PUBLIC TRANSPORT IMPROVEMENTS
WITH FOCUS ON ON-DEMAND BUS SERVICES
USING TRAFFIC SIMULATION

Supervisor : Dr. Nicholas Holyoak

Student : Phan Hong Lan Tran

Student ID : 2224915

College of Science and Engineering

Flinders University

A thesis submitted for the degree of

Master of Engineering

Adelaide, May 2021

Acknowledgements

First and foremost, I would like to show my sincere gratitude to my supervisor, Professor Nicholas Holyoak. He has guided me through the research process, which was a big challenge for me. His patience and expertise stimulated me to keep trying with the meaningful but demanding engineering tasks in transport planning and operating even though the directions have changed a lot.

I am also lucky to receive technical support in using transport planning programs such as Cube, Infrawork, Sidra, and Aimsun from Professor Branko Stazic who taught me two transport topics namely Transport System Engineering, Transport Planning and Modelling. Students often called him non-official working hours professor because he has got back to students swiftly. He is a role model in Transport Planning and Modelling as well as driverless vehicles.

I would like to thank my teachers, Mr. Sandor Hovarth, Mrs. Helen Palmer, Mr. Trevor, Mrs. Katja, Mrs. Neda Yazdani, and her family, the Vietnamese community in Upeksa Meditation Village, for their unconditional supports, which have contributed to unforgettable memories with my daughter in Adelaide. I am excited to express my appreciation for my friends and roommates (Son, Giang, Tuan, Kim Anh, Hieu, Rider, Liz, Hang, Ai Vy, Nino) who guided or accompanied us during many exploring trips for shopping, entertainment. We visited many beautiful places in Adelaide using Public Transport such as Port Noarlunga Jetty, Onkaparinga River Mouth, Morialta Conservation Park, Belair National Park, and Kangaroo Island.

Finally, I would like to express my admiration to my family, especially my father and my younger brother, who work as long-distance drivers. They have told me humorous and inspiring stories through their journey, such as a miss death experience. Therefore, I have a fetish for road and bridge infrastructure construction and maintenance to provide smoother, safer journeys. After my further study in Australia, my knowledge upgrade from cost estimating and technical checking to planning and modelling the network.

Deeply from my heart, I acknowledge the Australian Award Scholarship that has provided my husband, my daughter and I two valuable chances to come to Adelaide in 2013 and 2019.

Flinders University's International Student Support team always support me during my journey. I never feel lonely because they not only give financial support but also mentally care for our lives.

The above-mentioned features have tackled the willingness to give back, to keep traffic moving effectively, safer so that no-one is left behind. Senior citizens should have more chance to pass on and feel connected.

DECLARATION

I certify that this work presented in the thesis is the author's original work unless it is referenced.

Signed: 

Dated: 20 May 2021

Executive Summary

Public Transport (PT) has played an important role in ensuring society mobility, active travel, social equality, and relieving traffic congestion (Cao et al. 2017). However, Adelaide Public Transport has been assessed as an extensive yet underused network with spare capacity (Infrastructure SA 2020) because of the lack of integration for linking services, low frequency and improper coverage which makes PT less attractive. The aims of this thesis are to gain understanding about Public Transport in Adelaide and methods for shortening travel times, which would result in better public transport patronage and the reduction in private vehicle trips. Specifically, assessing the effectiveness of the new train line extension from Tonsley station to Flinders station and the operation of the network connecting two Flinders University Campuses, Tonsley and Bedford Park will be investigated. Since, the focus of this research is on Tonsley loopbus, Flinders Express and autonomous vehicle FLEX, these transport services are the main objectives of the detailed transport modelling to be undertaken. In addition to detailed study of the Darlington area, the other Adelaide Public Transport corridors were experienced by the author using different means of tranport such as bus, train, tram, the Bus Rapit Transit, and Sealink station to door bus-ferry-bus to understand the transit services in Adelaide in a customer point of view. Thereby, PT improvements were proposed with evidence-based benefits of linking local services to the current government transit service by Flinders line train. Although, the travel time investigation is the main focus of this research, an estimation of other transport key performance indicators (KPIs) is carried out, such as the potential for reducing vehicles' emissions. The traffic microsimulation approach, using start-of-the-art Aimsun software package, is utilised in thorough transport network operation.

Contents

List of tables

List of figures

Road traffic terms definition

SCATS is an abbriviation terms for Sydney Coordinated Adaptive Traffic System which is one of an intelligent traffic control system. According to data on SCATS website, this technology has been installed in over 55,000 intersections across 187 cities and 28 countries worldwide (Transport for New South Wale 2021),(Bing et al. 2019).

DIT: Department for Infrastructure and Transport.

GEHE bus : gas-electric hybrid electric buses.

CNG bus: compressed natural gas buses.

EURO 4 bus: EURO 4 heavy-duty diesel engine buses.

EURO 5 bus: EURO 5 heavy-duty diesel engine buses (Wang et al. 2018).

Chapter I: INTRODUCTION

1. Back ground

Public Transport patronage in Australia is very low and significant efforts and resources are needed to achieve a shift away from private car travel. Thus, the Australian Governments, Federal, State and Local, are investing money in Public Transport improvements. There are numerous examples of such projects throughout the country and one of the recently completed projects in South Australia, Flinders Link Project is the focus of this research. Public transport enables mobility, reduces traffic congestion, connects social needs with resources, enhances preventative care for community especially the notable growing population of senior citizens around the world (Liu et al. 2021) (The International Association of Public Transport 2004; Transport For London 2010). Firstly, good practice in public transport helps vulnerable people travel around such as senior citizens, disable people, low income households who do not have driving licence (Ricciardi, Xia & Currie 2015),(Truong & Somenahalli 2015),(Liu et al. 2021). Secondly, mass transit is a feasible solution to traffic congestion in developed countries such as the United States, Hongkong, London, and Japan (Tang & Thakuriah 2012) (HongKong Transport Department 2021). Therefore, making public transport more effective is the crucial measure to increase patronages proportion from private car to public transport (Nuzzolo & Comi 2016). In addition to reducing the traffic congestion levels, an increased public transport patronage has a potential to significantly reduce the adverse environmental effects of traffic.

2. Review of the South Road, Darlington Aimsun construction staging model and the model calibration Report

The model was built and calibrated following the recommended steps specified in DIT's AIMSUN Development Manual (Department for Infrastructure and Transport 2019). Modelling periods, the morning AM peak (7:00-9:30) and the afternoon PM peak (16:30-18:30) were selected to capture the traffic conditions during the busiest times of the day and to capture the influence of students and Flinders precint traffic on surrounding network.

In addition to model calibration that involved matching the observed turning volumes and capacities, three separate model validations were performed. These were done by the comparison of observed and modelled value for the section flows, queue lengths and paths travel times.

Traffic demand was specified through the use of Origin-destination (OD) matrices for cars and heavy vehicles. In addition to private vehicles, public transport demand was specified as fixed route services.

Several traffic signals exist in the area and the signal operation was specified as vehicle actuated using data from SCATS system.

Each of the scenarios modelled was run for 5-10 replication and results averaged in order to minimise the effects of microsimulation random nature.

It was found that the model is well calibrated and fit-for-purpose to be used as the base model to test construction staging scenarios.

The original Aimsun model and the calibration report was provided by DIT (Department for Infrastructure and Transport 2015).

The original DIT's Aimsun model was further expanded to include some addition roads that were deemed necessary for this research. Also, additional traffic signals, railway extension to FMC, driverless vehicle service, Bedford Park Flinders University car parks were added to the model. Another gap in the Darlington construction staging model was that the transit plan only catered for Public Transport schedules and routes that captured Adelaide Metro Buses. Other Public transport services were added to the model, such as rail, Flinders Express bus, FLEX and Tonsley loop bus.

3. Significance of the study

Roadway density and traffic congestion substantially increased over the last years across the world, especially near large metropolitan areas, primarily due to rapid industrialization, fast population growth in some areas, urban development, and increasing demand for passenger and freight transport (Markvica et al. 2018) (Rahimi, Dulebenets & Mazaheri 2021) (de Carvalho et al. 2020). This research investigated the operation of the South Road that has been listed as one of the top ten most congested roads in South Australia (Infrastructure Australia 2019).

According to Department for Infrastructure and Transport, the third target in the 30-year plan for Greater Adelaide is to increase the share of work trips made by active transport modes by residents of Inner, Middle and Outer Adelaide by 30% by 2045 (Department of Planning Transport and Infrastructure 2017).

There are five advantages of active travel (Department of Planning Transport and Infrastructure 2017, p. 144).

- increased capacity and reduced congestion in the transport network
- reduced environmental impacts
- improved public health
- reduced healthcare costs
- improved community wellbeing and social cohesion

From the above mention difficulties and strategic target, public transport study in the Tonsley area is highly necessary for improving traffic congestion and enhance patronages by encouraging commuters to shift from private vehicles to public transport.

The results from this study can be applied to other Adelaide traffic study areas and they can be a good starting point for further research. There was a real need for a traffic study in this area because the Tonsley innovation district has been built recently. In addition, the demographic and social, economic factors will change rapidly. Thus the model that was built as a part of this research can be used and further refine to accommodate studies that seek to capture the effects of these changes.

4. Reason to choose AIMSUN microsimulation

Through research, the author decided to choose AIMSUN because of its reputation, outstanding dynamic simulation capability (Casas et al. 2010), some unique characteristics and the fact that it has been selected as an exclusive microsimulation software by The Department of Transport in South Australia.

AIMSUN has a long history since 1986 when it developed a microsimulator prototype named AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) (AIMSUN a Siemens Business 2021).

It can be used for different types of analysis such as Mesoscopic, Microscopic or hybrid (combination of mesoscopic and microscopic). The study areas can be wider than the other conventional programs. In addition, AIMSUN can integrate well with other program such as GIS.

It has been aproved by Department for Infrastructure and Transport (Department for Infrastructure and Transport 2019). AIMSUN is the only company that successfully deploys individual vehicle simulation-based traffic prediction in Real Time (AIMSUN a Siemens Business 2021).

According to Hidas, a manager of Transport Model Application in New South Wales Department of Planning since 2005, AIMSUN outperforms other microsimulation packages such as Paramics and Vissim, in terms of the major transportation network performance indicators (i.e., vehicle flow, travel speed, and total travel distance). AIMSUN can store network model, traffic demand data, traffic control plan, public transport plan and the GETTRAM extension used for coding, therefore AIMSUN model can be utilise to run different scenarios in the same or different network that fit for the intended purpose. (Hidas 2005)

5. Purpose of the Study

This research aims at answering two questions:

What are the causes of low number of Public Transport users in Adelaide?

What are the possible suggestions to make Public Transport more appealing and safer?

Therefore, the objectives of the research are:

- Research about the transportation planning process
- Research about demographic profile to gain understanding about the dispersion of Public Transport in Adelaide
- Research to get an understanding of trip generation in terms of the integration of land-use and transport planning.
- Investigate microsimulation study area using AIMSUN.
- Synthesise the output and evaluate the effectiveness of the new innovative Flinders link project.
- Confest limitation of this research.
- Recommend future study.

6. Structure of the thesis

This thesis consists of the introductory chapter followed by four other chapters that are outlined as follows:

Chapter 2 reviews the current public transport system in South Australia, demographic profile investigation based on census data 2016, and transport planning process.

Chapter 3 presents the methodology for buiding the model and generating output.

Chapter 4 expresses the findings and discussion based on the input from chapter 3.

Chapter 5 draws a conclusion and recommendation for further research.

Finally, I acknowledges the sources of previous research in the references.

Appendices convey the whole set of results from Aimsun microsimulation in base year 2021 and future year 2031 and some parameter setting from Aimsun modelling process.

Chapter II: LITERATURE REVIEW

The purpose of this chapter is to review the previous studies relating to the research aims and the objectives of this research. Firstly, the system of public transport in Adelaide is explored in terms of facilities and the quality of the service provision. Secondly, extensive research on the geographical and people profiles in South Australia based on the 2016 census was done to gain an understanding of crucial factors for transport planning. Thirdly, reports from previous research in Flinders – Tonsley precinct on traffic, transport and parking was collated and analysed to achieve a better understanding of the network operation and enable a better transport planning process. Then, a summary of four stages in the transport planning process was presented with a detailed description of macro-level modelling for strategic planning and microsimulation for detailed network operation. Finally, the fixed-route level of service was examined through literature review and the annual reports from 2016 to 2020 by the Department for Infrastructure and Transport.

1. Public Transport in Adelaide

1.1. Transport facilities

In this part, a general review about PT service in Adelaide is summarised as below:

The Public Transport system in Adelaide has many components from light train, tram, bus rapid transit , normal bus, electric bus (Flinders University 2021), solar-powered bus (RenewEconomy 2013), park and ride facilities (Adelaide Metro 2020d) (Wiseman et al. 2012). Adelaide is famous for the lowest price for PT ticket with an integrated fare and ticket system within the whole system for 2 hours (Bray, Taylor & Scrafton 2011). This means that passengers are charged only once for a two-hour ride without considering the distance of travelling and unlimited transfer using different routes and modes such as bus, train, tram (Adelaide Metro 2020b). Railways are considered safe, efficient, reliable, comfortable and environmentally friendly mass carriers (HongKong Transport Department 2021).

1.2. Level of services

The level of public transport service reduces from the city centre to the other places. There are three main zones namely inner metro, middle metro and outer metro (Department of Planning Transport and Infrastructure 2017). Commuters need to do some research to figure out the most suitable routes. They may need to use family drop-off, pick-up service because local bus services on- demand support through a phone call for the residents only (Adelaide Metro 2020a). Commuters need an internet connection to use Adelaide transport services because of the complicated variation in boarding stations and skipping drop-off in the same routes during the peak and off-peak period which are presented on the printed timetable (Adelaide Metro 2020e).

The striking part of Adelaide metro is that there are free city services 98C, 98A, 99C, 99A clockwise and counter-clockwise route (Adelaide Metro 2021a), and free tram zone (Adelaide Metro 2021b). The free 40-seat bus provides air conditioning and free wifi, in line with the citizen's environmental support because it receives electric power from solar panels located on the city's central bus station (RenewEconomy 2013). It takes around one hour to travel the big loop around Adelaide city in 98 route which is bigger than the 99 route (Adelaide Metro 2021a).

At Flinders University, there is a digital interactive screen provided in a bus stop waiting kiosk. These colourful smart touchscreens provide a range of services such as wayfinding, promoting upcoming events to the community, the closest and most convenient services, points of interest, improving accessibility (Flinders University 2021).

2. Socio-economic characteristics investigation

Every five years, the Australian Bureau of Statistics conducts a national survey to collect sensus data including population, ethnicity, education, families, income, labour force, dwellings. The most recent census was 2016 (Australian Bureau of Statics 2017).

2.1. Population density

The 2016 census revealed that the highest population density of all urban areas in South Australia was in Adelaide with 86% of the state population, around 1.33 million people (Australian Bureau of Statics 2017). The other urban areas were only accounted for a small proportion from 0.28 percent to less than 2 percents.

One of the main factors for a successful public transport plan is population density which is expected to be from 3,000 people per square kilometre (Department of Planning Transport and Infrastructure 2017), (Chang et al. 2019), (Transport For London 2010). According to the Australian Bureau of Statistics, population density is affected by high-density housing and the proportion of non-residential land in a suburb such as parks, factories, and airports (Australian Bureau of Statistics 2002). In addition, this data has also changed quickly through time due to changes in the trend towards urbanisation and geopolitical power (Acworth 2014). A typical example from a case study of the urban renewal process in a 1,6 km^2 peninsula named Pyrmont, Sydney, New South Wales showed a dramatic change in population density of 12,500 people/km^2, from fewer than 5,000 people in 1994 to over 20,000 people in 2012 (Acworth 2014). Thus, the Tonsley innovation district is a perfectly inspirative location for Public Transport improvement research.

According to the ABS statistics, the population growth rate in different states and the average rate in Australia in 2019, and the net overseas migration (NOM) were double the natural increase rate. Victoria recorded the highest growth rate of all states and territories at 2.1% while The Northern Territory recorded the negative growth rate at -0.5%. It is noted that South Australia growth rate experienced the second-lowest growth rate at 0.85%. Data in September 2020; South Australia's population is 1.77 million people (Australian Bureau of Statistics 2020). This might indicate that the number of people in South Australia would increase by 15,045 people a year. In the 30 year plan for Greater Adelaide, it was estimated that the Greater Adelaide population will be increased by 545,000 people by 2045, nearly 350 people per week. This data was based on the population projections approved by Cabinet for land-use planning purposes in July 2015. (Department of Planning Transport and Infrastructure 2017) The figure below shows the age and sex distribution in South Australia as recorded in 2019.

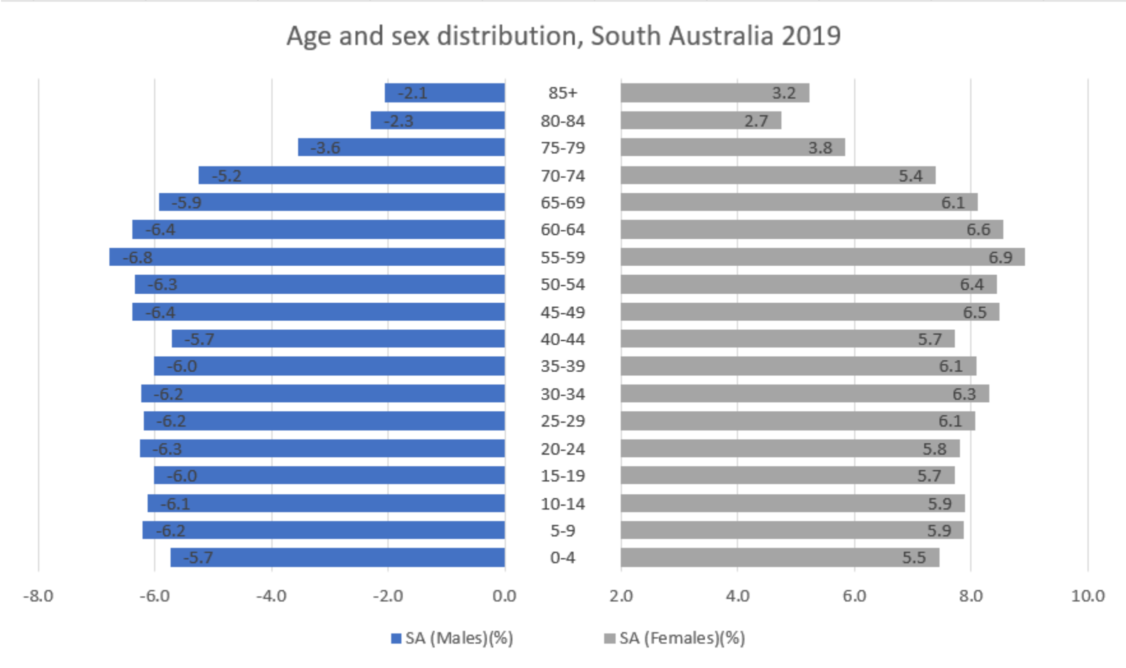


Figure 1: Age and sex distribution, South Australia 2019

2.2. Employment

There were 636,110 people reported being in the labour force in the week before the census night in Greater Adelaide (Greater Capital City Statistical Areas). Of these, 54.0% were employed full time, 33.5% were employed part-time and 7.7% were unemployed, and 4.8% were away from work (Australian Bureau of Statics 2017).

2.3. Motor vehicle ownership and discussion about trip generation

Many studies have been conducted using demographic and socioeconomic characteristics of households survey data for finding the relationship in average trip generation with monthly income and household car ownership (Kitamura 2009), (Tian, Park & Ewing 2019). Ryuichi claimed that household car ownership is the main determinant in trip generation while household income only plays a minor role in trip generation. However, household income is one of the most significant factors in the generation of mechanised trip, sample for modelling from Dutch National Mobility Panel data set.

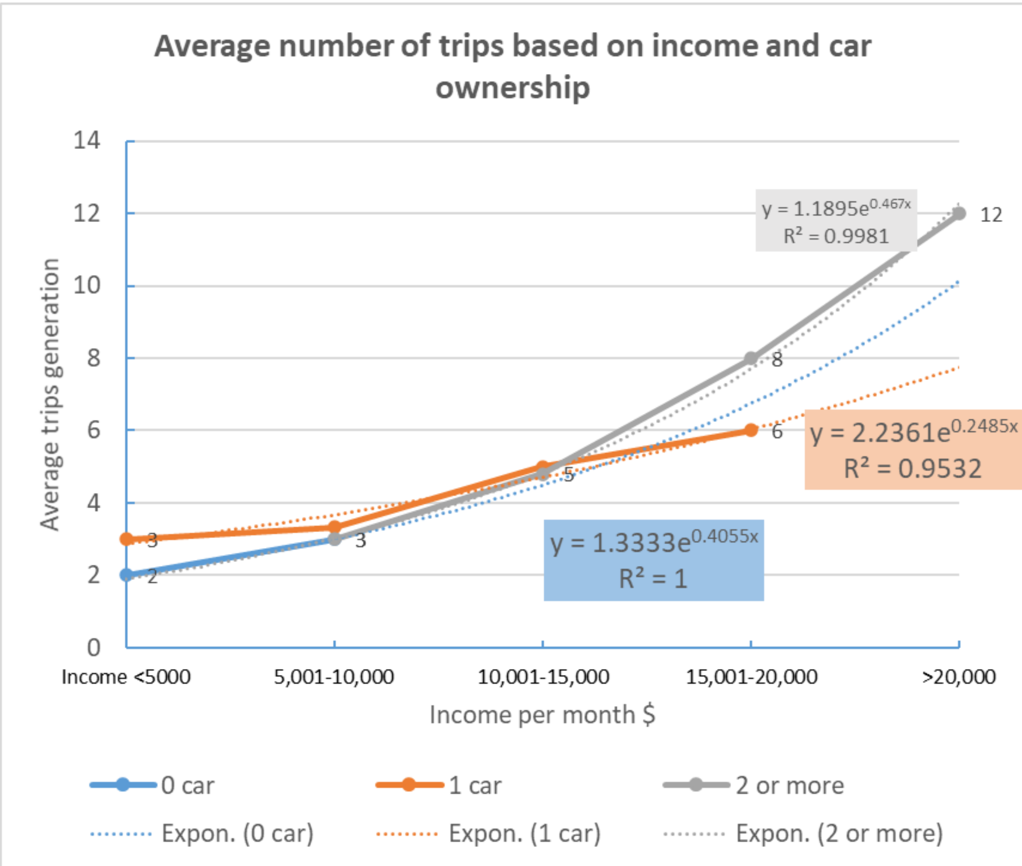


Figure 2: Graph of average number of trips based on income and car ownership

Table 1: Matrix of average number of trips based on income and car ownership

Income/ month [$]	Car Ownership		
	0 car	1 car	2 or more
Income <5000	2	3	
5,001-10,000	3	3	3
10,001-15,000		5	5
15,001-20,000		6	8
>20,000			12

(Note data for generating the graph in Figure 2 and Table 1 is taken from a tutorial example in Transport Modelling lecture by Dr. Nicholas Holyoak, a demographic survey is put in the appendices)

Discussion:

The graph shows the relationship between trip generation and car ownership as the main determinant factor. It can be seen that households with two or more cars possession tend to travel more than households with only one car. Households with no car possession have the lowest trip generation compared to the other family types. From Table 1, it can be seen that the average trip of household with income lower than $5000 is 2 to 3 trips, while these trips of household with income higher than $20,000 are six times higher than the low-income households.

Based on the matrix of average trip generation based on household income and car ownership, a researcher would derive the mathematical function to generalise trips from demographic data as shown in Figure 2 (page 10).

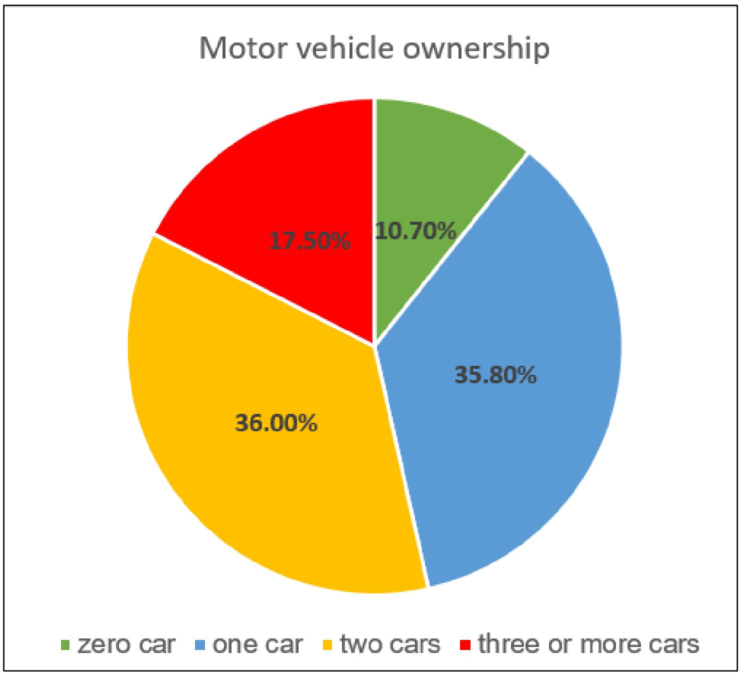


Figure 3: Motor vehicle ownership in South Australia (Australian Bureau of Statics 2017)

In South Australia, 89% of households had registered motor vehicles while nearly 11 % of the population has no means of private transport (Australian Bureau of Statics 2017). There were 72,068 households without a car (data based on the number of household types in the appendices). This data has significant meaning in transport planning because this graph could be read together with the low-income report to assess the extent of the dependency on public transport, active travel method or taxis.

In the 2016 Census, 161,649 households accounting for nearly 24 percent of households in South Australia received weekly income under $650. In Greater Adelaide (Greater Capital City Statistical Areas), 22.6% of households had a weekly household income of less than $650 and 11.9% of households had a weekly income of more than $3000. (Australian Bureau of Statics 2017)

2.4. Travel to work

In Greater Adelaide, as per census data in 2016, people travelling to work by car accounts for 70.5% including, 66% as a driver and 4.5% as a passenger. The carpooling rate is lower than 7%. Only 4.9% of employed people travel to work by bus. On the census day, 8.8% of employed people used public transport (train, bus, ferry, tram/light rail) while 72.5% used a car (either as a driver or as a passenger) (Australian Bureau of Statics 2017).

It is reported that transport costs are the second-largest component of household expenditures. (Government of South Australia 2017) This travelling cost will be significantly higher for people living in the outer metropolitan areas compared to those living in inner and central suburbs.

2.5. Living affordability and building better city program (BBCP)

South Australia has experienced a lower rate of population growth and a higher rate of young people leaving the State to pursue their career. The trend of increasing in demographic (lone-person, single-parent and couple-without-children households) has intensified the demand for well-designed smaller accommodation, aged care and age-in-place options (located next to services, public transport and other fundamental facilities). (Government of South Australia 2017)

According to Mr. Willis, the Minister for Housing and Regional Development, Ultimo Pyrmont was provided $117.04m total funding over 5 years for Area Strategy consisting of the redevelopment of the area for a mix of residential, commercial and recreational purposes. Ultimo Pyrmont was a typical example for socio-cultural and environmental lessons because the BBC project purposes are to improve public transport, private and public housing, to construct new and refurbish infrastructure and new community facilities. (Parliament of Australia 1994)

Discussion: New South Wales received the highest amount of money compared to the other states for projects in the building better city program. Meanwhile, Elizabeth Munno Para, South Australia was reported about $16.16m total funding for 5 years for living improvements including community facilities, redevelopment of public housing and new and upgraded drainage infrastructure. However, there are also some social-cultural and environmental advantages and disadvantages of high-density housing style as seen in the suburb of Pyrmont in Sydney (Acworth 2014).

2.6. A case study Pyrmont, Sydney, New South Wales

There are some interesting facts from the dramatic change in population density of this 1.6 km^2 peninsula next to the Sydney CBD. Looking back at the history of the 1900s, the Pyrmont suburb received investment to become the major port for Sydney and a large number of other services such as railway goods yards, wool stores and large wharf to accommodate the ships. In addition to that, a power station and a CSR sugar refinery played an important part in providing job opportunity for its residents.

A political power influenced during the 1970s and 1980s had pushed Pyrmont into urban decay for two main reasons. First, the relocation of the port facility to a nearby modern site at Port Botany. Second, the decentralisation of industry lead to the move of the sugar refinery to Queensland and the closure of the power station. As a result of this, the population fell dramatically; the past dreaming land had only about 900 people in the late 1980s. The facilities was left to decay.

Positive change experienced since the new modern bridge construction which connected Pyrmont and the Sydney CBD in 1902. Additional to that, a $241 million grant from the federal government namely Building Better Cities program has revitalised Pyrmont since 1992. In 1994, fewer than 5,000 people lived in the area (Acworth 2014), but Pyrmont population has increased to 20,500 in 2021 and projected to 29,000 in 2041. The Pyrmont peninsula population is young. The most popular group was from 18 to 49 years old. The median age differs across the suburb. In Ultimo, the high concentration of students is a reason for younger median age of about 21 years old while an older median age is 34 years in Pyrmont suburb (Cred Consulting 2020).

Social-cultural and environmental advantages:

Transport infrastructure received significant investments from light rail, cycleways to walkways.

More job opportunities were created during the renewal process.

Providing a range of high-density housing. A mix of residential, commercial, retail and recreational areas.

A range of services to provide necessary needs for residents (e.g. café, restaurants, bars, supermarkets). The liveability of the city comes from these commercial facilities.

The high-density housing, combined with the vicinity to the Sydney CBD and the development of services, has attracted the young professional demographic.

The area also appeals to medium-sized businesses (particularly technology and entertainment businesses). This combination enables people to live close to their job locations. These businesses include Channel Seven, Channel Ten, Fox Sports, Google, Nokia, the Star Entertainment Complex and Nova radio station.

Social-cultural and environmental disadvantages:

Besides the positive development, there are some negative issues relating to the imbalanced demographic and the high-density housing.

The dominant demographic in Pyrmont is the young professional people. This is not a real society as a whole. People may not have regular connection to their extended families. The community lacks variety and richness.

More waste productions in a small area.

It is hard for many people to consider living in Pyrmont because of its high rents and housing costs compared to other regions.

Discussion:

This case study was chosen because it has similar characteristic to the residential and community living of the Tonsley Innovation district (Renewal SA).

High-value manufacturing industries was mentioned in the development of the Tonsley Master plan including:

- Health, medical devices and assistive technologies
- Clean tech and renewable energy
- Software and simulation
- Mining and energy services

The following tables give the trip generation rate estimates for the Tonsley area for 2020 and 2030 years for different land uses. It can be seen that in the next 10 years trip generation rates will almost double due to rapid development in the area.

2.7. GTA traffic report

GTA consultants is the leading transport consultancy for Australia which was founded in 1989 (GTA consultants 2020).

Table 2: Daily traffic generation estimated for 2020 (intermediate plan) in Tonsley area (GTA report) [44]

Use	Total Area (sq.m)	Traffic Generation Rate	Source	Generation Traffic
Residential	400 units	5.0 trips / dwelling	RTA – Medium Density Residential	400*5 = 2,000
Retail	1,600	45 trips / 100sq.m	½ MFY / 10% peak to daily ratio	45*1600/100 = 720
Light Industrial	8,600	5.3 trips / 100sq.m	GTA	5.3*8600/100 = 456
Education / Training * Flinders	1000 car parks	4.5 trips / car park	10% peak to daily ratio	4.5*1000 = 4,500
Education / Training * TAFE	600 car parks/1,000 students	8 trips / car park plus 1 trip / student	10% peak to daily ratio	600*8+1000 = 5,800
Commercial	18,780	10 trips / 100sq.m	RTA - Office	10*18780/100 = 1,878
Advanced Manufacturing	20,900	5 trips / 100sq.m	RTA - Factory	5*20900/100 = 1,045
TOTAL				**Total = 16,400**

Table 3: Daily traffic generation estimated for Master plan 2030 in Tonsley area (GTA report)[44]

Use	Total Area (sq.m)	Traffic Generation Rate	Source	Generation Traffic
Residential	850 units	5.0 trips / dwelling	RTA – Medium Density Residential	850*5 = 4,250
Retail	4,000	45 trips / 100sq.m	½ MFY / 10% peak to daily ratio	45*4000/100 = 1,800
Light Industrial	59,000	5.3 trips / 100sq.m	GTA	5.3*59000/100 = 3,127
Education / Training * Flinders	1,500 car parks	4.5 trips / car park	10% peak to daily ratio	4.5*1500 = 6,750
Education / Training * TAFE	600 car parks/1,000 students	8 trips / car park plus 1 trip / student	10% peak to daily ratio	600*8+1000 = 5,800
Commercial	51,300	10 trips / 100sq.m	RTA - Office	10*51300/100 = 5,130
Advanced Manufacturing	43,700	5 trips / 100sq.m	RTA - Factory	5*43700/100 = 2,185
TOTAL				**29,042 trips**

Table 4: Comparison about the proportion in trip generation in 2020 and 2030 in Tonsley area

Use	Total Area (in 2020) (sq.m)	Total Area (in 2030) (sq.m)	Trip estimation 2020	Trip estimation 2030	Traffic Generation 2020	Traffic Generation 2030
Residential	400 units	850 units	2,000	4,250	12%	15%
Retail	1,600	4,000	720	1,800	4%	6%
Light Industrial	8,600	59,000	456	3,127	3%	11%
Education / Training * Flinders	1000 car parks	1,500 car parks	4,500	6,750	27%	23%
Education / Training * TAFE	600 car parks/1,000 students	600 car parks/1,000 students	5,800	5,800	35%	20%
Commercial	18,780	51,300	1,878	5,130	11%	18%
Advanced Manufacturing	20,900	43,700	1,045	2,185	6%	8%

It can be seen in Table 4 that the biggest proportion of trip generation were from educational facilities of the TAFE and Flinders University. Therefore, the need for exploring the most effective way for work-trip travelling in Tonsley area has been considered a significant and valuable task.

3. Transport planning

Transportation planning process includes travel demand analysis, travel forecasting, trip generation, trip distribution, mode choice, and traffic assignment. Transportation planning process might be used to see the impact of a proposed new road, or new changes to an area (Pushkin & Özbay 2018).

There are different levels in traffic analyses from strategic planning to the most detailed microscopic planning. Depending on available resources and the type of analysis desired, an appropriate scale of model should be chosen. It is worthwhile to notice that the multimodel transport modelling can be achieved on several level of spatial and temporal scales, however data output accuracy and consistency must be addressed. These levels include macroscopic, mesoscopic, microscopic and nanoscopic. (Holyoak & Stazic 2009)

Image removed due to copyright restriction.

Figure 4: Transport Modelling Hierarchy used at VicRoads (Laufer 2019)

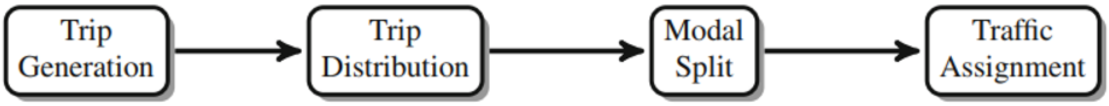


Figure 5: Four stages planning

3.1. Macroscopic models

According to Holyoak and Stazic (2009), travel movements with aggregate vehicles flows (such as in macro level models) over a given time period are presented without considering interactions between individual vehicles. Travel demands are estimated from socialdemographic and landuse data. Macroscopic models are suitable for wide-scale strategic policy testing with travel demands relating to many aspects such as:

Land-use strategies (e.g., population and industry rezoning)

Sociodemographic influences (e.g., changes in household structure)

Destination choice (e.g., introduction of new shopping centres or education institutions) Tonsley innovation centre

Mode selection (e.g., car, transit, freight and nonmotorized alternatives)

Route choice (e.g network closures or transit service introductions, transit service refurbishment and substitute train Grange bus service)

Broad-level intelligent transport system (ITS) applications (e.g., toll routes or high-occupancy vehicle (HOV) lanes.

Link travel time between two zones based on a relationship with travel time under free flow accounting to the coefficient and capacity of vehicles through that road per hour. This means that travel speed in each link defined based on road type and its capacity (veh/h).

There have been many trip distribution algorithms that have been proposed and used such as the opportunity model (Samuel 1940), gravity model (Voorhees 2013), and entropy models (Wilson 1967).

Example from CUBE: The input based on the map, the survey data such as the number of households, employment factors (retail, manufacture, service). To simplify the models, trips are classified into three types: home-based work trips (HBW), home-based other trips (HBO) and none-home-based trips (NHB). The percentage of daily trips generated in the period input is divided into five categories called night time (N), morning peak hours (M), interpeak hours (I) or business hours, afternoon peak hours (A), and evening hours (E).

According to Federal Highway (FHWA) which used to be the Bureau of Public Roads (BPR), Mathematical Programming Formulation is given by Equation (Pushkin & Özbay 2018, p. 28):

$$t_a(x_a) = v_f \left(1 + 0.15 \left(\frac{x_a}{c_a}\right)^4\right)$$

With $t_a(x_a)$ balanced travel time (at which traffic x_a can travel on a highway segment)

v_f free flow travel time observed travel time (at practical capacity) times 0.87

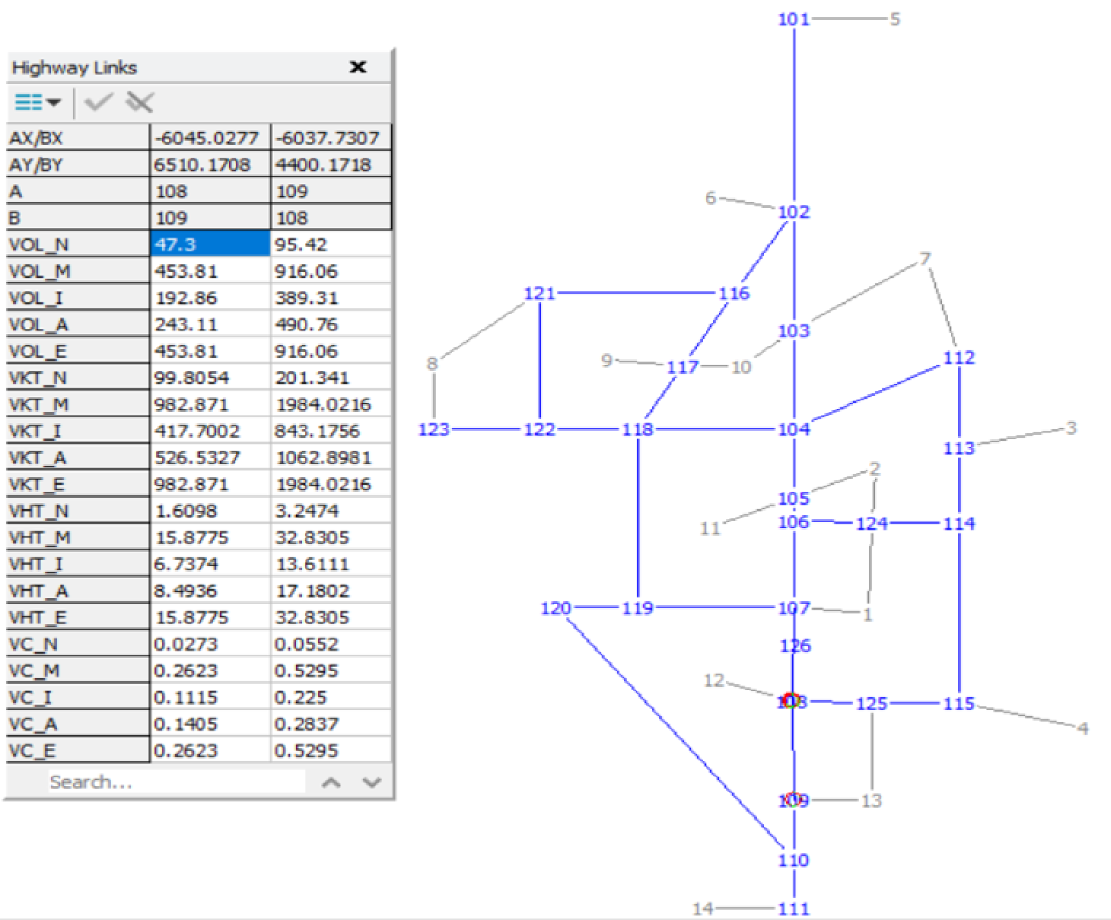
x_a the link traffic flow, assigned volume

c_a link capacity, practical capacity

The output comes after going through the process of building model, coding and analyzing by CUBE.

There are some important outputs namely: volume capacity report, network travel statistics, production and generation report, link volume report.

Volume capacity report highlights the capacity of all links from origin to destination in the network through all periods (night (N), morning peak (M), interpeak (I), afternoon peak (A), and evening (E)) in the model. In case the volume capacity ratio is smaller than 1, the link has sufficient capacity to serve. It is worthwhile to figure out methods to solve the congestion at those links which have this indicator greater than 1, the higher is the worse.



Highway Links

AX/BX	-6045.0277	-6037.7307
AY/BY	6510.1708	4400.1718
A	108	109
B	109	108
VOL_N	47.3	95.42
VOL_M	453.81	916.06
VOL_I	192.86	389.31
VOL_A	243.11	490.76
VOL_E	453.81	916.06
VKT_N	99.8054	201.341
VKT_M	982.871	1984.0216
VKT_I	417.7002	843.1756
VKT_A	526.5327	1062.8981
VKT_E	982.871	1984.0216
VHT_N	1.6098	3.2474
VHT_M	15.8775	32.8305
VHT_I	6.7374	13.6111
VHT_A	8.4936	17.1802
VHT_E	15.8775	32.8305
VC_N	0.0273	0.0552
VC_M	0.2623	0.5295
VC_I	0.1115	0.225
VC_A	0.1405	0.2837
VC_E	0.2623	0.5295

Figure 6: Network travel statistics example from Cube

Network travel statistics example delineates general travel statistics of the highway link between two centroids (center of each zonal in the study area) such as the total number of trips/ mean trip length, total vehicle-hours of travel in each period (VHT_period) and total vehicle-kilometers of travel in each period (VKT_period), VC stand for Volume capacity ratio. In this example picture, there is no congestion recorded in the link between node 108 and node 109.

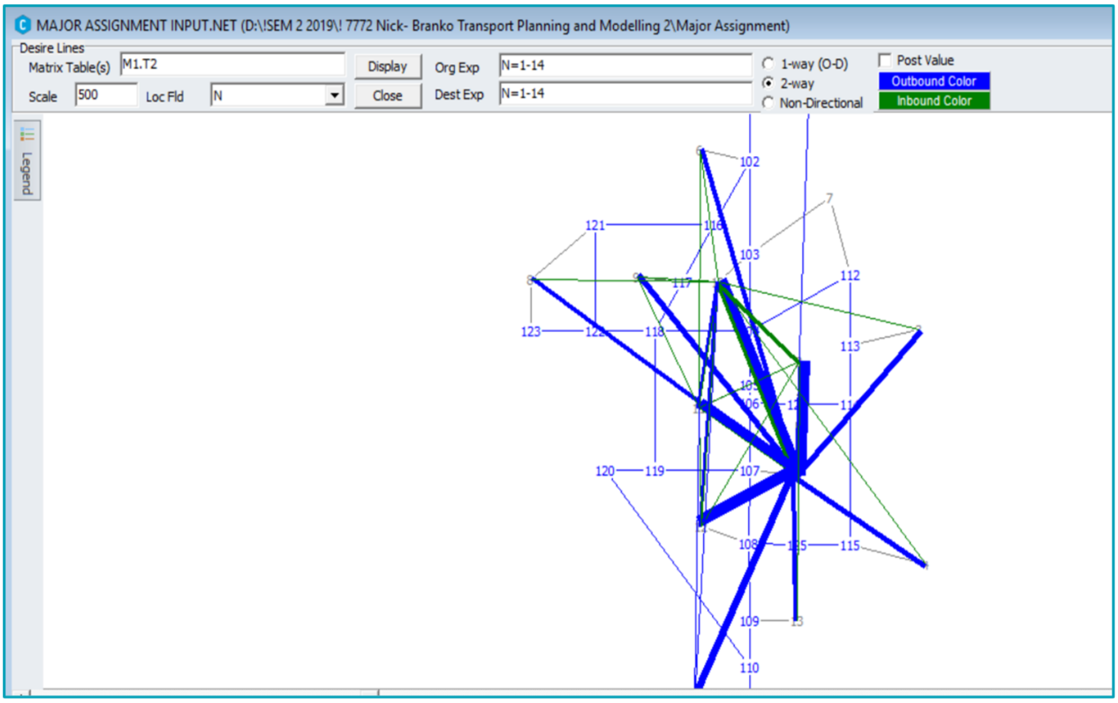


Figure 7: Desire line output from Cube

The thicker of the line shows the extend of the desire.The desire Lines showing the inbound and outbound routes differentiate by green and blue colour respectively. In the above example, the most favourite direction of travel is the south_westen.

3.2. Microsimulation

Many different traffic simulation packages with various features have been developed to date such as AimSun, SimTraffic, Paramics, Vissim microsimulation models. The SimTraffic and AIMSUN microsimulation models are compared in terms of the major transportation network performance indicators. The results from the conducted analysis indicate that AIMSUN returned smaller errors for the vehicle flow, travel speed, and total travel distance. On the other hand, SimTraffic provided more accurate values of the travel time. Both microsimulation models were able to effectively identify traffic bottlenecks (Rahimi et al., 2021).

4. The fixed-route quality of services framework provided by the transit system

4.1. Availability

The framework for the availability is based on frequency, hours of service and the service coverage. This has been assessed in part 1 chapter 2.

4.2. Comfort and convenience

Passenger load was heavy on tram in the city centre at peak hour and was severely light on the outer rim of public transport coverage.

The reliability of the service and the transit connection

4.3. Service quality tracking and improvement

Five factors that influence the quality of services provided by the bus transit system are fluency in the provision of the service; staff training; physical conditions in the provision of the service; convenience/accessibility; and integration between transport lines (Tomaz de Aquino et al. 2018) (Department for Infrastructure and Transport 2020b; Department of Planning Transport and Infrastructure 2019).

There have been many changes in tracking the public transport quality of service. From the DIT annual reports from 2015-2020, the public complaints have moved from tracking quantity in 2015 – 2017 to quantitative and qualitative in 2018-2020. In service quality in the DIT 2019-2020 annual report, there has been more atention about safety such as personal safety, security service/ premises was recorded which was not in the previous annual report. The resolved proportion increased from 71 to 78 percents in recent year. This means that passengers' feedback was reduced and solved quicker within the policy timeframe. The detailed report comparison was shown in Table 5: Comparision of public complaints received by other areas of DIT by category in 2018-2019 and 2019-2020 (Department for Infrastructure and Transport 2020b; Department of Planning Transport and Infrastructure 2019).

Table 5: Comparision of public complaints received by other areas of DIT by category in 2018-2019 and 2019-2020 (Department for Infrastructure and Transport 2020b; Department of Planning Transport and Infrastructure 2019)

ID	Complaint categories	Sub-categories	Example	Number of Complaints 2018-19	2019-20
1	Professional behaviour	Staff attitude	Failure to demonstrate values such as empathy, respect, fairness, courtesy, extra mile; cultural competencFailure to action service request; poorly informed decisions; incorrect or incomplete service providedy	10	14
2	Professional behaviour	Staff competency	Failure to action service request; poorly informed decisions; incorrect or incomplete service provided	4	2
3	Professional behaviour	Staff knowledge	Lack of service specific knowledge; incomplete or out-of-date knowledge	1	0
4	Communication	Communication quality	Inadequate, delayed or absent communication with customer	16	7
5	Communication	Confidentiality	Customer's confidentiality or privacy not respected; information shared incorrectly	0	0
6	Service delivery	Systems/technology	System offline; inaccessible to customer; incorrect result/information provided; poor system design	10	4
7	Service delivery	Access to services	Service difficult to find; location poor; facilities/ environment poor standard; not accessible to customers with disabilities	13	12
8	Service delivery	Process	Processing error; incorrect process used; delay in processing application; process not customer responsive	2	0
9	Policy	Policy application	Incorrect policy interpretation; incorrect policy applied; conflicting policy advice given	0	0
10	Policy	Policy content	Policy content difficult to understand; policy unreasonable or disadvantages customer	2	3
11	Service quality	Information	Incorrect, incomplete, out dated or inadequate information; not fit for purpose	56	21
12	Service quality	Access to information	Information difficult to understand, hard to find or difficult to use; not plain English	2	5
13	Service quality	Timeliness	Lack of staff punctuality; excessive waiting times (outside of service standard); timelines not met	12	7
14	Service quality	Safety	Personal or family safety; duty of care not shown; poor security service / premises		55
15	Service quality	Maintenance	Maintenance; poor cleanliness	274	98
16	Service quality	Service responsiveness	Service design doesn't meet customer needs; poor service fit with customer expectations	80	71
17	No case to answer	No case to answer	party; customer misunderstanding; redirected to another agency; insufficient information to investigate	0	15
			Total	**577**	**314**
	Additional Metrics		% complaints resolved within policy timeframes	71	78

Chapter III: METHODOLOGY

This chapter describes the steps undertaken in the traffic modelling and simulation of the different private vehicles and public transport services in the study area of Tonsley and Bedford Park areas.

Part 1 describes in detail the study area. To better represent the trip generation in the Aimsun model, Bedford Park car park data in 2013 and 2014 were analysed and implemented in the model as separate vehicle release/sink areas.

Part 2 of this chapter provides a modelling report from the executive summary to detailed modelling procedures, calibration and validation steps.

Part 3 depicts five scenarios for the base year 2021 and the future master plan in 2031. Part 3.3 expresses the discussion about the differences of characteristics and the rational explanation about the main aim of research in each scenario.

Part 4 presents four prominent outputs about the optimal scenario in travel time, a timetable proposal for Flinders Express Bus in the afternoon, the effectiveness of the linking service using FLEX and the environmental effect of different scenarios.

1. Study area definition

The study area stretches 5 kilometres north-south and 4 kilometres east-west based on two models of South Road Planning Study Darlington Construction Staging in 2015 and 2031 (DIT model) using Aimsun microsimulation for AM peak and PM peak period. Tonsley innovation area is 10 kilometres away from Adelaide Central Business District (CBD) about 20 minutes by train.

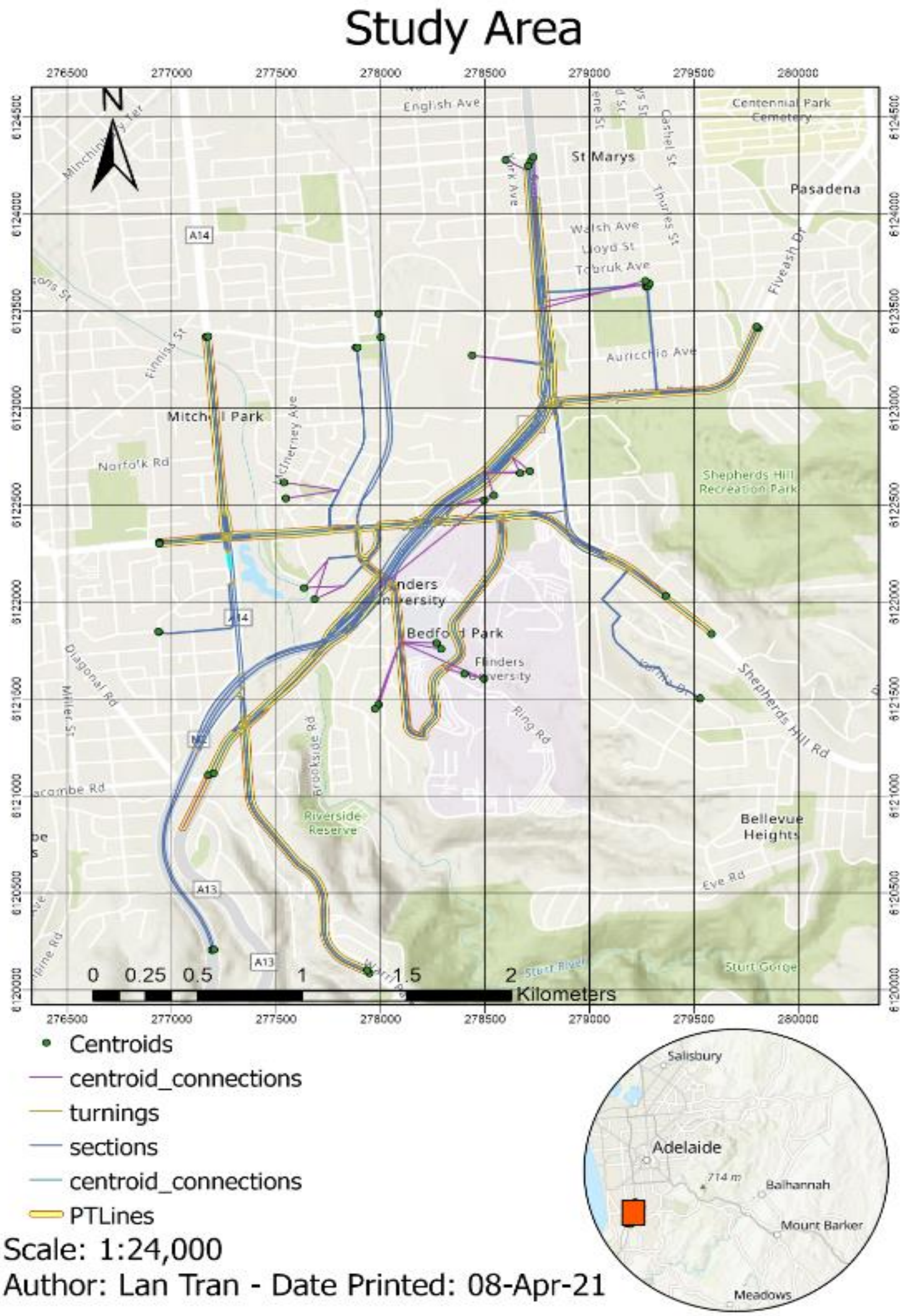


Figure 8: Study area located in Tonsley (10km southward from Adelaide CBD), South Australia

1.1. Tonsley development plan

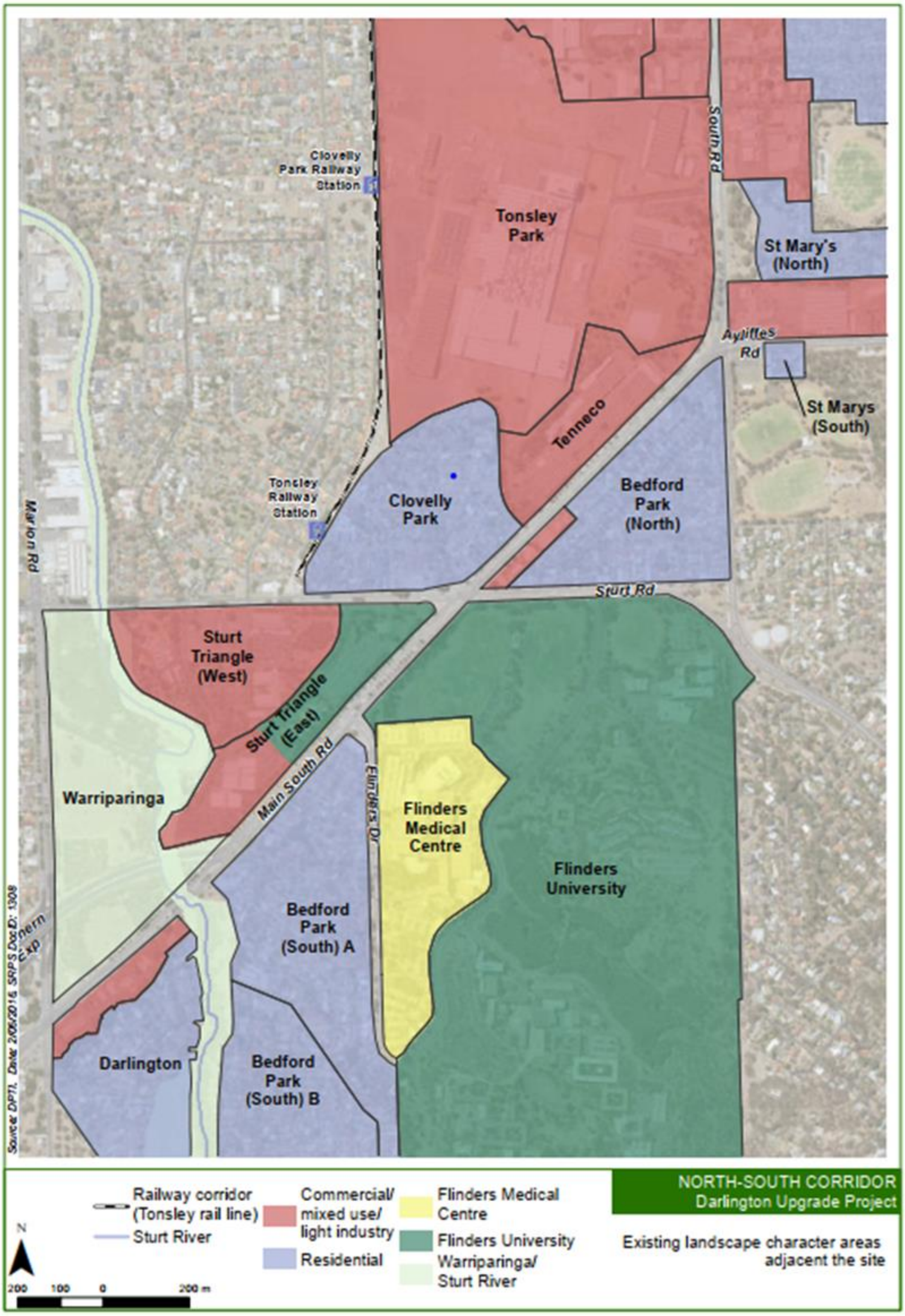


Figure 9: Tonsley area development plan

1.2. Flinders Car Parks

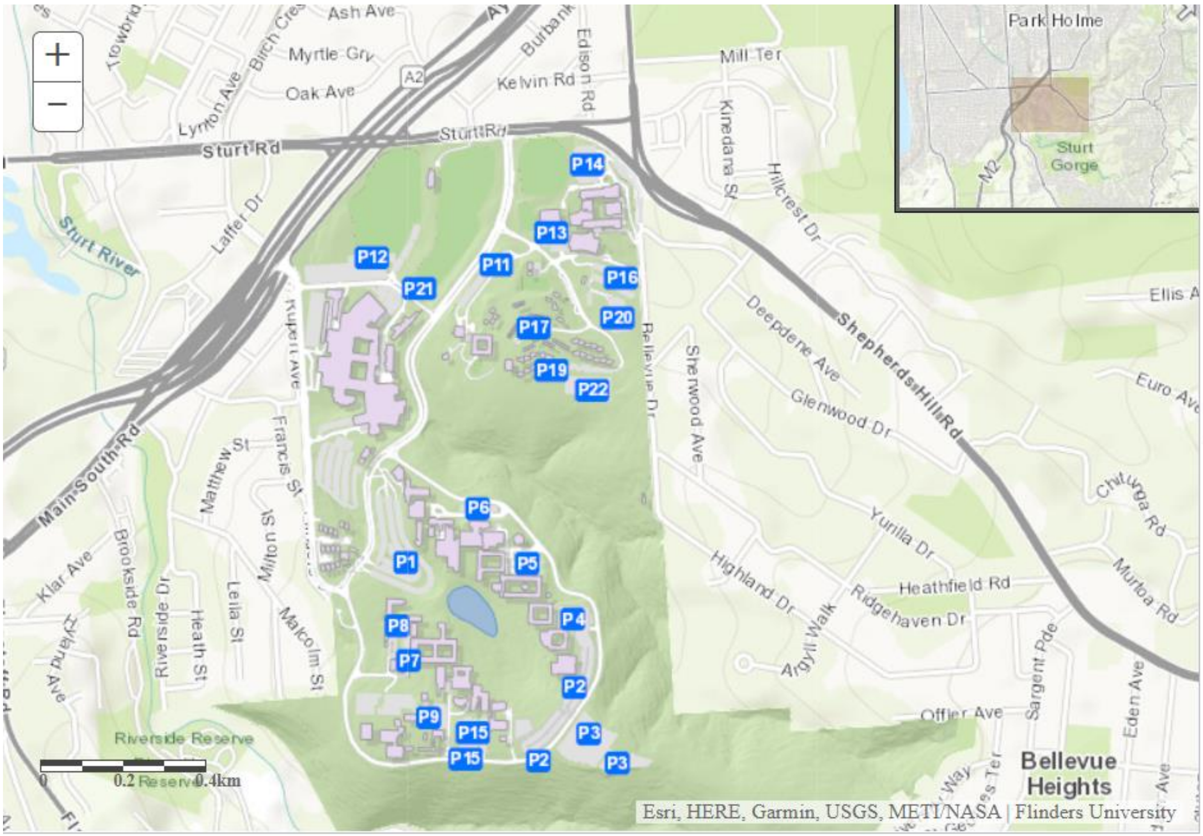


Figure 10: Parkings at Flinders University Main campus

There were 4390 bays at Flinders University main campus. The empty spaces were recorded every day during semester 1 and semester 2. Therefore, the occupied spaces were calculated by deducting the recorded empty spaces from

the number of total bays. The overflow vehicles were parked at the oval. It is noted that more cars coming on Tuesday, Wednesday and Thursday compared to Monday and Friday. Specifically, Flinders carpark occupied 93 percent on three days in the middle of the week, and 82 percent on Monday and Friday in 2014. In 2013, these numbers were recorded at 93 and 83 percent, which was nearly similar to 2014 data, average 4100 and 3600 cars coming to University every day during semester time. Overflow cars parked in the oval. The average number of cars in the oval ranged from 550 to 620 cars which showed that parking at Flinders was crowded. It might be difficult for new users to find an empty place, therefore parking in the oval was the favourite choice than searching for the leftover place around in the car park.

There have been significant improvements for parking at Flinders University recently. Firstly, Car park availability information is updated on Flinders website at https://vpermit.com.au/parkavail/flinders. Users can quickly navigate the suitable place by a green colour indicator which clearly shows the empty numbers, whereas red is full, and orange is nearly full. Secondly, data for parking bays and prices are also integrated into the CellOPark application which can provide information about parking rates, operating hours and time limitations. These fees are set by the parking operators and can be changed by the parking operators at any time which will be updated in real-time. Parking prices increase significantly from 2021 which leads more students to choose Public Transport to come to university.

Table 6: Parking price at Flinders university 2021

Zone Number:	**1500100**	**1500101**	**1500500**	**1500600**
Zone Name:	1500100 - General Parking (Staff and Students)	1500101 - General Parking (Visitors)	1500500 - 2P Short Term Parking areas	1500600 - Car Park 12 - Visitors
Zone Description:	General Parking (Staff and Students)	General Parking (Visitors)	2P Short Term Parking areas	Car Park 12 - Visitors
Parking Rates				
Visitor	Not Allowed	$2.8 per hour	$2.8 per hour	$5 per hour
Staff	$2.3 per hour	Not Allowed	$2.3 per hour	Not Allowed
Student	$1.15 per hour	Not Allowed	$1.15 per hour	Not Allowed

2. Model building

2.1. Executive summary

SCATS detector counts at the intersection of Main South Road and Tonsley Boulevard for 2015 and 2017 were analysed to calculate the yearly increase rate so that the traffic demands can be estimated for the year 2021 from the existing DIT model. This process was done due to COVID-19 affecting the current traffic levels and collecting the current traffic data was not found to be representative of the normal traffic conditions. SCATS detector counts and manual survey counts to substitute for missing data were used to generate traffic demands in 2015 model provided by DIT.

The majority of the local bus services have already been built in the model and those missing were added to the model.

The DIT model has been validated with section flows, queue lengths and paths travel times and achieved the appropriate accuracy to use as the base model. In this secondary study, the author aims at understanding the validation procedure by summarising the Aimsun model calibration report. The only validation for this model in reference to DIT AIMSUN Development Manual was done for travel times because of the missing parts on the adjustment of OD matrices, control plans and parameters affecting traffic behaviours.

Five scenarios have been made to delineate the fixed timetable and variable timetable of different vehicle types and their service links. Finally, some suggestions are proposed for optimal route choice and suitable time departure for loop bus to be better integrated with the Flinders line train schedule.

Model simulation vehicles are DTEI Car, DTEI Truck and Semi, DTEI Bus, DTEI train in AIMSUN Next version 8.4.3 was used. (DTEI: Department for Transport, Energy and Infrastructure)

2.2. Network description

Some additional features were added that were not included in the original models and are as follows:

- New signalised intersection designed at Allawoona Avenue and MAB Cct.
- New ring route from University Drive which links to Australian Science and Mathematics School, new Flinders railway station, Flinders University main campus at Registry road.
- A new railway line from Tonsley train station to Flinders station.
- Added two local bus lines (Station Express and Tonsley link)
- Added Flex autonomous vehicle to link from Tonsley railway station to Flex bus station in front of Flinders University Tonsley.

Channelised left turn on major road and minor road in the additional links.

2.3. Data for modelling

Traffic counts used for modelling were derived from SCATS data supplemented by manual turning counts for missing data in some detectors from late March to early April 2015 to consider the higher travel demands of university students throughout the year.

Control Plan was based on SCATS summaries from 2014 and 2015 as provided by DIT and all the signals were coded as actuated to better cater for traffic demand changes for future model scenarios.

Public Transport plan for the study area was added, with three extra local bus routes as above mentioned in part 2.2 with all bus schedules and routes according to Adelaide Metro (Department for Infrastructure and Transport 2021).

In order to assess the behaviour of vehicles in Flinders Main campus car park, data on parking for 2013 and 2014 was analysed in part 1.2 of this chapter. The proportion of trips was used to distribute the number of vehicle originated from the original single Flinders area centroid into five subcentroids as shown in table 7 and figure 11 below.

Table 7: Proportion of trips generation in Flinders Universtiy Main Campus

	Car Park	Total of bays	Proportion	Explanation
1	P1	687	26%	260+226+201 = 687 = 26 %
2	P2	375	14%	375 = 375 = 14 %
3	P3, P4	757	29%	638+119 = 757 = 29 %
4	P5, P6	190	7%	108+49+19+14 = 190 = 7 %
5	P7, P8, P9, P15	599	23%	355+30+18+196 = 599 = 23 %
		2608	100%	

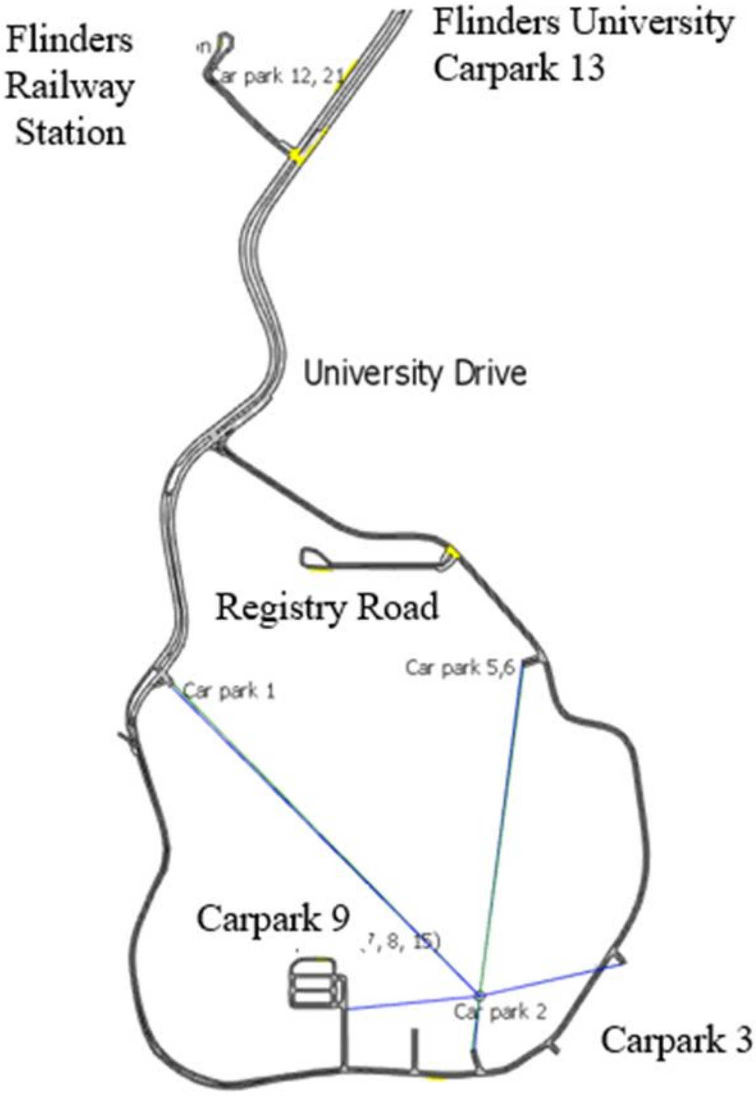


Figure 11: Flinders Express link from Flinders station to Registry Road, in AIMSUN modelling

2.4. Traffic demand

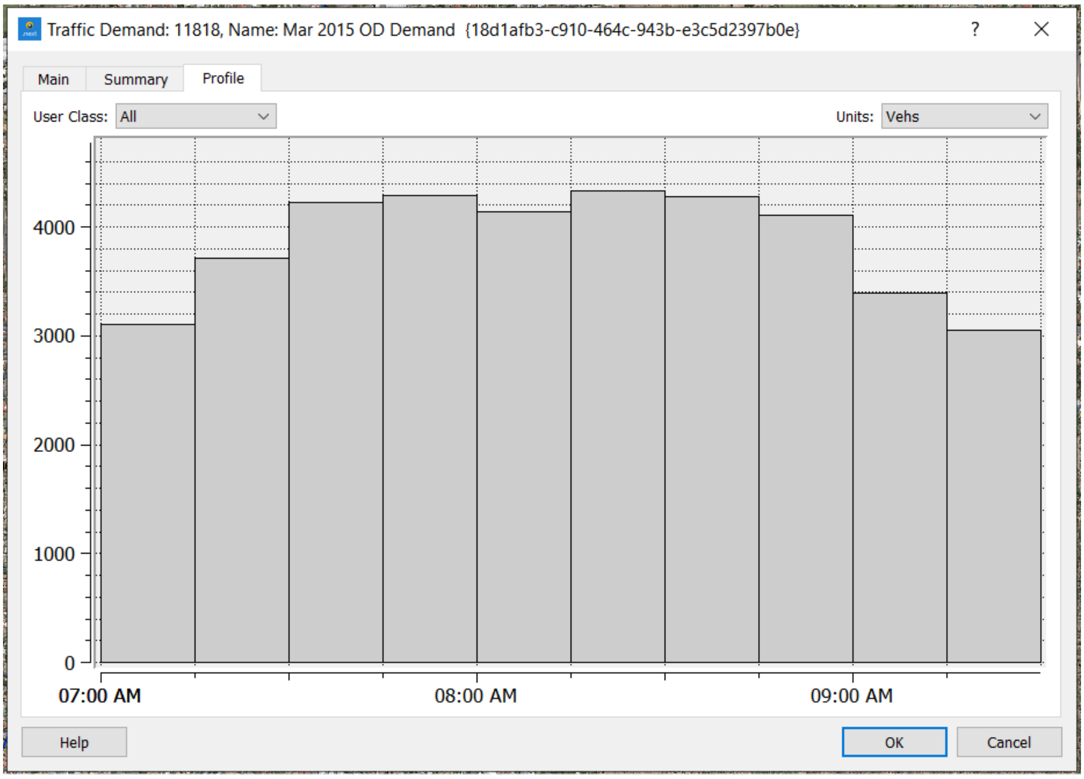


Figure 12: Traffic demand profile AM peak period (Department for Infrastructure and Transport 2015)

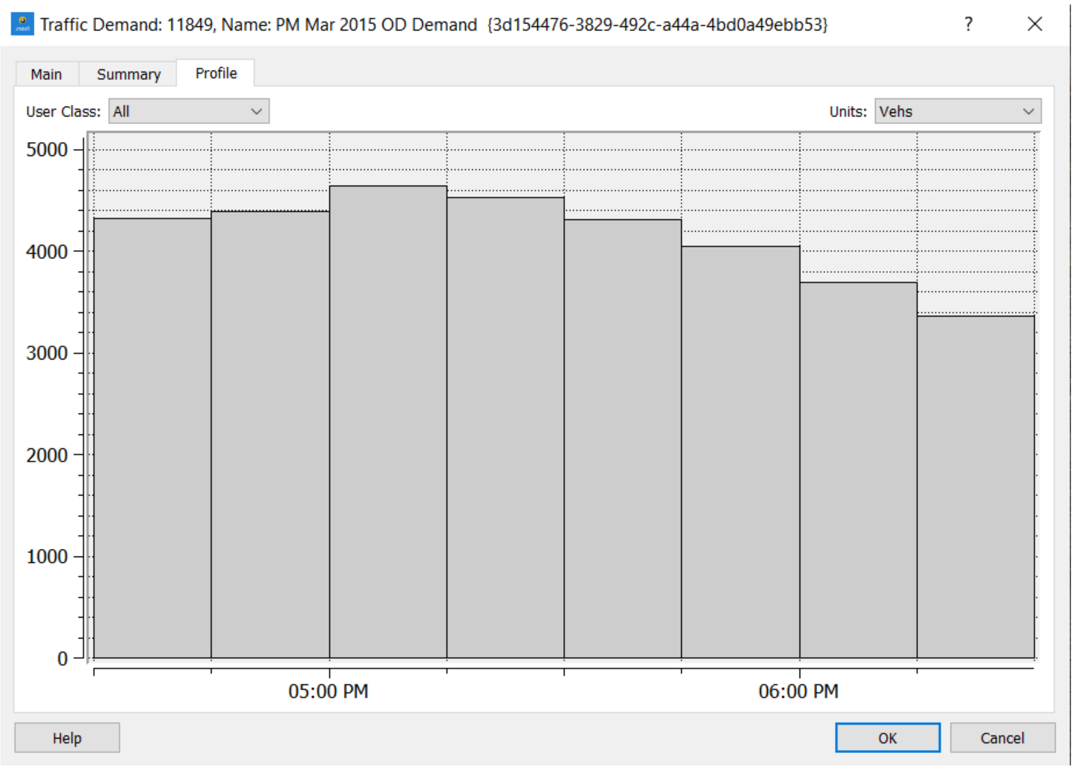


Figure 13: Traffic demand profile PM peak period (Department for Infrastructure and Transport 2015)

Figure 12, Figure 13 depict AM and PM Peak period traffic demand profiles. Total vehicles in the PM peak from 16:30 to 18:30 was 33,296 while in AM peak from 7:00 to 9:30 was 37,285. These traffic demands were based on the Department for Infrastructure and Transport model (Department for Infrastructure and Transport 2015). Traffic demand was specified separately for cars and heavy vehicles and it is in addition to fixed-route public transport vehicles. Pedestrians and cyclists were not included in the modelling process.

2.5. Local Transit lines and Train modelling description

Public transport (PT) modelling in Aimsun consists of three components: PT lines, PT stops, PT timetables. PT lines consist of a set of consecutive road sections. PT stops can be designed as normal bus stops, bus bay stops and bus terminals. There are two ways to define timetables which are fixed timetable and variable timetable. The stop times at each bus stop are determined by the mean stop time and its standard deviation. A passenger generation model is not applied in AIMSUN (Hidas 2005).

Flinders Train line is represented by two services, Tonsley to city and Tonsley from city. The trains use the current timetable for Seaford and Flinders lines from the Adelaide Metro website. The service runs 7 days per week. The earliest train departs from Adelaide at 6.15 a.m, and the latest train departs from Flinders station at 12.02 pm. The peak hour frequency is 20 minutes, the other time-frequency is 30 minutes. Travel time from Tonsley to Flinders Medical Centre (FMC) station is estimated 2 minutes. Total one way average travel time from FMC station to Adelaide Railway Station is about 20 minutes. (Adelaide Metro 2020c)

Station Express AM, Station Express PM run from Bedford Park campus, Registry Road to FMC station. The service starts at 6 a.m and ends at 5 p.m. The service frequency is 20 minutes.

Tonsley link AM, Tonsley link PM operate from Bedford Park campus – Flinders University to Tonsley – Flinders University. Service frequency is 15 minutes. There are five stations in the line including Tonsley, Flinders University Carpark 13, Registry Road, Flinders University Carpark 3, Flinders University Carpark 9. It takes from 11 to 13 minutes to travel from Tonsley to Flinders Registry Road. This variation depends on the traffic situation on the road, stopping time at traffic lights, the number of boarding and aligning passengers. The total average time for one loop is 20 to 23 minutes.

FLEX is Flinders University's self-driving shuttle bus which runs from Tonsley train station to Tonsley – Flinders University. Flinders University has partnered with the Department of Planning, Transport and Infrastructure, RAA and several industry project supporters to operate this autonomous vehicle which used to run from Alawoona Avenue, MAB circuit, and MAB Eastern Promenade. More information can be found on the Flinders University website at self-driving shuttle or email Flex@Flinders.edu.au (Flinders University 2021). It takes three minutes to travel from Tonsley train station to catch the Tonsley link bus. Owing to this connection, travel time saving is 6 minutes comparing to walking which takes around 9 minutes.

There are four sub-paths for train from Tonsley to FMC, Flinders Express Bus and Tonsley link loop bus, FLEX. To retrieve an average travel time for each route, users can check at Infrastructure/Subpaths. There are some other variables in the output such as delay time, speed, total distance travelled. These data can be seen as a graph or exported into excel for analysing and comparing purposes.

2.6. Replication

The nature of the microsimulation modelling is that there is a certain number of parameters used that are based on random number generation. This means that each run would produce slightly different results. To produce the final results, all the replications should be run and calculate the average for them. This average result is used when comparing models. It probably took around 30 minutes to run all 10 replications for one model. It could take longer time depending on the computer configuration. The seed values for each replication were specified as per DIT's model development specifications.

2.7. Calibration

According to Aimsun guideline verson 8, (Department for Infrastructure and Transport 2019, p. 25), reaction time is set 0.9 second, reaction time at stop = 1.5*0.9 =1.35 second and reaction time at traffic light = 2*0.9 = 1.8 seconds.

Modelling parameters used for experiments include:

- Reaction time of 0.9 seconds
- Simulation step of 0.45 seconds
- Exponential arrivals for all private vehicles
- Percentage overtake of 90% for lane changing

• Stochastic route choice by fixed using travel time calculated under free-flow conditions

It is a process of adjusting input parameters so that the output fits within the limitation provided in AIMSUN guideline (Department for Infrastructure and Transport 2019).

2.8. Validation

The initial model was already calibrated and validated according to DIT's guidelines and there was no need to complete the same process again for the thesis model. The only extra validation conducted was a comparison between travel time results in the model and real-life for Tonsley Loop bus every Tuesday from March to May 2021. Therefore, a theory about validation was presented as follows:

There are four main traffic parameters used for calibration and validation, namely turning counts, section flows, queue lengths and travel times.

The GEH statistic is calculated:

$$GEH = \sqrt{\frac{2(m-o)^2}{(m+o)}}$$

Where m is the modelled hourly flow and o is the observed flow.

The average traffic volumes for all turnings at an intersection (such as left turn, through and right turn) from the model compared with the real data set for observed vehicle turning movements and travel times from SCATS data for the base scenario. (Department for Infrastructure and Transport 2019).

Table 8: the GEH Discrete statistic classifies the GEH value, primarily for display to identify problem areas (AIMSUN Next 8.4 help)

Range of GEH	Assessment	Aimsun Next value
GEH < 5	Good fit	0
GEH 5-10 and Observed < Result	Requires investigation, too high	1
GEH >10 and Observed < Result	Unacceptable, too high	2
GEH 5-10 and Observed > Result	Requires investigation, too low	3
GEH >10 and Observed > Result	Unacceptable, too low	4

Table 9: Model Calibration / Validation Criteria (Department for Infrastructure and Transport 2019)

Criteria and Measures – Full Model Period, Warm-Up Period and Peak Hour(s) to be reported	Acceptability Level
Turning Movements	
GEH Statistic for individual flows / movements	
Defined non-critical flows / movements	All <5.0
(Any values >5.0 to be documented)	
All other flows / movements	All <3.0
(Any values >3.0 to be documented)	
Average GEH Statistic for all flows / movements	<1.5
Plot of observed vs modelled individual flows / movements	
Line of Best Fit	
Slope	1.00±0 01
R^2	>0.99
(Slope equation to be included, intercept = 0)	
Queue Lengths Comparison required	Maximum modelled queue lengths to match the maximum observed queue lengths
Travel Times Plot for the full modelled period of minimum and maximum observed vs average modelled travel times required.	Average modelled travel time to fit within the observed minimum-maximum travel time band.

3. Alternative Modelling Scenarios

This part describes different scenarios modelled in AIMSUN to assess the alternative public transport arrangements and their suitability for the study area. There were three scenarios modelled in 2021 and two scenarios for the future model in 2031.

3.1. Base model 2021

Scenario 1: Network is the existing model for 2021 without train extension and without the new South Rd freeway tunnel. Travel times were calculated for a passenger to get off from the Tonsley train station, to walk to Flinders Tonsley bus stop, wait for the bus and get on the bus to travel to Registry Road in Bedford Park. The average walking speed is 4.96 kilometres per hour (Tian, Park & Ewing 2019).

Scenario 1b: This is the existing model for 2021, similar to the above case with the FLEX connection provided between Flinders at Tonsley and the Tonsley train station

Scenario 2: This is the existing model for 2021 with the extension of the Flinders train line operated from 29 December 2020 (Department for Infrastructure and Transport 2020c). The network has not accounted for the effect of the new tunnel highway in South Road.

3.2. Future model 2031

Scenario 3: This is the future scenario for 2031 to estimate the effectiveness of the Flinders Link Rail extension as well as the operation of the Darlington Upgrade Project (Department for Infrastructure and Transport 2020a)

Scenario 4: This is the future scenario for 2031 similar to scenario 3 with the Flinders Express Bus linked to train arrivals at Flinders station in the morning peak period. In the afternoon scenario, the Flinders Express Bus timetable was adjusted to help commuter catch up with the closest train to the city.

3.3. Discussion about modelling scenarios

There are some significant differences between the base year scenarios and the future year scenarios.

Firstly, traffic volumes and physical network improvements will be changed significantly. Traffic volume for the base scenarios is lower than that of the future scenarios. However, there is a major change in the network for 2031 scenarios after the finishing of the Darlington Upgrade Project. Specifically, according to traffic data from MASTEM, the through volume in the North-South direction from Flinders Drive to Tonsley Boulevard will be reduced as a result of vehicles shifted to the underpass Main South Road highway. There will be some slight traffic increase for some turning movements at four main intersections namely Flinders Drive, Sturt Road, Ayliffes Road and Tonsley Boulevard with the Main South Road (at grade) surface roads along both sides of the lowered motorway.

Secondly, the reduction in bus route complexity that existed in base scenarios has resulted in the future scenarios having big improvements in travel time. Shorter routes with fewer signalised intersections and fewer stops in future models compared to the base ones contributes to the optimal trips for commuters.

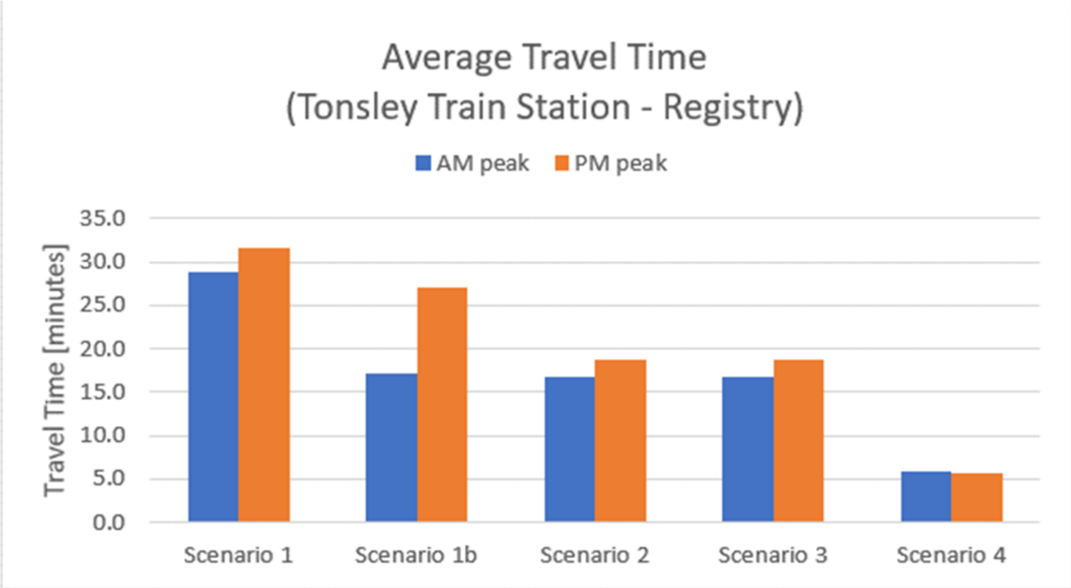
In scenario 4, environmental inputs, such as CO2, NOx and other emissions were included in the analysis.

4. Modelling Results

The full sets of results are given in the Appendices.

In this section, only four main output traffic performance indicators were presented. They are the optimal choice for travelling from Tonsley train station to Bedford Park, the effectiveness of linking FLEX to train arrival time in Tonsley station for morning peak in scenario 1b, and the proposal of a timetable for Flinders express bus. Finally, the results of emission modelling were presented in part 4.4.

4.1. The most effective service output due to the Flinders train line extension



	Scenario 1	Scenario 1b	Scenario 2	Scenario 3	Scenario 4
AM peak	28'55"	17'03"	16'46"	16'50"	5'49"
PM peak	31'40"	27'0"	18'40"	18'40"	5'44"

Figure 14: Summary of travel time of four scenarios

Comparing the two services showing in Figure 14, Tonsley link and Flinders Express, it can be seen that the Tonsley link option has significantly longer travel times. It took around 20 to 23 minutes to complete one full loop from Tonsley to Bedford Park campus. On this route, vehicles must pass through six signalised intersections, five stop sign control junctions, and four give way sign control junctions. These factors have increased in total travelling times. On the other hand, the Flinders Express route has only three stops and three to four unsignalised intersections depending on the direction of travel. Thus, passengers' travel times are significantly lower than the Tonsley Link route. It takes only 6 minutes to travel from Tonsley to Bedford Park or vice versa provided that the trips are made at a suitable time to ensure the integration with the Flinders train timetable as seen in scenario 4.

The predicted average waiting time is only 1 minute and 26 seconds while average travelling times is 5 minutes and 43 seconds.

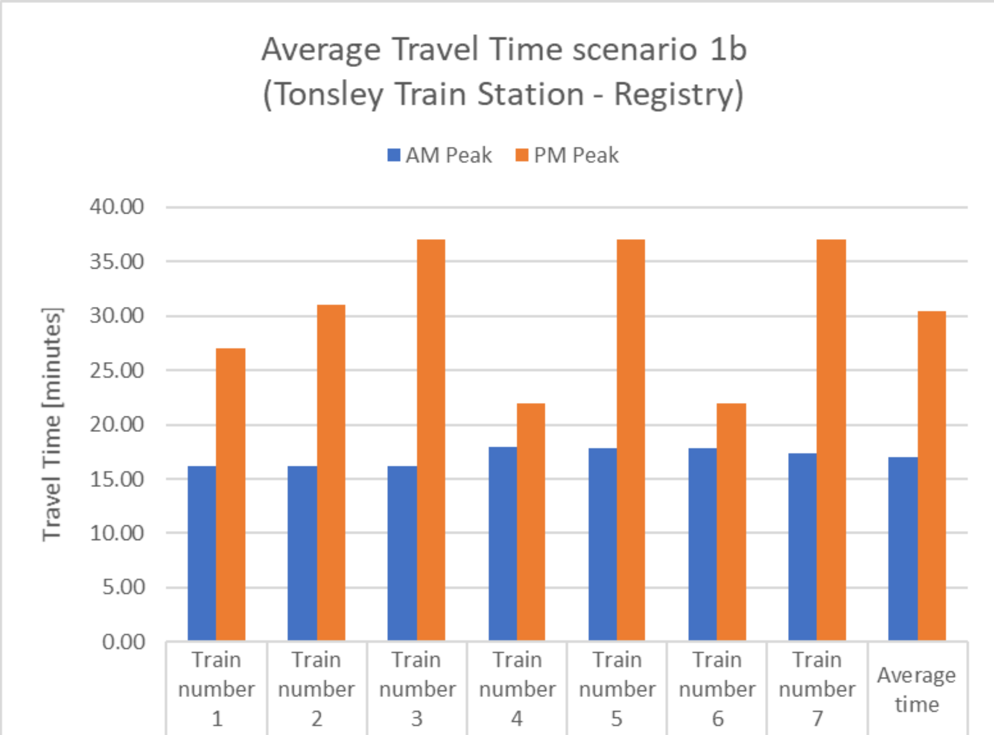
4.2. Bus integration with train arrival time in scenario 4 in the afternoon

Table 10: Flinders Express Bus timetable integration with train arrival time in the afernoon in scenario 4

Train number	Leave Registry	Arrival at Train FMC	Wait for train at FMC train	Ride the train to Tonsley	Waiting time	Total trave time [min]	Ride on express bus
1	16:33:00	16:36:00	16:37:00	16:39:00	1.00	6.00	3.00
2	16:53:00	16:56:00	16:57:00	16:59:00	1.00	6.00	3.00
3	17:12:00	17:15:00	17:16:00	17:18:00	1.00	6.00	3.00
4	17:33:00	17:36:00	17:37:00	17:39:00	1.00	6.00	3.00
5	18:03:30	18:06:00	18:07:00	18:09:00	1.00	5.50	2.50
6	18:33:00	18:36:00	18:37:00	18:39:00	1.00	6.00	3.00
7	18:58:00	19:01:00	19:02:00	19:04:00	1.00	6.00	3.00
Average Time					**1.00**	**5.93**	**2.93**

The departure time of the train from Flinders station frequency is 20 minutes from 16:39 to 17:39, and 30 minutes for train number 5,6, and 7 (Adelaide Metro 2020c). The average travel time on the express bus is 2 minutes and 56 seconds. Walking time from the bus station to Flinders train is less than 1 minutes and is shown in Table 10 as waiting time. It takes only two minutes for the train from Flinders to Tonsley station. This newly-built innovation train line runs separately on the bridge which leads to the exactly reliable time from the two stations in the study area. Therefore, to achieve the optimal travel time for passengers, a timetable for the Flinders Express bus was set as above in Table 10.

4.3. FLEX bus improve travel time



	Train number 1	Train number 2	Train number 3	Train number 4	Train number 5	Train number 6	Train number 7	Average time
AM Peak	16.18	16.18	16.18	17.93	17.78	17.78	17.40	17.1
PM Peak	27.00	31.00	37.00	22.00	37.00	22.00	37.00	30.4

Figure 15: Effective Flex, train, bus integration in AM peak and PM peak without that linking, travel time in scenario 1b

Linking FLEX with the Train and Bus arrivals provides significant time savings especially in AM peak for travel between Tonsley and Bedford Park. As seen in scenario 1b for PM peak, travel time has shown worse performance when compared with the AM peak due to the inability to link FLEX with the Tonsley loop bus and the train arrival time unless the Loop bus schedule times are adjusted. Results are illustrated in Figure 15.

4.4. Environmental model output

The instantaneous emission model considers Carbon Dioxide (CO2), Nitrogen Oxides (NOx), Volatile Organic Compounds (VOC) and Particulate Matter (PM) (Luc, Steven & Ronghui 2006). In AIMSUN, the emissions for each pollutant using the same formula, but considering different factor values according to the vehicle type, the fuel type and instant acceleration/deceleration measures. These types of emissions are produced for each vehicle type and given as total (e.g. in grams) and as emissions per kilometre (e.g. g/km). These pollutant results can also be reported for every link or every sub-path (Wang et al. 2018).

Users need to make the changes to vehicle fleet mix and re-run all of models to get new results. Method for adjusting fuel types in the fleet is done through Demand data/ Vehicle/ Bus DTEI/Microscopic Model/ Environmental Model to change from Diesel Bus to Electric Vehicle (EV) as shown in Figure 16.

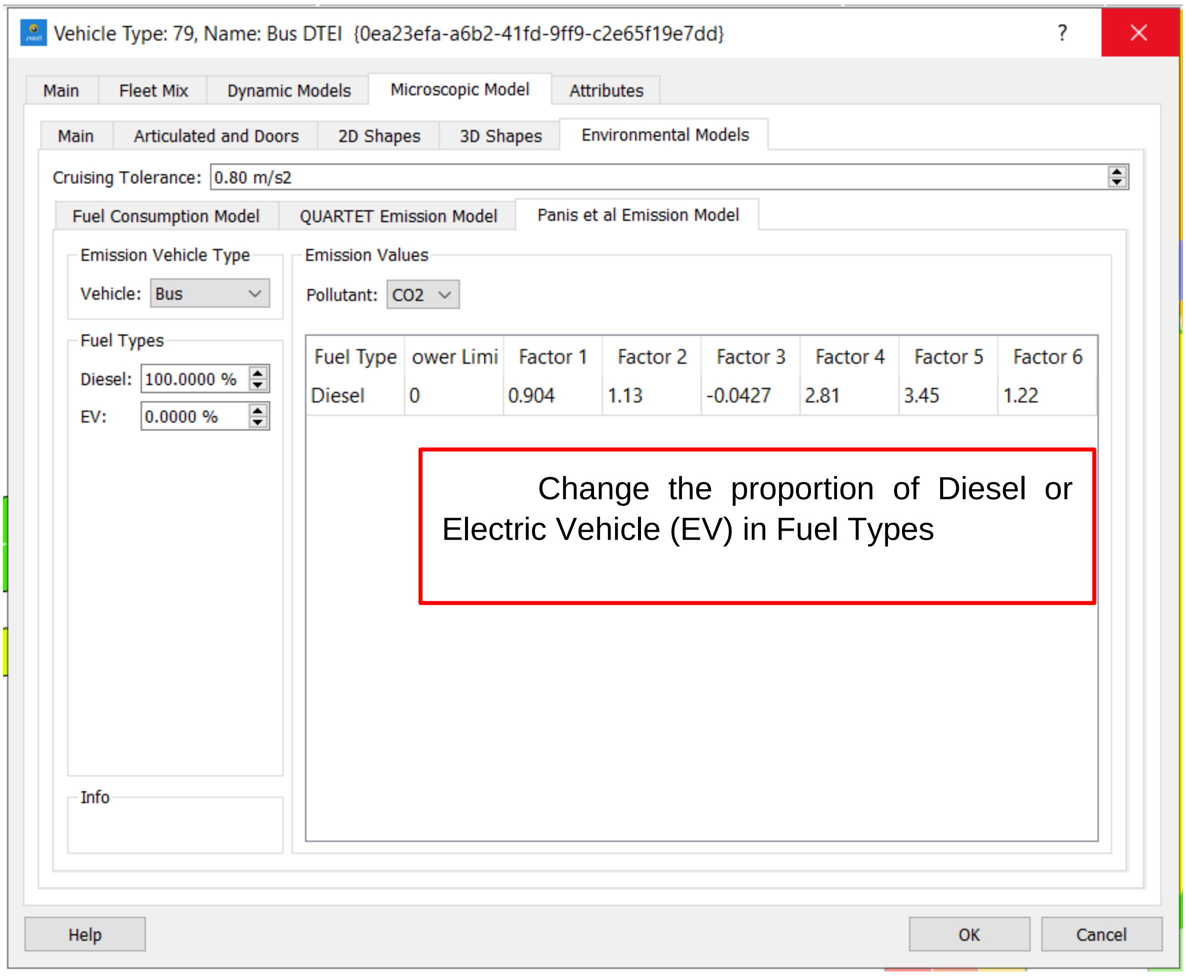


Figure 16: Parameters setting for environmental calculation in AIMSUN microsimulation

There are four different types of fuel used for bus including GEHE buses, CNG buses, EURO 4 buses and EURO 5 buses. The best performance is the GEHE buses, with lowest emission value for CO2, CO and NOX. CNG buses had lower CO and NOX emission but CO2 and HC emissions were higher. Both EURO 4 and EURO 5 buses had quite high in both CO and NOX. (Wang et al. 2018)

According to Acelic, 1982, for idling and decelerating vehicles, the rate (in ml/s) can be assumed to be constant while for an accelerating vehicle, the emissions depend on vehicle acceleration mode and speed which determined for each vehicle type though empirical method.

Emission values for petrol cars and buses, taken from QUARTET deliverable 1992, are summarised in the following two tables:

Table 11: Emission rates for cars depending on speed

Emission rates for cars (g/s)	CO	Nox	HC
Idling emission rate (g/s)	0.060	0.0008	0.0067
Accelerating emission rate (g/s)	0.377	0.0100	0.0200
Decelerating emission rate (g/s)	0.072	0.0005	0.0067
Cruising emission rate (g/s)			
10 km/h	0.060	0.0006	0.0063
20 km/h	0.091	0.0006	0.0078
30 km/h	0.130	0.0017	0.0083
40 km/h	0.129	0.0022	0.0128
50 km/h	0.090	0.0042	0.0097
60 km/h	0.110	0.0050	0.0117
70 km/h	0.177	0.0058	0.0136

Table 12: Emission rates for buses depending on speed

Emission rates for buses (g/s)	CO	Nox	HC
Idling emission rate (g/s)	0.050	0.0050	0.0383
Accelerating emission rate (g/s)	0.377	0.0100	0.0200
Decelerating emission rate (g/s)	0.072	0.0005	0.0067
Cruising emission rate (g/s)			
10 km/h	0.097	0.018	0.078
20 km/h	0.056	0.020	0.044
30 km/h	0.050	0.023	0.042
40 km/h	0.069	0.036	0.056
50 km/h	0.056	0.067	0.078
60 km/h	0.042	0.083	0.067
70 km/h	0.000	0.133	0.067

It is assumed in the model that Car can be Petrol, Diesel, LPG or Electric, by default 75% Diesel and 25% Petrol are considered; Bus and HDV vehicles have two options Diesel or Electric, by default is only diesel considered. PM level is set to zero for bus type if all buses change to electric version (Gerard et al. 2002).

Data for all buses emission has been produced in Table 13. Aimsun assumes that electric buses generate zero emissions in the model. Therefore, in case we use 100% electric buses in the future, similar to Tindo bus already used since 2013 in Adelaide, the amount of emission wil reduce 1 percent. Private cars are the dominant source for emission.

It should be noted that there are two types of emission (Publishing 2001). Aimsun produces figures for emissions that are coming out of the vehicles but does not include any emission dispersions into air and it does not take into account secondary emissions (e.g. emissions during electricity production, vehicle production, etc.).

Table 13: An example of emission output from AIMSUN microsimulation

Time Series	Value	Unit	Percentage
IEM Emission - All - CO2	41466988	G	
IEM Emission - TSD Car - CO2	38625857	G	93.15%
IEM Emission - TSD Bus - CO2	365359	G	0.88%
IEM Emission - TSD SU Truck - CO2	2469872	G	5.96%
IEM Emission - DTEI Train 3 Cars - CO2	5901.08	G	0.01%
IEM Emission - All - CO2 – Interurban	553144	g/km	
IEM Emission - TSD Car - CO2 - Interurban	515245.1	g/km	93.15%
IEM Emission - TSD Bus - CO2 - Interurban	4873.66	g/km	0.88%
IEM Emission - TSD SU Truck - CO2 - Interurban	32946.56	g/km	5.96%
IEM Emission - DTEI Train 3 Cars - CO2 – Interurban	78.72	g/km	0.01%

Chapter IV: FINDINGS AND DISCUSSION

1. Advantages of autonomous vehicles FLEX

The results of simulation scenario 4 showed that the travel time can be shortened down to six minutes. Thus, using autonomous vehicles would be beneficial to older people or parents with young children. This free ride offer would help them overcome the hurdle to get out of the house and make the trips more frequent due to the increased convenience. In addition, the population projection in 2031 shows that 22 percent of the population, about 400,000 people are in the 65-year-old or above age group (Infrastructure SA 2020) (see Figure 17 in the appendices for details)

Another advantage is that autonomous vehicles help commuters to avoid extreme weather discomforts.

2. Findings

There are many factors that contribute to the variations in the value of travel time saving such as by mode of travel, purpose, income, trip distance or duration, and productive use of travel time (Batley et al. 2019)

Express bus link with train is the most convenient option to get to Flinders University main campus from Tonsley train station and Adelaide City.

Flinders Link project not only provides an effective method for avoiding traffic conflicts but also enhances connectivity between Flinders precinct, Flinders University and Flinders Medical Centre to the other areas. As a result of this, more commuters will benefit from the improvement of the public transport service in terms of coverage, and frequency even during weekends. In addition, bike facility along the train line offers chances for more active and safer trips which remove dangerous risk for vulnerable road users.

Chapter V: CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

As a part of this thesis project, the Aimsun microsimulation models which tested the base intermediate plan and future master plan to provide an evidence-based conclusion was successfully created and applied. The proposal was made for a suitable timetable to enable commuters to experience the ideal link to the Flinders train timetable with the feeder bus services. It was shown that the FLEX service is another innovative solution for shortening travel time, improving commuters satisfaction and avoiding damaging weather condition. The observation of each modelled scenario simulation run provides an understanding of the interactions of different types of vehicles in the models and the influence of signalised intersections and other factors on the study area traffic network performance.

Tonsley TAFE, Flinders University main campus and Flinders at Tonsley are significant trip generators now but they will be even bigger generators in the near future. The microsimulation model built in this study can be used for future transport network performance evaluation.

The planning and building of transport network are rather costly and time-consuming tasks (Markvica et al. 2018). The model using AIMSUN microsimulation has enabled the testing of the recent train extension and its operation in future (e.g. 2031) and examine differences in on-demand strategies. In addition, this type of modelling could be extended onto the assessment of train arrival linking with other bus services in future research.

The research and results from the model improve the understanding of the number of emissions from the tail-pipe and the original production of the vehicles production process. The emission modelling would be more useful if the possible diversion from private cars to public transport due to train extension to Flinders Medical Centre and better service linking was estimated and implemented in Aimsun through travel demand changes (e.g. OD matrices) (Serrano et al. 2021).

2. Recommendations for future study

In conclusion, further research about the proximity analysis of old people and young children in the area near Tonsley innovation district is needed to provide a better understanding of the potential customers for public transport in Tonsley. There is an opportunity to update the models built as the new census data was released in 2021.

This model could be exploited further in terms of environmental effects by running different scenarios after adjusting the input parameters for energy generation, bus types and emissions calculation methodology. Due to time limitation, this report has not considered in details the environmental improvement gained from applying FLEX or other innovative bus models.

REFERENCES

Acworth, C 2014, *Geography for the Australian curriculum. 7*, Geography for the Australian curriculum seven, Port Melbourne, Vic : Cambridge University Press.

Adelaide Metro 2020a, *On-Demand Bus Services*, viewed 20 May 2021, <https://adelaidemetro.com.au/Timetables2/Special-services/On-Demand-Bus-Services>.

—— 2020b, *Popular fares*, viewed 08 January 2021, <https://adelaidemetro.com.au/content/download/1179621/6136359/version/2/file/Fare+print-out.pdf>.

—— 2020c, *Seaford and Flinsers timetable routes map 29 12 2020*, viewed 08 January 2021, <https://adelaidemetro.com.au/content/download/181516/1013264/file/seaford_ttable_routemap_29_12_20.pdf>.

—— 2020d, *Tea Tree Plaza Interchange Park 'n' Ride*, viewed 25 August 2020, <https://www.adelaidemetro.com.au/Using-Adelaide-Metro/Park-n-Ride/Tea-Tree-Plaza-Interchange-Park-n-Ride>.

—— 2020e, *Timetables, Planning your travel*, viewed 08 January 2021, <https://adelaidemetro.com.au/Timetables2>.

—— 2021a, *ADELAIDE FREE CITY SERVICES MAP*, viewed 15 April 2021, <https://adelaidemetro.com.au/content/download/166099/931156/file/FREE_City_Connector_routemap_Aug2019_WEB_VERSION.pdf>.

—— 2021b, *Glenelg tram route map*, viewed 15 April 2021, <https://adelaidemetro.com.au/content/download/959213/5013222/file/Glenelg_Tram_routemap.pdf>.

AIMSUN a Siemens Business 2021, *AIMSUN Fact sheet*, viewed 22 April 2021, <https://www.aimsun.com/about-aimsun/>.

Australian Bureau of Statics 2017, *2016 Census QuickStats*, viewed 14 March 2021, <https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/4GADE?opendocument>.

Australian Bureau of Statistics 2002, *Adelaide : a social atlas*, 2001 Census of population and housing, Canberra : Australian Bureau of Statistics, Canberra.

—— 2020, *Estimated resident population*, viewed 17 March 2021, <https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3101.0Main+Features1Jun%202019?OpenDocument>.

Batley, R, Bates, J, Bliemer, M, Börjesson, M, Bourdon, J, Cabral, MO, Chintakayala, PK, Choudhury, C, Daly, A, Dekker, T, Drivyla, E, Fowkes, T, Hess, S, Heywood, C, Johnson, D, Laird, J, Mackie, P, Parkin, J, Sanders, S, Sheldon, R, Wardman, M & Worsley, T 2019, 'New appraisal values of travel time saving and reliability in Great Britain', *Transportation (Dordrecht)*, vol. 46, no. 3, pp. 583-621.

Bing, Q, Qu, D, Chen, X, Pan, F & Wei, J 2019, 'Arterial travel time estimation method using SCATS traffic data based on KNN-LSSVR model', *Advances in mechanical engineering*, vol. 11, no. 5, p. 168781401984192.

Bray, DJ, Taylor, MAP & Scrafton, D 2011, 'Transport policy in Australia—Evolution, learning and policy transfer', *Transport policy*, vol. 18, no. 3, pp. 522-32.

Cao, Z, Jiang, S, Zhang, J & Guo, H 2017, 'A Unified Framework for Vehicle Rerouting and Traffic Light Control to Reduce Traffic Congestion', *IEEE transactions on intelligent transportation systems*, vol. 18, no. 7, pp. 1958-73.

Casas, J, Ferrer, JL, Garcia, D, Perarnau, J & Torday, A 2010, *Traffic Simulation with Aimsun*, New York, NY: Springer New York, New York, NY, 0884-8289.

Chang, Z, Chen, J, Li, W & Li, X 2019, 'Public transportation and the spatial inequality of urban park accessibility: New evidence from Hong

Kong', *Transportation research. Part D, Transport and environment*, vol. 76, pp. 111-22.

Cred Consulting 2020, *Pyrmont Peninsular demographic profile*.

de Carvalho, NL, Vieira, JGV, da Fonseca, PN & Dulebenets, MA 2020, 'A Multi-Criteria Structure for Sustainable Implementation of Urban Distribution Centers in Historical Cities', *Sustainability (Basel, Switzerland)*, vol. 12, no. 14, p. 5538.

decisions, II 2016, *South Australia household type*, viewed 20 May 2021, <https://profile.id.com.au/australia/households?WebID=130>.

Department for Infrastructure and Transport 2015, *South road planning study, Darlington construction staging Aimsun model calibration report*.

—— 2018, *Department of Planning, Transport and Infrastructure 2017-18 annual report*, viewed 28 February 2021, <https://www.dit.sa.gov.au/__data/assets/pdf_file/0006/501387/DPTI_Annual_Report_2017-2018.pdf>.

—— 2019, *Traffic Simulation Model Development Guidelines Aimsun Next Version 8*, <https://www.dpti.sa.gov.au/__data/assets/pdf_file/0009/532098/AIMSUN_Model_Development_Manual_V8_190>.

—— 2020a, *Darlington Upgrade Project*, viewed 28 February 2021, <https://dpti.sa.gov.au/infrastructure/nsc/darlington_upgrade_project>.

—— 2020b, *Department of Planning, Transport and Infrastructure 2019-20 annual report*, viewed 28 February 2021, <https://www.dit.sa.gov.au/__data/assets/pdf_file/0008/761381/DPTI_Annual_Report_2019-20.pdf>.

—— 2020c, *Flinders Link Project*, viewed 28 February 2021, <https://www.dpti.sa.gov.au/infrastructure/major_projects/flinders_link>.

—— 2021, *Adelaide Network Map*, viewed 29 March 2021, <https://adelaidemetro.com.au/content/download/1390611/7214709/version/3/file/20248_AM_network_map_675x1055mm.pdf>.

Department of Planning Transport and Infrastructure 2017, *The 30-year plan for Greater Adelaide - 2017 Update*, viewed 15 August 2020, <https://www.infrastructure.sa.gov.au/__data/assets/pdf_file/0006/197511/20-Year-State-Infrastructure-Strategy-Full.pdf>.

—— 2019, *2018-19 Annual Report*, viewed 28 August 2020, <https://dit.sa.gov.au/__data/assets/pdf_file/0006/624372/DPTI_Annual_Report_2018-19_-_Final_-_November_2019.pdf>.

Flinders University 2021, *'FLEX' Flinders University's self-driving shuttle bus takes a break*, viewed 07 May 2021, <https://www.flinders.edu.au/flex-bus#:~:text=Take%20a%20ride%20on%20a%20driverless%20shuttle&text=The%20shuttle%20is%20used%20on,within%20the%20Tonsley%20Innovation%20District.>.

Gerard, H, Bert, B, Sandra, G, Paul, F & A, VDBP 2002, 'Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study', *Lancet*, vol. 360, no. 9341, pp. 1203-9.

Government of South Australia 2017, *THE 30-YEAR PLAN FOR GREATER ADELAIDE 2017 UPDATE*, viewed 15 March 2021, <https://livingadelaide.sa.gov.au/>.

GTA consultants 2020, *GTA consultants, our company*, <https://www.gta.com.au/our-company/>.

Hidas, P 2005, 'A functional evaluation of the AIMSUN, PARAMICS and VISSIM microsimulation models', *Road & transport research*, vol. 14, no. 4, p. 45.

Holyoak, N & Stazic, B 2009, 'Benefits of Linking Macro-Demand Forecasting Models and Microsimulation Models', *Institute of Transportation Engineers. ITE Journal*, vol. 79, no. 10, pp. 30-2,7-9.

HongKong Transport Department 2021, *Transport in Hongkong / Public Transport*, viewed 19 April 2021, <https://www.td.gov.hk/en/transport_in_hong_kong/public_transport/railways/index.html>.

Infrastructure Australia 2019, *Urban Transport Crowding and Congestion, Greater Adelaide*, viewed 22 February 2021, <https://www.infrastructureaustralia.gov.au/sites/default/files/2019-08/Urban%20Transport%20Crowding%20and%20Congestion%20-%209.%20Greater%20Adelaide.pdf>.

Infrastructure SA 2020, *20-Year State Infrastructure Strategy*, viewed 15 August 2020, <https://www.infrastructure.sa.gov.au/__data/assets/pdf_file/0006/197511/20-Year-State-Infrastructure-Strategy-Full.pdf>.

Kitamura, R 2009, 'A dynamic model system of household car ownership, trip generation, and modal split: model development and simulation experiment', *Transportation (Dordrecht)*, vol. 36, no. 6, pp. 711-32.

Laufer, J 2019, *Transport Modelling Guidelines, Volume 4: Simulation Modelling*, viewed 20 April 2021, <https://www.vicroads.vic.gov.au/-/media/files/technical-documents-new/miscellaneous-guidelines/transport-modelling-guidelines-volume-4-simulation-modelling.ashx>.

Liu, S, Yamamoto, T, Yao, E & Nakamura, T 2021, 'Examining public transport usage by older adults with smart card data: A longitudinal study in Japan', *Journal of transport geography*, vol. 93.

Markvica, K, Hu, B, Prandtstetter, M, Ritzinger, U, Zajicek, J, Berkowitsch, C, Hauger, G, Pfoser, S, Berger, T, Eitler, S & Schodl, R 2018, 'On the Development of a Sustainable and Fit-for-the-Future Transportation Network', *Infrastructures (Basel)*, vol. 3, no. 3, p. 23.

Nuzzolo, A & Comi, A 2016, 'Advanced public transport and intelligent transport systems: new modelling challenges', *Transportmetrica (Abingdon, Oxfordshire, UK)*, vol. 12, no. 8, pp. 674-99.

Parliament of Australia 1994, *ANSWERS TO QUESTIONS Building Better Cities Program*, viewed 20 May 2021, <https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22chamber%2Fhansardr%2F1994-06-06%2F0131%22;src1=sm1>.

Publishing, O 2001, *Vehicle Emission Reductions*, Paris : Organisation for Economic Co-operation and Development, Paris.

Pushkin, K & Özbay, KMA 2018, *Feedback Control Theory for Dynamic Traffic Assignment*, 2nd ed. 2018. edn, Cham : Springer International Publishing : Imprint: Springer.

Rahimi, AM, Dulebenets, MA & Mazaheri, A 2021, 'Evaluation of Microsimulation Models for Roadway Segments with Different Functional Classifications in Northern Iran', *Infrastructures (Basel)*, vol. 6, no. 3, p. 46.

Renewal SA *About Tonsley*, viewed 15 March 2020, <https://renewalsa.sa.gov.au/projects/tonsley/>.

RenewEconomy 2013, *Adelaide creates world's first solar-powered public transport system*, viewed 12 May 2021, <https://reneweconomy.com.au/adelaide-creates-worlds-first-solar-powered-public-transport-system-32530/>.

Ricciardi, AM, Xia, J & Currie, G 2015, 'Exploring public transport equity between separate disadvantaged cohorts: a case study in Perth, Australia', *Journal of transport geography*, vol. 43, pp. 111-22.

Samuel, AS 1940, 'Intervening Opportunities: A Theory Relating Mobility and Distance', *American sociological review*, vol. 5, no. 6, pp. 845-67.

Serrano, JR, García, A, Monsalve-Serrano, J & Martínez-Boggio, S 2021, 'High efficiency two stroke opposed piston engine for plug-in hybrid electric vehicle applications: Evaluation under homologation and real driving conditions', *Applied energy*, vol. 282.

Tang, L & Thakuriah, P 2012, 'Ridership effects of real-time bus information system: A case study in the City of Chicago', *Transportation research. Part C, Emerging technologies*, vol. 22, pp. 146-61.

The International Association of Public Transport 2004, *Improving Access to Public Transport*, Amâeliorer l'accáes aux transports publics, Paris : Organisation for Economic Co-operation and Development, Paris.

Tian, G, Park, K & Ewing, R 2019, 'Trip and parking generation rates for different housing types: Effects of compact development', *Urban studies (Edinburgh, Scotland)*, vol. 56, no. 8, pp. 1554-75.

Tomaz de Aquino, J, Valença de Souza, J, Lima da Silva, VdC, Jerônimo, TdB & Melo, FJCD 2018, 'Factors that influence the quality of services provided by the bus rapid transit system', *Benchmarking : an international journal*, vol. 25, no. 9, pp. 4035-57.

Transport For London 2010, *Traffic Modelling Guidelines TfL Traffic Manager and Network Performance Best Practice*, viewed 09 April 2021, <http://content.tfl.gov.uk/traffic-modelling-guidelines.pdf>.

Transport for New South Wale 2021, *SCATS and Intelligent Transport Systems*, viewed 14 May 2021, <https://www.scats.nsw.gov.au/>.

Truong, LT & Somenahalli, SVC 2015, 'Exploring frequency of public transport use among older adults: A study in Adelaide, Australia', *Travel, behaviour & society*, vol. 2, no. 3, pp. 148-55.

Voorhees, AM 2013, 'A general theory of traffic movement: The 1955 ITE past presidents' award paper', *Transportation (Dordrecht)*, vol. 40, no. 6, pp. 1105-16.

Wang, C, Ye, Z, Yu, Y & Gong, W 2018, 'Estimation of bus emission models for different fuel types of buses under real conditions', *Sci Total Environ*, vol. 640-641, pp. 965-72.

Wilson, AG 1967, 'A statistical theory of spatial distribution models', *Transportation research*, vol. 1, no. 3, pp. 253-69.

Wiseman, N, Bonham, J, Mackintosh, M, Straschko, O & Xu, H 2012, 'Park and ride: An Adelaide case study', *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice*, vol. 21, no. 1, pp. 39-52.

APPENDICES

1. A full set of travel time output of all scenarios
2. A full set of environmental model output
3. Bus complaint categories
4. Number of household type in Greater Adelaide and South Australia in 2016
5. Consumer Price Index (CPI) in 2020
6. Demographic survey example
7. Aimsun modelling demonstrations
8. Flinders University 's parking data analysis
9. Public transport fares and writer 's travel history

1. A full set of travel time output of all scenarios

Table 14: Average travel time, scenario 1, AM peak

Train number	Arrival time at Tonsley	Walking to Tonsley (9 minutes)	Next Tonsley bus	Travel time on bus		Waiting time	Arrival at Registry	Total trave time [min]
				in seccond	in minutes			
1	7:15:00	7:24:00	7:30:00	744.14	12.40	6.00	7:42:24	27.40
2	7:35:00	7:44:00	7:45:00	744.14	12.40	1.00	7:57:24	22.40
3	7:55:00	8:04:00	8:15:00	854.89	14.25	11.00	8:29:14	34.23
4	8:14:00	8:23:00	8:30:00	817.48	13.62	7.00	8:43:37	29.62
5	8:35:00	8:44:00	8:45:00	817.48	13.62	1.00	8:58:37	23.62
6	8:54:00	9:03:00	9:15:00	697.84	11.63	12.00	9:26:37	32.62
7	9:24:00	9:33:00	9:45:00	697.84	11.63	12.00	9:56:37	32.62
			Average Travel Time		12.8	7.1		28.9

Table 15: Average travel time, scenario 1b, AM peak

Train number	Arrival time at Tonsley	Ride on FLEX (3 minutes)	Next Tonsley bus	Travel time on bus		Waiting time	Arrival at Registry	Total trave time [min]
				in seccond	in minutes			
1	7:15:00	7:18:00	7:19:00	731.75	12.20	1.00	7:31:11	16.18
2	7:35:00	7:38:00	7:39:00	731.75	12.20	1.00	7:51:11	16.18
3	7:55:00	7:58:00	7:59:00	731.75	12.20	1.00	8:11:11	16.18
4	8:14:00	8:17:00	8:18:00	836.73	13.95	1.00	8:31:56	17.93
5	8:35:00	8:38:00	8:39:00	827.03	13.78	1.00	8:52:47	17.78
6	8:54:00	8:57:00	8:58:00	827.03	13.78	1.00	9:11:47	17.78
7	9:24:00	9:27:00	9:28:00	804.46	13.41	1.00	9:41:24	17.40
			Average Travel Time		13.1	1.0		17.1

Table 16: Average travel time, scenario 2, AM peak

Train number	Arrival time at Tonsley	Train arrival at FMC (2 min)	Next Flinders Express bus	Travel time on bus		Waiting time	Arrival at Registry	Total trave time [min]
				in seccond	in minutes			
1	7:15:00	7:17:00	7:30:00	169.05	2.82	13.00	7:32:49	17.82
2	7:35:00	7:37:00	7:50:00	169.05	2.82	13.00	7:52:49	17.82
3	7:55:00	7:57:00	8:10:00	173.70	2.90	13.00	8:12:53	17.88
4	8:14:00	8:16:00	8:30:00	168.94	2.82	14.00	8:32:48	18.80
5	8:35:00	8:37:00	8:50:00	168.94	2.82	13.00	8:52:48	17.80
6	8:54:00	8:56:00	9:10:00	158.92	2.65	14.00	9:12:38	18.63
7	9:24:00	9:26:00	9:30:00	158.92	2.65	4.00	9:32:38	8.63
			Average Travel Time		2.8	12.0		16.77

Table 17: Average travel time, scenario 3, AM peak

Train number	Arrival time at Tonsley	Train arrival at FMC (2 min)	Next Flinders Express bus	Travel time on bus		Waiting time	Arrival at Registry	Total trave time [min]
				in seccond	in minutes			
1	7:15:00	7:17:00	7:30:00	171.87	2.86	13.00	7:32:51	17.85
2	7:35:00	7:37:00	7:50:00	174.31	2.91	13.00	7:52:54	17.90
3	7:55:00	7:57:00	8:10:00	179.48	2.99	13.00	8:12:59	17.98
4	8:14:00	8:16:00	8:30:00	169.17	2.82	14.00	8:32:49	18.82
5	8:35:00	8:37:00	8:50:00	169.17	2.82	13.00	8:52:49	17.82
6	8:54:00	8:56:00	9:10:00	167.18	2.79	14.00	9:12:47	18.78
7	9:24:00	9:26:00	9:30:00	167.18	2.79	4.00	9:32:47	8.78
			Average Travel Time		2.9	12.0		16.85

Table 18: Average travel time, scenario 4, AM peak

Train number	Arrival time at Tonsley	Train arrival at FMC [2 min]	Next Flinders Express bus	Travel time on bus		Waiting time	Arrival at Registry	Total trave time [min]
				in seccond	in minutes			
1	7:15:00	7:17:00	7:18:00	167.34	2.79	1.00	7:20:47	5.8
2	7:35:00	7:37:00	7:38:00	167.34	2.79	1.00	7:40:47	5.8
3	7:55:00	7:57:00	7:58:00	167.34	2.79	1.00	8:00:47	5.8
4	8:14:00	8:16:00	8:17:00	172.12	2.87	1.00	8:19:52	5.9
5	8:35:00	8:37:00	8:38:00	166.88	2.78	1.00	8:40:46	5.8
6	8:54:00	8:56:00	8:57:00	166.88	2.78	1.00	8:59:46	5.8
7	9:24:00	9:26:00	9:27:00	179.74	3.00	1.00	9:29:59	6.0
			Average Travel Time		2.8	1.0		5.82

Table 19: Scenario travel time comparision (Tonsley train station – Registry Road, AM peak summary

	Scenario 1	Scenario 1b	Scenario 2	Scenario 3	Scenario 4
AM peak	28.9	17.1	16.8	16.8	5.8
PM peak	39.0	30.4	20.3	20.3	5.9

Table 20: Average travel time, scenario 1, PM peak

Train number	Leave Registry	Arrival at Tonsley bus stop	Walk to train (9 minutes)	Wait for next Train	Waiting time	Total trave time [min]	Ride on loopbus
1	16:30:00	16:45:04	16:54:04	16:57:00	2.93	27.00	15.07
2	16:45:00	17:00:04	17:09:04	17:16:00	6.93	31.00	15.07
3	17:00:00	17:15:04	17:24:04	17:37:00	12.93	37.00	15.07
4	17:15:00	17:31:10	17:40:10	18:07:00	26.83	52.00	16.17
5	17:30:00	17:46:10	17:55:10	18:07:00	11.83	37.00	16.17
6	17:45:00	18:01:10	18:10:10	18:37:00	26.83	52.00	16.17
7	18:00:00	18:16:10	18:25:10	18:37:00	11.83	37.00	16.17
			Average Travel Time		14.3	39.0	15.69

Table 21: Average travel time, scenario 1b, PM peak

Train number	Leave Registry	Arrival at Tonsley bus stop	Ride on FLEX	Wait for next Train	Waiting time	Total trave time [min]	Ride on loopbus
1	16:30:00	16:45:04	16:48:04	16:57:00	8.93	27.00	15.07
2	16:45:00	17:00:04	17:03:04	17:16:00	12.93	31.00	15.07
3	17:00:00	17:15:04	17:18:04	17:37:00	18.93	37.00	15.07
4	17:15:00	17:31:10	17:34:10	17:37:00	2.83	22.00	16.17
5	17:30:00	17:46:10	17:49:10	18:07:00	17.83	37.00	16.17
6	17:45:00	18:01:10	18:04:10	18:07:00	2.83	22.00	16.17
7	18:00:00	18:16:10	18:19:10	18:37:00	17.83	37.00	16.17
			Average Travel Time		11.7	30.4	15.70

Table 22: Average travel time, scenario 2, AM peak

Train number	Leave Registry	Arrival at Train FMC	Wait for train at FMC train	Ride the train to Tonsley	Waiting time	Total trave time [min]	Ride on express bus
1	16:40:00	16:43:36	16:57:00	16:59:00	13.40	19.00	3.60
2	17:00:00	17:03:36	17:16:00	17:18:00	12.40	18.00	3.60
3	17:20:00	17:23:36	17:37:00	17:39:00	13.40	19.00	3.60
4	17:40:00	17:43:52	18:07:00	18:09:00	23.13	29.00	3.87
5	18:00:00	18:03:52	18:07:00	18:09:00	3.13	9.00	3.87
6	18:20:00	18:23:53	18:37:00	18:39:00	13.12	19.00	3.88
7	18:40:00	18:43:50	19:07:00	19:09:00	23.17	29.00	3.83
Average Travel Time						20.29	3.75

Table 23: Average travel time, scenario 3, AM peak

Train number	Leave Registry	Arrival at Train FMC	Wait for train at FMC train	Ride the train to Tonsley	Waiting time	Total trave time [min]	Ride on express bus
1	16:40:00	16:43:32	16:57:00	16:59:00	13.47	19.00	3.53
2	17:00:00	17:03:32	17:16:00	17:18:00	12.47	18.00	3.53
3	17:20:00	17:23:16	17:37:00	17:39:00	13.73	19.00	3.27
4	17:40:00	17:42:30	18:07:00	18:09:00	24.50	29.00	2.50
5	18:00:00	18:02:30	18:07:00	18:09:00	4.50	9.00	2.50
6	18:20:00	18:23:06	18:37:00	18:39:00	13.90	19.00	3.10
7	18:40:00	18:43:06	19:07:00	19:09:00	23.90	29.00	3.10
Average Travel Time						20.29	3.08

Table 24: Average travel time, scenario 4, AM peak

Train number	Leave Registry	Arrival at Train FMC	Wait for train at FMC train	Ride the train to Tonsley	Waiting time	Total trave time [min]	Ride on express bus
1	16:33:00	16:36:00	16:37:00	16:39:00	1.00	6.00	3.00
2	16:53:00	16:56:00	16:57:00	16:59:00	1.00	6.00	3.00
3	17:12:00	17:15:00	17:16:00	17:18:00	1.00	6.00	3.00
4	17:33:00	17:36:00	17:37:00	17:39:00	1.00	6.00	3.00
5	18:03:30	18:06:00	18:07:00	18:09:00	1.00	5.50	2.50
6	18:33:00	18:36:00	18:37:00	18:39:00	1.00	6.00	3.00
7	18:58:00	19:01:00	19:02:00	19:04:00	1.00	6.00	3.00
		Average Time			**1.00**	**5.93**	**2.93**

2. A full set of environmental model output

Table 25: Particulate Matter (PM)

Time Series	Value	Unit	Percentage
IEM Emission - All – PM	5668.73	g	
IEM Emission - DTEI Train 3 Cars – PM	0.94	g	0.02%
IEM Emission - TSD Bus – PM	56.35	g	0.99%
IEM Emission - TSD Car – PM	5362.05	g	94.59%
IEM Emission - TSD SU Truck – PM	249.39	g	4.40%
IEM Emission - All - PM – Interurban	75.62	g/km	
IEM Emission - DTEI Train 3 Cars - PM – Interurban	0.01	g/km	0.01%
IEM Emission - TSD Bus - PM – Interurban	0.75	g/km	0.99%
IEM Emission - TSD Car - PM – Interurban	71.53	g/km	94.59%
IEM Emission - TSD SU Truck - PM - Interurban	3.33	g/km	4.40%

Table 26: Volatile Organic Compounds (VOC) emission

Time Series	Value	Unit	Percentage
IEM Emission - All – VOC	63061.29	G	
IEM Emission - DTEI Train 3 Cars – VOC	13.34	G	0.02%
IEM Emission - TSD Bus – VOC	929.91	G	1.47%
IEM Emission - TSD Car – VOC	58511.97	G	92.79%
IEM Emission - TSD SU Truck – VOC	3606.08	G	5.72%
IEM Emission - All - VOC – Interurban	841.2	g/km	
IEM Emission - DTEI Train 3 Cars - VOC – Interurban	0.18	g/km	0.02%
IEM Emission - TSD Bus - VOC – Interurban	12.4	g/km	1.47%
IEM Emission - TSD Car - VOC – Interurban	780.51	g/km	92.79%
IEM Emission - TSD SU Truck - VOC - Interurban	48.1	g/km	5.72%

Table 27: Nitrogen Oxides (NOx) emission

Time Series	Value	Unit	Percentage
IEM Emission - All – Nox	75452.26	G	
IEM Emission - DTEI Train 3 Cars – Nox	9.8	G	0.01%
IEM Emission - TSD Bus – Nox	550.94	G	0.10%
IEM Emission - TSD Car – Nox	70259.16	G	12.70%
IEM Emission - TSD SU Truck – Nox	4632.36	G	0.84%
IEM Emission - All - NOx – Interurban	1006.49	g/km	
IEM Emission - DTEI Train 3 Cars - NOx – Interurban	0.13	g/km	0.01%
IEM Emission - TSD Bus - NOx – Interurban	7.35	g/km	0.73%
IEM Emission - TSD Car - NOx – Interurban	937.21	g/km	93.12%
IEM Emission - TSD SU Truck - NOx - Interurban	61.79	g/km	6.14%

3. Bus complaint categories

Table 28: Bus complaint categories for improving the quality of service

No.	Complaint categories	Sub-categories	Example
1	Professional behaviour	Staff attitude	Failure to demonstrate values such as empathy, respect, fairness, courtesy, extra mile; cultural competency
2	Professional behaviour	Staff competency	Failure to action service request; poorly informed decisions; incorrect or incomplete service provided
3	Professional behaviour	Staff knowledge	Lack of service specific knowledge; incomplete or out-of-date knowledge
4	Communication	Communication quality	Inadequate, delayed or absent communication with customer
5	Communication	Confidentiality	Customer's confidentiality or privacy not respected; information shared incorrectly
6	Service delivery	Systems/technology	System offline; inaccessible to customer; incorrect result/information provided; poor system design
7	Service delivery	Access to services	Service difficult to find; location poor; facilities/ environment poor standard; not accessible to customers with disabilities
8	Service delivery	Process	Processing error, incorrect process used; delay in processing application; process not customer responsive
9	Policy	Policy application	Incorrect policy interpretation, incorrect policy applied; conflicting policy advice given
10	Policy	Policy content	Policy content difficult to understand; policy unreasonable or disadvantages customer
11	Service quality	Information	Incorrect, incomplete, out-dated, or inadequate information; not fit for purpose
12	Service quality	Access to information	Information difficult to understand, hard to find or difficult to use; not plain English
13	Service quality	Timeliness	Lack of staff punctuality; excessive waiting times (outside of service standard); timelines not met
14	Service quality	Safety	Maintenance; personal or family safety; duty of care not shown; poor security service/ premises; poor cleanliness
15	Service quality	Service responsiveness	Service design doesn't meet customer needs; poor service fit with customer expectations
16	No case to answer	No case to answer	Third party; customer misunderstanding; redirected to another agency; insufficient information to investigate

Table 29: Public complaints from 2015 to 2018 (Department for Infrastructure and Transport 2018)

Public transport complaints by category below	2015-16	2016-17	2017-18
Service changes and service quality	6141	5508	6267
Punctuality	2218	2409	3088
Fares and ticketing	953	737	437
Passenger comfort	899	775	1130
Taxi and small passenger vehicle services	375	318	269
Other	377	358	323
Public complaints received by other areas of DPTI by category below	2015-16	2016-17	2017-18
Service quality/delivery	207	547	411
Behaviour of staff	18	72	78
Service access/processes/procedures	40	73	65
Other	28	95	122

Table 30: Customer feedback and complaints from 2017 to 2020 from DIT [7]

Feedback	2017-18	2018-19	2019-20
Commendations	914	897	692
Suggestions	1,134	1,336	908
Complaints			
Service changes and service quality	6,267	5,589	5,320
Punctuality	3,088	2,905	1,714
Fares and ticketing	437	332	454
Passenger comfort	1,130	1,346	306
Other	323	225	44
Total complaints	**11,245**	**10,397**	**7,838**

4. Number of household type in Greater Adelaide and South Australia in 2016

Table 31: Number of household type in Greater Adelaide and South Australia in 2016 (decisions 2016)

Area: South Australia | Benchmark area: Greater Adelaide | Comparison year: 2011 | reset

Household type

export | reset

South Australia - Total households (Enumerated)	2016			2011			Change
Households by type	Number	%	Greater Adelaide %	Number	%	Greater Adelaide %	2011 to 2016
Couples with children	183,765	27.3	28.7	177,538	27.6	28.5	+6,227
Couples without children	174,571	25.9	24.8	171,710	26.7	25.5	+2,861
One parent families	71,196	10.6	11.1	68,073	10.6	11.0	+3,123
Other families	7,277	1.1	1.2	7,046	1.1	1.2	+231
Group household	22,855	3.4	3.8	22,015	3.4	3.8	+840
Lone person	179,126	26.6	26.2	172,642	26.8	26.7	+6,484
Other not classifiable household	24,653	3.7	3.4	16,241	2.5	2.5	+8,412
Visitor only households	10,097	1.5	0.9	8,621	1.3	0.8	+1,476
Total households	673,540	100.0	100.0	643,886	100.0	100.0	+29,654

Source: Australian Bureau of Statistics, Census of Population and Housing 2011 and 2016. Compiled and presented by .id (informed decisions).

Please refer to specific data notes for more information

Image removed due to copyright restriction.

Figure 17: Age structure, 2019 versus 2031 (Infrastructure SA 2020)

5. Consumer Price Index (CPI) in 2020

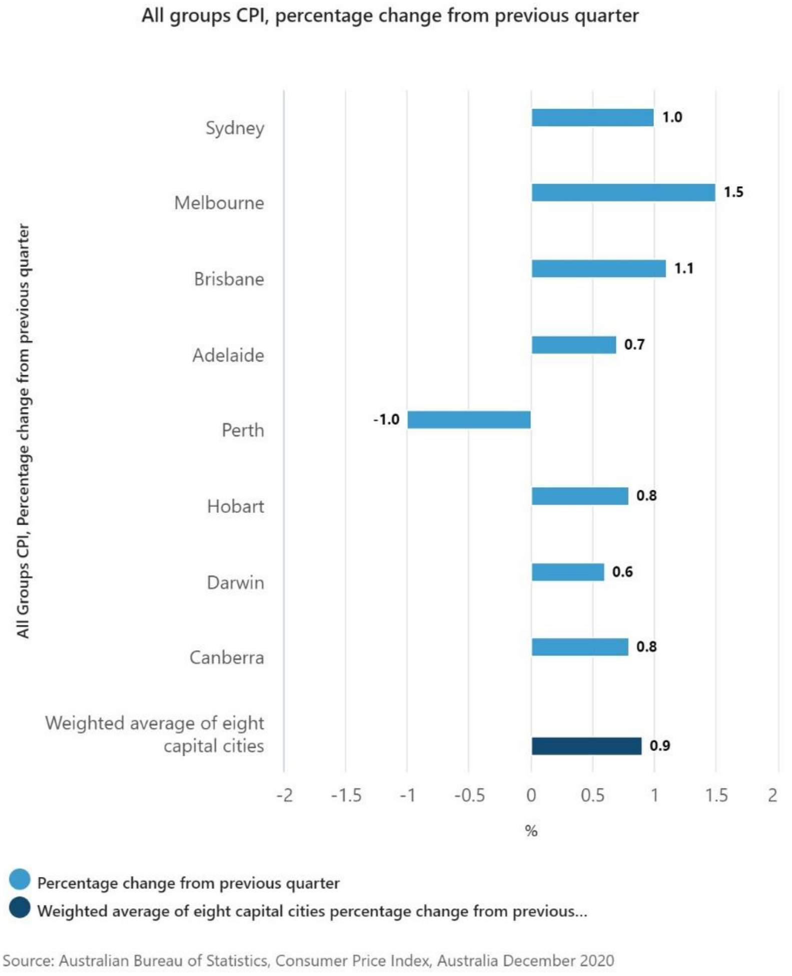


Figure 18: All group Consumer Price Index (CPI) at all States in Australia and weighted average of eight capital cities, 2020 From Australian Bureau of Statistics

Adelaide is the third lowest CPI, lower than the average value of eight capital city.

6. Demographic survey example

Table 32: An example of demographic survey

Household ID	Income/month [$]	Car Ownership	Number of trips
1	4,600	0	2
2	5,200	1	3
3	22,000	3	10
4	18,000	3	9
5	16,000	2	7
6	12,000	2	5
7	11,500	1	5
8	4,000	0	2
9	17,000	1	8
10	16,000	2	8
11	28,000	3	12
12	9,000	2	3
13	32,000	2	15
14	8,700	1	4
15	16,000	1	4
16	23,600	2	10
17	27,800	3	12
18	34,000	4	13
19	5,500	0	3
20	4,200	1	3
21	5,700	1	3
22	11,000	2	5
23	13,400	3	4
24	11,700	3	5
25	12,000	2	5

7. Aimsun modelling demonstrations

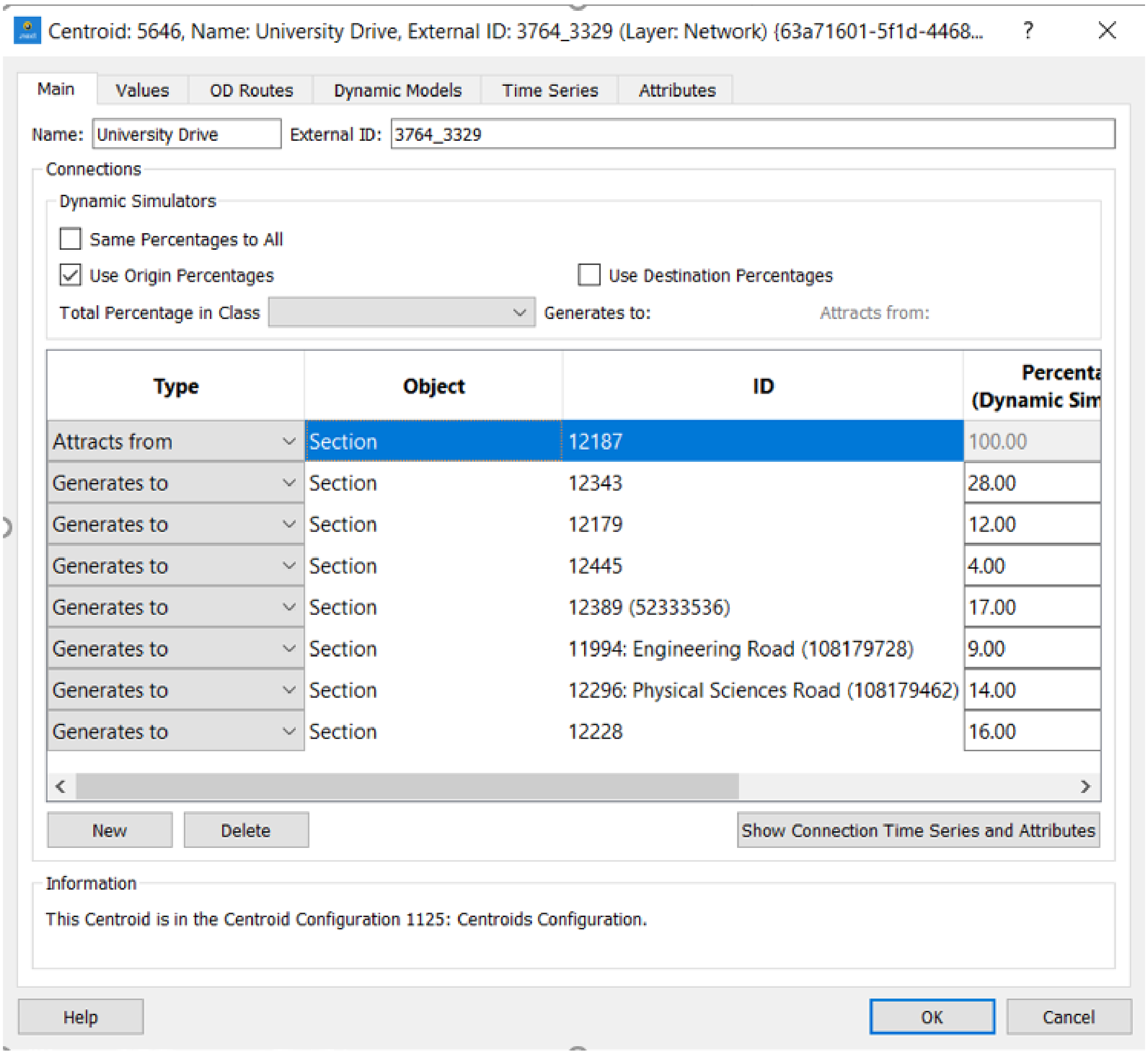


Figure 19: Proportion of vehicles generates to different Flinders car parks

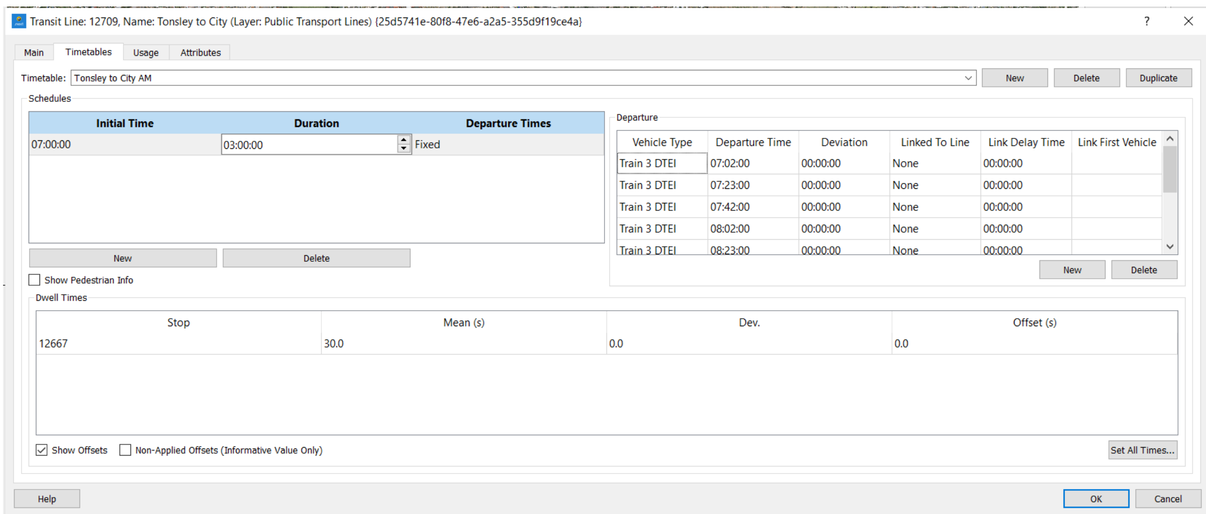


Figure 20: Train timetable setup

8. Flinders University 's parking data analysis

Table 33: Flinders University Carpark Capacity

Item	Carpark information		Bay	Rank
1	Carpark 1, 724 Bays	724 Bays	724	1
2	Carpark 2, 574 Bays	574 Bays	574	2
3	Carpark 3, 543 Bays	543 Bays	543	3
4	Carpark 3a, 115 Bays	115 Bays	115	14
5	Carpark 4, 116 Bays	116 Bays	116	13
6	Carpark 5, 164 Bays	164 Bays	164	8
7	Carpark 7, 21 Bays	21 Bays	21	25
8	Carpark 8, 24 Bays	24 Bays	24	24
9	Carpark 9, 134 Bays	134 Bays	134	11
10	Carpark 9a, 136 bays	136 bays	136	10
11	Carpark 11, 34 bays	34 bays	34	22
12	Carpark 11 (Hall), 106	106	106	15
13	Carpark 12, 90 Bays	90 Bays	90	17
14	Car Park 12A, 117	117	117	12
15	Carpark 13, 83 Bays Met	83 Bays Met	83	18
16	Carpark 14, 394 Bays	394 Bays	394	4
17	Carpark 15, 184 Bays	184 Bays	184	6
18	Carpark 16, 166 Bays	166 Bays	166	7
19	Carpark 17, 57 Bays	57 Bays	57	20
20	CarPark 18, 35 spaces	35 spaces	35	21
21	Carpark 19, 71 Bays	71 Bays	71	19
22	Car park 19a, 236	236	236	5
23	Carpark 20, 137 Bays	137 Bays	137	9
24	Carpark 21, 101	101	101	16
25	Uni Drive, 28 Bays	28 Bays	28	23
	Total		**4,390**	

Table 34: Parking counts 2013

2012	Mon	Tue	Wed	Thu	Fri	Oval	Mon&Fri	Tues-Wed-Thur	4390 -AMF	4390- ATWT
S1W1	10	75	177	140	833	2263	422	131	3969	4259
S1W2	85	7	7	130	706	2317	396	48	3995	4342
S1W3	160	28	22	42	504	2438	332	31	4058	4359
S1W4	167	29	52	89	544.5	2046	356	57	4034	4333
S1W5	222.5	44	24	20	585	1657	404	29	3986	4361
S1W6	278	14	41	45	779	1867	529	33	3862	4357
S1W7	557	19	125	74	777.5	1150	667	73	3723	4317
S1W8	543.5	20	86.5	161	776	866	660	89	3730	4301
S1W9	530	1	48	46	800	525	665	32	3725	4358
S1W10	694	7	205	208	763	184	729	140	3662	4250
S1W11	759	112.5	277	357	860	412	810	249	3581	4141
S1W12	666	218	366	369	957	278	812	318	3579	4072
S2W1	442	259	301	674	1120	475	781	411	3609	3979
S2W2	385	10	41	458	821	608	603	170	3787	4220
S2W3	400	4	63	242	795	556	598	103	3793	4287
S2W4	424	0	21	242	769	458	597	88	3794	4302
S2W5	536	2	66	144	784.5	587	660	71	3730	4319
S2W6	530	1	48	46	800	492	665	32	3725	4358
S2W7	705	0	205	275	887	391	796	160	3594	4230
S2W8	636	128	144	424	932	362	784	232	3606	4158
S2W9	607	503	501	573	977	150	792	526	3598	3864
S2W10	578	109	236	338	954	332	766	228	3624	4162
S2W11	627	152	208	420	931	349	779	260	3611	4130
S2W12	864	893	789	879	1252	329	1058	854	3332	3536
SUM	**13,612**	**4,838**	**6,363**	**8,878**	**22,247**	**21,239**	**17,929**	**6,693**	**96,211**	**107,447**
Average									**3,643**	**4,098**

Table 35: Parking Analysis in 2014

	Mon	Tue	Wed	Thu	Fri	Oval	Mon&Fri	Tues-Wed-Thur	4390 -AMF	4390- ATWT
S1W1	289	213	289	272	1265	733	777	258	3613	4132
S1W2	271	164	159	82	489	818	379.75	135	4010	4255
S1W3	252	31	154	182	580	1144	416	122	3974	4268
S1W4	241	3	177	79	656	1201	448.5	86	3942	4304
S1W5	210	62	78	111	642	1024	426	84	3964	4306
S1W6	221	68	61	137	863	582	542	89	3848	4301
S1W7	711	14	113	100	840	404	775.5	76	3615	4314
S1W8	563	71	262	233	835	478	699	189	3691	4201
S1W9	590	106	274	279	833	684	711.5	220	3679	4170
S1W10	797	177	328	356	837	852	817	287	3573	4103
S1W11	830	309	370	483	869	471	849.5	387	3541	4003
S1W12	817	280	356	635	1305	503	1061	424	3329	3966
S2W1	806	505	448	751	963	386	884.5	568	3506	3822
S2W2	592	106	181	407	1168	528	880	231	3510	4159
S2W3	894	212	311	512	1051	528	972.5	345	3418	4045
S2W4	742	209	215	388	1062	478	902	271	3488	4119
S2W5	710	173	192	353	913	350	811.5	239	3579	4151
S2W6	687	87	234	416	1147	409	917	246	3473	4144
S2W7	1122	255	361	426	867	418	994.5	347	3396	4043
S2W8	734	252	308	545	1251	383	992.5	368	3398	4022
S2W9	271	628	703	870	1336		803.25	734	3587	3656
S2W10	783	261	358	723	1164		973.5	447	3417	3943
S2W11	999	470	488	783	1264		1131.5	580	3259	3810
S2W12	888	367	453	658	1142		1015	493	3375	3897
SUM	**15,019**	**5,023**	**6,873**	**9,781**	**23,342**	**12,374**	**19,181**	**7,226**	**86,180**	**98,134**
Average									**3,591**	**4,089**

9. Public transport fares and writer 's travel history

Image removed due to copyright restriction.

Figure 21: Adelaide metro fares (Adelaide Metro 2020b)

Image removed due to copyright restriction.

Figure 22: writer 's travel history using public transport routes G40, 300, G10, Flinders and Seaford train

Transaction history

Date and time	Operation	Location	Amount	Balance	Route
29/04/2021 12:04	Transfer	Train	$0.00	$16.89	GATES
29/04/2021 11:42	Validation 1st Boarding	Train	$1.02	$16.89	FLNDRS
19/04/2021 15:54	Transfer	Train	$0.00	$17.91	FLNDRS
19/04/2021 15:39	Transfer	Train	$0.00	$17.91	GATES
19/04/2021 14:42	Transfer	Bus	$0.00	$17.91	502
19/04/2021 14:30	Validation 1st Boarding	Bus	$1.02	$17.91	411
19/04/2021 12:26	Transfer	Bus	$0.00	$18.93	411
19/04/2021 11:10	Transfer	Bus	$0.00	$18.93	502
19/04/2021 11:02	Transfer	Train	$0.00	$18.93	GATES
19/04/2021 10:42	Validation 1st Boarding	Train	$1.02	$18.93	FLNDRS

1 2 3 4 5 6 7 8 9 10

Figure 23: Travel history using public transport routes Flinders train, 502, 411 to North Adelaide

Date and time	Operation	Location	Amount	Balance	Route
18/04/2021 14:44	Validation 1st Boarding	Train	$1.02	$19.95	FLNDRS
18/04/2021 12:51	Transfer	Bus	$0.00	$20.97	G1
18/04/2021 11:42	Transfer	Bus	$0.00	$20.97	H1
18/04/2021 11:06	Validation 1st Boarding	Train	$1.02	$20.97	FLNDRS
05/04/2021 13:15	Transfer	Train	$0.00	$21.99	FLNDRS
05/04/2021 13:14	Validation 1st Boarding	Train	$1.02	$21.99	GATES
05/04/2021 09:27	Transfer	Train	$0.00	$23.01	GATES
05/04/2021 09:06	Validation 1st Boarding	Train	$1.02	$23.01	FLNDRS
31/03/2021 13:19	Transfer	Train	$0.00	$24.03	FLNDRS
31/03/2021 12:58	Validation 1st Boarding	Train	$1.02	$24.03	FLNDRS

1 2 3 4 5 6 7 8 9 10

Figure 24: Travel history using public transport routes Flinders train, G1, H1 which was substitute for the Outer Harbor train or Grange to Woodville North

Date and time	Operation	Location	Amount	Balance	Route
31/03/2021 12:28	Transfer	Train	$0.00	$25.05	OUTHA
31/03/2021 11:06	Transfer	Train	$0.00	$25.05	OUTHA
31/03/2021 10:42	Validation 1st Boarding	Train	$1.02	$25.05	FLNDRS
27/03/2021 13:35	Transfer	Train	$0.00	$26.07	FLNDRS
27/03/2021 12:27	Transfer	Train	$0.00	$26.07	GATES
27/03/2021 12:06	Validation 1st Boarding	Train	$1.91	$26.07	FLNDRS
15/03/2021 11:57	Validation 1st Boarding	Train	$1.02	$27.98	FLNDRS
15/03/2021 11:32	Transfer	Tramway	$0.00	$29.00	GLNELG
15/03/2021 11:23	Transfer	Tramway	$0.00	$29.00	GLNELG
15/03/2021 10:13	Transfer	Tramway	$0.00	$29.00	GLNELG

1 2 3 4 5 6 7 8 9 10

Figure 25: Travel history using public transport routes Outer Harbor train, Flinders train and Glenelg tram

Date and time	Operation	Location	Amount	Balance	Route
31/03/2021 12:28	Transfer	Train	$0.00	$25.05	OUTHA
31/03/2021 11:06	Transfer	Train	$0.00	$25.05	OUTHA
31/03/2021 10:42	Validation 1st Boarding	Train	$1.02	$25.05	FLNDRS
27/03/2021 13:35	Transfer	Train	$0.00	$26.07	FLNDRS
27/03/2021 12:27	Transfer	Train	$0.00	$26.07	GATES
27/03/2021 12:06	Validation 1st Boarding	Train	$1.91	$26.07	FLNDRS
15/03/2021 11:57	Validation 1st Boarding	Train	$1.02	$27.98	FLNDRS
15/03/2021 11:32	Transfer	Tramway	$0.00	$29.00	GLNELG
15/03/2021 11:23	Transfer	Tramway	$0.00	$29.00	GLNELG
15/03/2021 10:13	Transfer	Tramway	$0.00	$29.00	GLNELG

1 2 3 4 5 6 7 8 9 10

Figure 26: Travel history using public transport routes Outer Harbor train, Flinders train and Glenelg tram

Date and time	Operation	Location	Amount	Balance	Route
15/03/2021 10:05	Transfer	Tramway	$0.00	$29.00	GLNELG
15/03/2021 10:02	Transfer	Train	$0.00	$29.00	GATES
15/03/2021 09:42	Validation 1st Boarding	Train	$1.02	$29.00	FLNDRS
12/03/2021 12:01	Transfer	Train	$0.00	$30.02	FLNDRS
12/03/2021 11:55	Transfer	Train	$0.00	$30.02	GATES
12/03/2021 11:34	Validation 1st Boarding	Tramway	$1.02	$30.02	GLNELG
10/03/2021 12:57	Transfer	Train	$0.00	$31.04	FLNDRS
10/03/2021 12:56	Transfer	Train	$0.00	$31.04	GATES
10/03/2021 12:43	Validation 1st Boarding	Tramway	$1.02	$31.04	GLNELG
10/03/2021 12:01	Transfer	Tramway	$0.00	$32.06	GLNELG

1 2 3 4 5 6 7 8 9 10

Figure 27: Travel history using public transport routes Flinders train, and Glenelg tram at different time to explore the crowdedness

Date and time	Operation	Location	Amount	Balance	Route
27/02/2021 13:09	Validation 1st Boarding	Bus	$1.91	$14.10	H22C
27/02/2021 11:36	Transfer	Bus	$0.00	$16.01	300
27/02/2021 11:03	Validation 1st Boarding	Bus	$1.91	$16.01	721
23/02/2021 14:00	Transfer	Train	$0.00	$17.92	GATES
23/02/2021 13:52	Transfer	Tramway	$0.00	$17.92	GLNELG
23/02/2021 13:06	Transfer	Tramway	$0.00	$17.92	GLNELG
23/02/2021 13:02	Transfer	Train	$0.00	$17.92	GATES
23/02/2021 12:42	Validation 1st Boarding	Train	$1.02	$17.92	FLNDRS
16/02/2021 11:27	Transfer	Train	$0.00	$18.94	SEAFRD
16/02/2021 11:20	Transfer	Train	$0.00	$18.94	GATES

1 2 3 4 5 6 7 8 9 10

Figure 28: Travel history using public transport routes H22C, 300, 721, Flinders train and Glenelg tram

Date and time	Operation	Location	Amount	Balance	Route
27/02/2021 13:09	Validation 1st Boarding	Bus	$1.91	$14.10	H22C
27/02/2021 11:36	Transfer	Bus	$0.00	$16.01	300
27/02/2021 11:03	Validation 1st Boarding	Bus	$1.91	$16.01	721
23/02/2021 14:00	Transfer	Train	$0.00	$17.92	GATES
23/02/2021 13:52	Transfer	Tramway	$0.00	$17.92	GLNELG
23/02/2021 13:06	Transfer	Tramway	$0.00	$17.92	GLNELG
23/02/2021 13:02	Transfer	Train	$0.00	$17.92	GATES
23/02/2021 12:42	Validation 1st Boarding	Train	$1.02	$17.92	FLNDRS
16/02/2021 11:27	Transfer	Train	$0.00	$18.94	SEAFRD
16/02/2021 11:20	Transfer	Train	$0.00	$18.94	GATES

1 2 3 4 5 6 7 8 9 10

Figure 29: Travel history using public transport routes H22C, 300, 721, Flinders train and Glenelg tram

Date and time	Operation	Location	Amount	Balance	Route
14/12/2020 13:20	Transfer	Train	$0.00	$27.18	GATES
14/12/2020 13:17	Transfer	Train	$0.00	$27.18	GATES
14/12/2020 13:15	Transfer	Train	$0.00	$27.18	GATES
14/12/2020 13:15	Contract Reloading	TVM	$20.00	$27.18	
14/12/2020 12:33	Validation 1st Boarding	Bus	$1.02	$7.18	GA3
14/12/2020 09:25	Transfer	Bus	$0.00	$8.20	GA2
14/12/2020 09:24	Transfer	Train	$0.00	$8.20	GATES
14/12/2020 09:09	Transfer	Train	$0.00	$8.20	SEAFRD
14/12/2020 08:59	Validation 1st Boarding	Bus	$1.28	$8.20	N7
12/12/2020 12:30	Transfer	Bus	$0.00	$9.48	W90

Figure 30: Travel history using public transport routes W90, N7 substitute for Flinders train, GA2, GA3

Date and time	Operation	Location	Amount	Balance	Route
27/12/2020 16:28	Transfer	Bus	$0.00	$22.84	W90
27/12/2020 15:23	Validation 1st Boarding	Bus	$1.02	$22.84	251
26/12/2020 16:12	Transfer	Bus	$0.00	$23.86	251
26/12/2020 15:01	Validation 1st Boarding	Bus	$1.28	$23.86	W90
25/12/2020 17:46	Transfer	Bus	$0.00	$25.14	720H
25/12/2020 16:53	Validation 1st Boarding	Bus	$1.02	$25.14	251
25/12/2020 08:48	Transfer	Bus	$0.00	$26.16	239
25/12/2020 07:59	Validation 1st Boarding	Bus	$1.02	$26.16	W90M
14/12/2020 13:52	Transfer	Bus	$0.00	$27.18	N7
14/12/2020 13:20	Transfer	Train	$0.00	$27.18	SEAFRD

1 2 3 4 5 6 7 8 9 10

Figure 31: Travel history using public transport routes 251, 720H, 239, W90M

Date and time	Operation	Location	Amount	Balance	Route
04/01/2021 11:26	Transfer	Train	$0.00	$19.78	FLNDRS
04/01/2021 11:20	Validation 1st Boarding	Train	$0.00	$19.78	GATES
04/01/2021 10:05	Transfer	Train	$0.00	$19.78	GATES
04/01/2021 09:42	Validation 1st Boarding	Train	$1.02	$19.78	FLNDRS
03/01/2021 15:47	Transfer	Train	$0.00	$20.80	FLNDRS
03/01/2021 15:30	Transfer	Train	$0.00	$20.80	GATES
03/01/2021 14:19	Validation 1st Boarding	Bus	$1.02	$20.80	GA1
03/01/2021 08:12	Transfer	Bus	$0.00	$21.82	J1
03/01/2021 07:58	Transfer	Train	$0.00	$21.82	GATES
03/01/2021 07:36	Validation 1st Boarding	Train	$1.02	$21.82	FLNDRS

Figure 32: Travel history using public transport routes J1 Bus Rapid Transit, GA1

Date and time	Operation	Location	Amount	Balance	Route
18/01/2021 09:41	Validation 1st Boarding	Train	$1.02	$12.38	FLNDRS
13/01/2021 15:19	Validation 1st Boarding	Train	$1.28	$13.40	FLNDRS
13/01/2021 14:29	Transfer	Train	$0.00	$14.68	SEAFRD
13/01/2021 14:16	Transfer	Bus	$0.00	$14.68	751H
13/01/2021 12:58	Validation 1st Boarding	Bus	$1.02	$14.68	751
13/01/2021 11:22	Transfer	Train	$0.00	$15.70	SEAFRD
13/01/2021 11:19	Transfer	Train	$0.00	$15.70	GATES
13/01/2021 11:03	Transfer	Train	$0.00	$15.70	GATES
13/01/2021 10:42	Validation 1st Boarding	Train	$1.02	$15.70	SEAFRD
12/01/2021 10:59	Transfer	Train	$0.00	$16.72	FLNDRS

Figure 33: Travel history using public transport routes Seaford train and Flinders train, 751, 751H to Noalunga