These travel times account for a one way journey from home to work/education or vice versa including all time taken to access your selected mode and then finally your destination broken down below.
I'd choose one of the public transport options above because it is by far the cheapest option with comparable travel times.
I don't mind sharing my ride with members of the public

Flexibility of Departure time	10 minutes between scheduled services	20 minutes between scheduled services	you choose time of departure	Pre-arranged semi flexible meeting time
Access to your primary transport mode	15 minute walk to a bus stop	10 minute drive to an interchange/station	Your car is parked at home	You will leave from your house
Transit facilities (available all hours)	Road side bus stop no shelter	Current conditions + • Clean toilet • Transit office • Café	N/A	N/A
Egress distance (Distance to destination)	Bus stop directly outside destination	5 minute walk	10 minute walk	5 minute walk
✓ Your Choice, Please tick	☑	☐	☐	☐

The facilities are described with the following levels

Current conditions
at an interchange this is equivalent to a sheltered bus stop

Public toilet
of the automated variety

A transit office
a staff presence who can assist with transport and local information and intervene in case of emergencies day or night

A café
a transit office along with the provision of food and drink for purchase.

Of these remaining options I'd choose the bus route due to its higher frequency and proximity to my destination

Scenario 1

Please select one of the following mode choices for your regular commute
(your regular travel to a place of work or education) given the conditions below

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	3
Access to your primary transport mode	8 minute walk to a bus stop	5 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	45 minutes	20 minutes	25 minutes	40 minutes
Walking time from vehicle to destination	15 minutes	Station at Destination	15 minutes	10 minutes
One way Total Door to Door travel time	68 minutes	25 minutes	40 minutes	50 minutes
How often is the service available	every 10 minutes	every 15 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$7.25	$7.25	$9.20	$4.60
		$1.00	Free	$Free
TOTAL		$8.25	$9.20	$4.60
Public transport facilities (available all hours)	Road side bus stop No shelter	Current conditions + • Public toilet • Cafe	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 2

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	2
Access to your primary transport mode	4 minute walk to a bus stop	10 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	40 minutes	25 minutes	25 minutes	30 minutes
Walking time from vehicle to destination	5 minutes	Station at Destination	5 minutes	15 minutes
One way Total Door to Door travel time	49 minutes	35 minutes	30 minutes	45 minutes
How often is the service available	every 20 minutes	every 5 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$11.00	$11.00	$9.20	$4.60
		$1.00	$16.00	$10.00
TOTAL		$12.00	$25.20	$14.60
Public transport facilities (available all hours)	Road side bus stop No shelter	Current conditions	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 3

Please select one of the following mode choices for your regular commute (your regular travel to work or education) given the conditions below

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just you	2
Access to your primary transport mode	8 minute walk to a bus stop	12 minute Walk to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	40 minutes	20 minutes	35 minutes	35 minutes
Walking time from vehicle to destination	5 minutes	Station at Destination	15 minutes	5 minutes
One way Total Door to Door travel time	53 minutes	32 minutes	50 minutes	40 minutes
How often is the service available	every 10 minutes	every 10 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$11.00		$9.20 P $24.00	$3.50 P Free
TOTAL			$33.20	$3.50
Public transport facilities (available all hours)	Road side bus stop No shelter	Current conditions + • Public Toilet • Transit Office	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 4

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	4
Access to your primary transport mode	12 minute walk to a bus stop	10 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	35 minutes	35 minutes	30 minutes	30 minutes
Walking time from vehicle to destination	15 minutes	5 minutes	10 minutes	Parking at destination
One way Total Door to Door travel time	62 minutes	50 minutes	40 minutes	30 minutes
How often is the service available	every 5 minutes	every 20 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$4.00	$4.00 $1.00	$9.20 P $16.00	$2.30 P $15.00
TOTAL		$5.00	$25.20	$17.30
Public transport facilities (available all hours)	Road side bus stop With shelter	Current conditions + • Public toilets	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 5

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	2
Access to your primary transport mode	12 minute walk to a bus stop	10 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	35 minutes	35 minutes	30 minutes	30 minutes
Walking time from vehicle to destination	15 minutes	5 minutes	10 minutes	Parking at destination
One way Total Door to Door travel time	62 minutes	50 minutes	40 minutes	30 minutes
How often is the service available	every 5 minutes	every 20 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$6.00	$6.00 $1.00	$6.90 P $24.00	$4.60 P $10.00
TOTAL		$7.00	$30.90	$14.60
Public transport facilities (available all hours)	Road side bus stop With shelter	Current conditions + • Public toilets • Transit office	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 6

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	4
Access to your primary transport mode	4 minute walk to a bus stop	10 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	45 minutes	15 minutes	30 minutes	35 minutes
Walking time from vehicle to destination	stop at destination	15 minutes	5 minutes	15 minutes
One way Total Door to Door travel time	49 minutes	40 minutes	45 minutes	50 minutes
How often is the service available	every 5 minutes	every 20 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$7.25	$7.25 $1.00	$4.60 P $16.00	$2.30 P $5.00
TOTAL		$8.25	$20.60	$7.30
Public transport facilities (available all hours)	Road side bus stop With shelter	Current conditions	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 7

Please select one of the following mode choices for your regular commute (your regular travel to work or education) given the conditions below

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	4
Access to your primary transport mode	8 minute walk to a bus stop	12 minute Walk to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	40 minutes	25 minutes	30 minutes	30 minutes
Walking time from vehicle to destination	10 minutes	10 minutes	5 minutes	Parking at Destination
One way Total Door to Door travel time	58 minutes	42 minutes	35 minutes	30 minutes
How often is the service available	every 10 minutes	every 10 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$11.00		$4.60 P $16.00	$2.30 P Free
TOTAL			$20.60	$2.30
Public transport facilities (available all hours)	Road side bus stop No shelter	Current conditions + Public Toilet	N/A	N/A
✓ Your Choice, Please tick	☐	☐	☐	☐

Scenario 8

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	4
Access to your primary transport mode	8 minute walk to a bus stop	5 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	45 minutes	15 minutes	25 minutes	40 minutes
Walking time from vehicle to destination	10 minutes	10 minutes	Parking at Destination	5 minutes
One way Total Door to Door travel time	64 minutes	30 minutes	25 minutes	45 minutes
How often is the service available	every 15 minutes	every 5 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$11.00	$11.00 $1.00	$4.60 P $8.00	$2.30 P Free
TOTAL		$12.00	$12.60	$2.30
Public transport facilities (available all hours)	Road side bus stop NO shelter	Current conditions	N/A	N/A
✓ Your Choice, Please tick	☐	☐	☐	☐

Scenario 9

Please select one of the following mode choices for your regular commute (your regular travel to work or education) given the conditions below

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	2
Access to your primary transport mode	12 minute walk to a bus stop	12 minute Walk to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	35 minutes	20 minutes	35 minutes	30 minutes
Walking time from vehicle to destination	5 minutes	15 minutes	10 minutes	Parking at Destination
One way Total Door to Door travel time	52 minutes	47 minutes	45 minutes	30 minutes
How often is the service available	every 10 minutes	every 10 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$4.00		$6.90 P $24.00	$4.60 P $5.00
TOTAL			$30.90	$9.60
Public transport facilities (available all hours)	Road side bus stop With shelter	Current conditions + • Public Toilet • Transit office	N/A	N/A
✓ Your Choice, Please tick	☐	☐	☐	☐

Scenario 10

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	3
Access to your primary transport mode	12 minute walk to a bus stop	5 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	35 minutes	35 minutes	25 minutes	40 minutes
Walking time from vehicle to destination	stop at Destination	10 minutes	Parking at Destination	15 minutes
One way Total Door to Door travel time	47 minutes	50 minutes	25 minutes	55 minutes
How often is the service available	every 20 minutes	every 15 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$4.00	$4.00 $1.00	$6.90 P $8.00	$3.50 P $5.00
TOTAL		$5.00	$14.90	$8.50
Public transport facilities (available all hours)	Road side bus stop NO shelter	Current conditions + Public toilet	N/A	N/A
✓ Your Choice, Please tick	☐	☐	☐	☐

Scenario 11

Please select one of the following mode choices for your regular commute
(your regular travel to work or education) given the conditions below

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	3
Access to your primary transport mode	4 minute walk to a bus stop	10 minute Drive to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	35 minutes	30 minutes	30 minutes	40 minutes
Walking time from vehicle to destination	Stop at Destination	15 minutes	10 minutes	10 minutes
One way Total Door to Door travel time	39 minutes	55 minutes	40 minutes	50 minutes
How often is the service available	every 20 minutes	every 5 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$6.00	$6.00 $1.00	$4.60 P $24.00	$4.60 P $15.00
TOTAL		$7.00	$28.60	$19.60
Public transport facilities (available all hours)	Road side bus stop NO shelter	Current conditions + • Public Toilet • Café	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Scenario 12

Attribute	Public Transport		Private transport	
	Bus	Train/Obahn	Drive	Carpool
Persons	any members of the public		Just You	3
Access to your primary transport mode	12 minute walk to a bus stop	12 minute Walk to an interchange/station	car parked at home	leave from your house
In vehicle Travel time	45 minutes	15 minutes	35 minutes	35 minutes
Walking time from vehicle to destination	15 minutes	5 minutes	Parking at Destination	10 Minutes
One way Total Door to Door travel time	72 minutes	32 minutes	35 minutes	45 minutes
How often is the service available	every 15 minutes	every 15 minutes	Any time you choose	Pre-arranged semi flexible meeting time
Daily Cost to you	$7.25		$9.20 P Free	$3.50 P Free
TOTAL			$9.20	$3.50
Public transport facilities (available all hours)	Road side bus stop NO shelter	Current conditions + • Public Toilet • Café	N/A	N/A
Your Choice, Please tick	☐	☐	☐	☐

Please rank these travel attributes from 5 least important to 1, most important when you made your decisions in the final part (section 2) of the questionnaire.

Travel time	cost	Facilities	Access/Egress	flexibility
☐	☐	☐	☐	☐

<u>Thank you very much for your time.</u>

Please use the enclosed prepaid envelope to return this survey to us.

Any further comments?

University of South Australia

Adelaide Household Travel Survey

A Survey of Commuting Behaviour

In Confidence

Read this first

1. Please fill in this Household Form first.
2. Then fill in the inside of this form for every person who usually lives here
3. Please read the instructions on the back page of this form.
4. All responses will be treated as strictly confidential.

Household Form

A household is all people who usually live at this address.
A household can be just one person.

For office use only
Suburb ________________________, Cluster No ##

Please answer all questions on this page

How many people aged over 18, including yourself **usually live** in this household

How many people aged between 12 and 18, **usually live** in this household

How many years have you lived in your current home?

Where is this household located

Street ____

Suburb ____

Please identify the nearest public transport stop to this residence

Train Station ☐ Bus Stop ☐ Road or street Name Stop Number

Name ____________________

How many **vehicles** owned or used by members of this household are garaged or parked at or near this dwelling

Roadworthy Bicycles

Motorised Passenger Vehicles

Other Vehicles

Please answer all questions on the inside of this form

Please fill in for:	Everyone who normally lives at this address (including people who don't commute)					
Person Number	**First Person (with next birthday)**	**Second Person**	**Third Person**	**Fourth Person**	**Fifth Person**	**Sixth Person**
1. Age in Years	Less than 15 ☐	Less than 15 ☐	Less than 15 ☐	Less than 15 ☐	Less than 15 ☐	Less than 15 ☐
	15-24 ☐	15-24 ☐	15-24 ☐	15-24 ☐	15-24 ☐	15-24 ☐
	25-34 ☐	25-34 ☐	25-34 ☐	25-34 ☐	25-34 ☐	25-34 ☐
	35-44 ☐	35-44 ☐	35-44 ☐	35-44 ☐	35-44 ☐	35-44 ☐
	45-54 ☐	45-54 ☐	45-54 ☐	45-54 ☐	45-54 ☐	45-54 ☐
	55-64 ☐	55-64 ☐	55-64 ☐	55-64 ☐	55-64 ☐	55-64 ☐
	65-74 ☐	65-74 ☐	65-74 ☐	65-74 ☐	65-74 ☐	65-74 ☐
	75 and above ☐	75 and above ☐	75 and above ☐	75 and above ☐	75 and above ☐	75 and above ☐
2. Gender	Male ☐ Female ☐	Male ☐ Female ☐	Male ☐ Female ☐	Male ☐ Female ☐	Male ☐ Female ☐	Male ☐ Female ☐
	Other ☐ undisclosed ☐	Other ☐ undisclosed ☐	Other ☐ undisclosed ☐	Other ☐ undisclosed ☐	Other ☐ undisclosed ☐	Other ☐ undisclosed ☐
3. Area of Birth	Australia or NZ ☐	Australia or NZ ☐	Australia or NZ ☐	Australia or NZ ☐	Australia or NZ ☐	Australia or NZ ☐
	Europe inc Russia & UK ☐	Europe, including Russia ☐	Europe, including Russia ☐	Europe, including Russia ☐	Europe, including Russia ☐	Europe, including Russia ☐
	China, Japan, Korea ☐	China, Japan, Korea ☐	China, Japan, Korea ☐	China, Japan, Korea ☐	China, Japan, Korea ☐	China, Japan, Korea ☐
	South East Asia ☐	South East Asia ☐	South East Asia ☐	South East Asia ☐	South East Asia ☐	South East Asia ☐
	Indian Subcontinent ☐	Indian Subcontinent ☐	Indian Subcontinent ☐	Indian Subcontinent ☐	Indian Subcontinent ☐	Indian Subcontinent ☐
	Middle East ☐	Middle East ☐	Middle East ☐	Middle East ☐	Middle East ☐	Middle East ☐
	Africa ☐	Africa ☐	Africa ☐	Africa ☐	Africa ☐	Africa ☐
	USA and Canada ☐	USA and Canada ☐	USA and Canada ☐	USA and Canada ☐	USA and Canada ☐	USA and Canada ☐
	South America, including Mexico ☐	South America, including Mexico ☐	South America, including Mexico ☐	South America, including Mexico ☐	South America, including Mexico ☐	South America, including Mexico ☐
	Other country ☐	Other country ☐	Other country ☐	Other country ☐	Other country ☐	Other country ☐
4. Employment status	Full time, Conventional ☐	Full time, Conventional ☐	Full time, Conventional ☐	Full time, Conventional ☐	Full time, Conventional ☐	Full time, Conventional ☐
	Full time, Shift work ☐	Full time, Shift work ☐	Full time, Shift work ☐	Full time, Shift work ☐	Full time, Shift work ☐	Full time, Shift work ☐
Where part time study is selected please also select another status.	Causal or part time work ☐	Causal or part time work ☐	Causal or part time work ☐	Causal or part time work ☐	Causal or part time work ☐	Causal or part time work ☐
	Full time study ☐	Full time study ☐	Full time study ☐	Full time study ☐	Full time study ☐	Full time study ☐
	Part time study ☐	Part time study ☐	Part time study ☐	Part time study ☐	Part time study ☐	Part time study ☐
	Unemployed or retired ☐ skip to 7	Unemployed or retired ☐ skip to 7	Unemployed or retired ☐ skip to 7	Unemployed or retired ☐ skip to 7	Unemployed or retired ☐ skip to 7	Unemployed or retired ☐ skip to 7

5. Income (weekly)	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐	Under \$400 ☐ Under \$800 ☐ Under \$1250 ☐ Under \$2000 ☐ \$2000 or Over ☐
6. Primary Employer Or Educational institution	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____
7. Common transport modes **Please mark all modes you use for your most common weekly return journey discounting walking within a single property**	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/Obahn ☐	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/O-bahn ☐	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/O-bahn ☐	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/O-bahn ☐	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/O-bahn ☐	Walk ☐ Cycle ☐ Car as driver ☐ Car as passenger ☐ On street bus ☐ Tram/ Train/O-bahn ☐
8. Most common other journey destination	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____	Street ____ Suburb ____ OR Facility Name ____
	☐	☐	☐	☐	☐	☐
9.	____ Kilometres	____ Kilometres	____ Kilometres	____ Kilometres	____ Kilometres	____ Kilometres

	First Person	Second Person	Third Person	Fourth Person	Fifth Person	Sixth Person
10. Metrocard Ownership **Registered or otherwise Please tick all that apply**	Full Fare ☐	Full Fare ☐	Full Fare ☐	Full Fare ☐	Full Fare ☐	Full Fare ☐
	2 Section ☐	2 Section ☐	2 Section ☐	2 Section ☐	2 Section ☐	2 Section ☐
	Concession ☐	Concession ☐	Concession ☐	Concession ☐	Concession ☐	Concession ☐
	Student ☐	Student ☐	Student ☐	Student ☐	Student ☐	Student ☐
	Seniors card ☐	Seniors card ☐	Seniors card ☐	Seniors card ☐	Seniors card ☐	Seniors card ☐
	None ☐	None ☐	None ☐	None ☐	None ☐	None ☐
11. public transport access/egress **11.1. Distance**	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐
	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐
	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐
11.2. Footpath Quality	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐
	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐
	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐
11.3. Cycling would you combine cycling with a public transit trip if busses could carry bikes	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐
	No ☐	No ☐	No ☐	No ☐	No ☐	No ☐
	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐
12. Driverless Cars **Would you be comfortable sharing a driverless car with other people?**	Yes ☐ I am happy to share my ride with others	Yes ☐ I am happy to share my ride with others	Yes ☐ I am happy to share my ride with others	Yes ☐ I am happy to share my ride with others	Yes ☐ I am happy to share my ride with others	Yes ☐ I am happy to share my ride with others
	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers	Yes ☐ As long as I was alone for my trip. Afterwards, the car can pick up other passengers
	No ☐ I want to own my own vehicle	No ☐ I want to own my own vehicle	No ☐ I want to own my own vehicle	No ☐ I want to own my own vehicle	No ☐ I want to own my own vehicle	No ☐ I want to own my own vehicle

	First Person	Second Person	Third Person	Fourth Person	Fifth Person	Sixth Person
13. r's Does this have a current l ce rive a road vehicle	No Current Licence Skip to 14 ☐	No Current Licence Skip to 14 ☐	No Current Licence Skip to 14 ☐	No Current Licence Skip to 14 ☐	No Current Licence Skip to 14 ☐	No Current Licence Skip to 14 ☐
	Car Licence (inc. P) ☐	Car Licence (inc. P) ☐	Car Licence (inc. P) ☐	Car Licence (inc. P) ☐	Car Licence (inc. P) ☐	Car Licence (inc. P) ☐
	Motorbike Licence ☐	Motorbike Licence ☐	Motorbike Licence ☐	Motorbike Licence ☐	Motorbike Licence ☐	Motorbike Licence ☐
	Other License ☐ ______	Other License ☐ ______	Other License ☐ ______	Other License ☐ ______	Other License ☐ ______	Other License ☐ ______
14. How often do you drive a personal vehicle?	Every Day ☐	Every Day ☐	Every Day ☐	Every Day ☐	Every Day ☐	Every Day ☐
	5-6 Days a Week ☐	5-6 Days a Week ☐	5-6 Days a Week ☐	5-6 Days a Week ☐	5-6 Days a Week ☐	5-6 Days a Week ☐
	3-4 Days a Week ☐	3-4 Days a Week ☐	3-4 Days a Week ☐	3-4 Days a Week ☐	3-4 Days a Week ☐	3-4 Days a Week ☐
	2 days a Week ☐	2 days a Week ☐	2 days a Week ☐	2 days a Week ☐	2 days a Week ☐	2 days a Week ☐
	1 day a Week ☐	1 day a Week ☐	1 day a Week ☐	1 day a Week ☐	1 day a Week ☐	1 day a Week ☐
	On occasion ☐	On occasion ☐	On occasion ☐	On occasion ☐	On occasion ☐	On occasion ☐
15. Car sharing options Please mark the box if you've heard of the following initiatives	GoGet cars ☐	GoGet cars ☐	GoGet cars ☐	GoGet cars ☐	GoGet cars ☐	GoGet cars ☐
	Carpooling services ☐	Carpooling services ☐	Carpooling services ☐	Carpooling services ☐	Carpooling services ☐	Carpooling services ☐
	Ridesharing apps ☐	Ridesharing apps ☐	Ridesharing apps ☐	Ridesharing apps ☐	Ridesharing apps ☐	Ridesharing apps ☐
16. Have you ever used a shared car scheme? (eg. GoGet)	No, Skip to 17 ☐	No, Skip to 16 ☐	No, Skip to 16 ☐	No, Skip to 16 ☐	No, Skip to 16 ☐	No, Skip to 16 ☐
	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐
16.1. How often do you use such a service	Daily ☐	Daily ☐	Daily ☐	Daily ☐	Daily ☐	Daily ☐
	Weekly ☐	Weekly ☐	Weekly ☐	Weekly ☐	Weekly ☐	Weekly ☐
	Monthly ☐	Monthly ☐	Monthly ☐	Monthly ☐	Monthly ☐	Monthly ☐
17. Have you ever used Uber?	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐	Yes ☐
	No ☐	No ☐	No ☐	No ☐	No ☐	No ☐
18. with whom have you shared a ride in the last week	Nobody ☐	Nobody ☐	Nobody ☐	Nobody ☐	Nobody ☐	Nobody ☐
	Family/Housemates ☐	Family/Housemates ☐	Family/Housemates ☐	Family/Housemates ☐	Family/Housemates ☐	Family/Housemates ☐
	Friends ☐	Friends ☐	Friends ☐	Friends ☐	Friends ☐	Friends ☐
	Colleagues ☐	Colleagues ☐	Colleagues ☐	Colleagues ☐	Colleagues ☐	Colleagues ☐
	Members of public ☐	Members of public ☐	Members of public ☐	Members of public ☐	Members of public ☐	Members of public ☐

	First Person	Second Person	Third Person	Fourth Person	Fifth Person	Sixth Person
19. Walking access to local shops 19.1. Distance	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐
	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐
	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐
19.2. Footpath Quality	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐	Good ☐
	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐	Adequate ☐
	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐	Poor ☐
20. Do you ever feel like it would be unsafe walking around your neighbourhood?	Yes, always ☐	Yes, always ☐	Yes, always ☐	Yes, always ☐	Yes, always ☐	Yes, always ☐
	Why? ____________	Why? ____________	Why? ____________	Why?	Why?	Why?
	Yes, at night ☐	Yes, at night ☐	Yes, at night ☐	Yes, at night ☐	Yes, at night ☐	Yes, at night ☐
	Why? ____________ ____________	Why? ____________ ____________	Why? ____________ ____________	Why? ____________ ____________	Why? ____________ ____________	Why? ____________ ____________
	No, Never ☐	No, Never ☐	No, Never ☐	No, Never ☐	No, Never ☐	No, Never ☐
21. Do you walk regularly at least 10 minutes once a week	Yes, For leisure ☐	Yes, For leisure ☐	Yes, For leisure ☐	Yes, For leisure ☐	Yes, For leisure ☐	Yes, For leisure ☐
	Yes, For shopping ☐	Yes, For shopping ☐	Yes, For shopping ☐	Yes, For shopping ☐	Yes, For shopping ☐	Yes, For shopping ☐
	Yes as part of a public transport trip ☐	Yes as part of a public transport trip ☐	Yes as part of a public transport trip ☐	Yes as part of a public transport trip ☐	Yes as part of a public transport trip ☐	Yes as part of a public transport trip ☐
	Yes Other ☐ Purpose ____________	Yes Other ☐ Purpose ____________	Yes Other ☐ Purpose ____________	Yes Other ☐ Purpose ____________	Yes Other ☐ Purpose ____________	Yes Other ☐ Purpose ____________
	No ☐ Why? ____________ ____________	No ☐ Why? ____________ ____________	No ☐ Why? ____________ ____________	No ☐ Why? ____________ ____________	No ☐ Why? ____________ ____________	No ☐ Why? ____________ ____________

	First Person	Second Person	Third Person	Fourth Person	Fifth Person	Sixth Person
22. Have you Ridden a Bicycle in the last 12 months	Yes, every week ☐	Yes, every week ☐	Yes, every week ☐	Yes, every week ☐	Yes, every week ☐	Yes, every week ☐
	Yes, occasionally ☐	Yes, occasionally ☐	Yes, occasionally ☐	Yes, occasionally ☐	Yes, occasionally ☐	Yes, occasionally ☐
	No, ☐ Why__________	No, ☐ Why__________	No, ☐ Why__________	No, ☐ Why__________	No, ☐ Why__________	No, ☐ Why__________
23. How would you describe cycling your most frequent journey under current conditions?	Pleasant/relaxing ☐	Pleasant/relaxing ☐	Pleasant/relaxing ☐	Pleasant/relaxing ☐	Pleasant/relaxing ☐	Pleasant/relaxing ☐
	Safe ☐	Safe ☐	Safe ☐	Safe ☐	Safe ☐	Safe ☐
	Neutral ☐	Neutral ☐	Neutral ☐	Neutral ☐	Neutral ☐	Neutral ☐
	Unsafe ☐	Unsafe ☐	Unsafe ☐	Unsafe ☐	Unsafe ☐	Unsafe ☐
	Quite Dangerous ☐	Quite Dangerous ☐	Quite Dangerous ☐	Quite Dangerous ☐	Quite Dangerous ☐	Quite Dangerous ☐
24. If Cycle facilities eg showers and secure parking were located at/near your destination would you be more likely to cycle?	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐
	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐
	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐
25. Would you hire a bike for a short journey if there was a stand nearby and you had the flexibility to return it at your destination?	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐	Yes Definitely ☐
	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐	I'd consider it ☐
	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐	Probably not ☐

Please Turn Over

		Person 1	Person 2	Person 3	Person 4	Person 5	Person 6
26. Cycle Facilities **please rank** **from 1 most preferred** **to 4 least preferred**	Quiet backstreet cycle routes	☐	☐	☐	☐	☐	☐
	On road cycle lanes	☐	☐	☐	☐	☐	☐
	Shared use paths (fully separated but no traffic priority)	☐	☐	☐	☐	☐	☐
	Roadside footpaths	☐	☐	☐	☐	☐	☐
27. Dangers of cycling **please rank** **from 1 most frustrating** **to 7 least frustrating**	Parked cars	☐	☐	☐	☐	☐	☐
	Busses stopping on left of road	☐	☐	☐	☐	☐	☐
	Unnecessary waiting at traffic lights	☐	☐	☐	☐	☐	☐
	Aggressive motor vehicle drivers	☐	☐	☐	☐	☐	☐
	Difficulties Negotiating intersections	☐	☐	☐	☐	☐	☐
	Other ______________________________	☐	☐	☐	☐	☐	☐

LOW CARBON LIVING CRC

RP2021: Modelling Suburban Low Carbon Commuter Mode Choices

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

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Acronyms

ABM	Agent-Based Model
ABM-TMC	Agent-Based Model Transport Mode Choice
AT	Active Transport
CRCLCL	Cooperative Research Centre: Low Carbon Living
DZN	Destination Zone
MNL	Multinomial Logit
NEIC	National Employment and Innovation Cluster
PT	Public Transit
TOD	Transit Orientated Development

Executive Summary

Suburban transport is a significant contributor to greenhouse gas emissions in Australian cities. Therefore, in transitioning to a low carbon future that mitigates the potential impacts of human-induced climate change there is the need to increase the adoption of low carbon transport modes, such as public transit and active transport modes, in the suburban context. Suburban transport is currently heavily car-dependent which, in addition to greenhouse gas emissions, contributes to traffic congestion, poor local air quality, social inequity, and health impacts due to lack of physical activity. Suburban development was partially enabled by increased car ownership, which allowed for mobility in areas not serviced by transit and/or distant from employment locations. The ongoing predominance of car use in suburban areas can be attributed to a lack of planning and investment in transit systems that meet service levels required by the travelling population, and induced demand for car travel from extensive development of highways and arterial roads. In order to reduce car dependence, and associated carbon emissions in Australian suburbs, there is the need to identify effective interventions that will enable a greater proportion of trips to be taken by sustainable transport modes.

This research, which was part of the larger RP2021-Greening Suburban Transport, was mostly focussed on understanding the behavioural drivers that are likely to impede or encourage shift to low carbon transport modes, and developing a tool to analyse different interventions designed to increase the uptake of low carbon transport modes, and resulting impacts on greenhouse gas emissions.

The project involved the following activities:

- Review of international best practice and trends for enabling public transport and active transport that addresses the mobility challenges facing suburban communities;
- Investigation (through travel surveys and literature review) the factors that influence travel mode choice and the determinants of shifts in travel behaviour from private vehicles to public transport and active transport choice;
- Development of an Agent-based Model (ABM) that represents travel data, demographics, urban infrastructure, and travellers' behaviour and response to investment in low carbon transport infrastructure; and,
- ABM tool applied to a suburban employment precinct (Monash National Employment and Innovation Cluster).

The literature review found that the uptake of low carbon transport modes is largely influenced by the utility (time and cost) of different modes, but also by a range of intrinsic preferences and values that influence travellers' behaviour. This suggests that when considering investment strategies to increase the use of low carbon transport modes there is the need to consider how receptive different segments of the travelling population are likely to be.

The analysis of travel surveys, undertaken for this project, highlighted the following insights on factors that influence the choice for low carbon transport modes:

- Interdependencies between active (walking and cycling) and public transit modes, which is reflected in the increased likelihood of public transit use in areas serviced by active transport infrastructure.
- There is a strong unfulfilled demand for active transport for people who can access their destination by safe cycling and walking paths. The choice for active transport was also influenced by their underlying values for factors such as health and the environment.
- The probability of active transport increases for destinations that can be accessed in less than 30 minutes by walking or cycling, which highlights the need for investment in active transport infrastructure around activity centres and transit nodes.

Incorporating the decision making profiles, from the survey analysis, within an agent-based modelling provided a flexible, bottom-up approach for simulating transport mode choice. The human behavioural model can complement more traditional transport planning and modelling approaches, as it can help policymakers who want to reduce uncertainty around how commuters' mode choice is likely to be influenced by investment decisions or policy actions. The approach is able to model the behavioural complexities of transport mode choice in response to specific interventions (such as dedicated bus lane with associated walking/cycling path).

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Introduction

Suburban growth in countries like the United States and Australia has been characterised by low-density development, which has been enabled by the mobility provided by private cars and highway network [1]. However, this car-dependent urban sprawl has been implicated in increasing the environmental impact of cities through pollutant emissions, such as carbon dioxide [2, 3]. The reliance on car-based transportation is a major contributor to global warming [4]. Greenhouse gas emissions related to private transport contribute significantly to the overall carbon footprint of Australian cities. In 2014, road transport accounted for 15% of Australia's total Greenhouse Gas (GHG) emissions [5]. Cars were responsible for approximately 80% of these road transport emissions. There is the need to reduce the contribution of suburban travel to global emissions, and reducing these emissions requires improvements in not only transport technology and planning, but also in better understanding the factors that influence people's transport behaviour [6]. Natalini and Bravo [7] identified two issues in developing policies to reduce transport-related emissions, which are: new modelling approaches to assess the likely performance of different policies, and based on modelling insights, the design of more effective policies.

Suburban precincts in Australian cities are under pressure to accommodate a growing population while also reducing environmental impacts. Continued population growth and policies designed to limit sprawl has seen a shift from growth occurring primarily at the urban fringe of Australian cities to the renewal of suburban precincts through infill and brownfield development. This has resulted in increased population density and employment opportunities in these suburban precincts. However, these suburban precincts are often poorly serviced by the infrastructure for active transport and public transit, which as meant that cars are still used for the majority of trips with resulting increases in congestion and greenhouse gas emissions. Therefore, there is a need for targeted interventions that can improve the accessibility in suburban precincts and support the transition to low carbon transport modes. A barrier to improving accessibility infrastructure is understanding the different behavioural responses of travellers to interventions that improve the accessibility of low carbon transport modes. The Agent-based Model for Transport Mode Choice (ABM-TMC), described in this report, had the purpose of modelling the uptake of low carbon transport modes in a suburban precinct under different scenarios in a way that considers realistic models for commuter behaviour, and their responses to supply interventions that improved accessibility by active and public transport.

Project context

This report is for a component of the project entitled "RP2021 Greening Suburban Transport" which is a collaboration between the CSIRO, Swinburne University, University of South Australia and the University of Melbourne under the CRC for Low Carbon Living. This report primarily describes the CSIRO work packages.

The modelling approach described in this project builds on the work undertaken in related CRC for Low Carbon Living projects, In particular, RP3035 Modelling the uptake of water conservation and efficiency measures in Sydney" and "A "virtual market" for analysing the uptake of energy efficiency measures in residential and commercial sectors" RP3028. These projects used core Diffusion uptake algorithms developed over a number of years.

Activities of the CSIRO component RP2021 project have involved:

- Review of international best practice and trends for enabling public transport and active transport that addresses the mobility challenges facing suburban communities;
- Investigation (through travel surveys) the factors that influence travel mode choice and the determinants of shifts in travel behaviour from private vehicles to public transport and active transport choice;
- Development of an Agent-based Model (ABM) that represents travel data, demographics, urban infrastructure, and travellers' behaviour and response to investment in low carbon transport infrastructure; and,
- ABM tool applied to a suburban employment precinct (Monash National Employment and Innovation Cluster).

Literature review

Understanding approaches and policies for encouraging low carbon mode choice

This section reviews some of the approaches and policy responses to increase the number of trips taken by sustainable transport modes. The section also identifies the barriers for realising a more sustainable transport mix in the suburban milieu.

Vergragt and Brown [8] argued that there is a need to urgently address the societal dilemma, where individuals choose to travel by car to maximise personal utility at the expense of global sustainability. Mees, et al. [9] highlighted that current policy settings at state and federal government levels are supporting growth in car travel and associated GHG emissions. In particular, the authors maintained that there is a need to shift transport investment priorities away from building road infrastructure to investing in sustainable transport modes.

Market instruments

The shift to more sustainable transport modes requires an integrated response, which should include technological innovation, changes in the physical infrastructure and land use, and social, cultural, and institutional changes [8]. These changes need to consider the regulations, incentives and subsidies that may present market failures and barriers that impede the adoption of more sustainable transport modes. Brown [10] highlighted market failures and barriers that can impede clean energy policies, which can be adapted to the sustainable transport context. The examples provided by Brown [10] are included below, with the examples adapted to the transport context:

- *Misplaced incentives* – this is often called the "principal agent problem" in economics and refers to when an agent has the authority to act on behalf of users but does not always reflect the user's best interests. For example, transport planning engineers may first seek to minimise upfront costs, which determines the transport infrastructure available to the broader community. The dominant influence of these planning decisions may not be representative of the needs of the travelling public.
- *Distortionary fiscal and regulatory policies* - An example of a distortionary fiscal policy could be the government funding available for highway infrastructure relative to public transit, which may prevent markets from operating efficiently and subdue incentives for investing in sustainable transport modes.
- *Unpriced costs and public* goods – A range of negative impacts are associated with the use of fossil fuels for private vehicles. It could be argued the cost of fossil fuels for transport does not take full account of the social costs associated with their use, such as impacts on air quality and traffic congestion. Policy interventions can help ensure market choices reflect the full costs and benefits of options.
- *Insufficient and incorrect information* – the effective operation of markets, such as transport mode choice, assumes free and perfect information. If a person is not knowledgeable on the features and economics of different transport modes it may present a barrier to considering a shift to more sustainable modes.

Review of variables that influence transport mode choice

The following identifies variables that may be used to simulate travel mode choice, and the likely factors that may influence a shift to low carbon transport modes. While there are many factors that drive the potential for an individual to change travel behaviour the primary drivers of travel behaviour are structural variables such as trip distance, time, cost, urban density, road network quality and availability of public transit [11]. However, travel behaviour is also influenced by individual variables such as the purpose of the trip, time constraints, environmental ethics, age, income, gender, attitudes and lifestyle [11]. Gardner and Abraham [12] applied grounded theory analysis to understand the main motives that sustain high levels of car use. The top motives for car use were: minimising journey time, minimising the physical and psychological effort of the trip, minimising cost, creating personal space and maintaining control over the travel experience [12].

Key factors that influence the demand for different transport modes are discussed in the following sections.

Journey time and distance

Clark, et al. [13] used a longitudinal dataset to explore the relationship between changes in residential location and employment location. This demonstrated how sensitive households were to the length of commute. The study showed when commute distance was greater than 13 kilometres a household is more likely to try to reduce commute time when relocating homes. The study indicated that commute distance does matter to households, and households are aware of the trade-offs between commute distance and residential location. These spatial complexities increase for dual-income households, where two people are both trying to optimise their residential location with potentially different commute destinations.

Ahmed and Stopher [14] reviewed studies of Travel Time Budget (TTB). TTB differs from Travel-Time Expenditure (TTE), as the latter can be measured based on actual travel time while the former refers to the maximum amount of time a person would be willing to travel per day and therefore is not directly observable [14]. This review found that at the aggregate level TTB are remarkably stable despite the highly variable nature of individual travel. The margin between TTB and TTE indicates the additional time that might be spent on travelling. This has implications when considering mode shift, as people will try to stay within their TTB. Morris [15] found that when controlling for relevant demographic, socio-economic and temporal covariates that travel time per day is significantly and positively correlated with life satisfaction.

Kingham, et al. [16] surveyed workers at two large companies in England, where more than 85% employees travelled to work by car, to understand what factors might influence a shift to sustainable transport modes. This study found that even if cycling infrastructure and end-of-ride facilities were improved there would likely be little increase in cycling to work due to the distance that most employees need to travel to work. Therefore, policies to improve cycling infrastructure are likely to only have an impact where a significant number of employees live close to work [16]. Badland et al. [17] found that for people who lived 5 kilometres or less from their place of work there was a disconnect between their intent to travel by active modes and their actual behaviour. The World Health Organisation (WHO) advocates distances of up to 5 kilometres are realistic for active based transport. It has been demonstrated that people who live 5 kilometres or less from their place of work are more likely to ride or walk to work, with this likelihood decreasing as the commute distance increases [17].

Trip complexity and purpose

The purpose and complexity of a planned trip can influence mode selection. Trip purpose can be broadly categorised as commuting or non-commuting travel [18]. Commuting covers travel to work or education, and is generally much more predictable in terms of destination and behaviour than non-commuting travel. Studies have often focused on travel behaviour associated with commuting in part due to the fact that better data is available to characterise these trips [19].

Trips can also be categorised as simple or complex, where a simple trip is defined as a trip to a destination and then returning to home

Mode quality and accessibility

Paulley, et al. [20] noted that mode quality can be defined by a wide range of attributes, which include those that can be easily observed and included in models, such as access and egress time, service intervals and in-vehicle time. There is also a range of other mode quality factors, such as quality and comfort of rolling stock, the interchange between modes, availability of information. The valuations of these attributes are often derived from stated preference models [20].

Kingham, Dickinson and Copsey [16] reported on a survey that asked respondents what factors would encourage them to shift from the car to public transit. The main factors identified were: frequency, reliability, better connections and discounted fares. Frequency, accessibility and connectivity can be used to assess the quality of public transit [21]. However, Gaymer [22] found that commute choice by car can be extremely resilient to significant changes in mode quality. For example, Gaymer [22] found that travel times for car drivers could get 40% worse and there would be minimal defection to other modes, with the exception of those travellers who had stated a preference for public transit use. Gaymer [22] also found improved train service reliability (less chance of delay) substantially increases demand for train services, even from segments of the travelling population that who preferred car use. However, this did not hold for bus travel – with those people who preferred car use likely to continue to reject bus travel despite any improvements in service quality [22]. This suggested a problem with the perceptions of bus travel.

Actual and perceived safety of transport modes can influence the adoption of active and public transport. Woodcock, et al. [23] found that for some cities, as rates of cycling increased, there was a decrease in the rate of fatalities and serious injuries for cyclists. While this might indicate there is some effect from safety in numbers, it is also likely to be a result of improved cycling infrastructure that encouraged the increase in cycling for transport.

Economic factors

The selection of modes requires a traveller to consider trade-offs across different levels of attributes for each travel mode: time, monetary cost, reliability, comfort, convenience, safety, and so forth[24]. A traveller has to consider the relative importance and value of each attribute, and based on that, evaluate modes to identify the one that provides the greatest utility. Walker [24] noted that the most important behavioural trade-off in transportation is between the time cost and monetary cost, where the value of a traveller's value of time can be based on traveller's hourly wage rate and it represents the amount of money that one is willing to spend to save a certain amount of time.

Wardman [25] described the value of travel time as the ratio of the marginal utilities of time and money, while the marginal utility of time is the opportunity cost (wage rate) of time spent travelling and disutility of that time. The value of time will vary across modes, due in part to the comfort and conditions of different modes that influences how travel time can be spent [25]. This study suggested that time spent walking or waiting as part of a commute was around twice the value of in-car time. Wardman [25] suggested this justifies investment in providing high service frequency bus services that connect core areas.

An analysis by Litman [26] found that transit elasticities are influenced by the trip type and user type. Elasticities for off-peak and leisure travel were found to be double those of trips taken during peak and for commuting purposes. It was also found that transit price elasticities are lower for transit-dependent riders (those without access to a car) than for discretionary riders, who can choose to drive a car. This analysis showed that commonly used elasticity values often understate the potential for transit fare reductions and service improvements to address issues such as traffic congestion and GHG emissions [26].

Gaymer [22] explored the factors that drove the more rapid than expected growth in public transport use. The analysis found that three factors had the greatest influence on higher than modelled growth in public transit patronage, which were: population growth, CBD jobs growth and petrol price increases. The actual elasticities of the Melbourne market were higher than those used in the demand model, which meant increased petrol prices had a larger impact than anticipated. The interactive effect of these factors (petrol price increase, improved public transit service services and increased travel congestion) were greater than the sum of the parts.

Built environment

Previously, this review discussed the relationship between urban density and mode share, which suggested a complex relationship between urban density and an increased proportion of trip by sustainable transport modes. Particularly, unless increased urban density is supported by integrated and efficient multi-model transport system, it may not have a significant influence on reducing car use. There are many examples in the literature that argues urban form is an important component of reducing transport-related emissions [27-33]. Cervero [34] pointed out that while the literature contains numerous empirical observations that link more compact and diverse developments with an increased share of sustainable transport modes, often the relationship between urban form and mode share is not adequately specified.

There is an association between older neighbourhoods that have more granular, gridded networks with smaller lot sizes. In contrast, newer developments have cul-de-sacs and curvilinear road networks, which can impede connectivity for active transport modes [17].

Randall and Baetz [35] argued that to reduce the energy consumption and sustainability of suburban areas there is the need for retrofitting suburbs to enable people to walk to meet some of their needs and connect to the regional transit system. Pedestrian connectivity in suburban location is impeded by circuitous street layouts, lack of footpaths and long travel distance to intended destinations.

Badland, Schofield and Garrett [17] found that the disconnect between intention to use active modes and actual active commuting was seven times greater for those residents who lived in neighbourhoods with poor street connectivity compared to those living in neighbourhoods with good street connectivity. The relationships between active commuting and other urban design variables, population density and a mix of land uses, were not as strong as for street connectivity [17]. However, one possible explanation for this lack of a relationship was that this study focussed on commuting only, where many of the active transport for short trips may be for purposes other than accessing employment or school.

Mixed land use, residential density, street connectivity and commute distance have been found to influence levels of physical-based commuting [17]. Badlands et al. [17] suggested that increased adoption of physical-based transport can reduce traffic congestion, CO_2 emissions and traffic pollution, as well as providing health benefits. Low-density, single land use and car-centric neighbourhoods have reduced the opportunities for active transport [17]. Although commute distance may be the dominant driver for the adoption of low carbon transport, other urban features also influence active commuting, which are residential density, mixed land use and street connectivity [17].

Behavioural and social factors

A range of studies have demonstrated the strong habitual nature of daily travel mode choice [36-40]. Bamberg et al. [37] posed the following question: is the reported habitual nature of mode choice based on causal relationships or more likely deliberative justifications based on strongly established behavioural habits. The results showed that including past behaviour strongly improved the predictive power of the model. With the exception of two constructs (feelings of guilt and awareness of consequences), all other constructs listed above were significantly associated with past behaviour. Bamberg, Hunecke and Blöbaum [37] compared two case studies with differing population segments. The study showed that socio-normative factors had a significant impact on people's intention to use Public transit (PT), which justifies the importance of public awareness campaigns that aim to create a receptive public. Developing public awareness may be an important pre-requisite for the effectiveness of measures targeting individual mode shift [37]. Gardner and Abraham [41] undertook a meta-analysis into potentially modifiable correlates of car use and intentions to drive. Programs that target behavioural change are typically more acceptable to the community and less expensive than infrastructure modifications. The importance of attitudinal data has long been established in transportation research, where it has been suggested that it can improve prediction of mode choice [42].

Klöckner and Matthies [6] explored how habits can be integrated into a model of normative decision-making. Understanding individual decisions to use a car is important as it provides a starting point to consider the possible interventions that will reduce private car use and associated emissions. The choice of travel mode is a repeated daily action, particularly for habitual travel such as commuting. Therefore, the potential for a habit to influence travel mode choice is significant [6]. Possible habit indicators could include: the number of public transit trips in a given time period; distance to the regularly chosen location; the most frequent occurring departure time; past use and vehicle ownership; and past and current ownership of 'season tickets' for public transport [43]. An event such as moving house or changing jobs may prompt a re-evaluation of travel habits.

Carrus, et al. [44] examined the role that anticipated emotions and past behaviour have in influencing intentions for the use of public transport, which found that past behaviour is the best indicator of future intentions. Also, Rasouli and Timmermans [45] argued that most models of transport behaviour assume individuals choose between alternatives under conditions of certainty. However, in reality, there can be considerable uncertainty in the likely performance of a chosen transit mode.

Anable [46] argued that studies have also shown that habit influences mode choice, as a trip is not always preceded by deliberation of alternatives. There are broadly two approaches to segmenting a population of travellers, which are: groups that are defined based on a known characteristic (e.g. socio-demographic characteristics), or groupings that can be identified using multivariate statistical analysis. Therefore, in the latter, the segments are determined by the data and not the researcher (beyond the selection of the variables). Often socio-demographic characteristics are used to segment populations for travel behaviour and intention to shift mode. However, Anable [46] demonstrated that socio-economic variables did not influence behaviour but was related more to attitudes and beliefs around benefits and impediments to mode shift.

Summary

The uptake of sustainable transport modes is influenced by a range of observable and latent variables. Latent variables refer to unobservable factors that influence mode choice, such as preferences and values that drive travel behaviour. Vredin Johansson, et al. [47] explored the influence of latent variables on mode choice, in addition to observable modal time and cost. This study found that commuters' preferences for travel flexibility and comfort, as well their pro-environmental values, influenced commuters' mode choice. Beirão and Sarsfield Cabral [48] undertook a qualitative study to better understand attributes to public transit attitudes towards transport and to explore perceptions of public transport service quality. The key finding was that to increase public transport patronage the services should be planned to meet the levels of services required by the customer. In addition, they determined that mode choice is influenced by a number of other factors, which include:

"Individual characteristics and lifestyle, the type of journey, the perceived service performance of each transport mode and situational variables [48]."

This suggests that when designing policies and strategies to increase the use of sustainable transport modes there is a need for softer interventions, such as education or awareness programs, that should be targeted at segments of the travelling population most likely to be receptive.

Figure 1 depicts both the observable and latent variables that influence utility and mode choice. This section has highlighted that while the utility (time and cost) function of relative modes is the main influence on travel mode choice, there is a range of behavioural aspects that can influence the decision to shift to sustainable transport modes. Therefore, it is proposed to identify modelling approaches that can simulate the mode choice of different segments of the travelling population given constraints and changes in the supply of sustainable transport services and infrastructure.

Key learnings from the review

- The World Health Organisation (WHO) advocates distances of up to 5 kilometres are realistic for active based transport.
- Travel time for car drivers could get 40% worse and there would be minimal defection to other modes, with the exception of those travellers who had stated a preference for public transit use.
- Three factors had the greatest influence on higher than modelled growth in public transit patronage, which were: population growth, CBD jobs growth and petrol price increases.
- Disconnect between intention to use active modes and actual active commuting was seven times greater for those residents who lived in neighbourhoods with poor street connectivity compared to those living in neighbourhoods with good street connectivity.
- Past behaviour is the best indicator of future intentions.
- Socio-economic variables did not influence behaviour but was related more to attitudes and beliefs around benefits and impediments to mode shift.

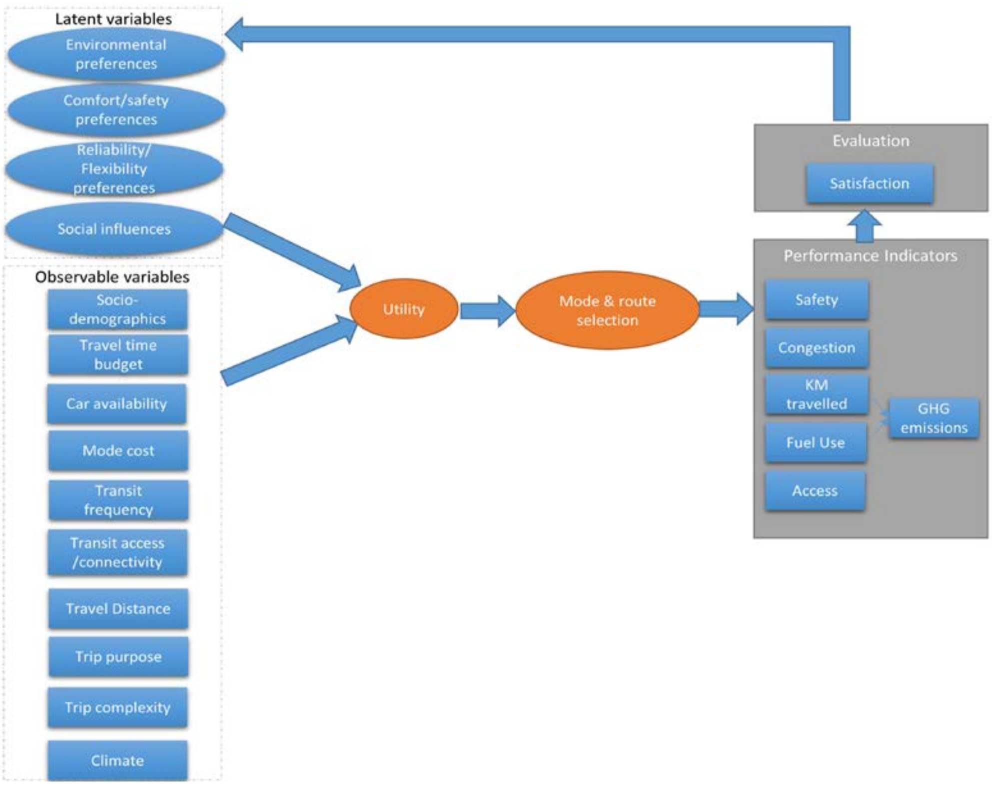

Figure 1: Latent and observable values that influence utility and mode choice

Agent-based Modelling

Agent-Based Models (ABMs) as an approach to modelling transport mode choice is explored in this section. Ziemke, et al. [49] argued that traditional integrated land-use and transportation models are not able to represent the complexity and dynamic nature of modern cities, which influences how individuals make transport decisions. ABM is an approach that has emerged out of Artificial Intelligence and Cellular Automatons and allow for software representations of agents' behaviours and decision making in interaction with each other and with their environment [50]. ABM has been used in a diverse number of areas, including archaeology, biological sciences, economics, ecology, electricity market analysis, financial analysis, social science, transport systems, water management, and many others [51-56]. ABM is well suited to modelling situations where the interaction between agents results in behaviour that is complex and non-linear due to being shaped by learning and adaption [57]. ABM provides a flexible, bottom-up approach for simulating emergent phenomenon. Simple rules that govern behaviour agents at a local level can result in the emergence of complex system behaviours [57].

There are two main approaches to modelling travellers' behaviour: equation-based modelling and ABM. Equation-based modelling uses approaches such as the Logit model, which applies a utility function to aggregate and evaluate system variables [58]. Mao et al. [58] compared equation-based modelling and ABM in simulating travellers' behaviour using data from a joint stated preference survey and web-based travel behaviour survey. This showed that when access to data is adequate, ABM has a similar predictive capacity for modelling transport behaviour as equation-based diffusion modelling but with greater flexibility in the assumptions and issues that can be explored [58]. Ultimately, ABM has the same limitations as any model in that any prediction is subject to conditional prediction, i.e. prediction only under the circumstances set out in the model [59]. A challenge in implementing ABM is that the patterns of emergent behaviour are inherently unpredictable and that ABM with human agents may need to account for irrational behaviour, subjective choices and complex psychology [57]. This can make validation of ABM problematic as it can be difficult to measure, quantify, calibrate and justify all factors.

Consumat Decision Framework

The Consumat framework is a generic conceptual framework that can be used to guide the development of ABMs as it provides an approach to simulate different human needs and decision strategies [60]. The Consumat framework has been applied to simulate the decision process associated with the adoption of more sustainable behaviours, including how travellers make a choice to adopt a sustainable transport mode or persist with their existing transport mode [61-63].

The fundamental drivers of behaviour in the Consumat framework are related to needs and if these needs are fulfilled [60]. A distinction is made between the types of human needs: existential needs and social needs. Existential need relates to criteria that guide transport mode choices which can be observed or revealed, such as trip time, cost, reliability, comfort, safety, and trip purpose. Social needs relate to how decisions are influenced by interactions with others [60]. These social needs can relate to the need to conform or be different when comparing behaviour to those who might influence the agent, such as friends, family, peer groups, etc. The Consumat framework also considers the 'uncertainty' in the existential and social needs being satisfied. Uncertainty might reflect individual perceptions (such as public transit safety). Uncertainty can also refer to lack of confidence in trip outcomes, such as public transit disruption or traffic congestion. Figure 2 outlines the decision modes that are used in the Consumat approach based on needs fulfilment and uncertainty. The decision modes are as follows:

Repetition: High level of needs satisfaction and certain. The repetition decision mode involves repeating the behaviour of the past.

Imitation: High level of needs satisfaction, as well as uncertain. The imitation decision process is normative and involves copying the behaviour of a connection in the agent's social network.

Optimisation: Low levels of needs satisfaction and certain, will mean an agent is motivated to invest effort in improving their level of satisfaction.

Enquiry: Low level of needs satisfaction, but uncertain. The inquiry decision mode involves evaluating the behaviour of others, and copying when expected satisfaction increases.

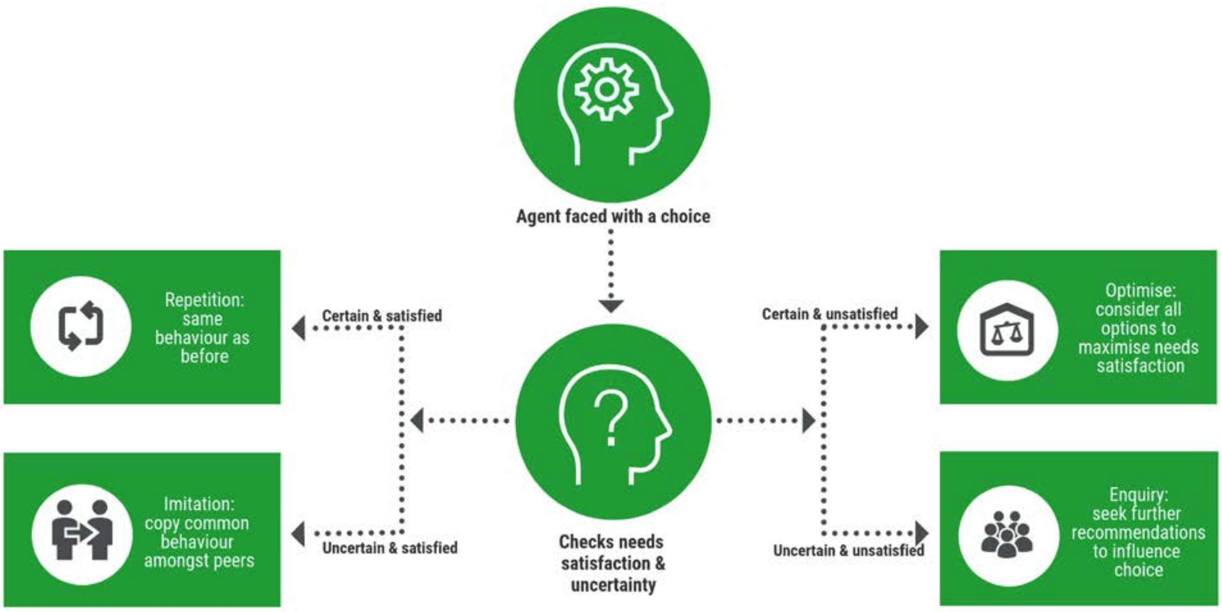

Figure 2: Consumat Decision Framework

Travel Surveys

Overview

Two surveys were undertaken on travel behaviour. The first survey collected responses from 270 commuters travelling into the Monash National Employment and Innovation Cluster (NEIC). This survey based on self-reported travel behaviour and perceptions of modes was able to discern variables that were statistically significant predictors of active transport. However, limitations of the survey included the fact the sample was not representative (over-sampled for males and highly educated workers), which meant that more information was needed to determine decision triggers for mode shift to active transport across the commuting population. Therefore, another travel behaviour survey of 547 households was undertaken outside of the case study as part of a larger survey undertaken for RP3035.

Monash NEIC Travel Survey

Survey design and Implementation

Table 1 outlines the survey sections that were designed to elicit information on current travel behaviour and the main factors that influence their choice of transport mode.

The survey was implemented using an online survey platform (Sawtooth Software). The survey received ethical clearance from CSIRO's Human Research Ethics committee (Approval Reference "Greening Suburban Transport – Research Proposal on Low Carbon Mobility" 024/16). Informed consent was obtained from the participants prior to the study.

Participants in the survey were recruited by email, with invitations targeted to people who travel to Monash NEIC for work and study. This included anchor tenants for the cluster: Monash Health, Monash University, CSIRO Clayton, and a limited sample from smaller employers in the cluster.

The survey was designed to develop an initial understanding of travel behaviour in the case study and on the variables that influence travel behaviour to enable an exploration in more detail in a subsequent study. Some limitations of this survey were: only 267 valid responses, with those responses, skewed to respondents with relatively high income and highly educated. Therefore, a travel survey was also included in a subsequent survey for a related project within the CRC for Low Carbon Living (RP3035) to better understand behavioural characteristics that might shape receptivity to the adoption of low carbon transport modes

Table 1: Monash NEIC survey structure

Survey Section	**Information collected**
Background information	Age, education level achieved, income, employment status, household structure, home and work address
Trip behaviour	Mode frequency, trip time and complexity, delays experienced
Private Vehicles	Access to car and parking, perceived benefits, and disadvantages of private vehicle travel
Public transport	Service accessibility from home and work, service frequency and number of connections, perceived quality of different transit modes, perceived benefits and disadvantages of transit
Active Transport	Access to end of ride facilities and secure bike parking, perceptions of quality by mode, and rating of mode quality and perceived influence of different infrastructure improvements in changing behaviour, perceived benefits and disadvantages of active transport
Factors that influence mode choice	Three most important factors when selecting mode choice (ranked), the most important information source used when considering mode choice
Pro-environmental attitudes	Based Psychological construct to reveal pro-environmental intentions and compare with behaviour.

Demographics

Figure 3 depicts that the 267 respondents were biased towards middle-aged males with a lack of female respondents. The respondents predominately travelled into the Monash NEIC from surrounding postcodes, with only a limited number of respondents starting their journey outside of south-east Melbourne. The respondents were a highly educated cohort, with more than 75% of respondents having a university undergraduate degree or higher. In comparison, the 2016 ABS census showed that of all workers travelling to the Monash NEIC around 39% had an undergraduate degree or higher.

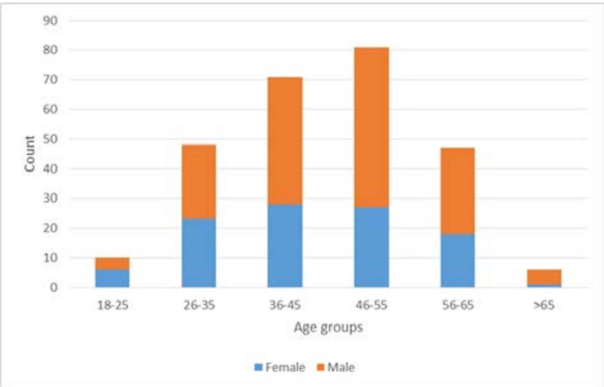

Figure 3: Age and gender profile of survey respondents

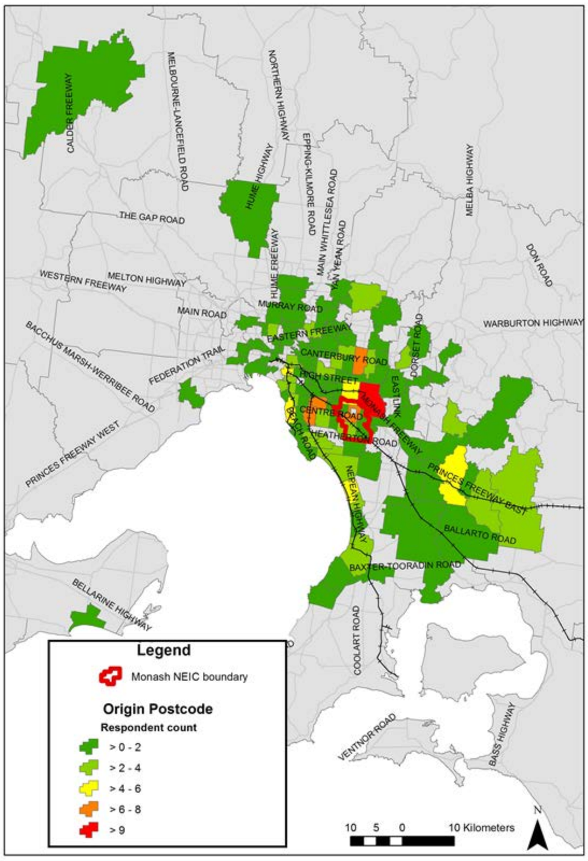

Figure 4: Origin postcode of respondents travelling to Monash NEIC

Self-reported behaviours

Figure 5 shows that three-quarters of the survey respondents most frequently travelled to work in the Monash NEIC by driving a car. This is mostly consistent with the ABS census where it was found that around 80% of workers were driving to work in the Monash NEIC. Figure 6 shows the average commute time of respondents was 38 minutes. Active transport modes were most frequently used when their place of work could be accessed in less than 40 minutes. However, public transit use was more frequently reported for commuters taking more than 40 minutes to get to work. This could be indicative of levels of service, as it was found that for around 70% of respondents it would take at least two connections to travel between their place of work and home (Figure 8). However, most respondents were able to walk to their nearest transit stop in less than 15 minutes (Figure 7).

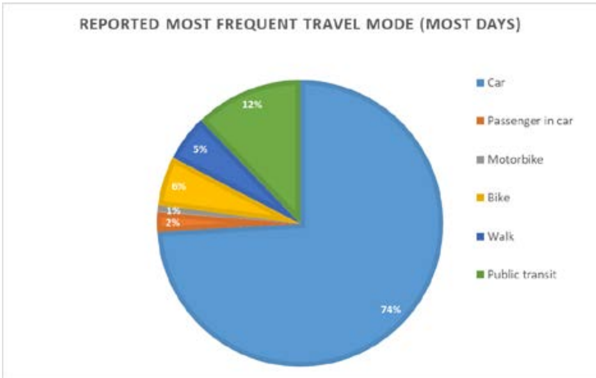

Figure 5: Travel mode most frequently used

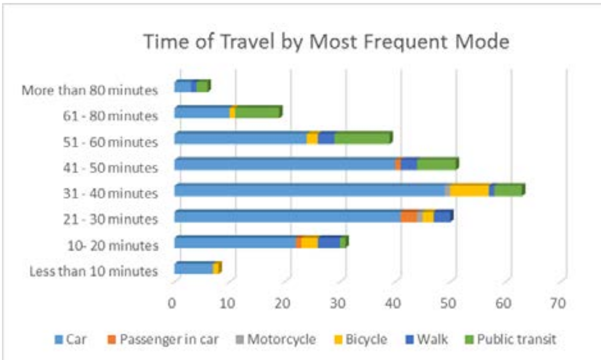

Figure 6: Travel time by mode

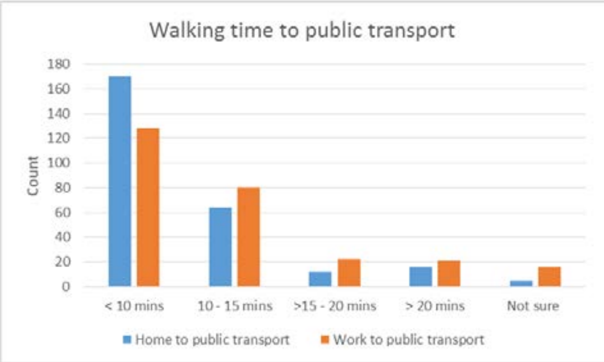

Figure 7: Walking to a nearest public transit stop (work/home)

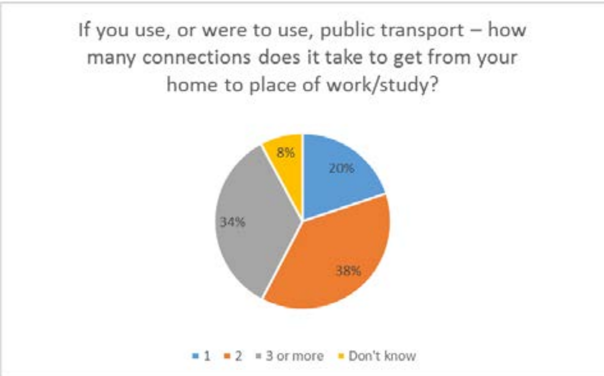

Figure 8: Transit connections between work and home

Traveller priorities

Figure 9 highlights the reported travel priorities of survey respondents. This shows that the first order priority is overwhelmingly the travel time, with flexibility and safety the next most commonly identified first order priorities. The second most important priority varied more amongst respondents, with flexibility, reliability and comfort being common responses.

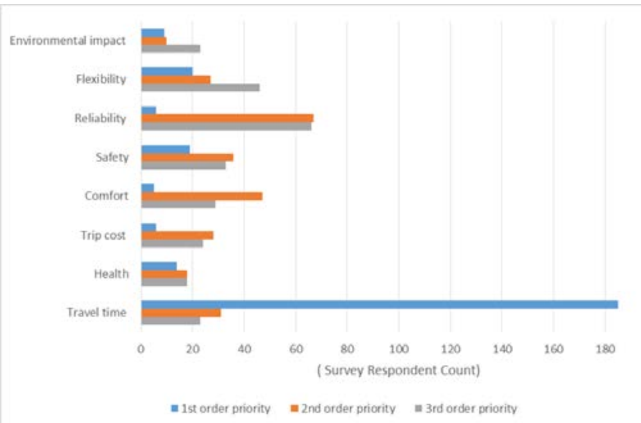

Figure 9: Traveller priorities

Supplementary travel survey

The survey was primarily designed to understand the relationship between residents and their complex responses to set of interventions implemented by Sydney Water to promote the uptake of water conservation behaviours and technologies. This survey was used as an opportunity to better understand variables that explained households' travel behaviour and their stated preferences for different modes. The survey also explored attitudinal and behavioural variables, such as pro-environmental attitudes, which could then be explored in relation to stated travel behaviour.

A total of 547 respondents completed the survey, which was approved by the CSIRO Human Research Ethics committee (Approval Reference 120/17). Informed consent was obtained from the participants prior to the study.

Figure 10 shows the age and gender breakdown of respondents. Overall, males and females were evenly represented in survey respondents. However, there was skew toward females in younger respondents and males in older respondents. Figure 11 depicts that younger respondents were more likely to use active transport and public transit modes.

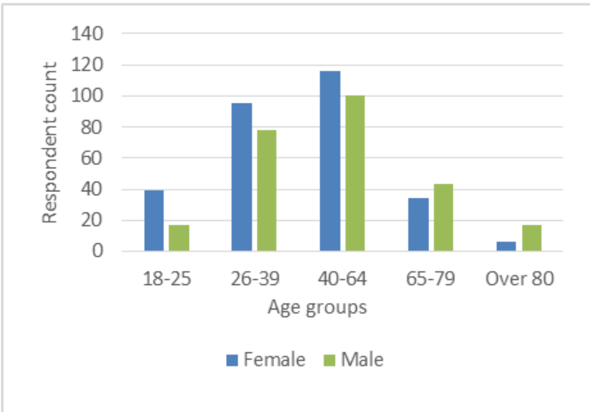

Figure 10: Age and gender breakdown

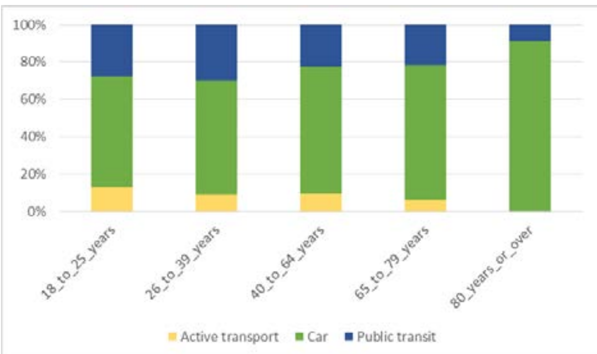

Figure 11: Age of traveller by mode

Figure 12 depicts that respondents most frequently used a car to commute (66%), followed by public transit use (25%), with only 9% of respondents reporting that they regularly used active transport modes for commuting. Figure 13 shows that amongst respondents public transit use was most common in the 30 to 75-minute range, which might indicate that people located at a commute time of 30 minutes or less are dissuaded by the average service frequency of 20 minutes. The stated use of active transport modes is highest where people are able to access their place of work in 15 minutes.

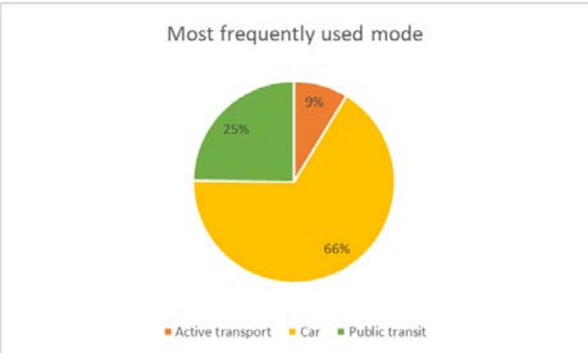

Figure 12: Breakdown of most frequent stated mode

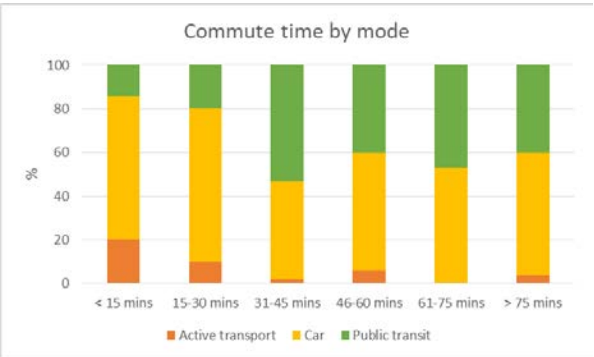

Figure 13: Commute time by mode

Figure 14 depicts how the respondents rated transport modes by different benefit categories. This shows that while active transport was most often considered to be the most environmentally friendly and healthy mode, these modes are not likely to be foremost priorities making travel mode choice (Figure 9). Car was more often considered by respondents to be the quickest, most flexible and most comfortable relative to active transport and public transport modes.

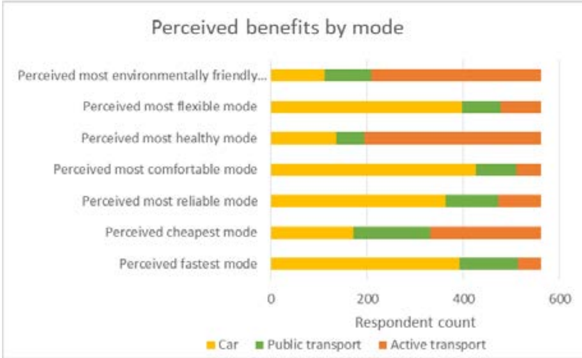

Figure 14: Perceived benefits of travel mode by stated travel mode

Figure 15 and Figure 16 show that for respondents who prioritise their health and the environment were more likely to state that they used active transport modes frequently.

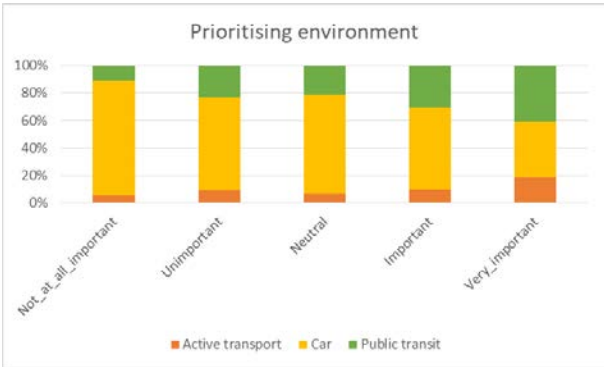

Figure 15: Environment priority by mode

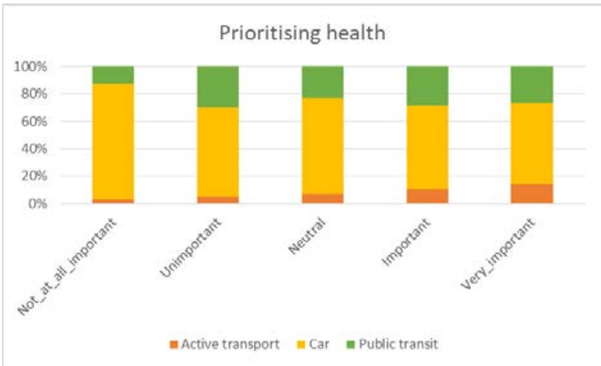

Figure 16: Health priority by mode

Statistical Adoption Modelling

Based on the survey data described previously a Multinomial Logit (MNL) model was developed to determine the factors that were most significant in determining the probability of traveller using public transit and active transport modes (Table 2). The MNL model was used to describe travellers' behaviour and decision making in the Monash NEIC, and potential response to policy interventions that included:

1. Upgrading of off-road active transport paths connecting origins and destinations (including transit nodes).
2. Improved public transit services that reduced the number of connections and frequency of services between origin and destination points.
3. Combination of both upgrading of off-road paths and improved transit services.

Multinomial regression models were fitted to the data to describe the likelihood of 'stated intention' to switch to low carbon transport modes. We have adopted a standard multinomial regression model described by the following equation.

$$P_{ij} = \frac{e^{X_{ij}\beta + Z_i\delta_j}}{\sum_{k=1}^{J} e^{X_{ik}\beta + Z_i\delta_k}} \quad . \qquad (1)$$

i refers to the commuter, and j refers to the mode. Each traveller has a set of priorities and circumstances embedded into the vector X(i,j), and trip attributes embedded into the vector Z. α are the intercept parameters of the model, fitted through statistical estimation. The statistical estimation algorithm, using the R statistical software, establishes the α and β parameters. As part of the statistical estimation of parameters, a very large number of covariates were explored. The variables that remain statistically significant in explaining the adoption of low carbon transport modes were the following:

- Travel time,
- Number of public transit connections between home and work,
- Public transit convenience (frequency of service and distance to stop),
- Access to suitable bike / footpaths,
- Availability of end of ride facilities,
- Car practicality (based on access to car and parking availability at work), and
- Intrinsic priorities (combined metric indicating stated importance of comfort, health, environment and flexibility).

Table 2 shows the outputs of the MNL regression analysis, which depicts the coefficient of the explanatory variables for both the adoption of active transport and public transit.

Not surprisingly, the likelihood of adopting public transit is heavily influenced by the convenience of the services available for the commute (walking time to stop, and the frequency of service). In contrast, car impracticality (due to no access to a car or parking limitations) influenced the choice to use either active or public transit modes.

Importantly, it was found that the intrinsic priorities of travellers were highly influential in explaining higher likelihoods of choosing public transport and active transport as travel modes. These intrinsic priorities (or values) related to the stated importance of natural environment, health, comfort and flexibility.

These results demonstrate that while observable trip characteristics, such as public transit and connectivity of off-road bike paths, can partially explain the likelihood of a traveller selecting low carbon transport modes, the choice of individuals will also be influenced by their underlying values for factors such as health and the environment.

Table 2: Explanatory variables for mode choice

Variables	Description	AT Coefficients	PT Coefficients
Travel time	Trip times	1.06 (Less than 30 mins) -1.20 (more than 60 mins)	-1.12 (Less than 30 mins) 0.40 (more than 60 mins)
PT connections	Number of PT connections between work/home	-0.59 (2 connections) -0.28 (3 connections) -0.66 (> 3 connections)	0.13 (2 connections) - 0.85 (3 connections) - 2.02 (> 3 connections)
PT convenience	A parameter indicating walking time (<10 mins) to transit node from work/home, and frequency of service (<20 mins) at transit node.	-0.786	2.53
No suitable active transit path	The absence of suitable active transport path linking origin and destination with	-1.556	-0.392
End of ride facilities	Availability of end-of-ride facilities – secure bike storage, showers, etc.	1.12	0.546
Car practicality	Parameter-based on access to a car, parking availability at work/home	-2.591	-2.783
Intrinsic priorities	Parameter-based on commuter responses indicating the importance of comfort, health, environment and flexibility	2.296	2.116

Agent-Based Model for Mode Choice

Purpose

The ABM for Transport Mode Choice (TMC) was developed to describe the uptake of low carbon transport modes in a suburban precinct under different scenarios in a way that considers realistic models for commuter behaviour, and their responses to supply interventions that improved accessibility by active and public transport.

Implementation

The ABM was implemented using an agent-based model (ABM) within the NetLogo (Version 5.3.1) environment [64] that applied a Consumat approach to simulating travellers' mode choice [63]. The Consumat theory, a meta-theory of human decision making, was used to simulate for each time-step travellers' decision-making based on satisfaction of travel needs in the previous step, and the perceived level of uncertainty. Based on criteria relating to uncertainty and needs satisfaction, four decision modes were simulated: repetition (satisfied and certain), imitation (satisfied and uncertain), optimisation (unsatisfied and certain) and enquiry (unsatisfied and uncertain).

The decision making profile was modelled for the population that are travelling into the Monash NEIC using characteristics from the origin-destination matrices. This was then validated against actual travel behaviour using ABS census (2016) data.

Design concepts

A schematic flowchart for the design of the ABM-TMC is depicted in Figure 17. The key elements in the development of the ABM tool included:

- Travel Survey – used to segment the travelling population and identify key attributes in choice modelling (described previously). The survey also provides a baseline of travel behaviour specific to the case study.
- Scenario development – scenarios were developed based on discussions with key planning stakeholders within the case study precinct, and review of existing strategies.
- Decision-making profiles – the decision-making processes within ABM-TMC apply the 'Consumat Approach'.
- Spatial network analysis – analysis of accessibility by modes was undertaken within the ArcGIS environment and was used to highlight origins and destinations of trips to work on a daily time-step. The accessibility index was based on travel impedance (travel time) between activity nodes and node attractiveness (number of jobs and residents relative to a metropolitan area), where accessibility is defined as 30-minute isochrones. The transport demand modelling was undertaken at the macro-level, which considers impedance of movement between different origins and destinations, and changes in the resident population and employment density of different nodes within the case study.
- Scenario outputs – the scenario outputs visualise changes in mode share over time, highlighting the adoption of active and transit. The net reduction in CO_2 emissions from increased adoption of low carbon transport modes is calculated based on the greenhouse gas intensities of different modes.

Input Data

Table 3 shows the main data inputs used to develop the ABM, with a more detailed description of the data in the following case study section.

Table 3: Input data

Data type	Description	Source
Traveller survey	Traveller decision making profiles	Online survey within the precinct
Residential population	Change in residential population by surrounding local government areas.	Victoria In Future
Employment projections	Changes in employment (attraction) in planning zones	Victorian Planning Authority
ABS Census data	Trip production and attraction by zone	Australian Bureau of Statistics
Primary land use	Used to assign resident and employment-population to zones within LGA.	ABS Mesh Blocks
Transport network	The configuration of transport network servicing the case study area precinct	Victorian Government Data Portal

Running the ABM-TMC

Initialising the model involves creating a number of software agents that represent the travelling population, where individual commuter's attributes are assigned on the basis of survey responses (from the survey previously described in this report).

There is an algorithm for assigning attributes to agents which in order to maintain correlations in the data, assigns commuter attributes from individual rather than aggregated survey responses. Further description of the process is found in related papers [65, 66].

To run the model, the user selects a commuter file, which can segment the travelling population to be modelled into age and gender cohorts (e.g. commuters under 25 years, women, commuters over 65 years, etc.).

The user can also adjust the Uncertainty Parameter which represents the level of uncertainty for commuting agents around their needs (on a scale of -1 to 0 where -1 is absolutely certain and 0 is absolutely uncertain).

The user then selects to intervention scenarios to model and can adjust parameters such as emissions intensity of each travel mode. 18 provides an overview of the ABM-TMC interface.

Outputs

Table 4 depicts some of the key outputs for the ABM-TMC. Changes in mode share and per capita emissions were the main measures. The mode share was displayed for both trips less than 30 minutes and those 30 minutes or greater, an analysis of the survey results indicated that the choice for active transport modes is more likely where the destination can be reached in 30 minutes.

Table 4: ABM-TMC key outputs

Key Outputs	Performance measure	Unit
Change in share of trips by low carbon modes	Increase in share of trips by active and public transit.	% of trips by each mode
Average annual per capita emissions	CO_2-e emissions per commuter each year	Tonnes of CO_2-e/year
Mode split by journey time	A number of trips by each mode split by trips (<30 minutes and >30 minutes.	Trips

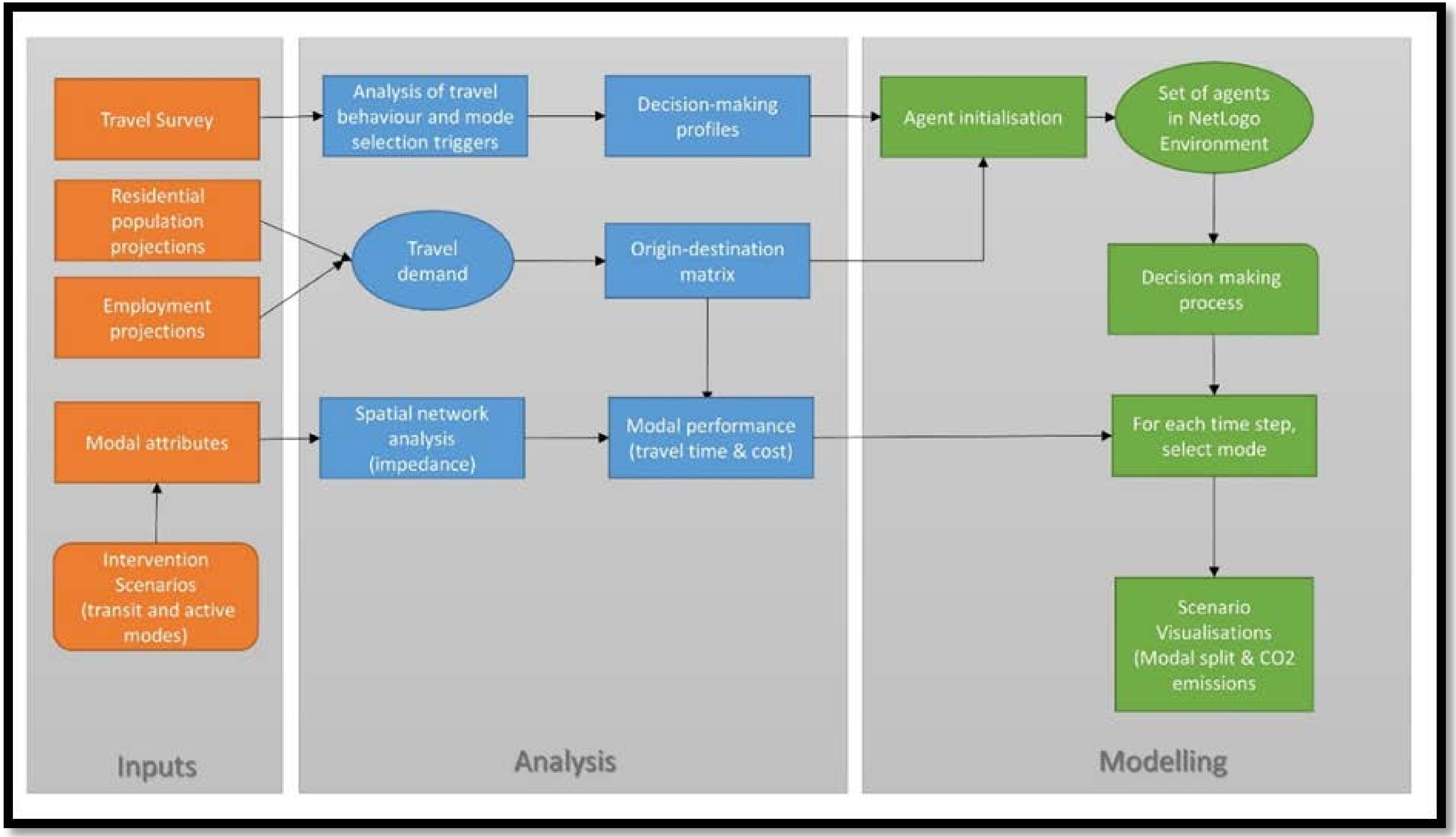

Figure 17: Process overview ABM-TMC

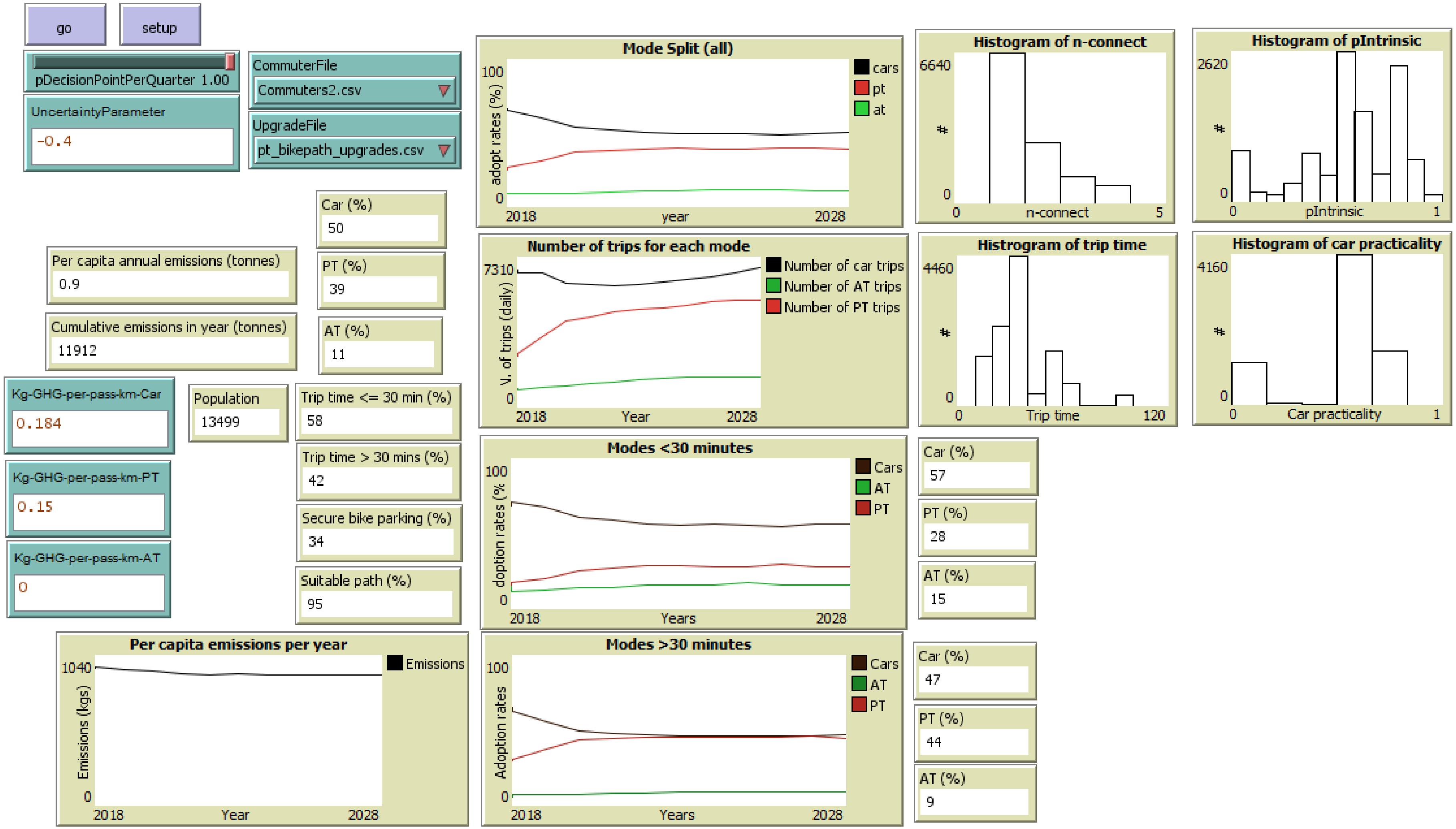

Figure 18: ABM-TMC interface

Application of model: Monash National Employment and Innovation Cluster

Background

The model was applied to the Monash NEIC The Monash NEIC is one of six National Employment Clusters that have been identified as areas in Victoria that have significant potential to provide for future growth in employment and housing densities associated with good transport connections [67]. However, improved local access and transport connections were the most important components of planning for the future of the Monash NEIC [67].

The Monash NEIC was historically an area that specialised in manufacturing and logistics employment. However, the Monash NEIC is now a hub for the growth of job in the health, education, technology and research sectors. Anchor tenants include Monash University, CSIRO, Monash Medical Centre and the Australian Synchrotron. These anchor tenants are providing the environment to attract a range of commercial and advanced manufacturing businesses [67].

The Victorian Planning Authority (VPA) is developing a Framework Plan to guide future land use, development and infrastructure planning to support job growth in the Monash NEIC over the next 30 years. This growth is being planned around 11 precincts, with the projected growth of jobs and residential population by 2051 by precinct is shown in Figure 19. To accommodate the increased residential and working population there is a significant emphasis on planning for improved transportation connections both within and outside the Monash NEIC. A survey of Monash NEIC stakeholders identified that improved local access and transport connections were the most important components of planning for the future of the Monash NEIC [67].

Baseline travel patterns

The Monash NEIC is serviced by a number of major arterial roads. This includes the Monash Freeway and Princes Highway, as well as the following major arterial roads: Westall Road/Blackburn Road, Huntingdale Road, Clayton Road, Centre Road Wellington Road, Ferntree Gully Road and Springvale Road. The Monash NEIC has 3 stations on the Dandenong railway line, which operate 15 services in the AM peak (in-bound to the city) and 15 services in the PM peak (outbound) [68]. There are 25 bus routes servicing areas with the Monash NEIC, with many of these services routed through Monash University interchange. Bus services include a shuttle bus between Huntingdale station and Monash University, which runs every 4 minutes during peak times and carries 6,000 passengers per day [69]. This makes it the busiest bus route in Victoria. The pedestrian and bicycle network has limited connectivity and integration with other modes across the Monash NEIC. Specific issues with active transport include gaps in network, missing connections, lack of signage and route information and safety concerns [68].

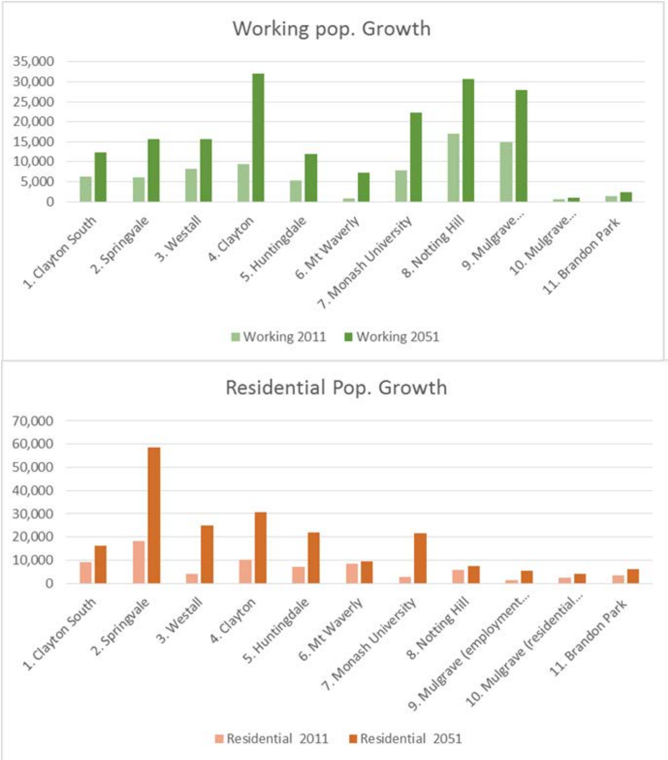

Figure 19: Projected growth in population and jobs for Monash NEIC by precinct

Source: Phillip Boyle and Associates (2014)

Figure 20 shows the origin of workers travelling into the Monash NEIC based on the 2016 ABS census. This shows that most trips to the Monash NEIC originate from the surrounding area. Figure 21 depicts the mode of trips by destination zone. Active transport trips to the Monash NEIC are most common for trips that originate from the Clayton suburb with the destination of Monash University. Overall travel to the Monash NEIC is heavily car dependent with around 81% of all trips being made by a private vehicle.

Major transport issues for the Monash NEIC include [68]:

- Increasing traffic congestion on the arterial road network;
- Lack of viable public transport alternatives to access employment across the cluster;
- Poor connectivity of active transport modes within the cluster; and,
- Current reliance on cars.

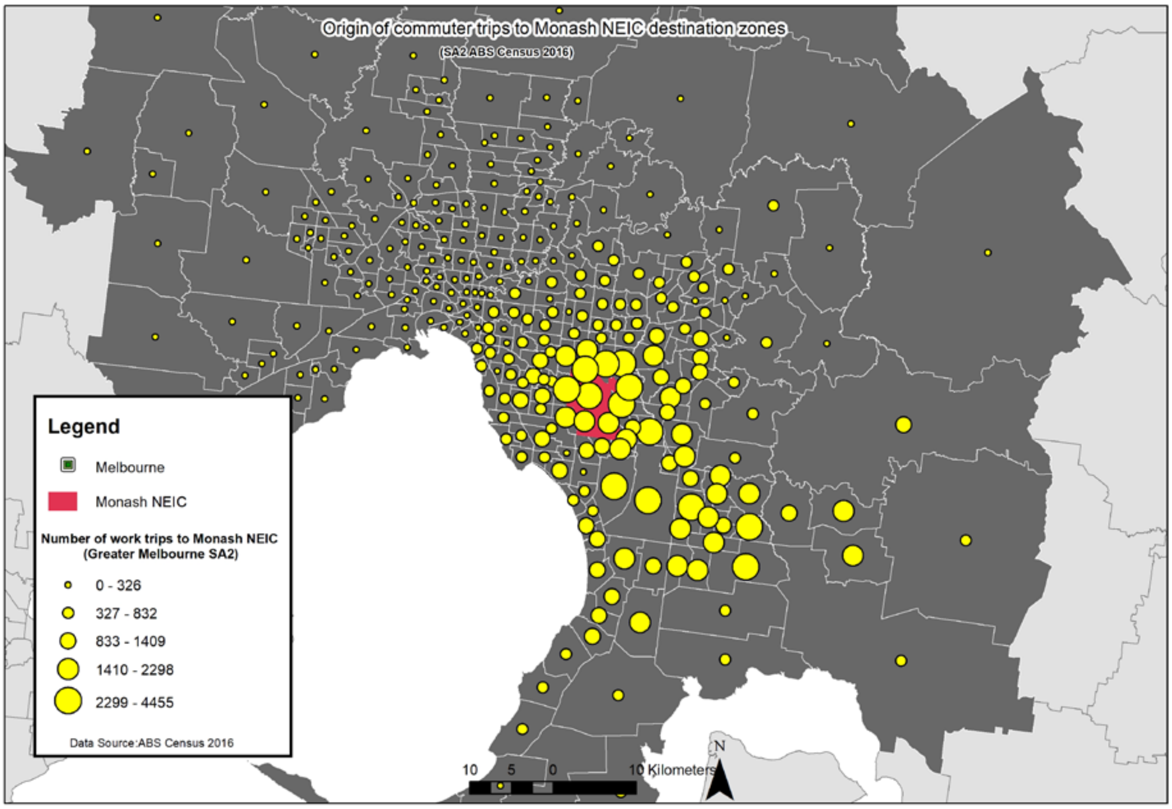

Figure 20: Origin of trips to Monash NEIC

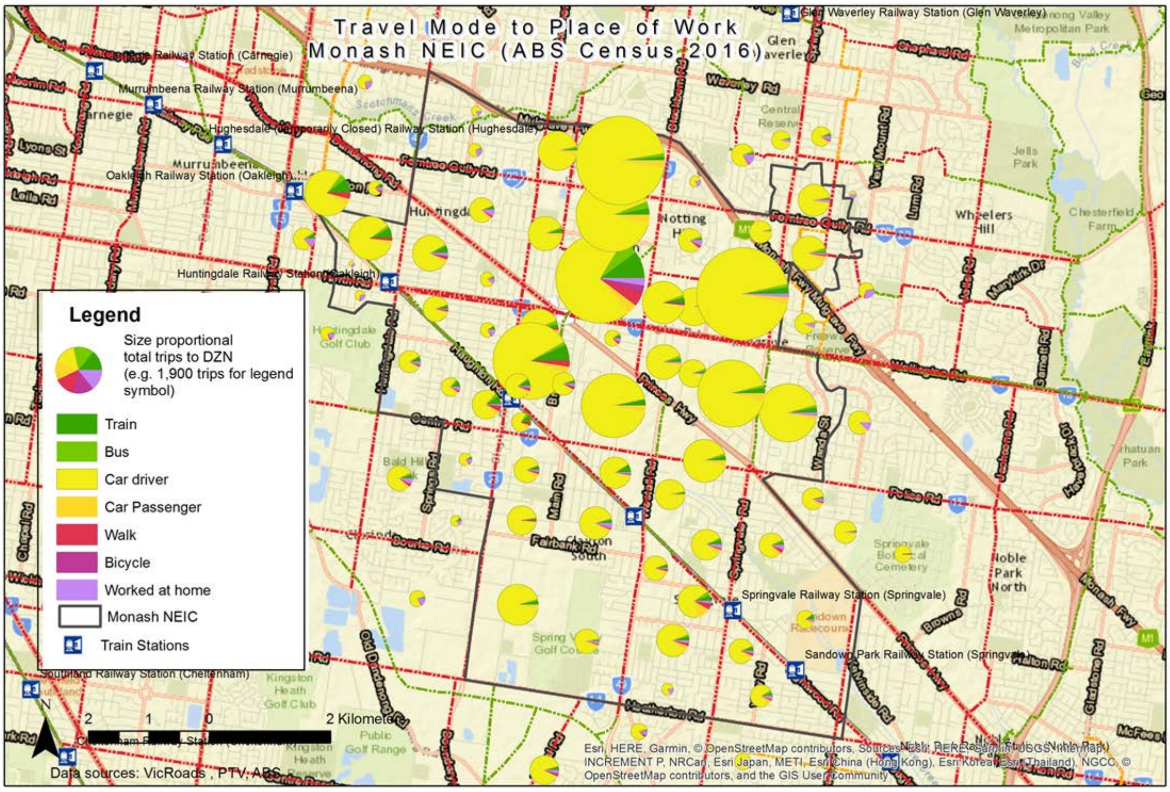

Figure 21: Mode by destination zone in Monash NEIC

Data

This section describes case-specific data inputs. Origin and destination matrices were developed using ArcGIS's Network Analyst extension. Origins were represented by surrounding 28 suburbs (ABS State Suburbs), where predominately Monash NEIC workers' trip originates. Destinations were represented by 10 employment nodes in the Monash NEIC (aggregation of ABS Destination Zones) (see Figure 22).

Table 5 depicts for each origin-destination (O-D) pair the fields calculated.

Table 5: Origin-destination matrices

O-D matrices	Description	Unit
Trip time by mode	Trip time between each O-D by each mode (car, public transit, cycling & walking)	Minutes
Public transport connections	Number of connections for O-D (AM peak)	Connections/trip
Public transit service frequency	The frequency of transit service at the origin (AM peak)	Services/hour
Active transport path connectivity	Rating by researcher of active transport route directly linking O-Ds based on % trip off-road and barriers (e.g. freeways, highways, etc.)	Rating from: 0 (poor) to 1 (good)
Greenhouse gas emissions by mode	Greenhouse gas emission factors (CO_2-e /passenger-km)	kg CO_2 –e/trip
Trips per O-D	Baseline travelling population from ABS Census, with projected growth from Victoria in Future and employment projections from Victorian Planning Authority.	Trips

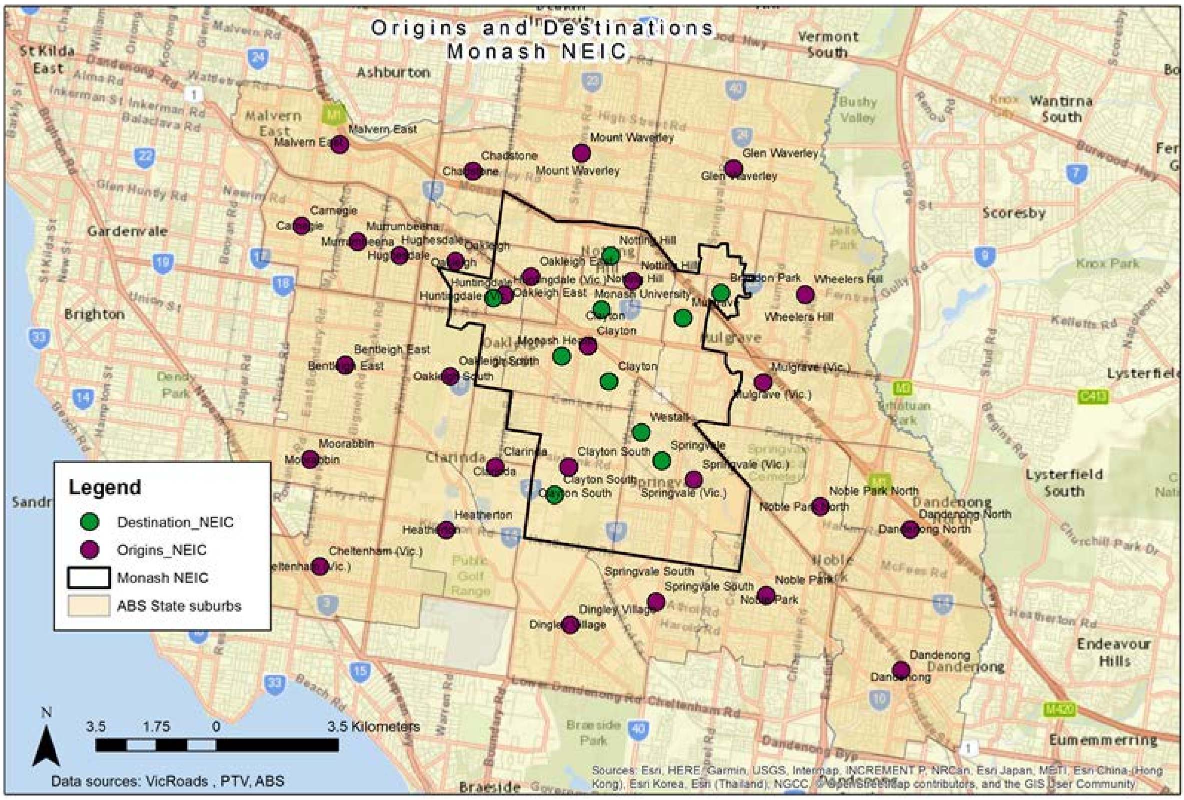

Figure 22: Monash NEIC modelled origins and destinations

Results

The following scenarios were modelled for the Monash NEIC:

1. Upgrading of off-road active transport paths connecting origins and destinations (including transit nodes).
2. Improved public transit services that reduced the number of connections and frequency of services between origin and destination points.
3. Combination of both upgrading of off-road paths and improved transit services.

The scenarios were simulated over the period 2018 to 2028, with a summary of results shown in Table 6.

Table 6: Summary of scenario results for the Monash NEIC

Scenario	**Annual avg. CO_2-e per commuter (tonnes)**	**Low Carbon modes adoption rate in 2028**		**Net CO_2-e reduction (Δ)**
		AT %	PT%	
Baseline (no intervention)	1	5	22	-
Improved connectivity of off-road active transit paths between origins and destinations	0.89	15	30	-11%
Improved public transit services	0.95	7	26	-5%
Combination of both upgrading of off-road paths and improved transit services.	0.91	12	38	-9%

Insights

The Monash NEIC is projected to grow rapidly over the next ten years, both in the resident population and number of workers. A current impediment to growth is the dependence on private vehicles for most trips, which is leading to increased congestion and higher levels of greenhouse gas emissions. The modelling process has provided the following insights:

- There is a strong latent demand for active transport for people who can access their destination by safe cycling and walking paths. However, at present in the Monash NEIC, there is poor active transport accessibility. The probability of active transport increases for destinations that can be accessed in less than 30 minutes by walking or cycling, which highlights the need for investment in active transport infrastructure around activity centres and transit nodes.
- The model considered primary transport modes only, but the MNL revealed the strong interdependencies between active and public transit modes, which is reflected in the increased likelihood of public transit use in areas serviced by active transport infrastructure. This highlights the potential for investment in improved transit services to be complemented by upgrades of active transit paths that provide last mile connectivity to link transit nodes with employment activity centres.
- The strong influence of commuters' intrinsic priorities for health, safety, flexibility and the environment on the adoption of active and public transit modes. This highlights the need for building awareness of the benefits of active transport modes where a decision to shift to active transport can be triggered in receptive people through investment in bike/walking path infrastructure.

Planning for the sustainable growth of suburban employment precincts, such as the Monash NEIC, requires a shift to a more sustainable transport mix. In the Monash NEIC, there is the need to consider active transport in combination with upgrades to transit services in order to maximise increased accessibility in the catchment surrounding transit nodes.

Reflections

The suburbs are often envisaged as sprawling areas of low-density residential development around the city core. However, analysis of employment locations in Australian cities, such as Melbourne, shows that while the greatest density of jobs occur in the core of the city that the vast majority of jobs are located in the suburbs. This decentralisation of jobs is not supported by current transit infrastructure, especially rail, which is designed around getting people in and out of the city core. The reliance on cars for transport in Australia's suburbs presents challenges for reducing transport emissions in our cities, and also the future liveability of suburban precincts due to increased congestion.

The Monash NEIC is situated in the suburban heartland of southeastern Melbourne, and typical of areas that developed in the post-war period, the transport infrastructure supports the majority of trips being made by private vehicles. It has been identified that a major constraint to the growth of this employment cluster is car dependence and associated traffic congestion. The Monash NEIC provided an opportunity to model and evaluate interventions in the suburban context that have the purpose of increasing the uptake of low carbon transport modes.

The analysis of travel surveys demonstrated that transport mode choice is mostly driven by a traveller selecting the mode that maximises their utility in terms of travel cost and time. However, it was also shown that an individual's attitudes and values influence their receptivity to changes in transport modes. This included their intrinsic values around the environment and health, as well as comfort and flexibility. Therefore, in developing a tool to evaluate the effectiveness of interventions in increasing the adoption of low carbon transport modes there was the need to consider different decision making profiles of the travelling population, and how they might react to improvements in public transit and active transport.

Incorporating the decision making profiles, from the survey analysis, within an agent-based modelling provided a flexible, bottom-up approach for simulating how simple rules that govern transport mode choice at a local level can result in the emergence of complex system behaviours at a precinct scale.

The human behavioural model, demonstrated by the ABM-TMC, can complement more traditional transport planning and modelling approaches. Whilst it is recognised that there is significant merit in traditional approaches to transport demand modelling that is focussed on identifying the most efficient mode on the basis of 'rational behaviour theory, these models may not reflect that a traveller's behaviour is shaped by previous experiences, cognition and attitudes, and therefore there may be a role for a model that simulates the impacts of these factors on mode shift behaviour. The approach outlined in this report can help policymakers who want to reduce uncertainty around how commuters' mode choice is likely to be influenced by investment decisions or policy actions. The approach is able to reflect the complexities around commuter decision making.

Ongoing activities: Where to next?

The case study analysis and ABM-TMC outputs were presented to a *Transport for Victoria* transport planning team, who were engaged in previous workshops for this project. The feedback indicated the model's capacity to incorporate human decision making profiles would potentially be of value in evaluating likely behavioural responses in transport demand for specific interventions (such as dedicated bus lane with associated walking/cycling path). Also, the approach might help to support the integrated assessment of transport projects that includes the understanding the role of active transport at the local scale around activity centre and transit nodes under their Movement and Places framework.

Related projects

RP3028 - Mapping the adoption processes of energy efficient products in the residential sector

RP 3035 - Modelling Uptake of Water Conservation and Efficiency Measures in Sydney

These projects will be showcased on the following website www.ned-abm.com.au/ which includes the following information:

- Lite web-hosted versions of the models, with associated user guides
- Background on the modelling approach, with links to associated reports and papers
- Case studies
- Contact details for more information

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Summary of travel supply analysis

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The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

Final report on *Greening Suburban Travel* (Work Package 2: Travel supply analysis – University of Melbourne)

The University of Melbourne's contribution to this work package was chiefly through investigation of the potential for the use of a recently developed tool for modelling the impact of changes in suburban public transport network quality on accessibility to employment.

We also contributed to understandings of the current situation regarding opportunities for reducing the carbon footprint of suburban transport through disruptive technologies, shared car ownership and on-demand access to public transport and mobility options

The major project was MPhil research conducted by Jana Perkovic under the supervision of Dr John Stone and Dr Jan Scheurer. This project revealed some of the limits to achieving low-carbon access to suburban employment centres under current planning regimes in Australian cites.

Short summaries of these projects are found below.

1. *Using SNAMUTS to Plan for Change: The Place for Accessibility Modelling in Strategic Planning Processes for Urban Transitions*

Visualisations of the impact of possible planning interventions are an important tool in planning processes, particularly for engagement with decision makers and the wider public. This research tested the use of maps and other visualisations produced with SNAMUTS – a supply-side public transport accessibility model – to explore the changes required in land-use and public transport supply to achieve significant shift to 'low carbon' modes for travel.

The case study explored the relationship between technical-rational planning practice (exemplified by discursive use of the SNAMUTS model developed by Curtis and Scheurer–www.snamuts.com) and the current opaque and politicised planning practice in Victoria.

It did this by:

- Analysing outputs of existing planning processes with a case study for the Monash National Employment and Innovation Cluster (NEIC). NEICs are areas of Melbourne designated by the State Government as locations for future investment to support growth in jobs and services.
- Identifying scenarios for possible planning interventions to achieve a shift to low-carbon modes (this included changes in demographics, land-use and supply of opportunities for lower-carbon travel).
- Production of maps and other visualisations to illustrate changes in accessibility
- Using these visualisations in workshops led by developers of the model to address the objectives listed above
- Evaluating the usefulness of the tool to support and improve planning practice.

This tool is useful at the precinct or metropolitan scale and was applied here at the precinct level in Melbourne's south-east. It can be used either as means to evaluate accessibility changes from current proposals, or as a method of testing what types of change in transport supply and land-use are required to achieve a desired level of accessibility for a precinct such as the Monash NEIC.

The Monash NEIC does not have a direct connection to the suburban rail system. The principal link to the CBD is via a frequent shuttle bus from Huntingdale Station (~3km to the centre of the NEIC). Other public transport is provided by buses on major arterials at low frequencies and hours of service.

The SNAMUTS tool (described graphically in Figure 1) provides indicators of:

1. relative ease of movement to and from a node in the public transport network (speed and frequency of service);
2. average minimum numbers of transfers required to reach all other nodes in the network;
3. "movement energy': the number of transit journeys passing through each node;
4. jobs and residents within 30-minute travel time by any combination of public transport modes (expressed as percentage of the metropolitan total accessible from each node);
5. potential for transit-oriented development ('connectivity' measured by the number of lines and services at each node);
6. latent demand: potential mismatch between actual service levels and number of lines passing through a node;
7. efficiency change: geographical distribution of changes in accessibility resulting from any proposed changes in public transport provision;
8. A legible composite index of public transport performance.

Outputs, findings and implications

- Modelling the existing public transport network showed that the Monash NEIC was one the most poorly connected nodes in Melbourne. This emphasised the difficulty of attracting employees of the Monash NEIC to public transport.
- SNAMUTS modelling was used to compare the changes in connectivity at the centre of the Monash NEIC achieved through two scenarios for public transport improvement:

    1. Upgrading bus services linking the NEIC to multiple stations on the Dandenong, Glen Waverley and Ringwood lines in a grid- pattern at 10-min frequencies;

    2. A new light-rail from Caulfield to Nunawading (on the Ringwood line (via Chadstone Shopping Centre and the Monash NEIC).

- The analysis showed that the bus option improved connectivity for the Monash NEIC to around the mean for Melbourne. The tram option performed only half as well.

    SNAMUTS is a supply-side model and so does not estimate the ridership of a re-structured network. However, a shift of 20 percent of car travel to the Monash NEIC to public transport powered by renewably generated electricity would avoid around 0.32 MT CO_2-e per annum in 2027 on conservative projections for growth of the NEIC.

- Planners found the SNAMUTS modelling of various scenarios useful. Particularly, they felt that the visual representations of the network impacts of various scenarios for new bus and light-rail services into the NEIC would be valuable for communication with politicians and the public. These scenarios were suggested by the project team and by representatives of major employers in the NEIC but, as discussed below, were not included as options in the formal planning processes.

- A strong limiting factor in the planning process for improved public transport to the Monash NEIC was revealed in interviews with participants. These planners revealed that politicians do not allow transit proposals to be considered even in semi-public planning processes such as those conducted for the NEIC. This is to avoid any community 'expectations' that investment will take place. The result is that planning processes cannot properly investigate the potential for enhancing public transport to meet desired objectives.

Jana Perkovic's MPhil dissertation was completed in late 2018 and received an H1 grade. It will be published in April 2019 following minor revisions.

Perkovic, J. (2019). *Using SNAMUTS to Plan for Change: The Place for Accessibility Modelling in Strategic Planning Processes for Urban Transitions* (MPhil), University of Melbourne, Melbourne.

2. Understanding the potential for shared and autonomous vehicles to reduce carbon footprint of suburban passenger travel

The LCL CRC support has allowed Dr John Stone to continue work with colleagues at University of Melbourne and Curtin University, Perth to develop a strong research agenda on this question and to undertake several pilot projects that have been used to build industry support for a large ARC Linkage proposal (Planning the Driverless City) that is now under review.

This project has five key objectives:

1. Co-create understandings of the implications of emerging pathways to MaaS and AV deployment with industry and government by establishing and maintaining a Knowledge Hub.
2. Build scenarios for MaaS and AV deployment in Melbourne, Perth and Sydney based on variation in degrees of sharing and integration with existing transport systems.
3. Identify impact measurements and conduct assessment of future transport systems in different urban systems, land use patterns, and planning contexts under identified scenarios.
4. Develop a planning decision-support tool to inform policy, regulatory and planning interventions.
5. Assist our industry partners to build on the connections created in the project to develop new practices to meet the challenges of the new transport technologies.

Partners include Keolis, Mirvac, Minter Ellison, BMW Munich, K2 Sweden, and state transport agencies in Victoria, NSW and WA.

This work has international recognition. (Dr Stone was one of 8 international invitees to a research symposium at the 2017 International Transport Forum in Leipzig.)

Outputs include:

Stone, J, Legacy, C, Curtis, C (2019), The Future Driverless City?, Planning Theory and Practice, 18:5, 753-778

Legacy, C, Ashmore, D, Scheurer, J, Stone, J & Curtis, C (2019), 'Planning the Driverless City', *Transport Reviews*, 39:1, 84-102, DOI. 10.1080/01441647.2018.1466835

Stone, J et al. (2018), 'Planning for disruptive transport technologies: how prepared are Australian transport agencies?', in Marsden, G & Reardon, L (eds), *Governance of Smart Mobilities*, Emerald Publishing, UK.

Stone, J & Kirk, Y. (2017), 'The "disruption" we really need: public transport for the urban millennium' in Dia, H (ed.), *Low Carbon Mobility for Future Cities: Principles and Applications*, Institution of Engineering and Technology, Stevenage, UK.

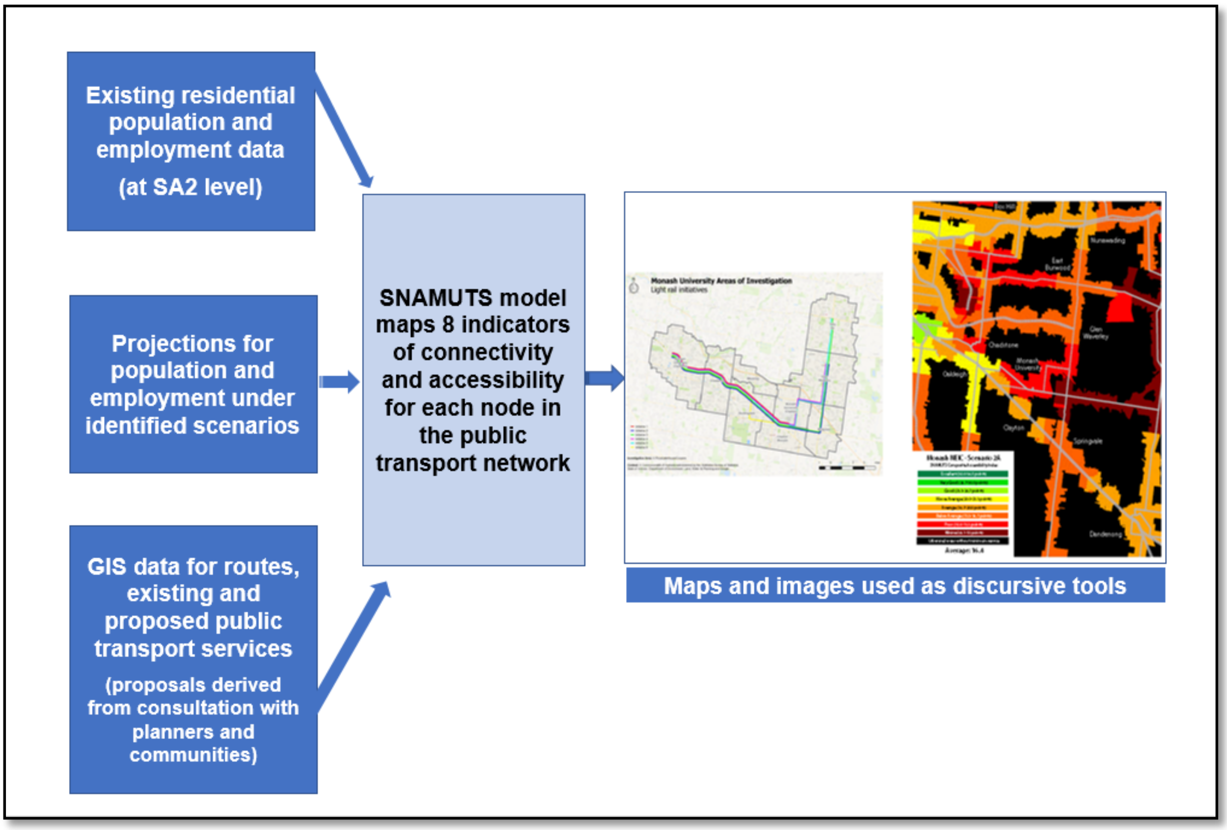

Figure 1: Inputs and outputs for the SNAMUTS accessibility tool for public transport planning