# Analysis of public transport options for Adelaide's Western suburbs.

**ENGR9700A-D: Thesis Project**

Keywords: Tram extension, Microsimulation, SCATS, OD Matrix

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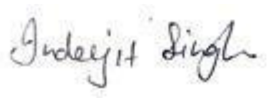
## DECLARATION

I certify that this work does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief. It does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: 

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| | |
|---|---|
| ITULP | Integrated Transport and Land Use Plan |
| DPTI | Department of Public Transport and Infrastructure |
| MASTEM | Metropolitan Adelaide Strategic Transport Evaluation Model |
| SCATS | Sydney Coordinated Adaptive Traffic system LOS Level of service |
| OD | Origin Destination |
| CT | Cycle time |

## ABSTRACT

Tram networks provide the opportunity to help provide advantages for the environment, the economy and reducing levels of traffic congestion in urban areas around the world. In South Australia, the Government has launched an Integrated Transport and Land Use Plan (ITLUP), which provides detail information about the future tram networks in Adelaide. AdeLINK is responsible for connecting the tram network in Adelaide and surrounding areas through the 30-year plan for Greater Adelaide (Government of South Australia, 2015). Future tram networks have been already suggested for connecting Adelaide communities i.e. WestLINK, EastLINK, Port LINK, Prospect LINK and Unley LINK (AdeLINK Multi-criteria analysis summary report). As a part of the tram, extension WestLINK is proposed to connect Adelaide Airport and in this research, a Tram network is proposed to connect West Beach with North Terrace and Adelaide Airport via Sir Donald Bradman Drive making a network stretch of 8.7Km. This tram network will help in reducing the emission of $CO_2$, $NO_x$, travel time and will increase the level of service with the more economic public transport system.

Autodesk's Infraworks Mobility simulation software package is used in this whole analysis for the existing and proposed 9 future scenarios as software models. In this analysis, future models are prepared for a range of possible scenarios. An initial model is made in the Mobility Simulation to match real-life traffic conditions including traffic counts, lane geometry, signal phasing and, intersections. For all the signalized intersection traffic counts are provided by SCATS data, supplied by DPTI (SCATS, 2017) and for unsignalized intersections, data has been collected by manual surveys. The proposed Future Model 1 is designed with one sharing lane with tram service frequency of 15-min and future model 1a to 1d is performed with tram frequency 5-min with different proportions of people boarding tram as 5%, 15%, 4%, 0% to check the best suitable and realistic model for future. Future model 2 also has a shared lane with private vehicles and tram but the tram frequency changes from 5-min to 10-min and model 3 has fewer stops.

In the future model 4, trams are using one lane exclusively with a frequency of 5-min, without having any additional lane, however in model 5, private vehicles are allowed to use right lane inside CBD and at an intersection within 50m for making turns. Finally, Future model 6 has an additional lane for trams to provide serviceability for both trams and private vehicles but it needs an extra space for additional lanes, which makes this model expensive when compared to others.

After simulating all the 10 models, results indicate that Future Model 1 performed the best, among all other 9 models in all performance indicators. Comparing Future model 1 with Initial Model, Model 1shows a reduction of total cost by7.3% and reducing the CO2 and NOx emissions by 10.80% and 10.35% respectively. Most extensively, in the end, there is a great level of service compared to the existing model, most of the intersections are at LOS B, and the average vehicle speed increases by .35km/h which proves the tram network to be a less congested and most efficient mode of transport.

The performance of the Future Model 5shows great performance in all aspects and closely matches the results of model 1 in terms of the total cost, average speed, CO2 and NOx emissions. The performance of the Model 4 is worst among all other models with a bad level of service and longer travel times. The future model 6 is an expensive option because it needs an additional lane and does not show significant improvements compared to other results.

Future Model 1 and 5, both provide significant reductions in total cost comparisons, average speed, level of service and the emission of CO2 and NOx, which shows that these models are fit for both an economic and environmental point of view. Both models show a reduction in travel times along the route from the beach to the city. However, for the final execution of future model 1, it is recommended that the right turn should be banned on some intersections and make a free travel zone within CBD, which will lure more passengers toward Adelaide Airport and West Beach.

# 1 INTRODUCTION

Light rail has the potential to play a very important role in a transportation system as it is very useful in reducing traffic congestion and has reduced harmful effects on the environment. Trams help in developing the economy for urban regions by reducing travel costs and uplifting social engagements because it provides an opportunity for people to spend some time together during travel (Zhong & Li, 2016). Climate change is a big issue internationally and it is now timely to adopt renewable or cleaner energy sources. Trams are gaining great popularity around the world as shown in cities such as Philadelphia, Dallas, Paris, Porto, Bordeaux(Cliché & Reid, 2007), along with their positive environmental impacts trams are really useful in improving economic factors, providing accessibility to different urban areas and this network helps in building more trade and business opportunities. Infrastructure associated with the tram network in certain areas allows more property value by providing an opportunity for more efficient use of land (Mohammad, Graham, C. Melo, & Anderson, 2013).

The Australian city of Melbourne has one of the oldest networks in the country and it has run very successfully over the past years and continuously under development in the other big cities of Australia. New technologies associated with tramway operations also present themselves for a more creating environment-friendly and economical mode of transportation. There is continuous extension of tram network all over Australia including in different locations such as Sydney, Gold Coast, Canberra and Adelaide(Government of South Australia, 2015)In Adelaide tram network has reached Festival plaza along the King William Street and East which is part of Integrated Transport and Land Use Plan for transport and infrastructure (Government of South Australia, 2015). This plan has proposed various tram routes to connect cities such as WestLINK, Port LINK, Prospect LINK, EastLINK, and all these plans are under AdeLINK to create tram networks by 2030. Figure 1.1 shows the proposed link to connect Adelaide by tram network.

## 1.1 Objective

This tram network will provide an opportunity to connect the city for more employment, education, healthcare, and entertainment opportunities. Interestingly in the year 2013, ITLUP involves a 2500 participant survey and they support tram as their priority (Multi-criteria analysis summary report). This shows the interests of the people in building more tram network and this encourages to provide more economic and environment-friendly trams. The main objective of this thesis is to evaluate the feasibility of the tram extension to the western suburbs. Possible benefits will be measured in terms of delay savings, environmental benefits, level of service and other key transport performance indicators.


*Figure 1.1 This image has been removed due to copyright restrictions: AdeLINK Multi-criteria analysis summary report*

## 1.2 Aims

This thesis will investigate the feasibility of the tram extension from City to West beach, in which a tram network will connect West Beach from the Adelaide CBD providing an 8.7Km long tram network, as shown in Figure 1.2. This thesis will determine the economic impacts of the possible travel time, delay and fuel consumption savings. In addition, this study will evaluate the benefits of the potential mode shift changes and increased public transport patronage. This investigation will be conducted using the microsimulation technique.

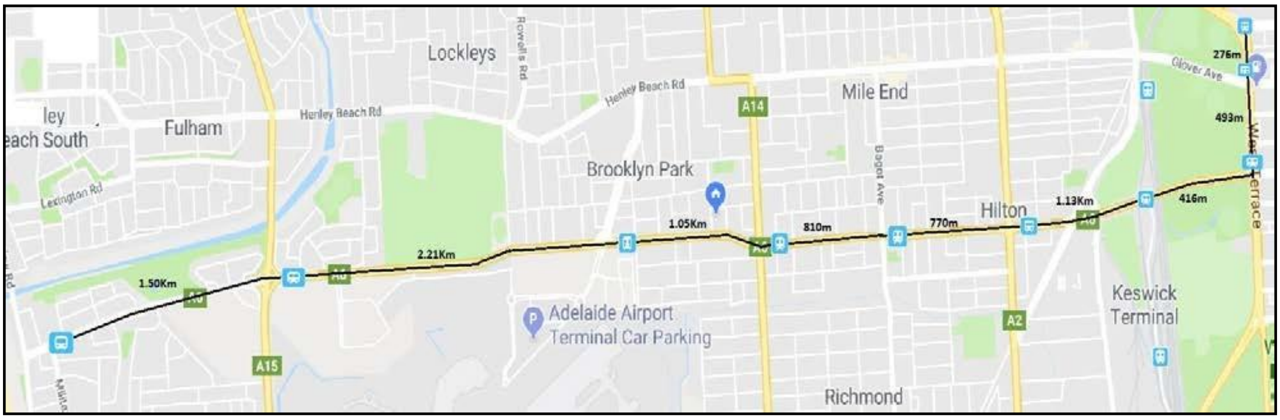


*Figure 1. 2 Proposed tram network*

## 1.3 Software used

In this analysis, Autodesk Infraworks- Mobility Simulation software package (Azalient 2008) is used to run different models based on the existing conditions. Mobility simulation provides detailed results about the economic evaluation, Emissions, Level of Service (LOS) and delays. However, the modeling of the existing or base situation as it exists at present is one of the toughest tasks in this whole analysis. After the initial model, all other potential models will be under analysis. In this research, ten models were developed with the help of five base models in the Mobility Simulation. Base models are further used to create sub-models for further simulation. Then all these models are compared with the initial model and the results are displayed in the result section to show the comparison. In Figure 1.3 all the base models are displayed, which has been used in Mobility Simulation. Future model 2 and 3 and sub-models of 1 and has no change in lane configuration, their details are displayed in Chapter 3.

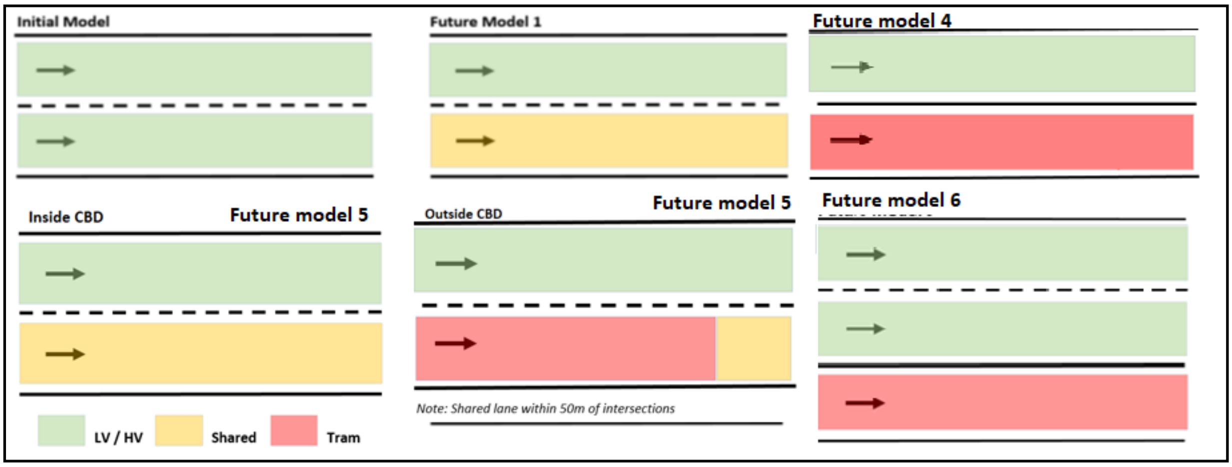


*Figure 1. 3 Lane configuration for different models in Mobility Simulation*

The image above (Figure 1.3) shows all the future models, which are under consideration in Mobility simulation, as you can see in the picture there are 6 base model. For the model description, LV/HV stands for Light vehicles and heavy vehicles. Yellow color shows the shared zone by tram and private vehicles, Red color shows exclusive lane for the tram, Light green color shows the lane for the private vehicle only. But in model 5 a combination of red and yellow color shows the shared lane configuration only within the 50m of the intersection.

## 1.4 Research Significance

- This study will investigate the feasibility of tram extension from City to West beach. This study has a significant impact on the Department of Planning, Transport and Infrastructure, tourists, students, and daily commuters. It will provide an opportunity to connect with City for various Healthcare, Education, Entertainment and Business opportunities.
- It will provide a detailed mobility simulation model for this route via Sir Donald Bradman Drive as DPTI has only MASTEM (Metropolitan Adelaide Strategic Transport Evaluation Model) model for this route.

## 1.5 Scope

- Network investigation: the model will only investigate traffic movements on the main road and intersections and only covers the area from city to beach. There are 14 signalized and 3 unsignalized intersection in this network and other streets are not under consideration
- Am peak only: it does not include PM peak because the morning peak is busier as observed from the SCATS count for one month.
- This study will concentrate only one route between city and western suburbs which is sir Donald Bradman drive since it would connect some of the major traffic generators such as airport
- Possible mode shift from private cars to tram will be accessed using a range of different values between 0 and 10%

## 1.6 Thesis Roadmap

This roadmap will provide guidance to the reader about the different chapters included in this thesis. It will provide a brief description of each chapter so that the reader can better understand the flow and strategy used in writing this thesis.

- The introduction provides a great knowledge about the background of this thesis. which includes a piece of detailed knowledge about the objective, aims, research significance and scope of this study. This chapter also provides brief information about the software used and the different types of models used in this analysis to get the results for economic evaluation, level of service, emissions and delays.

- The next chapter is a Literature review, and this will provide great knowledge about the history of Adelaide's first tram and the reasons why it becomes unsuccessful. Afterward, it will provide insight over the positive effects of light rail networks around the world including the environmental impacts. Additionally, it provides an example of Utah and Denver, in which light tram was useful in reducing congestion and CO2 levels. Then it shows important national researches in which light rail shows a decrease in congestion by the implementation of light trams.

- The methodology is the next chapter, which will provide an overview of the modeling process and the methodology adopted in this research.

- Data collection, which provides information about surveys, data collection, Origin-Destination matrix. Various manual surveys and SCATS data are used to get a total number of vehicles. The procedure for selecting the catchment area is also mentioned in this section and displayed with postcodes.

- Development of initial model, validation and calibration is the next chapter which shows the procedures followed during the development of models and how it is going to affect the traffic conditions. All the design indicators are briefly explained in this chapter such as validation, calibration, stands, turn count, mid-block count, etc.

- The development of future models chapter briefly describes all the future models with different proportions of people boarding a tram for instance 0%, 4%, 5%, 10%, and 15%. Restrictions applied to all the different models are also displayed in this section which will allow trams to provide a better level of service.

- Result and Analysis chapter will shed light on result outcomes from all the future models in Mobility Simulation. It also provides information about result outcomes from the survey performed on unsignalized intersections and the assumptions made during the analysis. All Future models produce results for economic evaluation, average vehicle speed, level of service, delays, $CO_2$ and NOx emissions and based on these results best-performing model is selected.

- Discussion chapter summaries all the future models and existing models and compared against each other in terms of economic evaluation, level of service, delays, average speed, $CO_2$ and NOx emissions and delays. However, some of the models show very impressive results but they need a bigger infrastructure. So, after the comparison, the best performing model is ready for a conclusion.

- Future research is a part of the conclusion in which some recommendations and research gaps are discussed in order to provide a more useful link to future research. The conclusion will also shed light on the best performing model

Following chapter will provide insight on background, global impacts, environmental impacts, research gaps, and the proposed tram network. All these sections provides important information about the thesis.

# 2 LITERATURE REVIEW

## 2.1 Background

Adelaide's first tram network was in operation during the 1950s. But the network of Adelaide was ripped up in the 1950s because of the poor financial management, and a perhaps misguided view about the future of the city all played a role. The tram network was highly profitable and an engineering feat to be proud of. But the enviable web of public transport options didn't last long as the MTT (Municipal Tramways Trust) struggled with the financial woes. (ABC news by Candice Prosser, 2017).

The construction of modern light rail positively affects the economy of particular areas. It was reported by Knowles & Ferbrache (2016) that it helped at various places, for instance, Newcastle Croydon and Manchester, to improve not only demand but also productivity. However, this improvement provides a direct link to public transport between activities centers in a short way.

Moreover, in big cities, which are growing due to increasing population, are in favor of transit system to combat with the problems of congestion on roads, and it can be an effective solution by helping to produce a sustainable transportation system (Islam, Tiwana, Bhowmick, & Qiu, 2016). Many cities, for example, Sacramento, St Louis, Vancouver, and San Diego improved their transportation systems in the context of reducing congestion of traffic on roads along with a positive impact on economic factors (Ferbrache & Knowles, 2016).

Since the share of Adelaide for work trips is lowest, and the per capita usage rates is also lowest and having initially fallen like Brisbane and Perth. Generally, in peak hours, the levels of service is low. 30 year plan for Greater Adelaide is planning for more tram network, which will help to reduce congestion in peak hours. The frequency of service depends on the development of the system to a good quality public transport network. (Paul Mees and Jago Dodson, 2011).

Light Rail Transit is now steadily growing in Australia. Melbourne has expanded its extensive tramway system, Adelaide has built the tram extension to Glenelg and 30 year plan for Greater Adelaide is planning for more tram network, and the Gold Coast has committed to its Rapid Transit system using the Light Rail mode. In Sydney, extensions into the CBD and Inner West of its one line are now planned. Much of this activity, excepting the Sydney Inner West, reflects application of the Light Rail mode in a form that draws on its street tramway heritage – its ability to share road space with buses, cars, bicycle and pedestrian traffic (Kym Norley, 2010).

### 2.1.1 Global Impacts

In 2000, Montpellier in France started with the first tram line and nowadays it has been extended up to 56 KM by implementing 4 lines (Kołoś & Taczanowski, 2016). This system helped the people of that city to use public transportation as compared to private vehicles. "There were about 80% of people traveled in private cars and urban buses had a speed of 7 km/h in the year 1990 (Taczanowski & Kołoś, 2016)." Nowadays, journeys by public transportations are increased to 40%, while journeys by private cars decreased to 25%. The interest in light rail transport in last few years has been increased, as the roads are more congested in metropolitan areas and it also concerns about sustainability and traffic congestion (Batty, Besussi, & Chin, 2003; Ewing & Cervero, 2010; Richardson & Bae, 2016; Squires, 2002). The New York City of North America has invested in transit systems, which have encouraged many scholars to do a research to find out development in detail, travel behavior in these transit systems (Ewing & Cervero, 2010; Freemark, 2014; Mohammad, Graham, Melo, & Anderson, 2013). Another important factor in this analysis is the economic impact of this system because they have invested a large amount of infrastructure and fixed cost in order to use this system as economic development and also a major part of urban revitalization.

The congestion on roads due to increasing traffic in Utah and Denver has been positively affected because of the implementation of the tram network. It was investigated that the volume of traffic rose up 31% inside the influence zone in comparison with 41% increase outside the influence zone sign Bhattacharjee and Goetz (2012). Before and after the completion of the Light Rail Transit (LRT) line at the University of Utah, experiment design and data were used. The positive results were found after the implementation of LRT in the reduction of traffic on the street. This can be said as the crucial development in the expansion of university (Bhattacharjee & Goetz in 2012 and Ewing, Tian, Spain, &Goates in 2014). This implementation of LRT along 400/500 helped to save around 362,000 gallons of petroleum gas and to reduce the level of $CO_2$ (Ewing, Tian, Spain, &Goates, 2014). Therefore, for the reduction of $CO_2$ and traffic congestion, LRT networks can be helpful.

### 2.1.2 Nation Scenarios

Our cities will continue to grow, and Australia has the third-highest growth rate in the Organization for Economic Co-operation and Development (OECD), and the projected population increases of between 200 and 400% in the next 80 years and this is going to increase congestion and with worst traffic conditions. Australia's second-tier cities can cater to a new population and can cultivate their advantage over the large capital cities: better lifestyle, amenity, and economic agility, with lower costs of living, congestion, and competition. These cities are unburdened yet by congestion and offer a distinctive opportunity to capitalize on a growing population without the legacy of 20th-century thinking. (Toby Lodge, 2016).

Most of the populations of Australia reside in the growing capital cities which are significant drivers of the national economy. Traffic congestion deteriorates urban standards, increases environmental emissions & costs the economy $10Bp.a in wasted resources. Public transport such as light rail trams can be an efficient solution to urban transport however in Australia this mostly involves buses sharing road space in congested traffic. (Professor Graham Currie, Monash University, 2017).

The growth of population in metropolitan areas and increasing travel between central cities and surrounding suburbs and towns has led to the development of this dual-mode light rail transit system which in turn will decrease the congestion on road. (Urban Transit Systems and Technology, V. R. Vuchic, 2007).

### 2.1.3 Environmental Impacts

The contribution of transportation in greenhouse gas (CHG) emissions cannot be neglected because more than 23% of total CHG emissions were due to the use of vehicles (Yanga, Wanga, Liub, & Zhouc, 2017). Similarly, Graham, Gargett, Evans & Cosgrove estimated that about 87% of transport greenhouse emissions were caused by road transportation (Graham, Gargett, Evans, & Cosgrove, 2012).

For stabilization of CHG concentration at the desired level and prevention of its negative impacts, more than 100 countries signed an agreement which is known as The Paris Agreement. The aim of this agreement is to fix a global warming limit of 2 °C that should be at least equal to half the levels in 1990 (Pérez-López, et al., 2013). Therefore, by 2050, the aim of reducing 80% of the 2000 levels of emission is set by the Australian government for the economy of Australia (Graham, Gargett, Evans, & Cosgrove, 2012).

Changes in the transportation industry including the reduction of private vehicles on roads should be implemented to achieve this. For making a first carbon-neutral city in the world with the help of a zero-emission transportation system, 30 Year Plan for Greater Adelaide planned by the Government of South Australia is supporting it (Government of South Australia, 2017).

### 2.1.4 Research gap

- department of transport is using a macro-level strategic model called MASTEM (Metropolitan Adelaide Strategic Transport Evaluation Model) to evaluate major transport projects in Adelaide, but, there is no microsimulation model of the study area in existence at the moment that can provide a detailed analysis of all the network parts such as individual intersection operation.
- MASTEM is not capable of simulating and displaying individual vehicle movements as it can be done by microsimulation.
- Some of the intersections are missing the SCATS detectors and during this research traffic, data will be collected for the entire network.

## 2.2 Proposed Network

The implementation of the tram network in inner parts of Adelaide in the future by The Integrated Transport and Land Use Plan (ITLUP) and the overwhelming justifications on the base of this research is provided by 30 Years Plan for Greater Adelaide (Government of South Australia, 2016). The aim of my thesis is to investigate the most appropriate way of a tram from CBD to West Beach with a connection to Adelaide Airport; a proposed route for the 30 years plan, at the early stages of implementation, is shown below in figure 2.1.

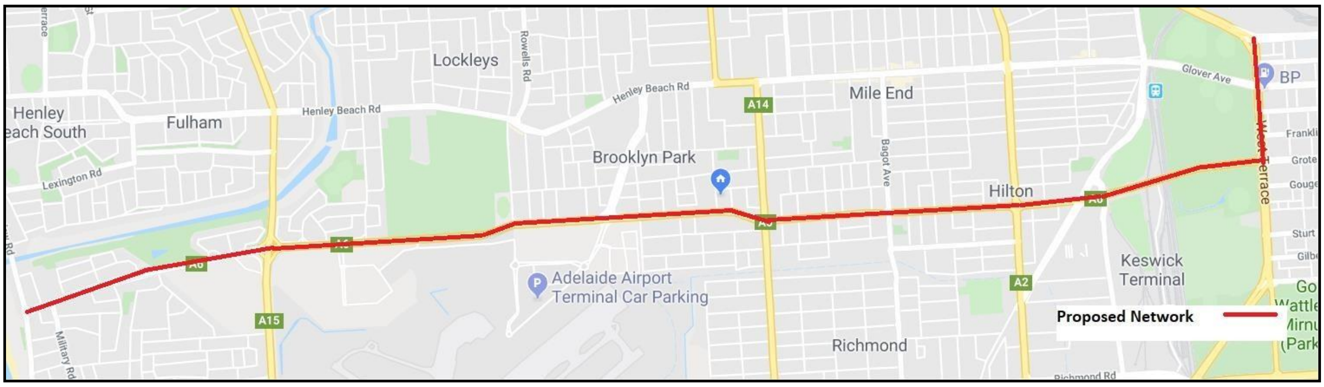


***Figure 2. 1 Routes for Option 1***

***Option 1:***North terrace to Sir Donald Bradman Drive, connecting the Adelaide Airport and finishes at the west beach.

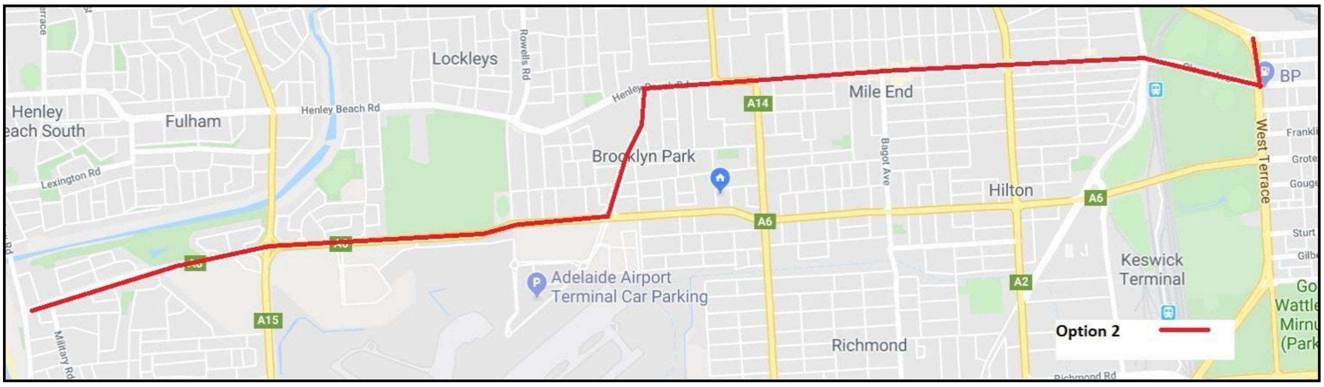


*figure 2. 2 Option 2 for the tram network*

***Option 2:*** Henley Beach Road ITLUP Route (via West Terrace and Glover Ave) including Airport spur via Airport Road and then connecting to west beach.

**Benefits of 1 option:** Large employment, benefits to students and local residents living in this area, more Government's land for development and accessibility due to open space are key factors which provide strength to choose option 1 in contrast to Henley Beach Road.

a. More zoning area for development according to 30-Year Plan for Greater Adelaide, and a number of development applications along the same route, the attraction of the market.
b. The uses of Transit supportive land and a more percentage of people located within the corridor, since it would help to make the city financially sound and to rise up the cost of land.
c. A better arrangement of the road according to its functional importance.
d. More active front of buildings and uses of the Main Street land, which is ideal for tram routes.

The careful and innovative design would help to preserve heritage, manage traffic and parking spaces and proper integration with other services of public transportation. Although Sir Donald Bradman drive has a high initial cost including the construction of the road for Airport, it can play a significant role in development by providing the abovementioned benefits (30 Year plan for greater Adelaide)

**Other suburban route options:**

- An option of Richmond Road gives space for storage of tram (corner of Marion and Richmond Roads), and opportunity for the redevelopment of Marleston TAFE site by connecting it with tram system, integration of Keswick interstate rail terminal, and hubs for employment like RAA headquarters and world business park. However, this road has a restricted scope for uplift.
- Greenhill Road can provide an opportunity to connect by an East-west link from Burnside to the Airport via the Marion Road entry. It would be helpful in getting benefits from a growing development catchment, near to the show-ground and connecting to Burnside Village. However, the route is not providing help in financial benefits for the given catchment due to its size. This route also has limitations in the management of traffic.

## 2.3 Current Network

In 2013, Currie & Burke investigated alteration in light rail and in working of system operations over the last two decades and published a review on developments in the present time and planning of future of all cities in Australia (Currie & Burke in 2013). In comparison with Melbourne and Sydney, the performance of trams in Adelaide was worst in terms of effectiveness, having only 2.9 M boarding annually (Light Rail in Australia-Performance and Prospects, Currie & Burke, 2013)." This gives an innovative idea of significant use of tram system in areas which are with more population or are growing in term of population density.

Additionally, Adelaide is well known for more number of personal vehicles among all the cities of Australia, for instance, 550 vehicles over 1,000 people (Currie & Burke, 2013). The most important question rises about the benefits of WestLINK whether it would help to combat the problem of traffic congestion in Adelaide. Though, this information is based on one tram line which is 15 km long along with the outer-city suburbs, with population density per kilometer between 1500-2000 (Government of South Australia, 2018). As defined in the MCA, the prefigured track has a population of greater than3000, signifying that it is more expected for there to be a mode to change away from private vehicles to public transport following the application of EastLINK and WestLINK.

From 2001 to 2012, there was a 40% increase in tram ridership in Adelaide, whereas there was a rise of 8% in system-wide public transport ridership. This is due to the network extensions to the city west and partially due to the enhancement in tram services by 77% during this period, consequently the vehicle upgrades to modern low floor vehicles and network extensions to City West and eventually the Adelaide Entertainment Centre (Currie & Burke, 2013). This would facilitate the residents who are willing and would prefer to use trams if interesting services are offered.

Currie also publishes that scrutinizing performance end results and regulatory contexts of Light Rail in Australia and the US, which explores the operations and performance of the tram services across Australia and the US are comparative to their similar structures (Currie & De Gruyter, 2016). "During the period of 2001-2012, the yield (boarding's/v km) reduced by 21%in Adelaide (Currie & De Gruyter, 2016)." This study recommends that the reduction of Adelaide's productivity is due to the State Government agency operated the light rail network, which doesn't have any relative terminating or franchising to private agencies to provide the services. Unlike Melbourne and Sydney, they have privatized agencies for the services with a competitive tender. A range of performance criteria is put in position, such as the punctuality of service, trustworthiness and customer satisfaction, resulting in either a penalty or reward to service providers as a part of their agreement for operations (Public Transport Victoria, 2012).

Between the years 2000-2012, 28 major urban passenger rail projects were constructed in Australia, at a cost of approximately $8.8 billion. The projects represented in this paper include heavy rail and light rail projects constructed in Australian capital cities between 2000 and 2012 involving the construction of new rail lines and extension, amplification, and electrification of existing rail lines (CORE, 2012).

Nevertheless, the information contributes to lower results than it otherwise would when the productivity data for Adelaide exclude 'free travelers'. This would have a considerable impact on the outcomes when the amount of Adelaide's free-tram-zone is considered. Among 'Stop: Tram South Terrace' and 'Stop: Tram Entertainment Centre', 11 stations out of the 28 stations on the Glenelg to Entertainment Centre service lie in the free-tram-zone (Government of South Australia, 2018). The free-tram-zone is particularly important while considering that the suburbs lie within or adjoining the CBD. Furthermore, the free-tram-zone employs almost1/3rd of the total 15 KM trail. Therefore, it could also be expected that the actual service strength and the ridership of the light rail may be undoubtedly more than exploring performance results and regulatory contexts of Light Rail in Australia and the US.

## 2.4 Transport Micro-simulation

It is the technique that is widely used around the world to investigate potential options by simulating the exact model. This technique is widely used to provide visual images and videos to present current traffic conditions and the futuristic model to show the difference in the level of service in traffic conditions. The Transport Micro-simulation operates the tram unit throughout the network which works on the basis of event and agent. During the micro-simulation, various events, like the assumed interruption at the beginning of the simulation and later the decisions of each and every individual unit that occurs. The program of the simulation is based on the impact of events that trigger the program (Duy Q. Nguyen-Phuoc, Graham Currie, William Young, Chris De Gruyter).

"Micro-simulation Traffic Models have turned out to be a very helpful tool among the road and transport authorities in recent times for analyzing and classifying solutions for traffic and transport planning (Austroads, 2006)." This model helps in simulating and forecasting the effects of transport conveniences and services on trip creation, mode split, trip routing, travel times and costs, and environmental issues (Currie, Aftabuzzaman, &Sarvi, 2010).

There are a lot of instances that show the analysts are implementing the micro-simulation to model transport. To begin with, Yanga, Wanga, Liub, & Zhouc (2017) used micro-simulation designing to show the carbon emissions from everyday transport in Beijing and calculates the impacts of low carbon policies in Beijing in 2025. Especially, investigation of public transportation enhancement policy had been done (Yanga, Wanga, Liub & Zhouc, 2017).

The result of the micro-simulation model is due to the diverse modes of transport of Beijing drivers, which were used to estimate the carbon emissions from travelers daily. The results formed by the model found that "under the combined effects of public transport improvement, public bike development, energy efficiency improvement, and electric vehicle development, the carbon emission in daily travel can be reduced by 43% in Beijing, which amounts to 4.3 million tons of $CO_2$ per year (Yanga, Wanga, Liub & Zhouc, 2017)." This is a huge paradigm of the significance of micro-simulation on transportation.

Even though Yanga, Wanga, Liub, & Zhouc (2017) did not imitate the network, however, it implements the methods of simulation which might be carried out without difficulty. In this dissertation to examine the reliability of the tram route extensions in the metropolitan area of Adelaide and following these strategies can help us to consider environmental issues while modeling the tram network.

One more illustration of the network is of Barmpas, Kopsacheilis& Dr. Politis (2017), which executes the micro-simulation on the busiest and overcrowded signalized crossing in Thessaloniki, in the northern part of Greece. The dissertation work is stationed on planned substitutive designs for the infrastructure, consider using the methods of micro-simulation. The base model was correlated to two diverse situations each residing in a subterrestrial route along with a set of different traffic administration involvements.

The outcomes recommended that travel time profits are equal for both situations A and B, while situation B is twofold more beneficial in terms of environmental issues (Barmpas, Kopsacheilis& Dr. Politis, 2017). This illustration is very efficient presenting the research capabilities of using the micro-simulation technique. As Barmpas, Kopsacheilis, & Dr. Politis (2017) not concerning a light rail network, but it is just an instance of designing the potential future infrastructure enhancements. This example is valid for my research work also while putting into effect the network of the tram into my model on existing roads, such as Henley Beach Road and Sir Donald Bradman Drive.

Zhao, Li, Xu & Zhai (2018) researched transportation in China and present a tiny model for a light rail system incorporated with the simulation of traffic on roads. This model representation suggests the different types of traffic essential implicated in the system which contains six components: the passenger, the tram vehicle, the equipment, the road traffic, the contact and performance (Zhao, Li, Xu & Zhai, 2018). The outcomes are found to be that the model for Suzhou Tram Line 1 form delimitation outcomes inside 4% of the total values of real data of field (Zhao, Li, Xu & Zhai, 2018).

The main results of the model were passenger's average waiting for time and number travelers waiting on stations. These figures were evaluated based on numerical assessments, manifesting that the outcomes of the model have a similarity with the real scenario with a fine level of assurance. The study of Zhao, Li, Xu & Zhai (2018) had numerous affinities to my thesis work. Remarkably, Zhao, Li, Xu & Zhai in 2018 produced a model using microsimulation inspecting the passenger's average waiting time and number of waiting for travelers on an existing rail system, Suzhou Tram Line 1.

Nonetheless, my study will employ only review data concerning how much time travelers are keen to wait on the station and the number of travelers who agree to use a tram for Sir Donald Bradman Drive, to study the results like route travel times, optimum route frequency and environmental impacts. Furthermore, Zhao, Li, Xu & Zhai (2018) correlated 6 different components to locate the paramount scenario, an analogous procedure is used in this thesis work in which there will be 10 different models for ananlsis.

The literature review of the thesis has implemented a complete investigation of the networks of trams around almost all of the cities in the world and their prospective communal paybacks like relief on the overcrowded roads, social equality enhancement, reduction in carbon emissions and financial progression. The South Australian Government's Integrated Transport and Land Use Plan provide liberal validation for this research to be done. Even though Currie & De Gruyter (2016) and Currie & Burke (2013) had present varying information concerning the efficiency of Adelaide's existing light rail or tram network, innumerable successful transport micro-simulation considerations restated the latent figure in carrying out this study into the practicability of light rail or tram network developments in the metropolitan cities of Adelaide. .

# 3 METHODOLOGY

In order to investigate traffic performance in more detail than the macro models are capable of the detailed microsimulation, model of the study area will be built from scratch. The microsimulation model will be built using a software called Infraworks from Autodesk. Since the microsimulation models do not optimize the traffic lights there was a need for SIDRA modeling to be conducted for all of the signalized intersection. A series of future models are designed in mobility simulation to check various performance indicators, all the data used in this analysis is sourced from the Department of Planning, Transport, and Infrastructure in the form of the SCATS system. Since SCATS do not contain data for unsignalized intersections additional manual count survey was performed. All the data collection procedures and future model analysis are discussed below.

Various surveys were conducted in order to get traffic count for unsignalized intersections and slip lanes. Collected data is used in microsimulation models to calibrate the results for initial existing model. Signaliszed intersections traffic count is provided by DPTI for morning peak hour.

In the mobility simulation, 10 different models have been created by using Infraworks Moblility simulation. All these models are used to compare the various performance indicators. All these future models are based on different proportion of mode shift from private vehicles to tram range between 0-10% and frequency of tram for every 5-min and 10-min. Results, are used to compared the models against existing model.

In the following chapter process of data collection is explained, which will provide information about all the various sources from where data is collected. The main source of traffic count is provided by DPTI in the form of SCATS. This SCATS data include the number of vehicles on each lane and these counts are detected by the detectors on signalized intersections.

# 4 Data Collection

The strategy for data collection is a combination of SCATS data from DPTI (Department of Planning, Transport, and Infrastructure) and manual surveys. There are 14 signalized intersections in this tram network, and the count for each turn can be accessible form SCATS data. However, there are three intersections and some slip lanes which do not have any detectors and for those intersections and slip lanes, a manual survey has been performed to get traffic count.

## 4.1 Survey

The main reason for the survey was to find the actual number of vehicles on the un-signalized intersection. Throughout the network, there are some major intersections and slip lanes, which have no detectors. The scats data provided by the DPTI was very useful in getting the accurate number of vehicles on signalized intersections. Most of the important intersections have detectors but some of them such as Military Road and Burbridge road intersection, Seaview road and Burbridge road intersection, slip lane to Airport from Sir Donald Bradman Drive, Waymouth street, etc. these are the some of the main intersection and roads which carry a large amount of traffic in peak hours, see figure 4.1. So, it is very important to get real numbers for these intersections and for that manual counting and video counting has been performed.

The results from this survey were very satisfying because it was expected that a large number of people are traveling toward the city from this suburb. This survey was for a 5-minute duration at each intersection to get an accurate result for that time. After getting all the left, right and straight through movements, to get an estimate for the whole hour count by simply multiplying a 5-min survey result4 with 12 (12*5=60, 60min=1h).


*Figure 4. 1 Waymouth Street, Sea-view road, Military road intersections*

For slip lanes count an average number of vehicles through the intersection also play an important, for example on the Airport road slip lane 49 vehicles were found in 5 minutes and to get the hourly count multiplying 49 with 12 and it becomes 588. considering 513 as an observed value because through movements are under consideration. Choosing a smaller number of vehicles is to ensure that this reduced figure is true.

Another survey has been adapted from one of the previous year university student and this survey plays a crucial role in understanding the expectations of the public towards the Tram journey, waiting period, tram catchment area, tram stops, etc. This thesis helps in understanding people's behavior and expectation from the tram network and it also covers all age groups (The viability of light rail network extensions in Adelaide metropolitan regions, 2018). He found that what are the impacts of tram networks on residents and members of the public who visited the Adelaide CBD area regularly and those results were used for the development of Mobility Simulation. The survey was based on various issues like

**4.1.1** How they travel there?

**4.1.2** Do they frequently use public transport between Adelaide CBD and the surrounding areas?

**4.1.3** Would they really like the tram connecting the city?

**4.1.4** How far they are willing to walk for the tram?

**4.1.5** How much time they can wait for a tram to arrive?

**4.1.6** Would they be willing to stand throughout the journey?

**4.1.7** Would they be willing to pay the standard MetroCard fare?

The answers to these questions were in the form of YES/NO or multiple choice so that the results were produced directly to the model simulation (The viability of light rail network extensions in Adelaide metropolitan regions, 2018).

## 4.2 Network Catchment Size

This is important to know because it determines who is going to use trams as people from a walking distance often choose trams as public transport. All the suburbs and postcodes which are just at walking distance from the tram network are considered as a part of network catchment and image of the catchment is given below in figure 4.2.


*Figure 4. 2 Network catchment along with postcodes*

People who use trams and how commonly they use it can be determined by ‘the network catchment size’. The data of the survey which was based on the resident’s postcode and the maximum distance they were willing to walk for a tram stop helps in the catchment. A catchment is consisting of all areas within the range of tram station walking distance (The viability of light rail network extensions in Adelaide metropolitan regions, 2018)

| Postcode | Suburb(s) |
|---|---|
| 5000 | Adelaide |
| 5024 | Fulham |
| 5022 | Henley beach |
| 5950 | Adelaide airport |

| | |
|---|---|
| 5032 | Brooklyn Park |
| 5033 | Hilton |
| 5031 | Mile End |

*Table 4. 1 Postcodes within the network catchment*

It is possible that using the postcode when determining the catchment area may not be the best way to determine the possible mode shift on to the proposed tram due to areas being too large and varying in size. Because of this, it was decided to instead of using values from the previous study to build multiple models that used different mode shift proportion varying from 0 to 10%. Maximum preferred walking distance is 1.3 to 1.5 Km, which is adopted from survey conducted in Norwood (The viability of light rail network extensions in Adelaide metropolitan regions, 2018).

### 4.2.1 SCATS Traffic Volume Data

SCATS is the abbreviation of The Sydney Coordinated Adaptive Traffic System, which is a traffic management system used for monitoring and controlling the traffic. The traffic volumes and flows are measured by SCATS with the help of inductive loop detectors on the surface of the road and automatically collect the data of performance (NSW Government, 2011). These methods are usually used at the signal intersections to count each vehicle and their moving direction. In my thesis research, SCATS data has been requested from DPTI for 14 signalized intersections.

Investigation is performed on Tuesday 5$^{th}$ of September 2017; the reason behind this specific date is that this month there are no public holidays and no long weekend. Hence, all professionals, students, trades and other commuters on-road and thus give us a real picture of the busy day. The detailed traffic count was done in every 5-minute intervals for each lane. The total summation was then calculated for each lane to signify the total traffic volume over each 5-minute interval.

There were some detectors which were not producing any outcomes during this whole month I.e. TCS 3084, 83 and TCS 61. For getting the value of these intersections 18$^{th}$ and 27$^{th}$ of October used, which exactly meet the same circumstances and traffic flow. Below is a picture showing the SCATS data collected for all 14 signalized intersections, this data is for the morning peak starting from 7:30 to 8:30 AM.SCATS data shows that West terrace and the Sir Donald Bradman Drive intersection is the busiest one having 7385 vehicles per hour.

However, the lowest counts are at Ikea intersection with only 2151 vehicles per hour.

| Intersection | 1 | 2 | 3 | 4 | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tapleys hill | 805 | 710 | 60 | 880 | 885 | 385 | 407 | 265 | 285 | 177 | 61 | 58 | 100 | 93 | | | | | | | | |
| Airport road | 184 | 215 | 144 | 486 | 563 | 176 | 252 | 165 | 395 | 419 | | | | | | | | | | | | |
| Marion Road | 431 | 432 | 31 | 313 | 562 | 122 | 658 | 718 | 630 | 373 | 353 | 130 | | | | | | | | | | |
| Ikea | 332 | 295 | 702 | 741 | 26 | 8 | 5 | 25 | 17 | | | | | | | | | | | | | |
| Business Park | 13 | 333 | 217 | 836 | 690 | 359 | 41 | 38 | 161 | 156 | | | | | | | | | | | | |
| Brooker Terrace | 392 | 373 | 30 | 579 | 640 | 60 | 144 | 198 | 252 | 224 | 0 | 0 | 0 | 0 | | | | | | | | |
| South road | 272 | 225 | 97 | 69 | 682 | 729 | 241 | 231 | 660 | 632 | 106 | 375 | 368 | 48 | | | | | | | | |
| james congdon | 403 | 372 | 104 | 745 | 866 | 91 | 215 | 202 | 99 | 96 | 272 | 313 | 170 | 283 | 185 | | | | | | | |
| Connection Road | 642 | 463 | 949 | 836 | 31 | 21 | | | | | | | | | | | | | | | | |
| sir Donald/ West TCE | 76 | 266 | 250 | 77 | 139 | 454 | 452 | 238 | 425 | 713 | 404 | 302 | 196 | 176 | 127 | 333 | 621 | 639 | 715 | 166 | 145 | 471 |
| Franklin st/west TCE | 601 | 772 | 500 | 327 | 401 | 328 | 569 | 595 | 722 | 224 | 241 | 203 | 156 | | | | | | | | | |
| Curriest/west TCE | 454 | 439 | 394 | 373 | 407 | 545 | 459 | 438 | 148 | 155 | 225 | 28 | 41 | 395 | 498 | 381 | 35 | 140 | 192 | 171 | | |
| Hindley st/west Tce | 359 | 412 | 446 | 408 | 252 | 273 | 330 | 240 | 518 | 289 | 325 | 177 | 68 | 88 | 0 | 0 | | | | | | |
| North Tce/ West Tce | 301 | 42 | 254 | 256 | 184 | 10 | 386 | 409 | 541 | 528 | 472 | 8 | 321 | 468 | 258 | 25 | 296 | 288 | 10 | 8 | 662 | 708 |

*Table 4. 2 SCATS data for signalized intersections*

### 4.2.2 Manual Traffic Counts

Manual traffic counts are required on some of the intersection where there are no detectors or traffic signals. This tram network consists of 14 signalized intersections and 3 un-signalized intersections and for all of these un-signalized intersections manual counting is required. However, there are some important slip lanes which carry heavy traffic in peak hour and there is no data for slip lanes. So, in this case, it becomes necessary to do manual surveys.

A manual survey has been conducted for 5-minutes on 3 intersections some of the major slip lanes to estimate the exact figures. This manual survey was done in accordance to get the accurate generation of the trips in simulation. For the Sea-view road, Military road intersections with Burbridge road, and the Waymouth street intersection (see figure 4.1) with west terrace the best way to collect the data is to make a video of the whole intersection for 5-minutes and then count individual turns. Because it is relatively hard to count all the turning movements at the same time without video, so everything went smooth by following the same strategy on other intersections and these results were calculated in Excel to get the count for an entire hour by multiplying with 12 (12*5=60, 60min= 1hr). Below are the Images for the Military road and Seaview road intersection.


*Figure 4. 3 Survey images for Military road and Seaview road intersection*

The next step was to collect the data for a slip lane, and it is comparatively easy to count manually. For an instance, slip lane from Sir Donald Bradman Drive to Airport carries heavy traffic in peak time and for that, manual count of vehicle passing every 5-minutes and after multiplying the result with 12 you can get the counts for an entire hour. On minor slip lanes where there is no significant traffic, 10% of vehicles are assumed to be on slip lane to calculate traffic volume.

### 4.2.3 SCATS Intersection Phasing

This data for 5th September 2017 is provided by the DPTI in the form of text files for a 24-hour period. For the morning peak 7:30 to 8:30 AM, this data has been tabulated in the form of an excel sheet and each phase was input in the form of sec in Mobility simulation. Additional data was provided in the form of word files for an inter-green time, turning movement. Phasing data plays an important role in mobility simulation because based on this data signal changes from Green to Yellow and then Red and this data are specially designed by DPTI to meet the demands for every single road. This data changes every hour based on the traffic flow and peak hours.

| AM Peak (7:30-8:30) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intersection | Intersection phases(seconds) | | | | | | | | | | | | | | | |
| | A | | | | B | | | C | | | D | | | E | | |
| | Cycle Time | G | Y | R | G | Y | R | G | Y | R | G | Y | R | G | Y | R |
| Tapleys hill road | 140 | 55 | 4 | 3 | 6 | 4 | 3 | 18 | 4 | 3 | 33 | 4 | 3 | | | |
| Business park | 130 | 94 | 4 | 2 | 6 | 4 | 2 | 12 | 4 | 2 | | | | | | |
| Ikea | 130 | 86 | 4 | 2 | 7 | 4 | 2 | 19 | 4 | 2 | | | | | | |
| Airport road | 130 | 40 | 4 | 3 | 22 | 4 | 3 | 33 | 4 | 3 | 7 | 4 | 3 | | | |
| Marion Road | 130 | 30 | 4 | 2 | 46 | 4 | 2 | 24 | 4 | 2 | 6 | 4 | 2 | | | |
| Bagot avenue | 130 | 59 | 4 | 2 | 8 | 4 | 2 | 23 | 4 | 2 | 16 | 4 | 2 | | | |
| South road | 130 | 52 | 4 | 2 | 7 | 4 | 2 | 34 | 4 | 2 | 13 | 4 | 2 | | | |
| James congdon | 130 | 60 | 4 | 4 | 5 | 4 | 4 | 28 | 4 | 4 | 5 | 4 | 2 | | | |
| Connection Road | 130 | 101 | 4 | 2 | 6 | 4 | 2 | 4 | 4 | 2 | | | | | | |
| Sir donald/ West TCE | 152 | 31 | 4 | 3 | 25 | 4 | 3 | 34 | 4 | 3 | 14 | 4 | 3 | 13 | 4 | 3 |
| Franklin st/ west TCE | 152 | 78 | 4 | 2 | 32 | 4 | 2 | 24 | 4 | 2 | | | | | | |
| Currie st/ west TCE | 152 | 39 | 4 | 3 | 16 | 4 | 3 | 38 | 4 | 3 | 29 | 4 | 3 | | | |
| Hindley st/west Tce | 152 | 78 | 4 | 2 | 26 | 4 | 2 | 30 | 4 | 2 | | | | | | |

***Table 4. 3 SCATS Intersection Phasing***

## 4.3 Origin - Destination Matrix

This matrix represents the demands between different locations, and demand is a person traveling from one location to another. In the mobility simulation, the whole network is divided into 28 zones for generating trips and based on the SCATS data trips are generated from one location to another. An OD Matrix is very helpful in running the simulation model in Infraworks. SCATS havee limited data for traffic in the form of SCATS count and it can be only know the number of vehicles passing through the various intersection, which is collected by detectors. So, it is very tough to get accurate origin and destination of a trip and to overcome this problem, it is assumed that vehicles will travel to their nearest available zones and step by step to manage these counts to distribute among all zones.

Tram network starts from North Terrace to West beach, which consists of 17 intersections out of which 14 are signalized intersections and for such a long network it has 28 zones. For such a long network it was cumbersome to match all the counts. Because, in these zones manual data is used for 5 zones and SCATS count for all other zones.

A large amount of traffic is clearly visible on the west terrace and Sir Donald Bradman intersection due to which it has large delays, and these numbers quite match the SCATS count. Some of the intersections have 22 detectors and managing all the turns was a big challenge for the existing model. For the calculation, all the intersections were drawn over the paper and each turn was calculated separately and distributed among the nearest available zones, The final OD matrix for the initial model and future models is shown in Appendix.

Following chapter will provide more information about the model development process in the Infraworks Mobitlity Simulation. Which include initial model building and this is used as a base for all other future models. Because most of the future models have same lane configuration. All the parameter used in Mobility simulation is briefly described in the next chapter so that reader should understand the process of building model.

# 5. Infraworks Model Development, Calibration, and Validation

This chapter will include description about the existing and all the future models. It will provide a good knowledge about the various parameter used in the model building process. It will also provide information about the number of tram stops and distance between each tram stops. Calibration and Validation process is briefly explained in this chapter and turn counts are used to validate the results produced by the mobility simulation.

## 5.1 Infraworks Mobility Simulation

Mobility is used to analyze traffic movements in Autodesk Infraworks; it consists of various ranges of traffic modeling such as Parking, Tram network, Bus stops, Transit or taxi mode. It can create different zones for incoming and outgoing traffic and exact figures can be used in demands to match real-life situations. After adding OD Matrix, Signal phasing and timing and observations. Initial model simulate in Infraworks to analyze Delays, Level of Service, Economic Evaluation, $CO_2$, $NO_x$, etc. Then similarly, initial model can be amended to run for other future models for comparing the results and choosing the best option.

| S. No. | Model Name | Model configuration |
|---|---|---|
| 1 | Existing model | matching existing lane configuration, signal phasing and OD matrix |
| 2 | Future model 1 | 10% of people using trams, tram frequency of 5-min |
| 3 | 1a Future model | 5% of people using trams, tram frequency of 5-min |
| 4 | 1b Future model | 15% of people using trams, tram frequency of 5-min |
| 5 | 1c Future model | 4% of people using trams, tram frequency of 5-min |
| 6 | 1d Future model | 0% of people using trams, tram frequency of 5-min |
| 7 | 2 Future model | 10% of people using trams, tram frequency of 10-min |
| 8 | 3 Future model | 10% of people using a tram, tram skipping stations, tram frequency of 5-min |
| 9 | 4 Future model | Trams using existing one-lane exclusively, 10% of people using a tram, tram frequency 5-min |

| | | |
|---|---|---|
| 10 | 5 Future model | Trams using existing one-lane exclusively outside CBD except at intersections, 10% people using a tram, tram frequency 5-min |
| 11 | 6 Future model | Tram using addition one lane exclusively, 10% of people using a tram, tram frequency 5-min |

*Table 5. 1 Configurations of all Models*

## 5.2 Initial Network Development

The initial model is built by using a model builder in Infraworks and this can be easily done by selecting the area of the network, but it is not precise. So, still there is a need to make amendments in it, cut down unwanted roads building new roads and checking each connection that matches the same condition. While using this model in the simulation, still there were many mismatches in the number of lanes, improper intersections, and unusual diversions. It takes quite a while to build the exact same model in simulation because it covers a long-distance and a number of intersections. Accuracy in this model is very important because this is a base for all future models and it needs a, all the lane configuration, signal phasing, observations, SCATS counts should match exact numbers.

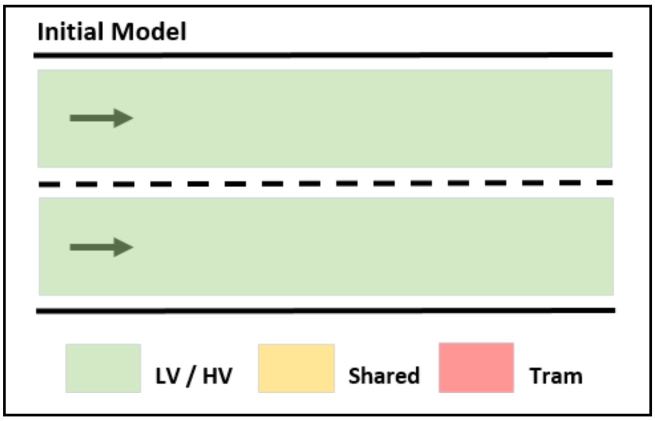


*Figure 5. 1 Initial Model*

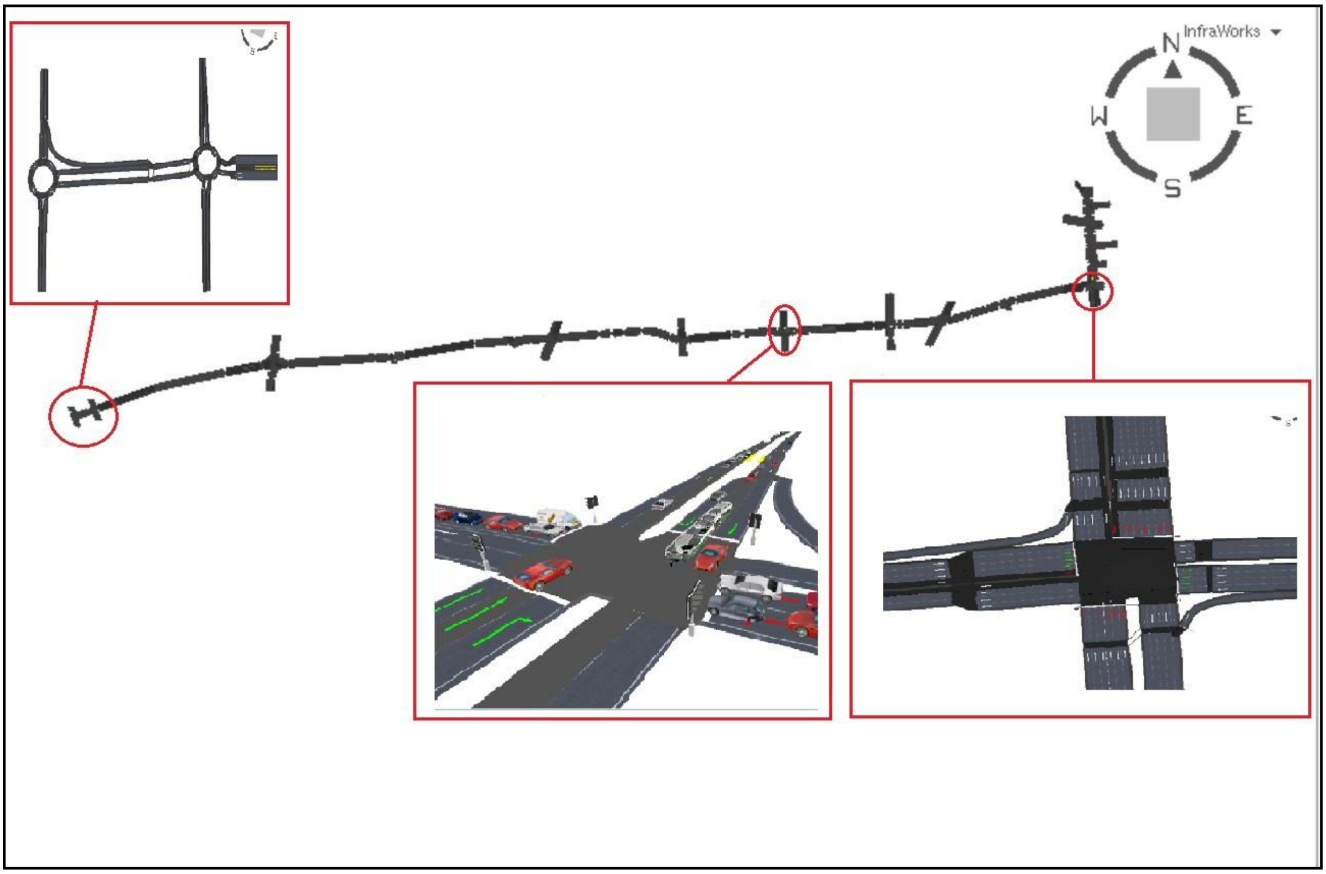


*Figure 5. 2 Complete networks from North terrace to West beach, 17 intersections, and 28 zones*

Figure 3.4 shows the complete initial model in mobility simulation, the whole network consists of 17 intersections and 28 zones. Due to its large size, it is hard to show the lane configuration of the complete model. Enlarged images show the lane configuration of a model on different locations i.e. Seaview road, Military road, Bagot avenue, West terrace, and Sir Donald Bradman Drive intersection. Tram network start from West beach and ends at the North terrace.

### 5.2.1 Lane Geometry and intersections

For the lane, geometry main source of the design was DPTI and Google MAPS, however, for cross-checking manual survey has also been done in accordance to match exactly the same roads, intersections and elevation. In the design, it need to specify the standard width of the road, how many lanes are turning right, left or through the intersection. On the bridge, there are different elevation than the normal roads and all these configurations are important for accurate model building in mobility simulation. Following things were considered while modeling in mobility simulation:

- Width of lane
- Number of turning, sharing and through lanes
- Width of median
- Elevation
- Number and length of short lanes
- Speed of lanes
- Intersection geometry (roundabout, T-intersection, slip lanes, etc.)

### 5.2.2 Signalized

Signalized intersections play an important role in simulation because these signalized intersections are based on data provided by DPTI known as SCATS phasing data and this data is cross-checked with site investigation. In mobility, this data can be edited by using Control – intersections. Cycle length is the time after which the signal phase repeats itself usually it varies from 130 to 152, however, for different intersections it is designed separately for an instance for Tapley hill road cycle length is 140 and for Grote Street intersection it is 152. Phase timing is the time for individual Red, Green and Yellow light. For the accuracy of the model, all parameters are matched with data provided by DPTI.

- Phases
- Phase Timing
- Cycle length
- Turns
    - Direct group
    - Filter group

### 5.2.3 Un-signalized

For the un-signalized intersections, there is need to do manual surveys to count all the left, right, and through movements, and there are 3 un-signalized intersections Seaview road intersection, Military road intersection, and Waymouth street intersection, see figure 5.3.

Video and manual counting have been done on these intersections to get the real-life figure and the results were used to input the OD matrix in the model following the same strategy as per the signalized intersections.


*Figure 5. 3 Waymouth street, Seaview road, Military road intersection*

### 5.2.4 Zones

Zones play an important role in sending vehicles from one place to another, the number of vehicles releasing and accepting is based on SCATS data and this data is created in the form of a spreadsheet known as the OD matrix. OD matrix is responsible for allowing the vehicle to enter and release zones. There are 28 zones in this whole network out of which 5 zones data is based on manual survey and the rest of the data is from SCATS count. Figure 5.4 shows the number of zones along with the network.

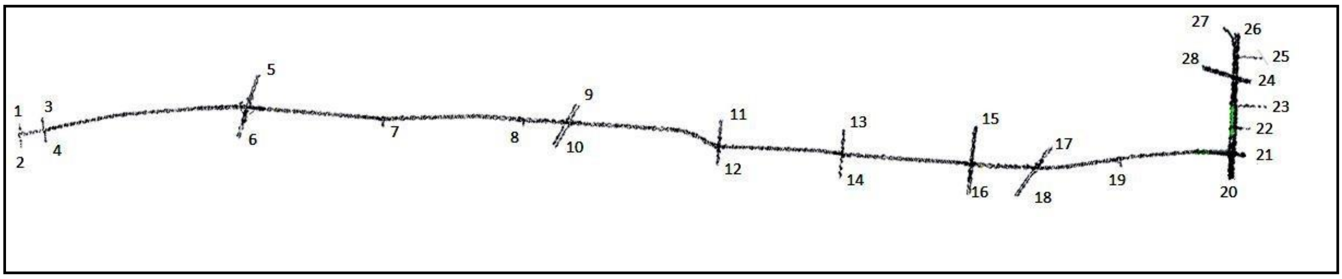


*Figure 5. 4 Tram network showing 28 zones in mobility simulation*

### 5.2.5 Demands

This command is used to generate the OD matrix, in the mobility simulation for creating the OD matrix. Then a matrix opens up and according to zones and SCATS data, it creates an OD matrix. Raw OD matrix was created in Excel using SCATS data for the initial model and then the same OD matrix is used as a base matrix to generate the OD matrix for future models based on predictions and formulas.

### 5.2.6 Calibration

This is an important tool to cross-check results created by mobility simulation, before the final design or implementation of the model. There are two ways to cross-check the model, first is by using software and another is by having manual surveys. So, in this study, both methods have been used in order to produce an accurate result. In the mobility simulation, there is a very important tool under the calibration known as validator and this provides a GEH value for all the intersection and if the GEH value is less than 5 then the design is ok. However, manual surveys have also been done on random sites to check the queue length, waiting period and number of vehicles.

### 5.2.7 Validation

It is a tool in Infraworks simulation to cross-check the results produced by a mobility simulator. Validator produces the result in the form of GEH and if the value of GEH is less than 5 then the results are good under the DPTI guidelines (Government of South Australia Department of Transport, Energy and Infrastructure, 2010). The results produced by the validator are shown below in appendix section B. The value of GEH can be determined by using the equation below.

$$GEH = \frac{\sqrt{2(M-C)^2}}{M+C}$$

Where M depicts modeled traffic volume for an hour, C stands for actual traffic counts per hour. If the value of GEH lies between 5 to 10 then it is a partial match and it needs improvement. Any values of more than 10 are not acceptable.

- Turn counts

It is a part of calibration and very useful in cross-checking the values of turning vehicles at every intersection. From the SCATS count provided by DPTI, it can calculate the number of vehicles passing through every single intersection and then this tool (Turn counts) compares the observed value with the OD matrix. In this network, there are 145 turn counts that are under investigation and all of the results are under permissible value see figure 10.15 in the appendix section B.

- Auditor

This tool is used to verify that the model is running successfully without any trouble and if any problem occurs while simulation, Auditor was used to get the empty zones, unconnected roads, unconnected strands, unreleased vehicles, etc. for an instance, Future model 4 has unreleased vehicles because of one exclusive lane for the tram (figure 6.5) and all the zones which are not able to send more vehicles are visible in Auditor.

### 5.2.8 Route Analysis

This tool is used to find an accurate or more realistic route for a trip generation. In big network areas, there are different ways to reach the same destination by following different routes and the software allows the vehicles to choose the best and easiest way to get there. So, in this condition vehicles choose less congested routes, but in this network, there is only route option from city to beach, so this tool has no use in this analysis.

### 5.2.9 Site Investigation

This was done in accordance to verify the calibration process and it is important to cross-check existing model lane configuration, speed limit, slip lane, etc. This investigation assured that the base model is matching exact lane configuration and traffic conditions. Busiest intersection slip lanes and un-signalized intersections were investigated to verify queue length, number of vehicles and travel time.

## 5.3 Future Models development

### 5.3.1 Trails

This tool was used to create a tram network from westbound to eastbound throughout the road network and the length of trails is 8870m. These trails will allow trams to travel from West Beach to North terrace and the trails are on both sides of the road to allow travel in both directions.

### 5.3.2 Stands

As the name suggests it is the tool to add stops for tram so that people can board a tram from various locations. There are 10 stops for the tram, on each way from the beach to city and these are located on different location throughout the network and the distance between the two stops is calculated from the Google maps (see table 5.2) and location of the tram stops are predicted based on amenities around the network.

| From | To | Distance |
|---|---|---|
| Stop 1 | Stop 2 | 276m |
| Stop 2 | Stop 3 | 493m |
| Stop 3 | Stop 4 | 416m |
| Stop 4 | Stop 5 | 1.13Km |
| Stop 5 | Stop 6 | 770m |
| Stop 6 | Stop 7 | 810m |
| Stop 7 | Stop 8 | 1.05Km |
| Stop 8 | Stop 9 | 2.21Km |
| Stop 9 | Stop 10 | 1.50Km |

*Table 5. 2 Distance between all stops of the tram network*

This information about the distance between the tram stops will allow the user to choose the nearest tram station and these stops are designed to get the maximum number of passengers. The image 5.5 shows the location of all the stops on the map and it can be seen that the first three steps are so close to each other because of proximity to the city and then they have more gaps between 8 and 7 because there are no great attractions.

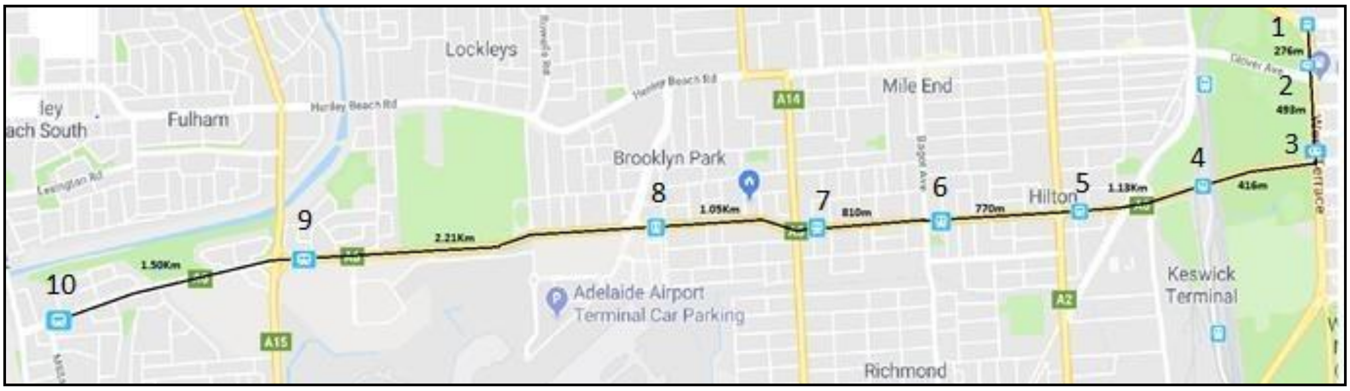


*Figure 5. 5 Stops of the Proposed tram network*

### 5.3.3 Schedule

To figure out the best performance model different time-frequency trams are used in future models, and this feature allows us to choose the schedule for a tram. Future models 1 and 2 are prepared with different time schedules such as tram at every 5, 10 and 15 minute. This feature allows us to compare results with a different time schedule and then best time was choosen.

The next chapter will show future models lane configuration, restrictions, mode shift, frequency of trams and result output. There are 9 future models which are based on initial model and SCATS data. Mode shift from 0 to 10% is used in this analysis to match practical figures.

# 6. Modeling future scenario

This chapter includes the information about the future models used in Mobility Simulation. All the future models have different restriction, mode shift, and tram frequency. All the results for future models are explained in result chapter. This chapter will familiarize the reader with all future models used in this thesis research.

## 6.1 Future Model 1

This model was created in order to connect tram network from North terrace to West beach, tram lane is along the right side of the road network on both ways and it is shared a lane for a private vehicle, buses, and tram. There are 10 stops for the tram on this network and tram follows Sir Donald Bradman drive all the way from city to west beach. Figure 6.1 shows the mobility simulation model on the West Terrace and Sir Donald Bradman Drive intersection. The mobility simulation model is the same for future model 1, 1a, 1b, 1c, 1d, 2 and 3. However, there is a change in the number of people boarding tram, tram station and tram frequency.

- Future model 1: is performed with only 10% of people are traveling on the tram with a tram frequency of 15-min.
- Future model 1a: is performed with only 5% of people are traveling on the tram.
- Future model 1b: is performed with 15 % of people traveling on the tram.
- Future model 1c: is performed with only 4% of people traveling on the tram.
- Future model 1d: is performed with 0% people traveling on the tram.

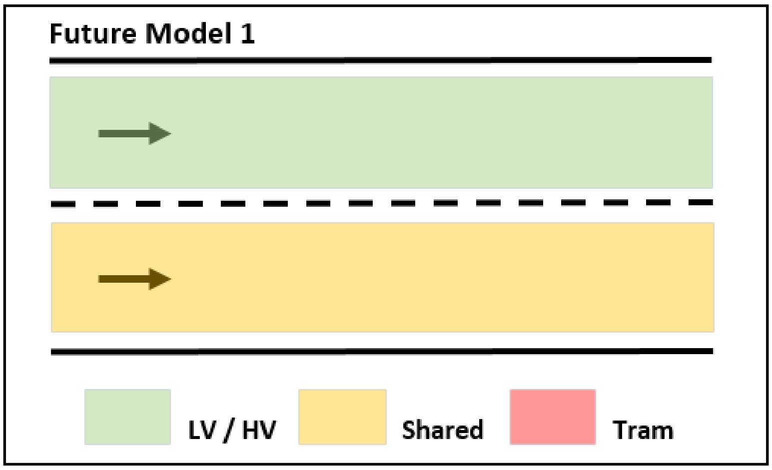


*Figure 6. 1 Future Model 1*

Figure 6.2 shows the lane configuration for tram and private vehicles, where LV/HV stands for light vehicles and heavy vehicles. Yellow color lane is shared for tram and private vehicles, but the entry of tram in green lane is restricted.

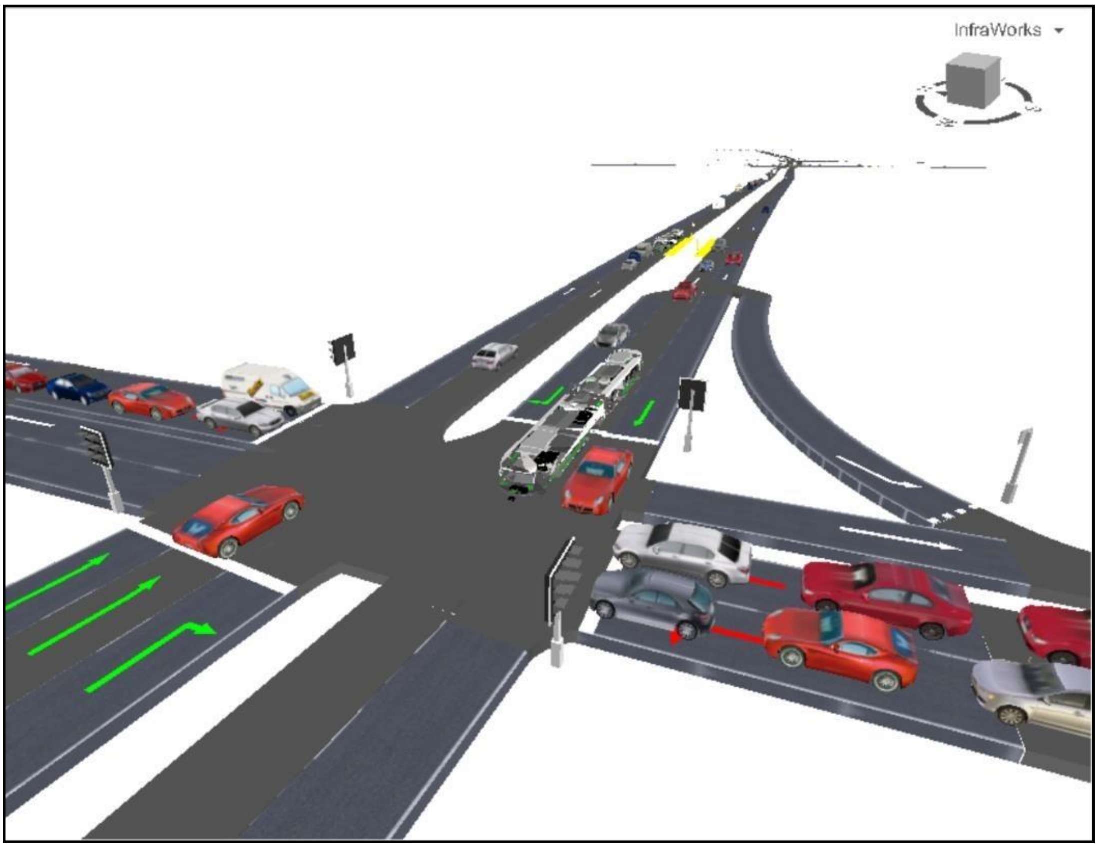


*Figure 6. 2 Infraworks Model for Future Model 1*

Figure 6.3 shows the tram network in mobility simulation and it is clearly visible that tram is sharing an existing lane with other private vehicles.

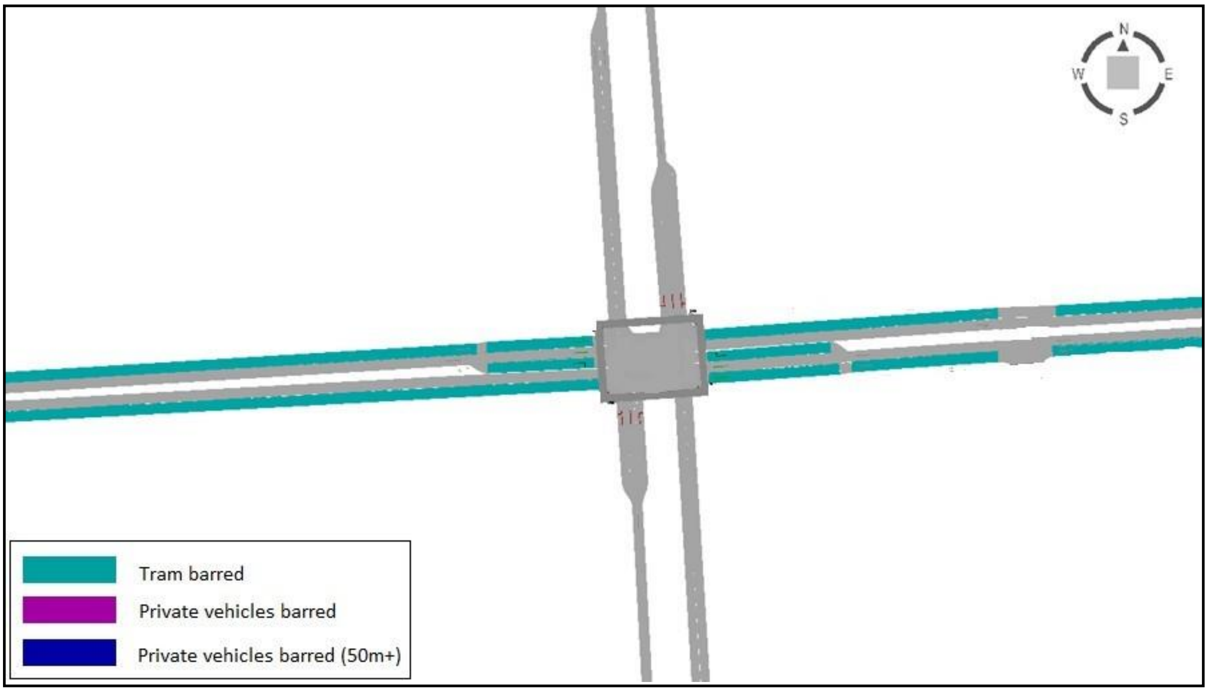


*Figure 6. 3 Restriction in Mobility simulated Model*

In figure 6.3, the lane restriction layer is used to show restrictions used in this model, as it can see that the tram is barred to use the left-hand lane on each side. But private vehicles can access both lanes as they no restrictions.

## 6.2 Future Model 2

In this model, tram frequency changed from 5-min to 10-min and all other configurations are the same for this model. Tram is still sharing the lane with other private vehicles, but the tram frequency changes from 5 to 10 minutes. This model doesn't require any changes in future model 1, for the lane configuration see figure 6.1, however, the tool used for changing tram interval is Network-Services-interval. A result from this model does not show a significant difference from model 1, hence it is not recommendable for future development. All the results outcomes from this model are displayed in result section.

## 6.3 Future model 3

This model is based on future model 1 and the entire lane configuration, restrictions are similar to model 1. The main difference in this model is that tram using fewer stops to have better results. Tram stop 2, 4 and 9 were skipped (see figure 6.4) to check speed, level of service, total cost and other performance indicator but there was no significant difference found with future model 1, however, skipping tram stations is not the motive of study. A good discussion about the result outcomes is displayed in discussion section.

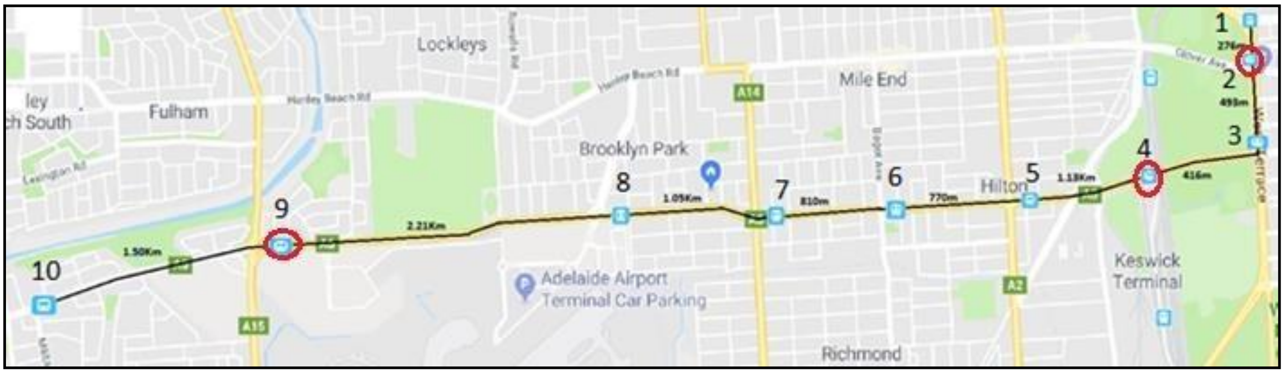


*Figure 6. 4 Skipped tram station during simulation*

## 6.4 Future model 4

This model is prepared to measure the efficiency of Tram. In this model, Trams have an exclusive lane in order to provide better serviceability and prevent delays from other vehicles. For instance, the right-hand lane is banned for other private vehicles and only tram can access this lane. In figure 6.5 red color depicts tram only lane and the green color depicts private light and heavy vehicles only.

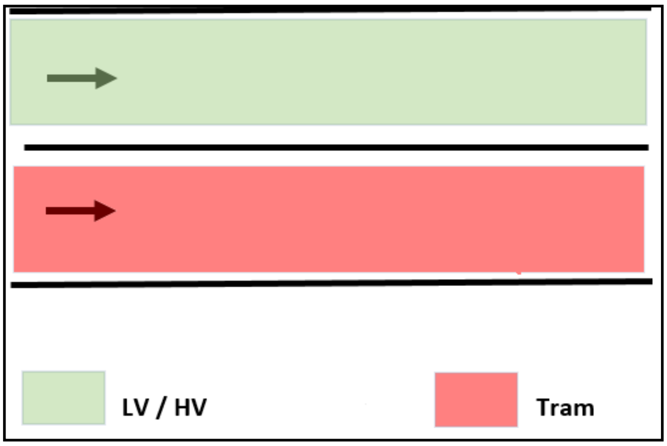


*Figure 6. 5 Future Model 4*

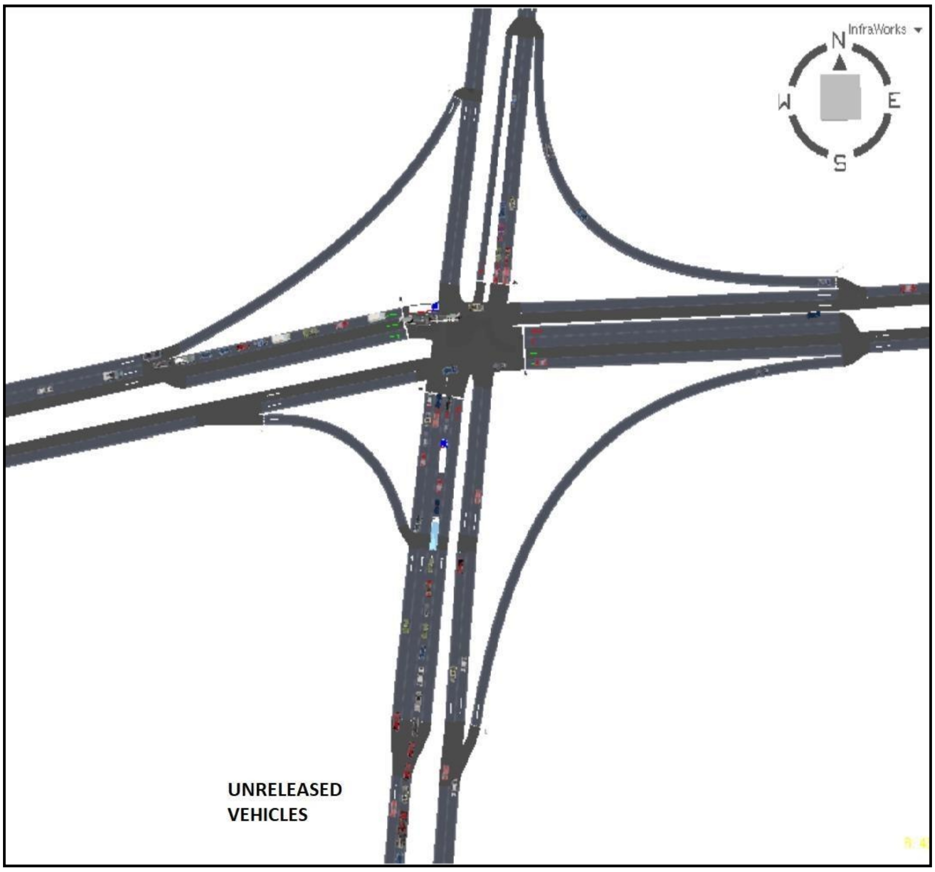


*Figure 6. 6 Infraworks Model for Future Model 4*

This model produces a complete network gridlock due to insufficient traffic capacity. This model is based on existing model infrastructure and there is no additional lane for a tram. Tram is using one of the two lanes from the existing network exclusively, which has a really bad impact on other road users. In figure 6.6 it can be seen that there are long queues in one lane and more vehicles are not able to access the road as there are so many unreleased vehicles. level of service and other performance indicators are worst as there are long queues and higher total costs compared to other future models. Results and more discussion is in the result and discussion section respectively.

### 6.4.1 Restrictions

In this model, Trams are allowed to use the right lane exclusively and all other private vehicles are barred to enter in this lane, and this allows great serviceability to tram but it has an adverse effect on other road users. Figure 6.6 long queues are observed in one lane on Mobility Simulation.

## 6.5 Future Model 5

This model provides great serviceability to trams as well as to private vehicles who want to turn right. This model provides an exclusive lane for Trams outside CBD and except intersection, this means all private vehicles can share the lane within the CBD. The figure 6.7 shows the lane configuration for trams and other private vehicles in case of Inside CBD and outside CBD. Results achieved by this model are very impressive and competitive with future model 1.

In figure 6.7 LV/HV stands for light and heavy vehicles and Red color for trams, however, Inside CBD model shows that trams and private vehicles are sharing one lane inside the city. In figure 6.7 outside the CBD, the model shows that private vehicles are allowed to enter tram lane within 50m of intersection for turns.

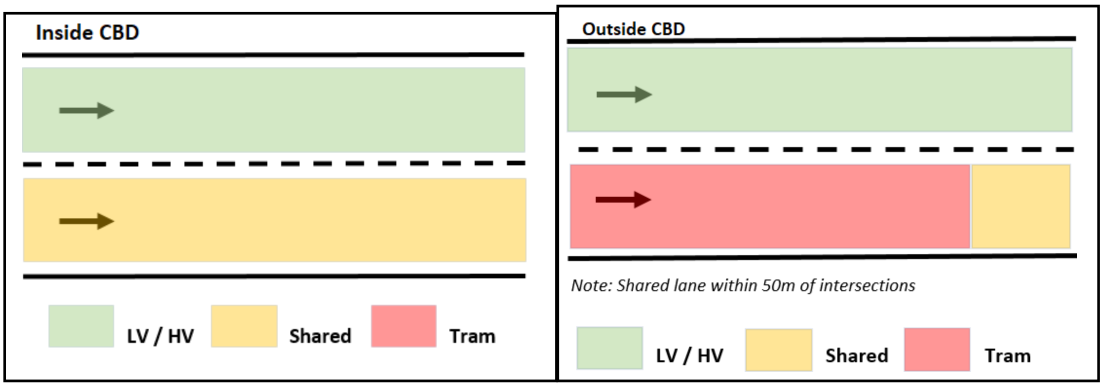


*Figure 6. 7 Future Model 5*

*Figure 6. 8 Infraworks model for Future Model 5*

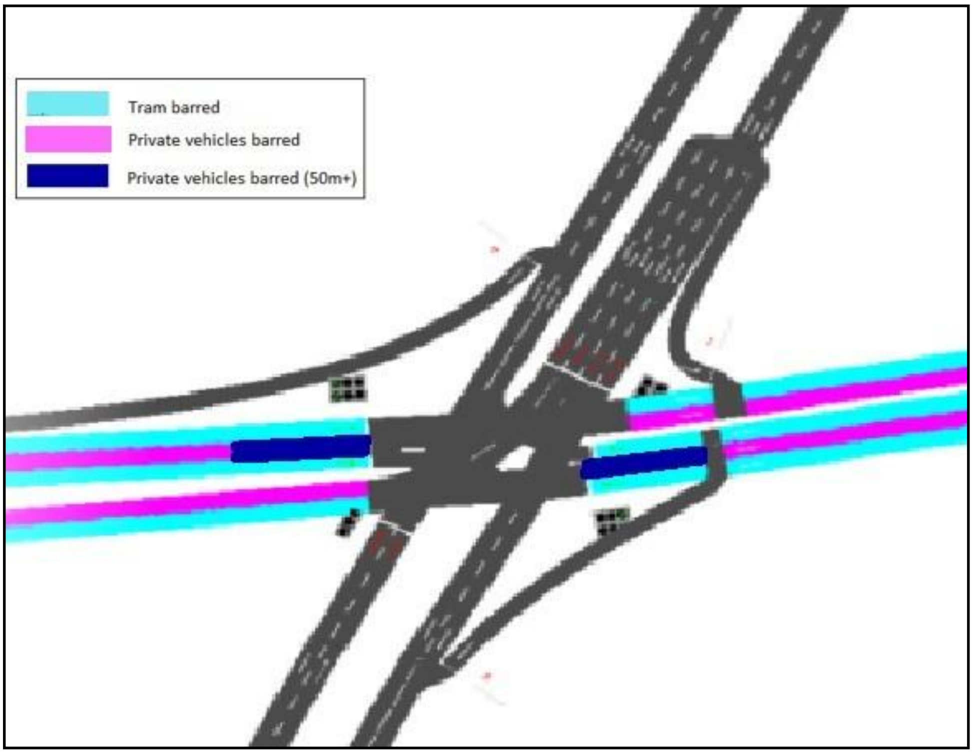


*Figure 6. 9 Restrictions for Future Model 6*

Figure 6.9 shows the restrictions used for outside CBD models in mobility simulation, as trams are barred to enter in the left-hand lane on each side and private vehicle are barred to enter right-hand lane except at intersection within 50m. The result of this analysis is competitive with future model 1. Both the models are performing best in all performance indicators and more discussion about the result is provided in the discussion section.

## 6.6 Future Model 6

In this model, Trams are using the additional separate lane to provide serviceability to normal traffic and Trams. This model is best among all other which is as expected but this is the most expensive model and it requires extra space for adding an additional lane. The image below shows the lane configuration of the model.

In figure 6.10 LV/HV stands for light vehicles and heavy vehicles and Green color shows that there are two lanes for private vehicles and the tram is barred in those two lanes. Red color depicts tram lane and, in this model, an additional lane is provided for trams.

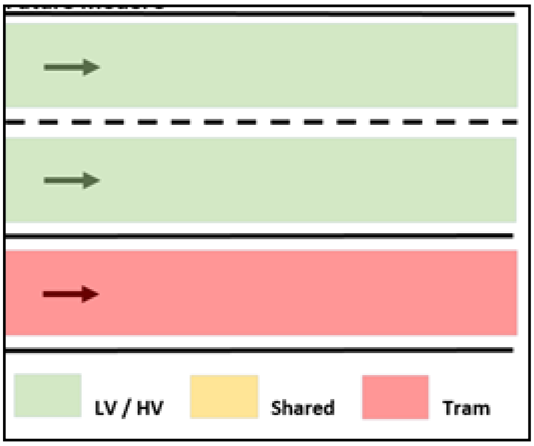


*Figure 6. 10 Future Model 6*

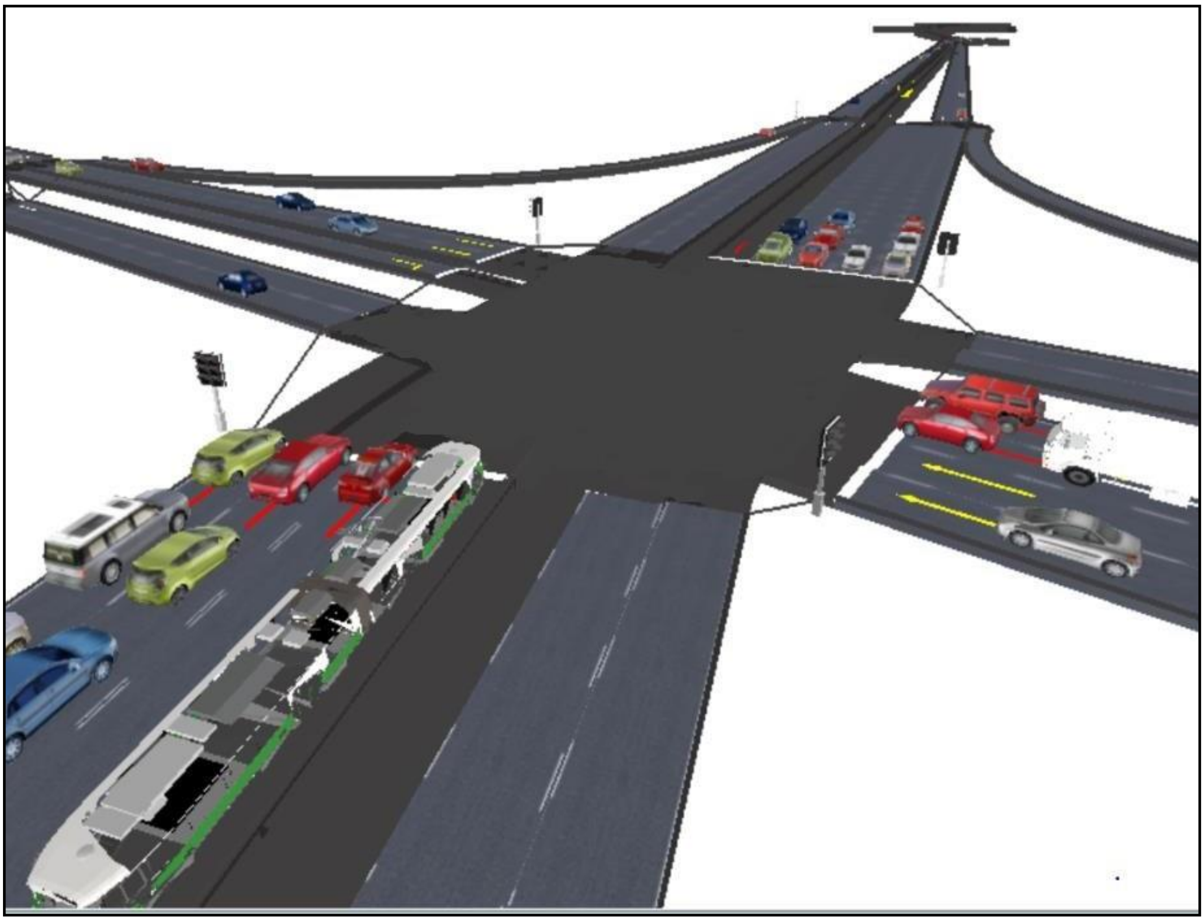

*Figure 6. 11 Infraworks Model for Future Model 6*

Figure 6.11 shows the mobility simulation model with one additional lane for trams only. The purpose of adding one lane is to increase serviceability to other road users as well as tram. The results of this model are explained in the result section.

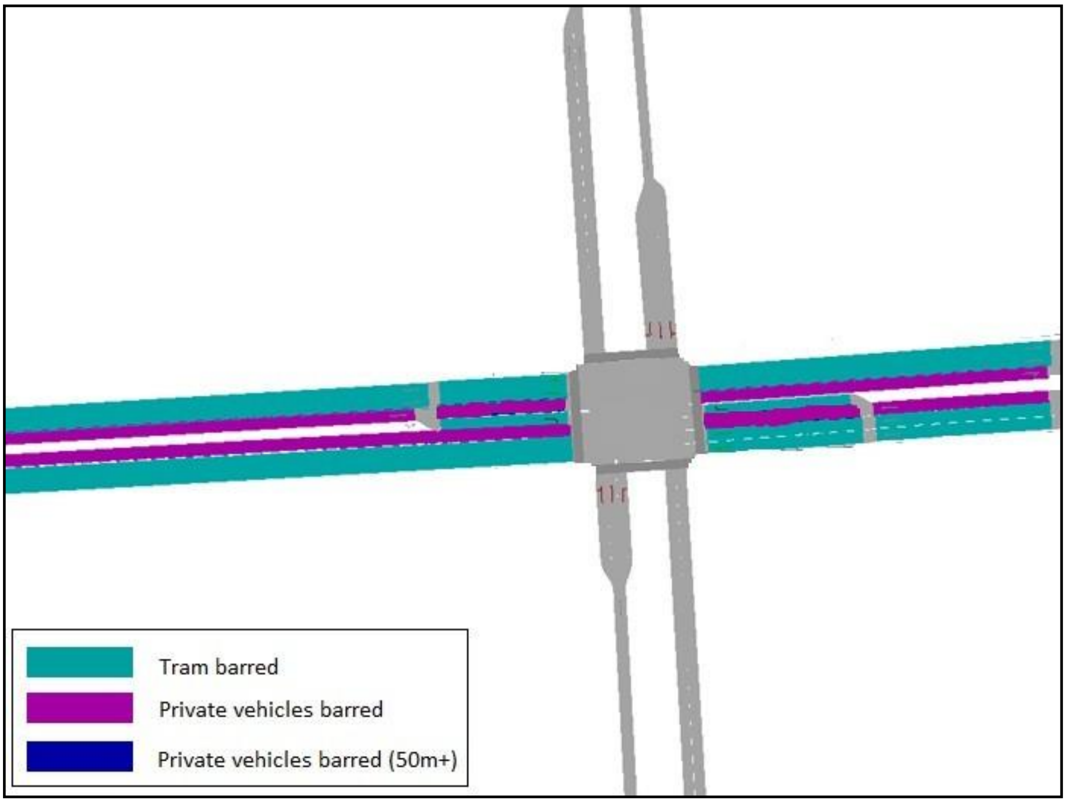


***Figure 6. 12 Restrictions for Future Model 6***

Figure 6.12 shows the restrictions for future model 6 and from the purple color, it is clear that there is an additional one lane for tram where all other private vehicles are barred and on the other two lanes tram is banned.

Next chapter includes all the results from the initial and future models, results provided by mobility simulation are based on various performance indicators. Results includes level of service, CO2 and NOx emissions, total cost comparison and increase in speed. It also include the result outputs form the survey conducted on various sites.

# 7 RESULTS AND ANALYSIS

This chapter includes the results from survey conducted on various sites in order to get traffic count volume. It also includes the traffic count volume from various slip lanes which do not have any detectors. It also include the survey response from people about the tram extension and other questions. In the last section, comparison between different future models outputs is displayed in the form of graphs.

## 7.1 Survey

**Manual counts and observations**

Manual counts have been collected from three major intersections and other major slip lanes at the interval 5-min. The reason for these surveys was to collect the vehicle count for the Mobility simulation model. The survey was conducted on un-signalized intersections because there are no detectors on these intersections.

1. **Sea-view road intersection:** 5-min video graphical survey has been done on this intersection to count all the left, right movements from all different directions then these counts can be calculated for a whole hour by multiplying the count with 12. Results obtained from the survey are tabulated in the form of zones Table 7.1, for instance, zone 1 and 2 zones come under Sea-view road intersection. The picture shows the scene from the survey at Sea-view road intersection.

*Figure 7. 1 Sea-view Road Intersection*

2. **Military road intersection:** Similar strategy is adapted for this intersection as well and

the results obtained from this intersection are tabulated in the form of zones in table 7.1. The figure 7.2 shows the Seaview road intersection and Military road intersection along with the number of zones 1, 2, 3, 4. East approach is the vehicles that are coming from the east direction towards the Military and Seaview road intersection.


*Figure 7. 2 Military Road Intersection*

| Zones | Left | Right | Straight | East entry to zones |
|---|---|---|---|---|
| From 1 | 0 | 2 | 348 | 552 |
| From 2 | 540 | 0 | 216 | 70 |
| From 3 | 240 | 240 | 10 | 30 |
| From 4 | 5 | 0 | 5 | 4 |

*Table 7. 1 Results obtained from the Survey*

1. **Waymouth street intersection:** Video graphical survey is used to find the traffic count in all direction and the result are from 5-min survey shown in below table

| Intersection | Left | Right |
|---|---|---|
| West terrace to Waymouth street | 15 | 45 |
| Waymouth Street to West terrace | 21 | 5 |

*Table 7. 2 Results from Video Survey*

1. **Slip lane to Airport form Sir Donald Bradman Drive:** Manual counts have been done on this lane because in peak time this lane carries heavy traffic and 49 vehicles have been observed in 5-minutes.

## Assumptions

1. All the minor slip lanes carry only 10% of the through traffic counts.
   Minor slip lanes are those which do not have any public attraction, Airport, Shopping areas, School, etc.
2. All the major slip lanes carry 30% of the through traffic count.
   Major slip lanes are those which provide access to the public attraction, Airport, Shopping complex, School and residential areas.

### 7.2 Survey response

According to a survey conducted by James Royle, the past student of Flinders University in Norwood concludes a very important figure, which clearly shows the interest of people in connecting the tram with CBD. He got responses from a variety of age group along with various types of questions for instance, do you favor connecting The Parade with CBD via Tram, do you in favor to pay MetroCard fare, etc. (The viability of light rail network extensions in Adelaide metropolitan regions, 2018)

From the survey result, he concludes that 50% of the total population use public transport as their daily commuter. 63.9% of the residents would like to see the tram network linking the CBD out of which the majority of people who responded no is from age group 65+, which places a great impact on this result. 75% of passengers are willing to stand throughout the tram's journey if they have the opportunity to go city by tram. 91.9% of the people are willing to pay MetroCard fare from Norwood to CBD.

According to the different age groups response, the 65+ group was highly represented with 22.7% of responses and only 22.2 % of them say yes for tram connecting from Norwood, followed by people aged 55-64 with 68% of them happy to see connecting tram to CBD. 39.5% of the responses were from the age group below 45 years and people having age 45 years or above gave maximum response around 60.5%. However, the least represented groups are 18-24, 25-34 and 35-44. All the results are displayed in the graph and this shows the interest of people in connecting the tram from the city to Norwood.


***Figure 7. 3 This image has been removed due to copyright restrictions: Response to the question 'Would you like to see a tram connecting The Parade to the CBD (The viability of light rail network extensions in Adelaide metropolitan regions, 2018)***

From this survey, it is clear that 63.9%, of people, are willing to see a tram connection between CBD and Norwood and these responses are very helpful in understanding people's view about the tram connection (The viability of light rail network extensions in Adelaide metropolitan regions, 2018). From this result, it can be assumed that more than 50% of the population surrounding the network area will agree to use tram instead of other private vehicles and based on that assumption tram network is built from City to West beach including Airport. Using public transport is a lot of economic than using personal vehicles and will reduce the stress of parking.

## 7.3 Mobility Simulation

### 7.3.1 Tram Implementation

There are six major models and four sub-models that have been simulated in Mobility simulation, Initial model was made to match all the lane configuration, signal phasing, intersection and traffic counts. Then future model 1 is made with different proportions of people traveling tram 4%, 5%, 10%, 15%. Then the other future models 2, 3, 4 and 5 were

simulated to find the best performance of the models. The results produced by all the 10 models in the Mobility simulation are well explained below.

#### 7.3.1.1 Economic Evaluation Report

For all the future model's Economic evaluation report has been produced by the Mobility simulation model and this report is crucial in describing each model which is based on different figures such as Cost, Delay, Speed, Trips completed, number of stops etc. this report can be generated by selecting Economic evaluation report before publishing the final reports.

Data generated by all the existing and future models have been utilized in creating cost comparison graphs and provide useful facts in choosing the best performing model. The graphs below show the cost comparison between all the future models and the initial model for the morning peak time from 7:30 to 8:30 AM.

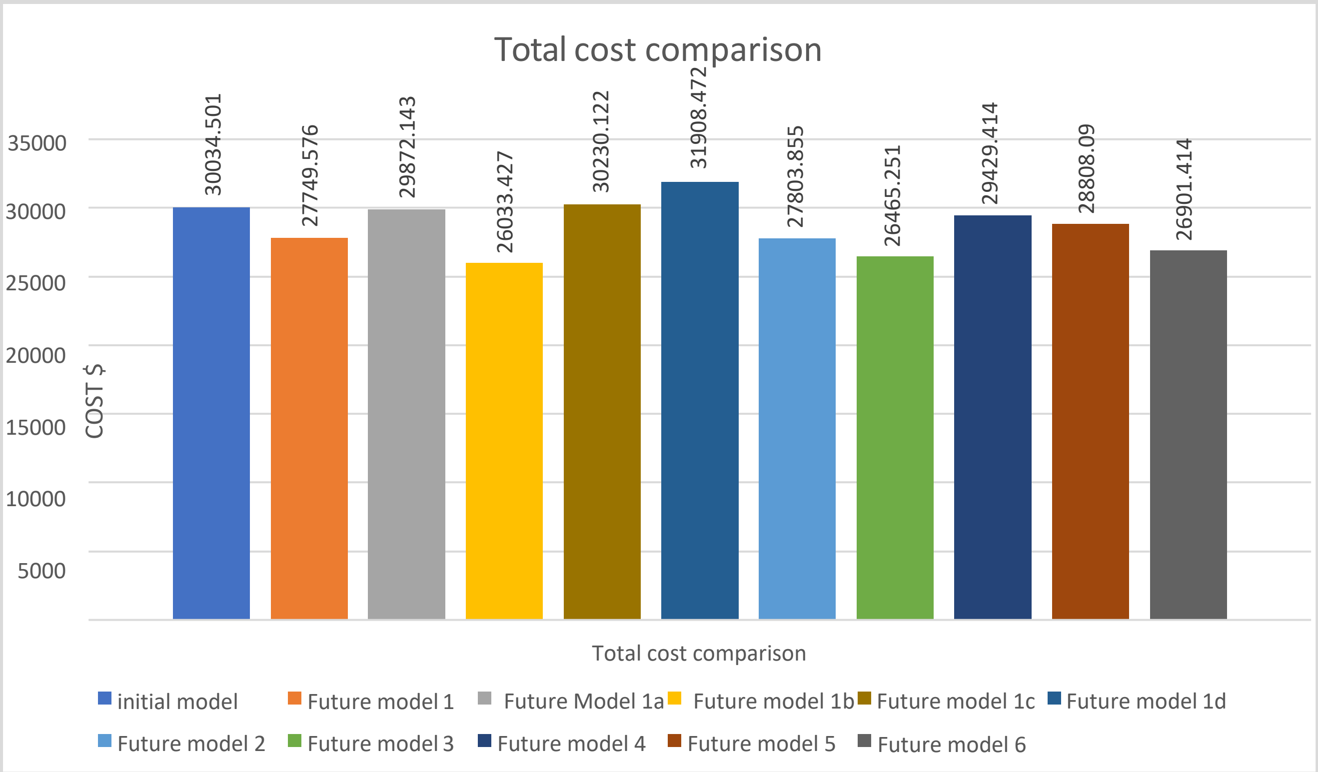


*Figure 7. 4 Total Cost Comparisons*

All the data from mobility simulation for total cost is displayed in appendix section10.1 and this is based on some factors such as time, stop and distance. It is also shown in the appendix below at 9.11 and the hour price is taken $25, this price is half of the average wage and based on this all the calculations have been made in Mobility simulation.

As shown in the above figure it is very clear that the Existing model has an approximately equal value to future model 1c, this model was created intentionally to match the Cost. In the future model, 1c is designed to have only 4% of people boarding the tram and this is the worst-case scenario that if people are not showing any interest in catching a tram for their daily commuter.

Future model 1 is one of the best because the prediction used in this based on the survey is that 10% will use a tram, which is quite reasonable. The cost difference in the existing and Future model is around $2177 in just one hour, which shows that it is 7.3% more economical than the existing infrastructure. The results produced by the model Future model 1b are even more interesting, which is showing a difference of $4001 and that means it is 13.3% more economical than the existing scenario. So, relying on the fact that at least 10% of people will choose trams to travel to the city.

However, future model 2 and 3 did not show a big difference from future model 1 in whichumost frequent tram i.e. every five minutes and using fewer stops respectively but the results produced by them don't show a big difference which is only $53 and $1392 and it is not worth to skip stations because tram is designed to provide more flexibility and serviceability to everyone. Future model 6 shows very impressive results as there is a difference of $3127, which makes a benefit of 10.41%. For this model, an extra space was taken to built an extra lane and over the bridge, it is really expensive to build an extra lane.

Future model 1 and 5 is the most recommended model among the peers because results produced by all other are not very realistic and it is important that model should match real-life scenario and it doesn't cost heaps of money to establish the infrastructure. Future model 1 is relying on that 10% of people will board the tram for traveling which is not a hypothetical and very reasonable figure from the survey (The viability of light rail network extensions in Adelaide metropolitan regions, 2018).

#### 7.3.1.2 Average vehicle speed

It can be calculated from the results obtained from the Mobility simulation for Economic evaluation. The result obtained includes the completed and total trips and the mean of them

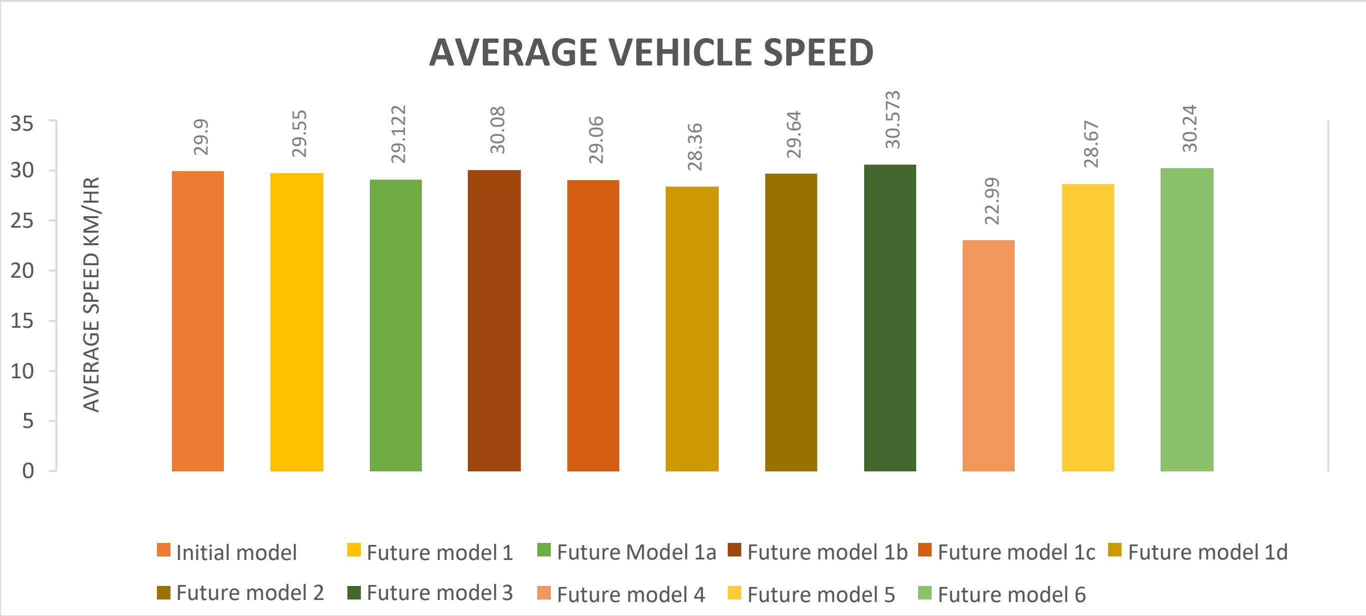


*Figure 7. 5 Average Vehicle Speed*

gives the results for average vehicle speed and these values are used to show the result in the graph for comparison.

Future model 1 is having an average vehicle speed of 29.53km/h, which is slightly less than the existing model and the results produced by model 3 and model 6 are even better than the initial model has a speed of 30.57km/h and 30.24km/h respectively. But these models are not recommended models because in model 3 Tram is actually skipping some of the stops and in model 6 a separate additional lane was modified, which makes this model quite expensive relative to other models.

From this analysis model, 1 is the most recommended one because this is having a shared lane with other private vehicles and this is also the most economical one as well. The worst model in this analysis is Future model 1d which has only 28.36km/h of speed. Future model 4 is not displayed in this analysis because 5568 vehicles were unreleased and not a part of analysis, which makes the results quite unrealistic see fig. 6.6.

#### 7.3.1.3 Intersection Performance

This performance is helpful in predicting the best suitable model for future development because all the traffic from the different zones come to halt on intersections. In the Mobility, simulation intersections are analyzed for the Level of Service and delays and this is depending on how long vehicle queues are on intersections. For all the future models and existing model, the LOS is tabulated in table 7.3 below.

Level of Service for all of the Signalised intersection shows an important result, how the implication of trams improves the LOS of networks. Future model 1 and 5 show very great result for all the intersection however, model 6 is also performing very well. The standard values for LOS A to F are shown in table 10.5, in the appendix. All the future models are performing better than the existing model except the model 4, where it shows large queues and worst level of service reach LOS E. From this analysis model 1 and 5 and 6 shows quite similar results for all intersections having most of the intersections at LOS B and worst with LOS D. Model 1c shows better results than model 1 because in model 1c 15% people are using trams instead of private vehicles. Overall model 1 is the best performing model in this analysis as only 10% of people are using trams and there is one sharing lane, which has most of the intersections at LOS B only 1 intersection at LOS D.

| | Level of Service | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Intersection | Ex Model | F model 1 | F model 1a | F model 1b | F model 1c | F model 1d | F model 2 | F model 3 | F model 4 | F model 5 | F model 6 |
| Seaview Road | B | B | C | A | B | B | B | B | B | B | B |
| Military Road | B | B | B | B | B | B | B | B | B | B | B |
| Tapleys hill road | E | D | E | D | E | E | D | D | E | D | D |
| Business park | C | B | B | A | C | C | B | B | C | B | B |
| Ikea | C | B | C | B | C | C | B | B | C | B | B |
| Airport road | C | B | B | B | C | C | B | B | B | B | B |
| Marion Road | C | B | B | B | C | C | B | B | C | B | B |
| Bagot avenue | C | B | B | B | B | C | B | B | C | B | B |
| South road | B | B | B | B | C | B | B | B | C | B | B |
| James congdon | C | B | B | B | C | C | B | B | C | B | B |
| Connection Road | C | B | C | B | C | C | B | B | C | B | B |
| Sir donald/ West TCE | E | C | C | C | D | D | C | C | E | C | C |
| Waymouth street | D | B | C | B | C | D | B | B | C | B | B |
| Franklin st/ west TCE | C | B | C | B | C | C | B | C | C | B | B |
| Currie st/ west TCE | D | C | C | C | D | D | C | C | D | C | C |
| Hindley st/west Tce | B | A | B | A | B | C | A | B | B | A | A |

***Table 7. 3 Level of Service***

#### 7.3.1.4 Environmental Impact

This is an important figure in determining the best-designed model, Environment is most concerned topic before designing any public transport system. In the Mobility simulation, results for $CO_2$ and $NO_x$ for the present and future models and the result are displayed in figure 7.6. However, both $CO_2$ and $NO_x$ are the worst pollutant which is destroying our atmosphere and need consideration. Along with these two environmental impacts results of following terms was assessed-

- Origin and destination of zones

- Type of vehicle
- Time of travel
- Traveled distance
- Time for arrival and departure
- $CO_2$ and $NO_x$ emissions

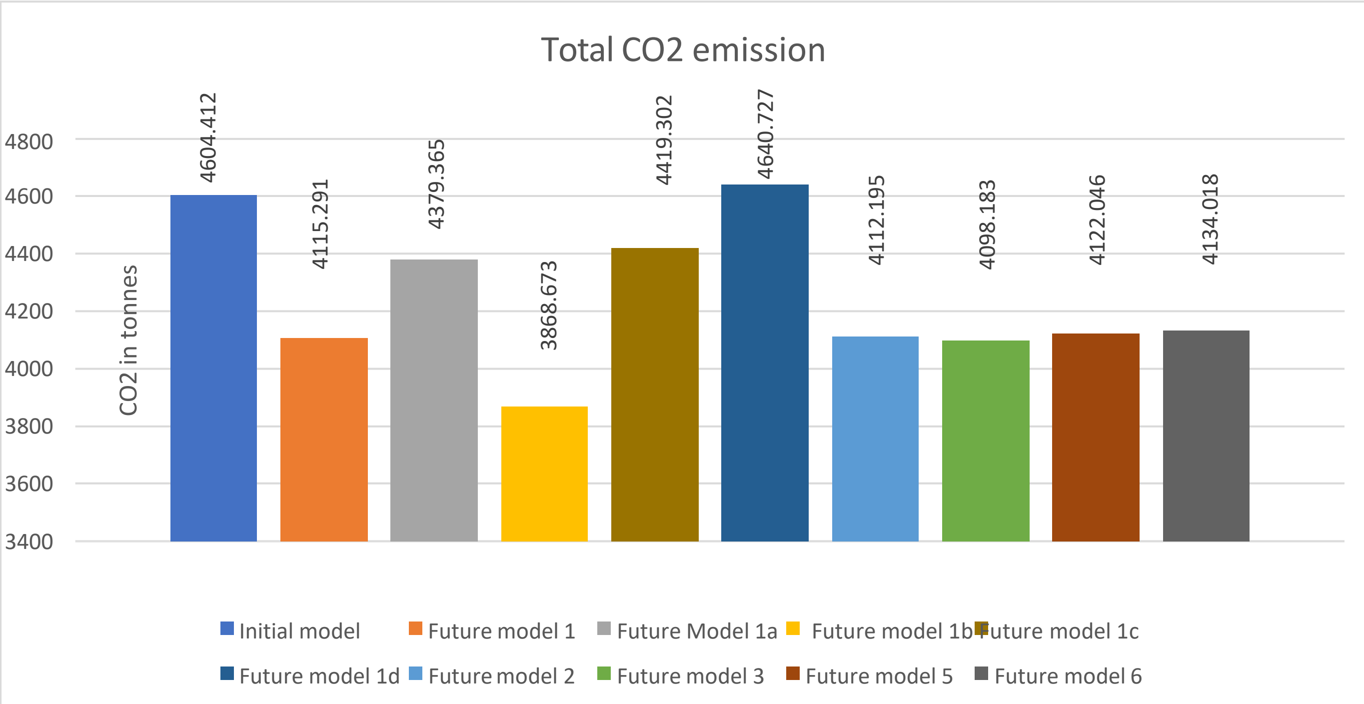


*Figure 7. 6 Total CO2 emissions for all models*

Results produced by the Mobility simulation show a significant difference between the initial model and the future models and it is very clear from this analysis at the first sight that the trams played their role very well in reducing the CO2 content.

Future models 1 and 5 perform really well in terms of reducing CO2 content with a significant difference of 497 tonnes/h and 482 tonnes/h respectively. This shows a reduction in CO2 content by 10.80% and 10.5% respectively. The future model shows a more significant figure having a reduction of 736 tonnes/h which makes an approximate 16% reduction in CO2 content but in this model 15%, people are using trams for daily transportation.

In the beginning stages, it is a little bit hard to attract such a higher number of people but as the congestion is increasing, it is the best way to lure more people to use public transport to save time, money and the environment. From table 7.4 below it can be seen that future model 1d has more $CO_2$ emissions as compared to the initial model, which is expected because this model is based on the assumption that no percentage of people are boarding a tram. So this is just a check to see how much worse it could be. Future model 4 results are exceptional and not under consideration because many of the vehicles have not been released from the zones because of the traffic congestion.

From this analysis model, 1 and 3 is the best performing model with a 10.65% and 10.99% reduction in $CO_2$ content and worst-performing models are 1a and 1c with a percentage of 4.88 and 4.01. However, other models perform very well for instance model 5 shows a reduction of 10.47% of $CO_2$ content.

| Model | CO2 in Tonne | % Reduction in CO2 |
| --- | --- | --- |
| Future model 1 | 4115.29 | 10.65 |
| Future model 1a | 4379.36 | 4.88 |
| Future model 1b | 3868.67 | 15.9 |
| Future model 1c | 4419.302 | 4.01 |
| Future model 1d | 4640.72 | -0.78 |
| Future model 2 | 4112.195 | 10.69 |
| Future model 3 | 4098.18 | 10.99 |
| Future model 4 | 3858.96 | 16.22 |
| Future model 5 | 4122.046 | 10.47 |
| Future model 6 | 4134.018 | 10.21 |

*Table 7. 4 Comparison of CO2 emission*

From figure 7.7 existing model is producing a higher amount of NOx compared to all other future models, future model 1b is producing only 6777.3 Kg/h of NOx which is least among all other models and reducing the NOx production by 15.14%. Future model 1 is only producing 7155.84 kg/h, which is a reduction of 10.35%, however, future model 1d is worst performing because nobody is boarding tram and all the conditions are the same as the existing model.

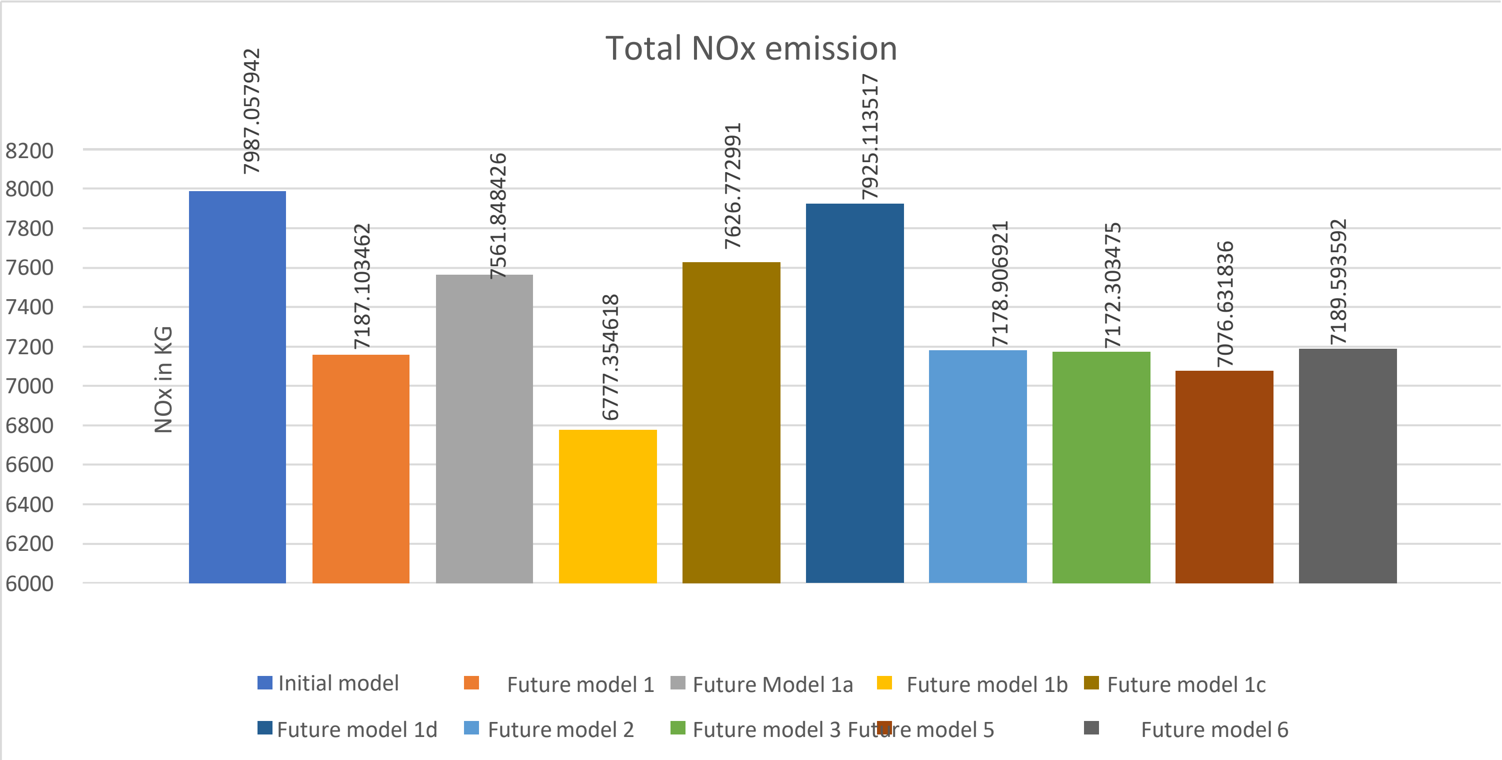


***Figure 7. 7 Total NOx Emissions***

Next chapter will provide a good discussion on existing and all the future models in terms of Level of Service, environmental impacts, total cost comparison, reduction in speed and other important factors. This chapter will also cover the most recommendable model. Recommended model is based on the comparison between the results for all future models and existing model.

# 8 DISCUSSION

This study was focused on to explore the performance and potential options of a tram network on the route of Sir Donald Bradman drive to West beach including Airport, in different aspects like; environmental impacts, financial viability, intersection LOS, travel time. By doing all the study and research, the outcomes recommend that future model 1 & 5 are best suitable for this network as well as then the Model 6. However, future model 4 is performing really bad results in terms of Total cost, $CO_2$& $NO_x$, LOS and speed because of the exclusive lane for the trams.

There are four sub-model for future model 1 and all these models are based on different proportions of people traveling in tram 10%, 5%, 15%, 4%, 0% respectively from model a to d. Based on these proportions these models are simulated in Mobility simulation and all of the models show quite impressive results in compared to the initial model. Model 1 shows a 7.3% reduction in total cost in comparison with an existing model with an improved level of service on all of the intersections see figure 4.6, CO2 has been reduced by 10.65% and NOx has been reduced by 10.35% as compared to the initial model. However, the vehicle speed is slightly decreased by only .55km/h on same infrastructure and all these figures affirm the statement that model 1 is performing much better than the existing model.

Model 1a is performed on the analysis that only 5% population is using tram and tram is also sharing the existing lane as per model 1. The only change is in the proportion of people using the tram and this result shows slightly improved from the existing model as total cost reduced by 0.54%, the average vehicle speed is slightly reduced by .28km/h. CO2 is reduced by 4.82% and the NOx is reduced by 5.32%.

Model 1b is performed with 15% of people using the tram and this assumption shows a significant difference in the performance indicators. The level of CO2 and NOx is reduced by 16.01% and 15.13% and this is the maximum reduction seen among all other models. The total cost is reduced by 13.32%, which is best among all of the future models and the average speed increased by 66km/h. Future model 1c is performed with only 4% of people using tram and Model 1d is performed with 0% of people using trams and the result produced by these two models are quite similar.

The total cost comparison model c shows an increase of .65% and model d shows a 6.2% increase in cost as compared to the initial model. However, model c shows a reduction of 4.5%

and 4.06% in NOx and CO2 content respectively. Model d shows a reduction of 0.77% in NOx content and shows an increase in CO2 content by 0.74%. Both models c and d show bad results for vehicle speed having a decrease in speed by 0.4km/h and 1.04km/h respectively.

Future model 2 is almost the same as future model 1, the only change is in the frequency of tram changed to 10min prior it was at every 5-min of interval. This analysis did not affect the results a lot and presenting quite a similar result with model 1. From the graphs, it can be observed that there is a 7.42% reduction in total cost comparison and the amount of CO2 and NOx reduced by 10.12% and 10.72% respectively. The average vehicle speed increased by only .24km/h.

Model 3 is performed with tram skipping ARTC, Tapleys Hill Road, Ikea, Business tram stops, to check the level of service and total cost analysis. Results generated by Mobility simulation show that there is a reduction of 11.88% in a total cost comparison with the initial model. $CO_2$ and $NO_x$ show a reduction of 11.03% and 10.2% and the average vehicle speed increases by 1.173km/h and this is the best speed increment among all other models. LOS is improved for all of the intersection but despite all of the factors, this model is not recommendable because the tram network is for connecting people.

Future model 4 is designed with one lane exclusively for the tram for better serviceability but this has a really bad impact over the other road users. Airport road intersection was not able to release more vehicles because there was so much congestion on the roads and all of the intersections were at bad Level of service all the results of the LOS are displayed in Figure 7.. $CO_2$ and $NO_x$ are decreased by 25.9% and 16.22% because there was a large of vehicles got stuck in zones as a result of congestion and the result produced by this model are not accurate. Hence, this model is not recommendable.

In the future model, 5 trams are using one lane exclusively outside the CBD except at the intersection within 50m and within the CBD tram is sharing the lane with other private vehicles. This model is one of the best performing models because the initial cost of infrastructure is not big, and it produces really good results in Mobility simulation. CO2 and NOx contents are reduced by 10.5% and 11.39% respectively, however, the LOS is the same as per the future model 1 because both of the models are working on a similar strategy. The average vehicle speed is slightly decreased by 0.8km/h because this model is giving priority to other vehicles in CBD as well on the intersections and the total cost is decreased by 4.9% in comparison with the initial model.

Model 6 is the final model of this analysis and in this model, an additional lane is added for the tram. $CO_2$ and $NO_x$ contents are reduced by 10.25% and 9.98% respectively. The level of Service is improved from the initial model see figure 4.6 and the average speed is increased by 0.84km/h. The total cost of the trips is reduced by 10.43% in comparison with the initial model. Results produced by this model is really good but there is problem with the practical implication of this model as some intersections in the CBD and outside CBD are compact and before adding a new lane by demolishing the surrounding buildings and acquiring more land and this model could be very expensive compared to other hence it is not recommendable.

**Best performing model**

After the analysis of the existing model as well as the Future models, the various performance indicators were used to determine the best performing model. The future model 1 is performing best in all performance indicators such as Level of Service, $CO_2$, and $NO_x$ content, average speed and total cost comparison. It was also shown that the Future Model 5 produced good results very similar to Future model 1. Since the total cost reduction predicted by model 1 is 2.1% more than the future model 5, this model can be taken as the preferred scenario. Although the average vehicle speed of model 5 is just slightly higher (less than 0.5 km/h) than model 1, the $CO_2$ and $NO_x$ reduction values are almost the same for both models. Hence, it is recommended that future model 1 with having some restrictions on the right turn movement for private vehicles could improve efficiency a bit more than model 5.

The results provided by future model 1 represent a transport network operation with the reduced total travel cost by 7.3% from the existing operation. This tram network is efficient in reducing congestion by improving the level of service for all intersections as now most of the intersections are at LOS B. $CO_2$ and $NO_x$ levels are reduced by 10.65% and 10.35% in comparison with initial model and all these results affirm that future model 1 is fulfilling the aims of this study.

# 9 CONCLUSIONS

This report provides in-depth knowledge about the Mobility simulation of the Tram extension from the North terrace to West beach including Airport. This report has been proposed keeping in mind the various parameters like impact on the environment, average travel time, intersection Level of Service and Economic viability. Most of the important information and data for the fulfillment of this research came from Multi-Criteria Analysis Report, West- Link and the 30-year plan for the Greater Adelaide and these reports are generated by InfraPlan with the cooperation of South Australia Government, in which they have a keen focus on joining the Airport with CBD. But in this study prime focus on tram network is from North Terrace to West Beach including Airport which makes it a stretch of almost 8.7Km. This network includes 14 signalized intersections and 3 unsignalized intersections and the whole of the network is designed for morning peak 7:30 to 8:30 AM.

Results show that Future Model 1performs better than the other nine models, however, all the models have been simulated on Mobility Simulation and Calibrated to cross-check the results. The reason behind choosing Model 1 as the best model is that Model 1 has attained a 7.3% reduction in average total cost, which makes this future model economic. Along with an improvement in intersection LOS, most of the intersections are on level B and only one intersection is at D, however, in the initial model worst level of service was at E and most of the intersections were at level C. However, there is a significant reduction in CO2 by 10.65% and NOx by 10.35% from initial model and the average speed increased by .55km/h. From these results, it is clear that the future model is capable of reducing congestion, vehicle emissions and will provide better serviceability to tram users.

Model 3 and 6 perform well in terms of the average speed of a vehicle and improves speed by 1.17 &0.84km/h. However, model 1 and 5 show slightly better results than the existing model. Comparing model 1 with model 6 and future model 6 shows competitive results but the initial cost of building one additional lane in model 6 is very expensive. Future model 1, where existing lanes are fit for implementation providing more serviceability and a better level of service to road users.

Overall, the result generated by mobility simulation shows that the network connection from City to West beach is best performed by model 1, and it is suggested that to lure more passengers it is important to make a free zone within the city. Future model 1 can provide better results if right turns is banned or provide extra space on some intersections, which will help in improving the level of service.

**Future research** is possible on other important scenarios which need to be considered while modeling tram network such as person total saving instead of vehicle total cost, person total saving can create a great impact on every individual mindset before choosing any mode of transportation. Benefit-Cost Ratio and tram phase optimization along with safety is not under investigation in this study. Additionally, public opinion surveys are adopted from other papers with a different location, as it is a tough and long procedure to get approval from councils and universities for more accurate results surveys can be organized in the same catchment.

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## Appendix:

## Appendix A: INTERSECTION PHASING

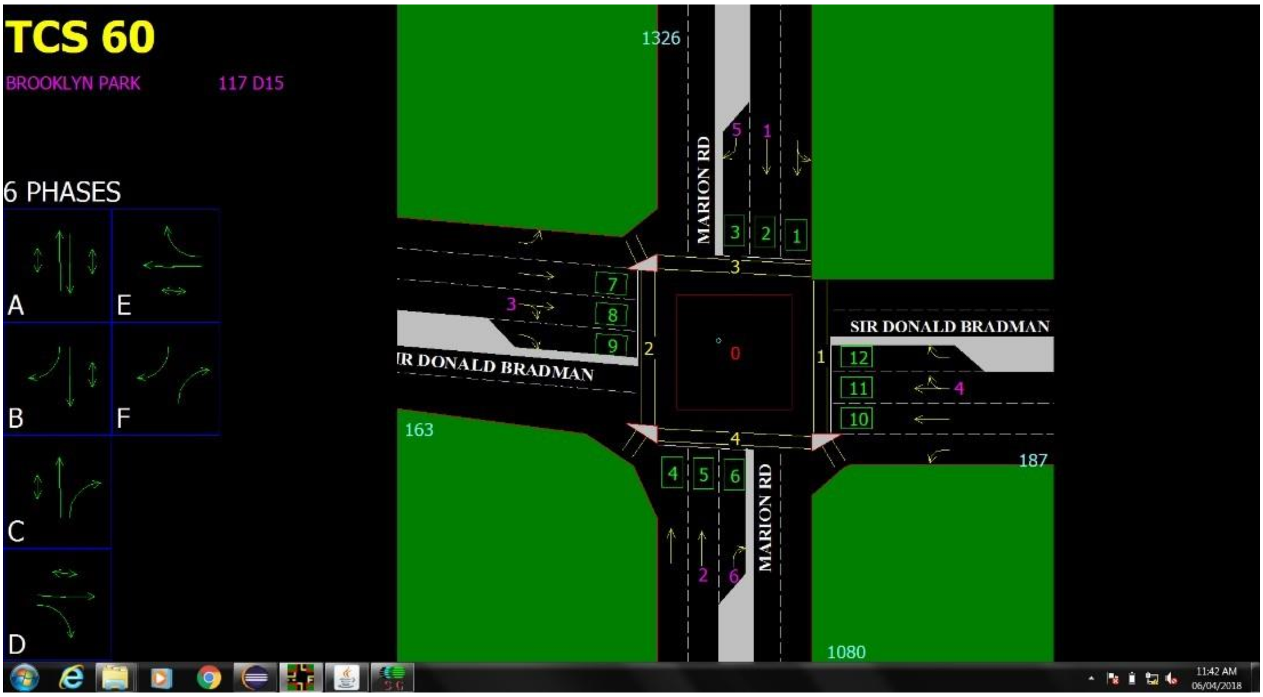



*Figure 10. 1 TCS 60*

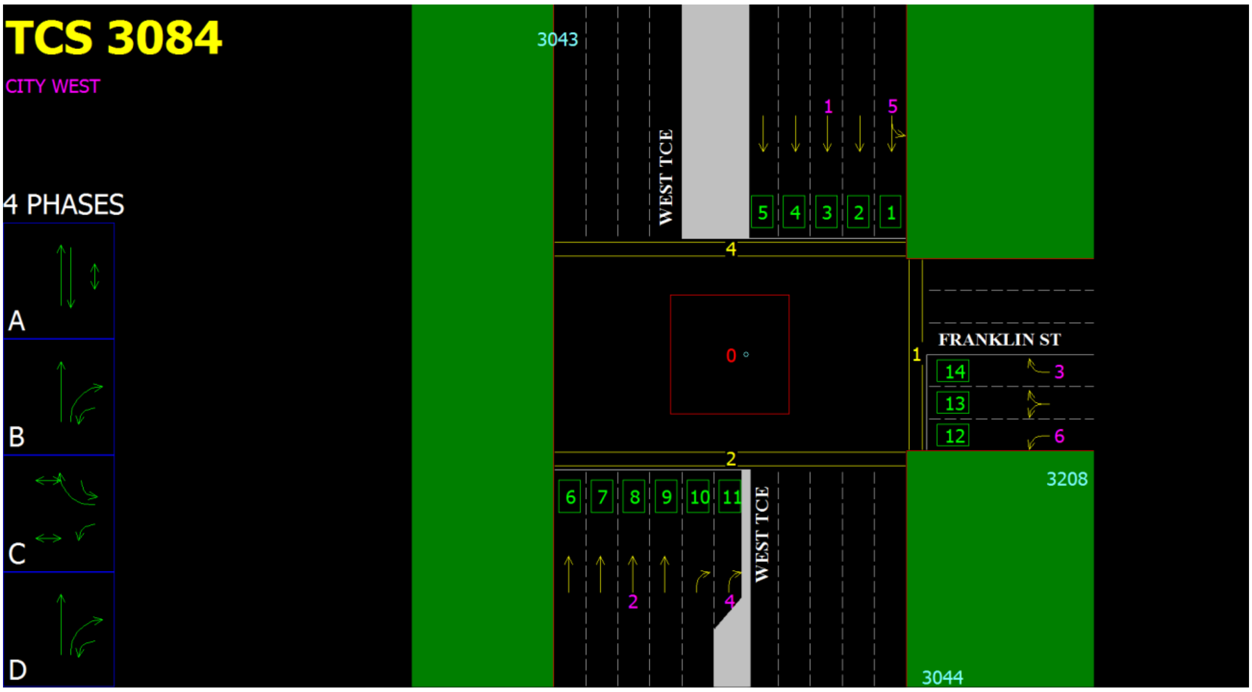



*Figure 10. 2 TCS 3084*

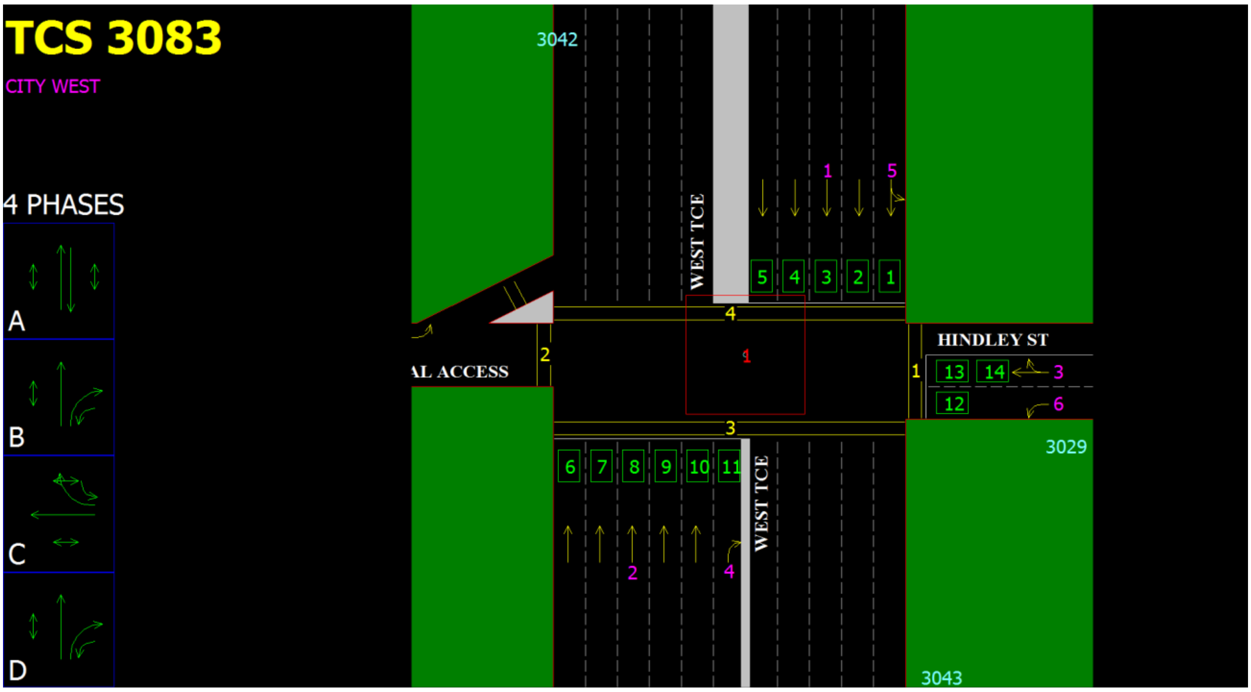



*Figure 10. 3 TCS 3083*


*Figure 10. 4 TCS 3044*


*Figure 10. 5 TCS 3043*

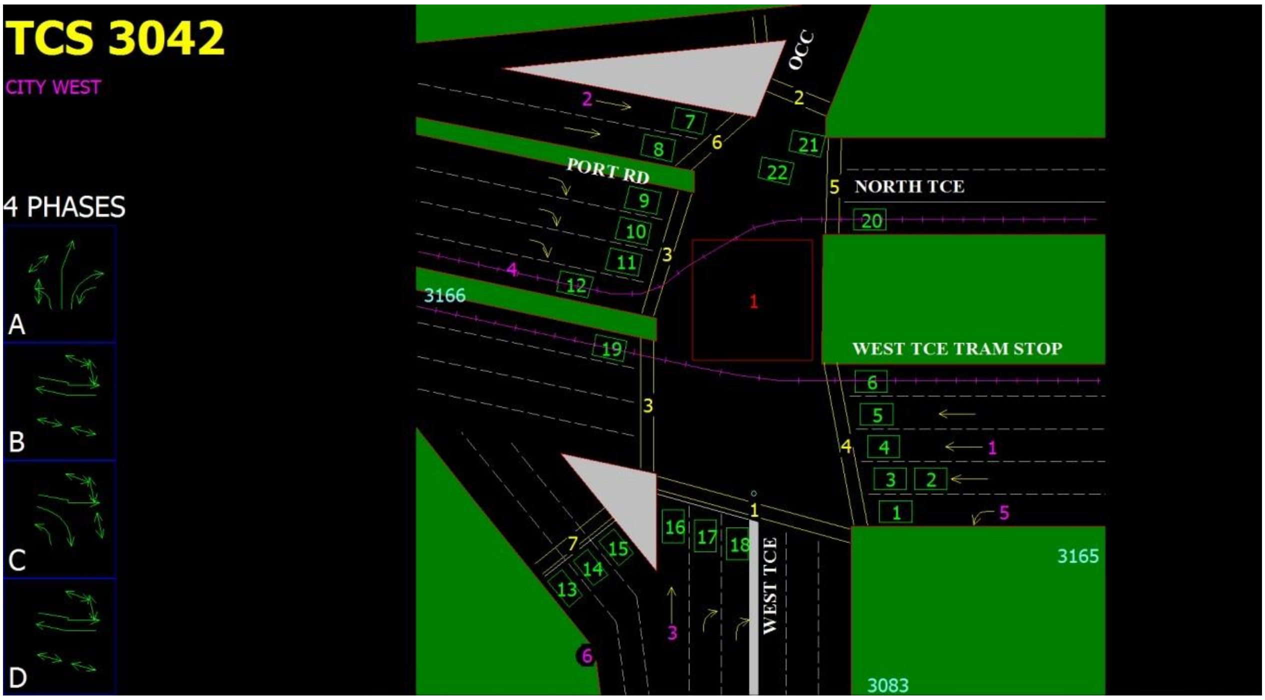



*Figure 10. 6 TCS 3042*


*Figure 10. 7 TCS 488*


*Figure 10. 8 TCS 326*


*Figure 10. 9 TCS 218*


*Figure 10. 10 TCS 187*

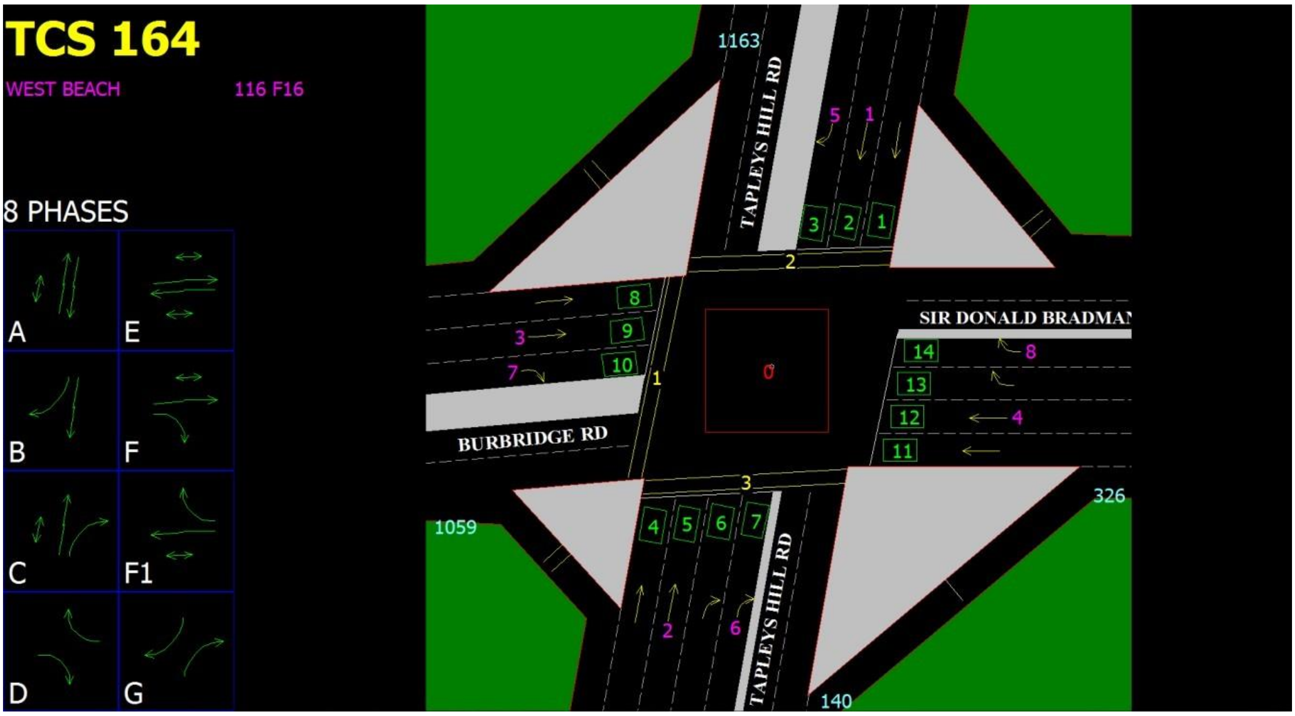



*Figure 10. 11 TCS 164*

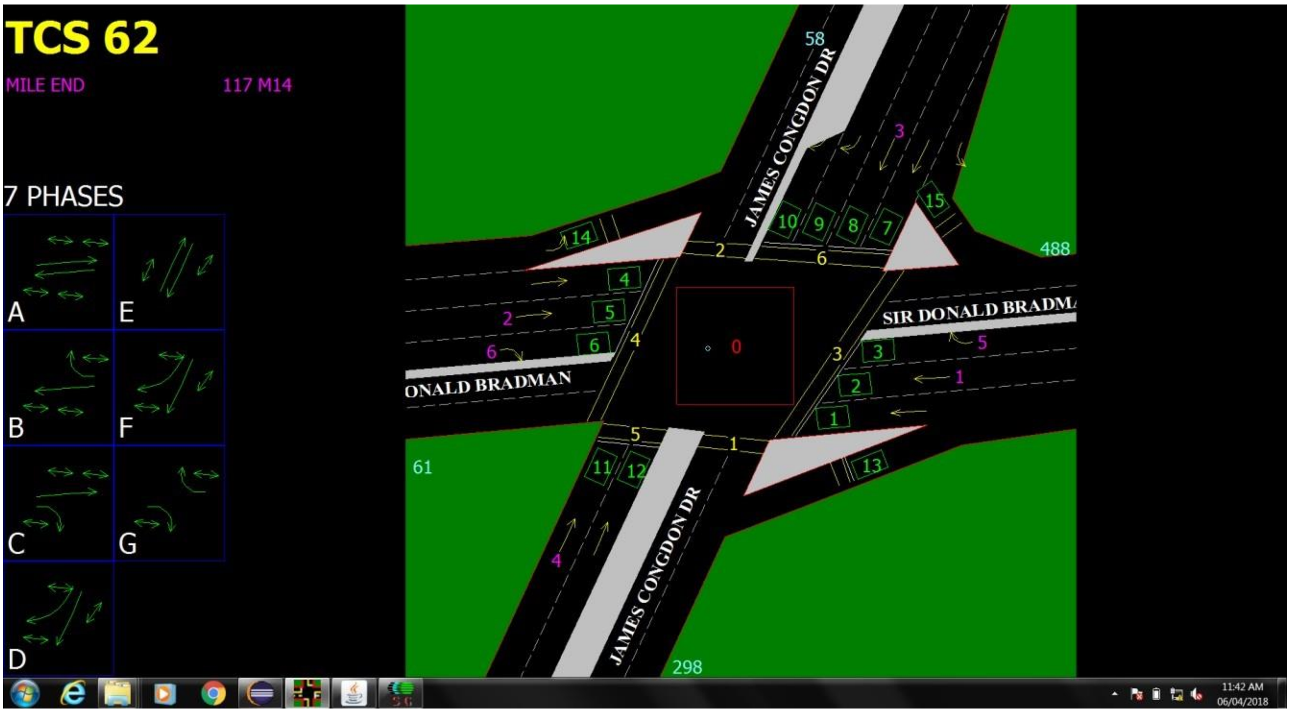



*Figure 10. 12 TCS 62*

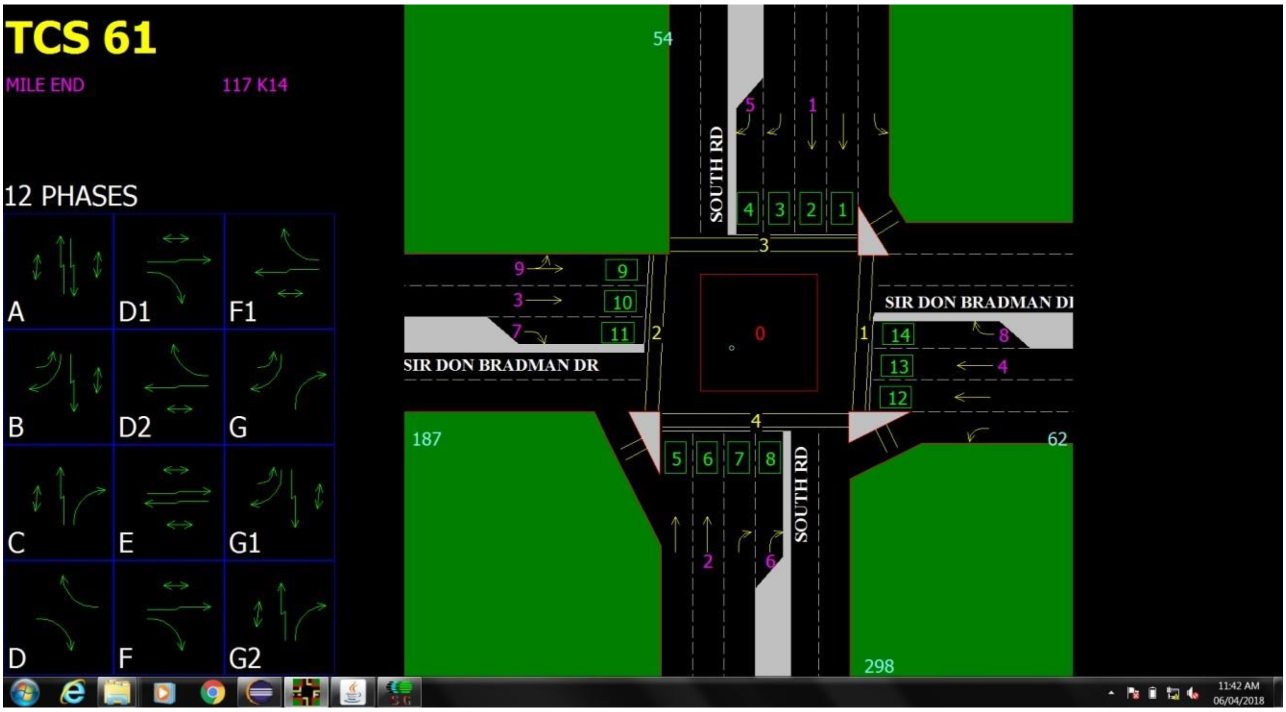



*Figure 10. 13 TCS 61*

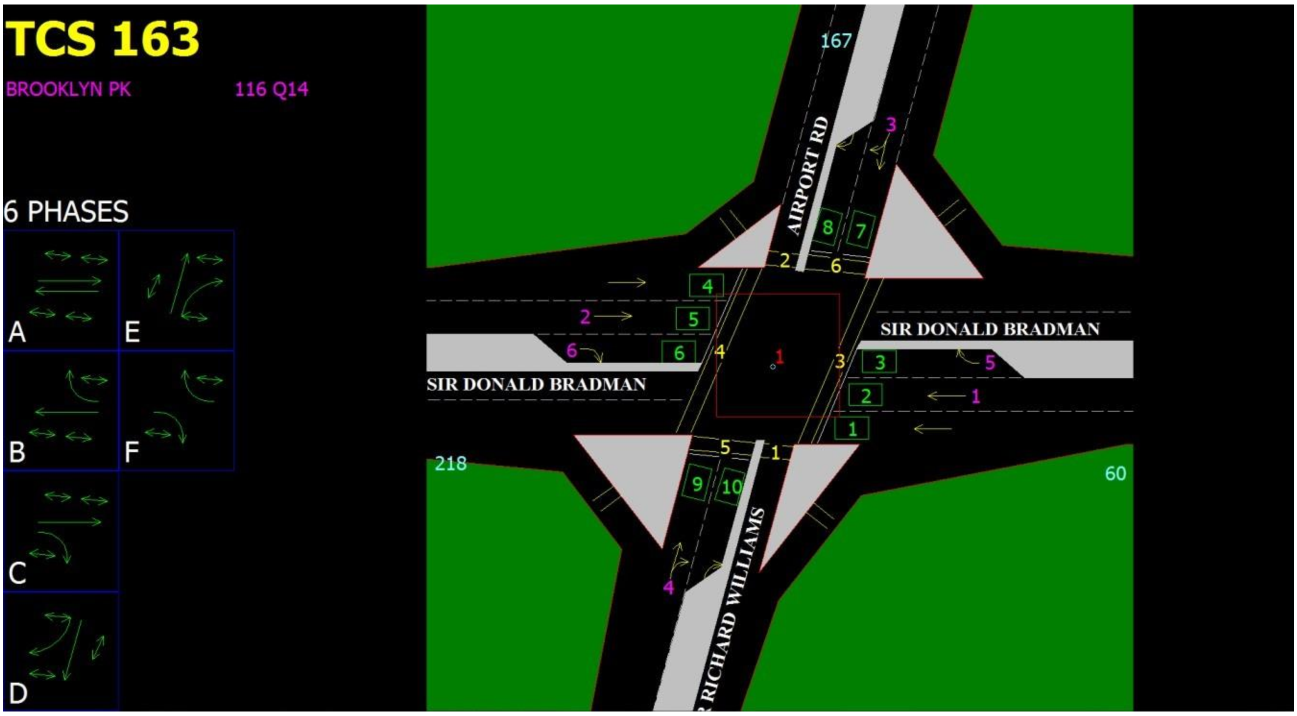



*Figure 10. 14 TCS 163*

## Appendix B: OD MATRIX

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 348 | 44 | 5 | 40 | 10 | | | | | | | | | | | | | | | | | | | | | | | 447 | |
| 2 | 216 | | 244 | | 105 | | 191 | | | | | | | | | | | | | | | | | | | | | | 756 | |
| 3 | 5 | 235 | | 10 | | | 166 | 4 | 70 | | | | | | | | | | | | | | | | | | | | 490 | |
| 4 | 5 | | 5 | | | | | 5 | | | | | | | | | | | | | | | | | | | | | 15 | |
| 5 | 5 | 5 | | | | 1618 | | 16 | 23 | 200 | 300 | | | | 100 | 34 | | 66 | | | | | | | | | | | 2367 | |
| 6 | 5 | 24 | | 10 | 1381 | | | | 61 | 105 | 190 | 5 | | | | | | 95 | | | 39 | | | | | | | | 1915 | |
| 7 | 45 | | 30 | | | 111 | | | | | | 5 | | | | | | | | | | | | | | | | | 191 | |
| 8 | | | | | | 18 | | | | | | | | | | | | | | | 12 | | | | | | | | 30 | |
| 9 | | 25 | | | 59 | | | | | 119 | 165 | | | 1 | | | 50 | 139 | | 100 | 100 | 50 | 99 | 61 | | | | | 968 | |
| 10 | | | | | 138 | 52 | | | 190 | | 111 | | 20 | 10 | | | | | | | | | | | | | | | 521 | |
| 11 | | | | | 200 | | 26 | 20 | 80 | | | 761 | 7 | | | 12 | 20 | | 20 | | 50 | | | | | | | | 1196 | |
| 12 | | | | | 34 | | | | | | 700 | | | | | | | | | | 80 | | | | | | | | 814 | |
| 13 | | | | | 41 | | 15 | | | | | | | 317 | 6 | 10 | 11 | 2 | 8 | 37 | | | | | | | | | 447 | |
| 14 | | | | | | | 55 | 4 | 59 | 20 | | | 60 | | | 10 | | | | | 9 | 7 | | | 3 | 11 | | 20 | 258 | |
| 15 | | | | | | | | | 140 | | | | | | | 1314 | | | | 50 | 174 | 150 | | | | | | | 1828 | |
| 16 | | | | | | | | | 145 | | | | | | 492 | | | | | | 255 | | | | | | | | 892 | |
| 17 | | | | | | | | | | | | | | | | | | 566 | | | | | | | | | | | 566 | |
| 18 | | | | | | | | | 86 | | | | | | | | 360 | | | 19 | 128 | | | | | | | | 593 | |
| 19 | | | | | | | | | | | | | | | | | | | | | 10 | | | | | | | | 10 | |
| 20 | | | | | | | | | 3 | 93 | 2 | 60 | | | | | | | | | 263 | 48 | 149 | 216 | 95 | 467 | 839 | 126 | 2361 | |
| 21 | | | | | | | | | | | | 58 | 211 | 25 | 85 | 52 | 105 | | | 60 | | 7 | | | | 20 | 20 | 20 | 663 | |
| 22 | | | | | | | | | | | | | | | | | 48 | 20 | | 289 | 10 | | | | | 50 | 50 | 56 | 523 | |
| 23 | | | | | | | | | | | | | | | | | | | 10 | 30 | | | | | | | 10 | 10 | 60 | |
| 24 | | | | | | | | | | | | | | | | | | 20 | | 170 | 10 | | | | | 63 | 100 | 345 | 708 | |
| 25 | | | | | | | | | | | | | | | | | | | 10 | 140 | | | | | | 10 | 40 | | 200 | |
| 26 | | | | | | | | | | | | | | | | | | 40 | 35 | 771 | 140 | 197 | 17 | 75 | 200 | | | | 1475 | |
| 28 | | | | | | | | | | | 98 | | | | | | | | | | 127 | 343 | 0 | 629 | 155 | | | | 1352 | |
| | 281 | 637 | 323 | 25 | 1998 | 1809 | 453 | 49 | 857 | 537 | 1566 | 889 | 298 | 353 | 683 | 1432 | 594 | 948 | 83 | 1666 | 1407 | 802 | 265 | 981 | 453 | 621 | 1059 | 577 | | 21646 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 21646 | |

***Table 10. 1 For Initial Model***

| 0.9 | 1 | 2 | 3 | 4 | 5 | 6 | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 313.2 | 39.6 | 4.5 | 36 | 9 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 402.3 |
| 2 | 194.4 | 0 | 219.6 | 0 | 94.5 | 0 | | 171.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 680.4 |
| 3 | 4.5 | 211.5 | 0 | 9 | 0 | 0 | | 149.4 | 3.6 | 63 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 441 |
| 4 | 4.5 | 0 | 4.5 | 0 | 0 | 0 | | 0 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13.5 |
| 5 | 4.5 | 4.5 | 0 | 0 | 0 | 1456.2 | 0 | 14.4 | 20.7 | 180 | 270 | 0 | 0 | 0 | 90 | 30.6 | 0 | 59.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2130.3 | |
| 6 | 4.5 | 21.6 | 0 | 9 | 1243 | 0 | 0 | 0 | 54.9 | 94.5 | 171 | 4.5 | 0 | 0 | 0 | 0 | 0 | 85.5 | 0 | 0 | 35.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1723.5 | |
| 7 | 40.5 | 0 | 27 | 0 | 0 | 99.9 | 0 | 0 | 0 | 0 | 0 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 171.9 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 16.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | |
| 9 | 0 | 22.5 | 0 | 0 | 53.1 | 0 | 0 | 0 | 0 | 107.1 | 148.5 | 0 | 0 | 0.9 | 0 | 0 | 45 | 125.1 | 0 | 90 | 90 | 45 | 89.1 | 54.9 | 0 | 0 | 0 | 0 | 871.2 | |
| 10 | 0 | 0 | 0 | 0 | 124.2 | 46.8 | 0 | 0 | 171 | 0 | 99.9 | 0 | 18 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 468.9 | |
| 11 | 0 | 0 | 0 | 0 | 180 | 0 | 23.4 | 18 | 72 | 0 | 0 | 684.9 | 6.3 | 0 | 0 | 10.8 | 18 | 0 | 18 | 0 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1076.4 | |
| 12 | 0 | 0 | 0 | 0 | 30.6 | 0 | 0 | 0 | 0 | 0 | 630 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 732.6 | |
| 13 | 0 | 0 | 0 | 0 | 36.9 | 0 | 13.5 | 0 | 0 | 0 | 0 | 0 | 0 | 285.3 | 5.4 | 9 | 9.9 | 1.8 | 7.3 | 33.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 402.3 | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 49.5 | 3.6 | 53.1 | 18 | 0 | 0 | 54 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 8.1 | 6.3 | 0 | 0 | 2.7 | 9.9 | 0 | 18 | 232.2 | |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 126 | 0 | 0 | 0 | 0 | 0 | 0 | 1182.6 | 0 | 0 | 0 | 45 | 156.6 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 1645.2 | |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 130.5 | 0 | 0 | 0 | 0 | 0 | 442.8 | 0 | 0 | 0 | 0 | 0 | 229.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 802.8 | |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 509.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 509.4 | |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 324 | 0 | 0 | 17.1 | 115.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 533.7 | |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.7 | 83.7 | 1.8 | 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 236.7 | 43.2 | 134.1 | 194.4 | 85.5 | 420.3 | 755.1 | 113.4 | 2124.9 | |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52.2 | 189.9 | 22.5 | 76.5 | 46.8 | 94.5 | 0 | 0 | 54 | 0 | 6.3 | 0 | 0 | 0 | 18 | 18 | 18 | 596.7 | |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43.2 | 18 | 0 | 260.1 | 9 | 0 | 0 | 0 | 0 | 45 | 45 | 50.4 | 470.7 | |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 9 | 54 | |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 153 | 9 | 0 | 0 | 0 | 0 | 56.7 | 90 | 310.5 | 637.3 | |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 126 | 0 | 0 | 0 | 0 | 0 | 9 | 36 | 0 | 180 | |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36 | 31.5 | 693.9 | 126 | 177.3 | 15.3 | 67.5 | 180 | 0 | 0 | 0 | 1327.5 | |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 88.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 114.3 | 308.7 | 0 | 566.1 | 139.5 | 0 | 0 | 0 | 1216.8 | |
| | 252.9 | 573.3 | 290.7 | 22.5 | 1798 | 1628.1 | 407.7 | 44.1 | 771.3 | 483.3 | 1409.4 | 800.1 | 268.2 | 317.7 | 614.7 | 1288.8 | 534.6 | 853.2 | 74.7 | 1499.4 | 1266.3 | 721.8 | 238.5 | 882.9 | 407.7 | 558.9 | 953.1 | 519.3 | | 19481.4 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 19481.4 | |

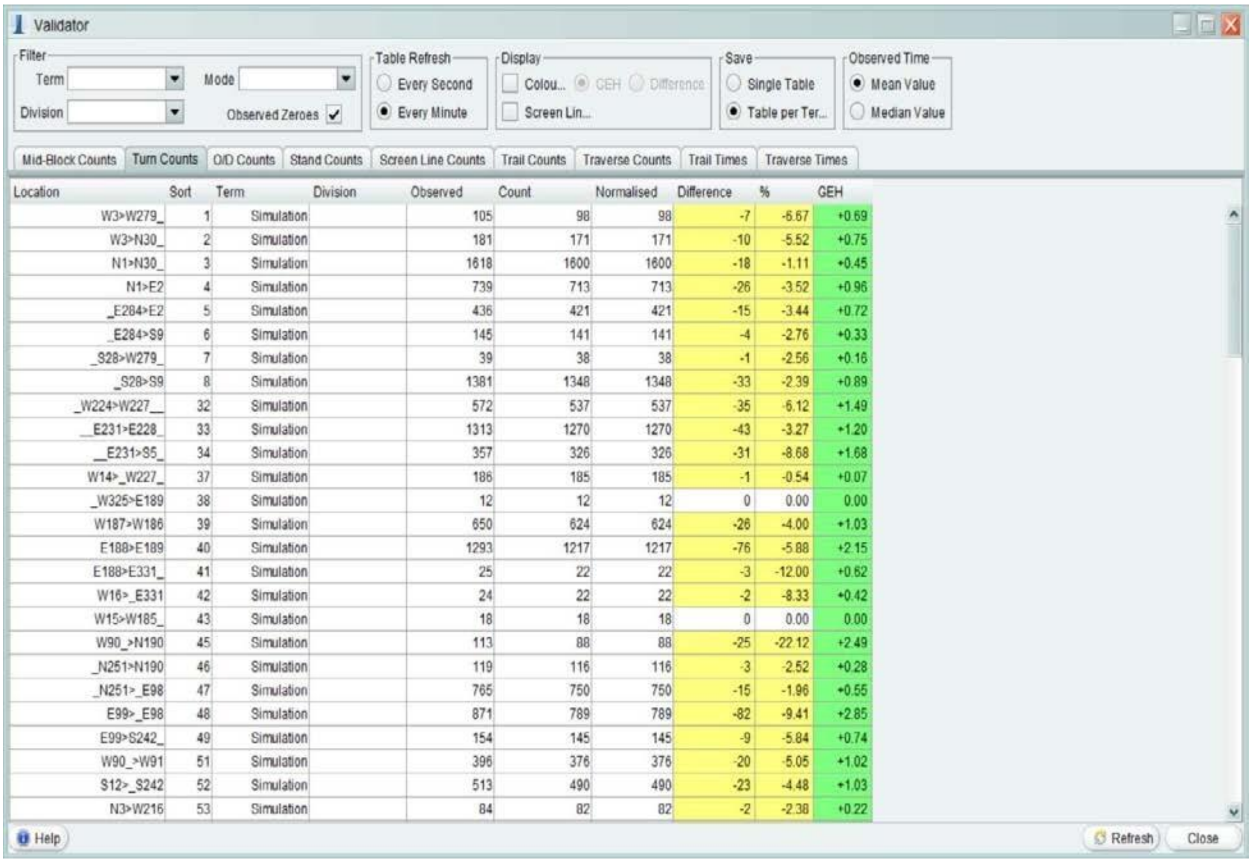
***Table 10. 2 For 10% of people using the tram***

| 0.95 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 330.6 | 41.8 | 4.75 | 38 | 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 424.6 | |
| 2 | 205.2 | 0 | 231.8 | 0 | 99.75 | 0 | 181.45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 718. | |
| 3 | 4.75 | 223.3 | 0 | 9.5 | 0 | 0 | 157.7 | 3.8 | 66.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 465. | |
| 4 | 4.75 | 0 | 4.75 | 0 | 0 | 0 | 0 | 4.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 14.2 | |
| 5 | 4.75 | 4.75 | 0 | 0 | 0 | 1537.1 | 0 | 15.2 | 21.85 | 190 | 285 | 0 | 0 | 0 | 95 | 32.3 | 0 | 62.7 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 2248.6 | |
| 6 | 4.75 | 22.8 | 0 | 9.5 | 1312 | 0 | 0 | 0 | 57.35 | 99.75 | 180.5 | 4.75 | 0 | 0 | 0 | 0 | 0 | 90.25 | 0 | 0 | 37.05 | 0 | 0 | 0 | | | | | 1819.2 | |
| 7 | 42.75 | 0 | 28.5 | 0 | 0 | 105.45 | 0 | 0 | 0 | 0 | 0 | 4.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 181.4 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 17.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.4 | 0 | 0 | 0 | | | | | 28. | |
| 9 | 0 | 23.75 | 0 | 0 | 56.05 | 0 | 0 | 0 | 0 | 113.05 | 156.75 | 0 | 0 | 0.95 | 0 | 0 | 47.5 | 132.05 | 0 | 95 | 95 | 47.5 | 94.05 | 57.35 | | | | | 919. | |
| 10 | 0 | 0 | 0 | 0 | 131.1 | 49.4 | 0 | 0 | 180.5 | 0 | 105.45 | 0 | 19 | 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 494.9 | |
| 11 | 0 | 0 | 0 | 0 | 190 | 0 | 24.7 | 19 | 76 | 0 | 0 | 722.95 | 6.65 | 0 | 0 | 11.4 | 19 | 0 | 19 | 0 | 47.5 | 0 | 0 | 0 | | | | | 1136. | |
| 12 | 0 | 0 | 0 | 0 | 32.3 | 0 | 0 | 0 | 0 | 0 | 665 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76 | 0 | 0 | 0 | | | | | 773. | |
| 13 | 0 | 0 | 0 | 0 | 38.95 | 0 | 14.25 | 0 | 0 | 0 | 0 | 0 | 0 | 301.15 | 5.7 | 9.5 | 10.45 | 1.9 | 7.6 | 35.15 | 0 | 0 | 0 | 0 | | | | | 424.6 | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 52.25 | 3.8 | 56.05 | 19 | 0 | 0 | 57 | 0 | 0 | 9.5 | 0 | 0 | 0 | 0 | 8.55 | 6.65 | 0 | 0 | 2.8 | 10.4 | | 1 | 245. | |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 133 | 0 | 0 | 0 | 0 | 0 | 0 | 1248.3 | 0 | 0 | 0 | 47.5 | 165.3 | 142.5 | 0 | 0 | | | | | 1736. | |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 137.75 | 0 | 0 | 0 | 0 | 0 | 467.4 | 0 | 0 | 0 | 0 | 0 | 242.25 | 0 | 0 | 0 | | | | | 847. | |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 537.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | 537. | |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 81.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 342 | 0 | 0 | 18.05 | 121.6 | 0 | 0 | 0 | | | | | 563.3 | |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 | 0 | 0 | 0 | | | | | 9. | |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.85 | 88.35 | 1.9 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 249.85 | 45.6 | 141.55 | 205.2 | 90.2 | 443.6 | 797.0 | 119. | 2242.9 | |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55.1 | 200.45 | 23.75 | 80.75 | 49.4 | 99.75 | 0 | 0 | 57 | 0 | 6.65 | 0 | 0 | | 1 | 1 | 1 | 629.8 | |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45.6 | 19 | 0 | 274.55 | 9.5 | 0 | 0 | 0 | | 47. | 47 | 53. | 496.8 | |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 | 28.5 | 0 | 0 | 0 | | | | 9 | 9. | 5 | |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 161.5 | 9.5 | 0 | 0 | | | 59.8 | 9 | 327.7 | 672. | |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.5 | 133 | 0 | 0 | 0 | 0 | 0 | 9. | 3 | | 19 | |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 33.25 | 732.45 | 133 | 187.15 | 16.15 | 71.25 | 190 | | | | 1401.2 | |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 93.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 120.65 | 325.85 | 0 | 597.5 | 147.3 | | | | 1284. | |
| | 267 | 605.2 | 306.85 | 23.75 | 1898 | 1718.6 | 430.35 | 46.55 | 814.15 | 510.15 | 1487.7 | 844.55 | 283.1 | 335.35 | 648.85 | 1360.4 | 564.3 | 900.6 | 78.85 | 1582.7 | 1336.65 | 761.9 | 251.75 | 931.9 | 430.3 | 589.9 | 1006.0 | 548.1 | | 20563. |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20563 | |

## *Table 10. 3 For 5% of people using a tram*

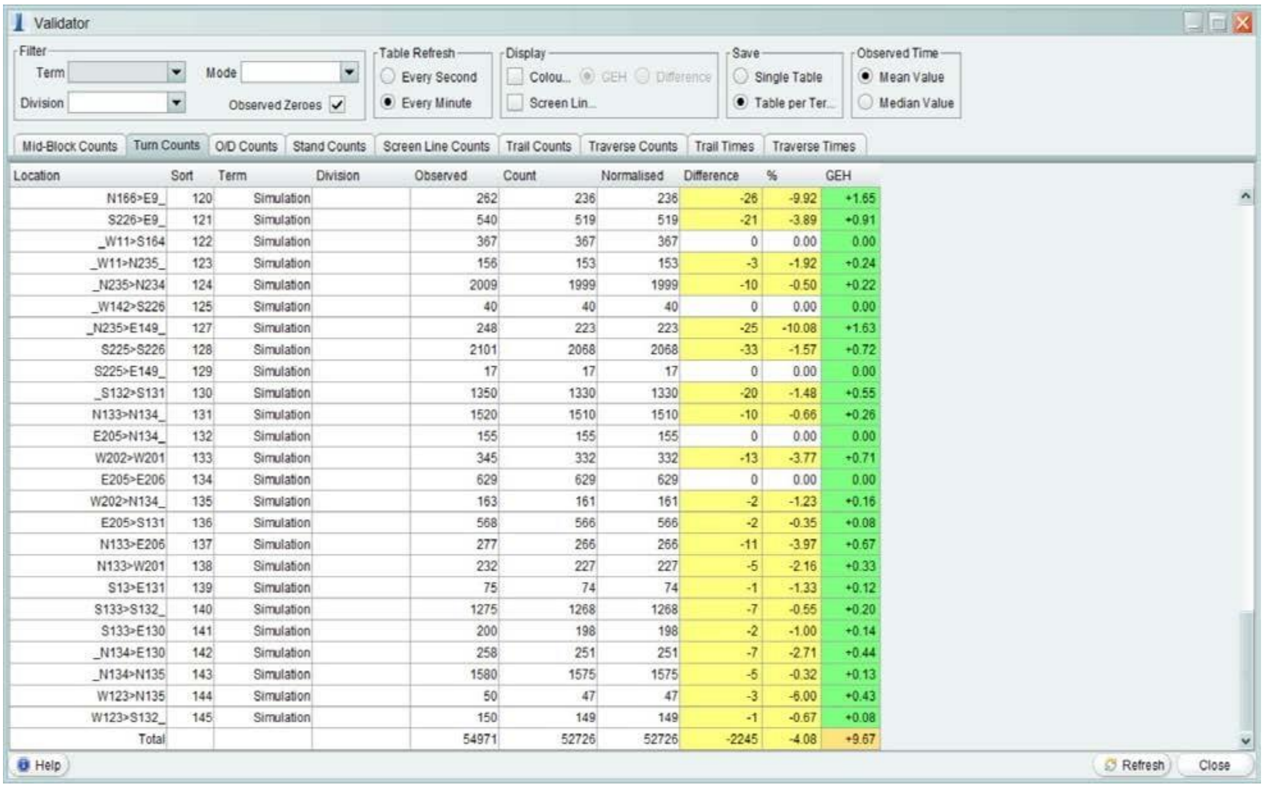
| 0.96 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 334.1 | 42.24 | 4.8 | 38.4 | 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 429.12 | |
| 2 | 207.4 | 0 | 234.24 | 0 | 100.8 | 0 | 183.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 725.76 | |
| 3 | 4.8 | 225.6 | 0 | 9.6 | 0 | 0 | 159.36 | 3.84 | 67.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 470.4 | |
| 4 | 4.8 | 0 | 4.8 | 0 | 0 | 0 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14.4 | |
| 5 | 4.8 | 4.8 | 0 | 0 | 0 | 1553.3 | 0 | 15.36 | 22.08 | 192 | 288 | 0 | 0 | 0 | 96 | 32.64 | 0 | 63.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2272.32 | |
| 6 | 4.8 | 23.04 | 0 | 9.6 | 1326 | 0 | 0 | 0 | 58.56 | 100.8 | 182.4 | 4.8 | 0 | 0 | 0 | 0 | 0 | 91.2 | 0 | 0 | 37.44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1838.4 | |
| 7 | 43.2 | 0 | 28.8 | 0 | 0 | 106.56 | 0 | 0 | 0 | 0 | 0 | 4.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 183.36 | |
| 8 | 0 | 0 | 0 | 0 | 0 | 17.38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28.8 | |
| 9 | 0 | 24 | 0 | 0 | 56.64 | 0 | 0 | 0 | 0 | 114.24 | 158.4 | 0 | 0 | 0.96 | 0 | 0 | 48 | 133.44 | 0 | 96 | 96 | 48 | 95.04 | 58.56 | 0 | 0 | 0 | 0 | 929.28 | |
| 10 | 0 | 0 | 0 | 0 | 132.5 | 49.92 | 0 | 0 | 182.4 | 0 | 106.56 | 0 | 19.2 | 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 500.16 | |
| 11 | 0 | 0 | 0 | 0 | 192 | 0 | 24.96 | 19.2 | 76.8 | 0 | 0 | 730.56 | 6.72 | 0 | 0 | 11.52 | 19.2 | 0 | 19.2 | 0 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1148.16 | |
| 12 | 0 | 0 | 0 | 0 | 32.64 | 0 | 0 | 0 | 0 | 0 | 672 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 76.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 781.44 | |
| 13 | 0 | 0 | 0 | 0 | 39.36 | 0 | 14.4 | 0 | 0 | 0 | 0 | 0 | 0 | 304.32 | 5.76 | 9.6 | 10.56 | 1.92 | 7.68 | 35.52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 429.12 | |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 52.8 | 3.84 | 56.64 | 19.2 | 0 | 0 | 57.6 | 0 | 0 | 9.6 | 0 | 0 | 0 | 0 | 8.64 | 6.72 | 0 | 0 | 2.88 | 10.56 | 0 | 19.2 | 247.68 | |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 134.4 | 0 | 0 | 0 | 0 | 0 | 0 | 1261.44 | 0 | 0 | 0 | 48 | 167.04 | 144 | 0 | 0 | 0 | 0 | 0 | 0 | 1754.88 | |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 139.2 | 0 | 0 | 0 | 0 | 0 | 472.32 | 0 | 0 | 0 | 0 | 0 | 244.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 856.32 | |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 543.36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 543.36 | |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82.56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 345.6 | 0 | 0 | 18.24 | 122.88 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 569.28 | |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.88 | 89.28 | 1.92 | 57.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 252.48 | 46.08 | 143.04 | 207.36 | 91.2 | 448.32 | 805.44 | 120.96 | 2266.56 | |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 55.68 | 202.56 | 24 | 81.6 | 49.92 | 100.8 | 0 | 0 | 57.6 | 0 | 6.72 | 0 | 0 | 0 | 19.2 | 19.2 | 19.2 | 636.48 | |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46.08 | 19.2 | 0 | 277.44 | 9.6 | 0 | 0 | 0 | 0 | 48 | 48 | 53.76 | 502.08 | |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 28.8 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 9.6 | 57.6 | |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19.2 | 0 | 163.2 | 9.6 | 0 | 0 | 0 | 0 | 60.48 | 96 | 331.2 | 679.68 | |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.6 | 134.4 | 0 | 0 | 0 | 0 | 0 | 9.6 | 38.4 | 0 | 192 | |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.4 | 33.6 | 740.16 | 134.4 | 189.12 | 16.32 | 72 | 192 | 0 | 0 | 0 | 1416 | |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 94.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 121.92 | 329.28 | 0 | 603.84 | 148.8 | 0 | 0 | 0 | 1297.32 | |
| | 269.8 | 611.5 | 310.08 | 24 | 1918 | 1736.6 | 434.88 | 47.04 | 822.72 | 515.52 | 1503.36 | 853.44 | 286.08 | 338.88 | 655.68 | 1374.72 | 570.24 | 910.08 | 79.68 | 1599.36 | 1350.72 | 769.92 | 254.4 | 941.76 | 434.88 | 596.16 | 1016.64 | 553.92 | | 20780.16 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20780.16 | |

## *Table 10. 4 For 4% of people using a tram*



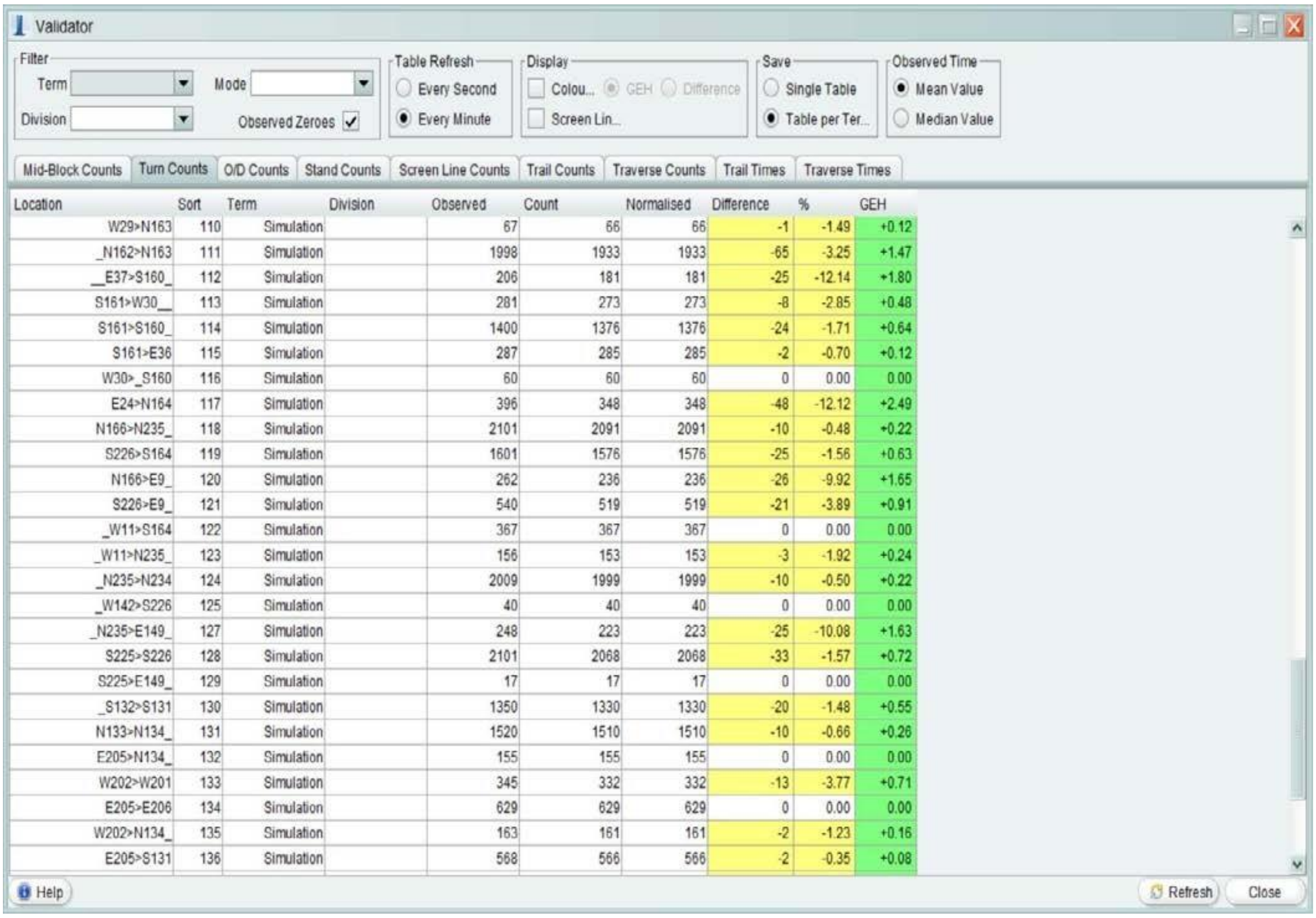
| Location | Sort | Term | Division | Observed | Count | Normalised | Difference | % | GEH |
|---|---|---|---|---|---|---|---|---|---|
| W3>W279_ | 1 | Simulation | | 105 | 98 | 98 | -7 | -6.67 | +0.69 |
| W3>N30_ | 2 | Simulation | | 181 | 171 | 171 | -10 | -5.52 | +0.75 |
| N1>N30_ | 3 | Simulation | | 1618 | 1600 | 1600 | -18 | -1.11 | +0.45 |
| N1>E2 | 4 | Simulation | | 739 | 713 | 713 | -26 | -3.52 | +0.96 |
| _E284>E2 | 5 | Simulation | | 436 | 421 | 421 | -15 | -3.44 | +0.72 |
| _E284>S9 | 6 | Simulation | | 145 | 141 | 141 | -4 | -2.76 | +0.33 |
| _S28>W279_ | 7 | Simulation | | 39 | 38 | 38 | -1 | -2.56 | +0.16 |
| _S28>S9 | 8 | Simulation | | 1381 | 1348 | 1348 | -33 | -2.39 | +0.89 |
| _W224>W227_ | 32 | Simulation | | 572 | 537 | 537 | -35 | -6.12 | +1.49 |
| _E231>E228_ | 33 | Simulation | | 1313 | 1270 | 1270 | -43 | -3.27 | +1.20 |
| _E231>S5_ | 34 | Simulation | | 357 | 326 | 326 | -31 | -8.68 | +1.68 |
| W14>_W227_ | 37 | Simulation | | 186 | 185 | 185 | -1 | -0.54 | +0.07 |
| _W325>E189 | 38 | Simulation | | 12 | 12 | 12 | 0 | 0.00 | 0.00 |
| W187>W186 | 39 | Simulation | | 650 | 624 | 624 | -26 | -4.00 | +1.03 |
| E188>E189 | 40 | Simulation | | 1293 | 1217 | 1217 | -76 | -5.88 | +2.15 |
| E188>E331_ | 41 | Simulation | | 25 | 22 | 22 | -3 | -12.00 | +0.62 |
| W16>_E331 | 42 | Simulation | | 24 | 22 | 22 | -2 | -8.33 | +0.42 |
| W15>W185_ | 43 | Simulation | | 18 | 18 | 18 | 0 | 0.00 | 0.00 |
| W90_>N190 | 45 | Simulation | | 113 | 88 | 88 | -25 | -22.12 | +2.49 |
| _N251>N190 | 46 | Simulation | | 119 | 116 | 116 | -3 | -2.52 | +0.28 |
| _N251>_E98 | 47 | Simulation | | 765 | 750 | 750 | -15 | -1.96 | +0.55 |
| E99>_E98 | 48 | Simulation | | 871 | 789 | 789 | -82 | -9.41 | +2.85 |
| E99>S242_ | 49 | Simulation | | 154 | 145 | 145 | -9 | -5.84 | +0.74 |
| W90_>W91 | 51 | Simulation | | 396 | 376 | 376 | -20 | -5.05 | +1.02 |
| S12>_S242 | 52 | Simulation | | 513 | 490 | 490 | -23 | -4.48 | +1.03 |
| N3>W216 | 53 | Simulation | | 84 | 82 | 82 | -2 | -2.38 | +0.22 |

***Figure 10. 15 Validator Turn count for intersections***



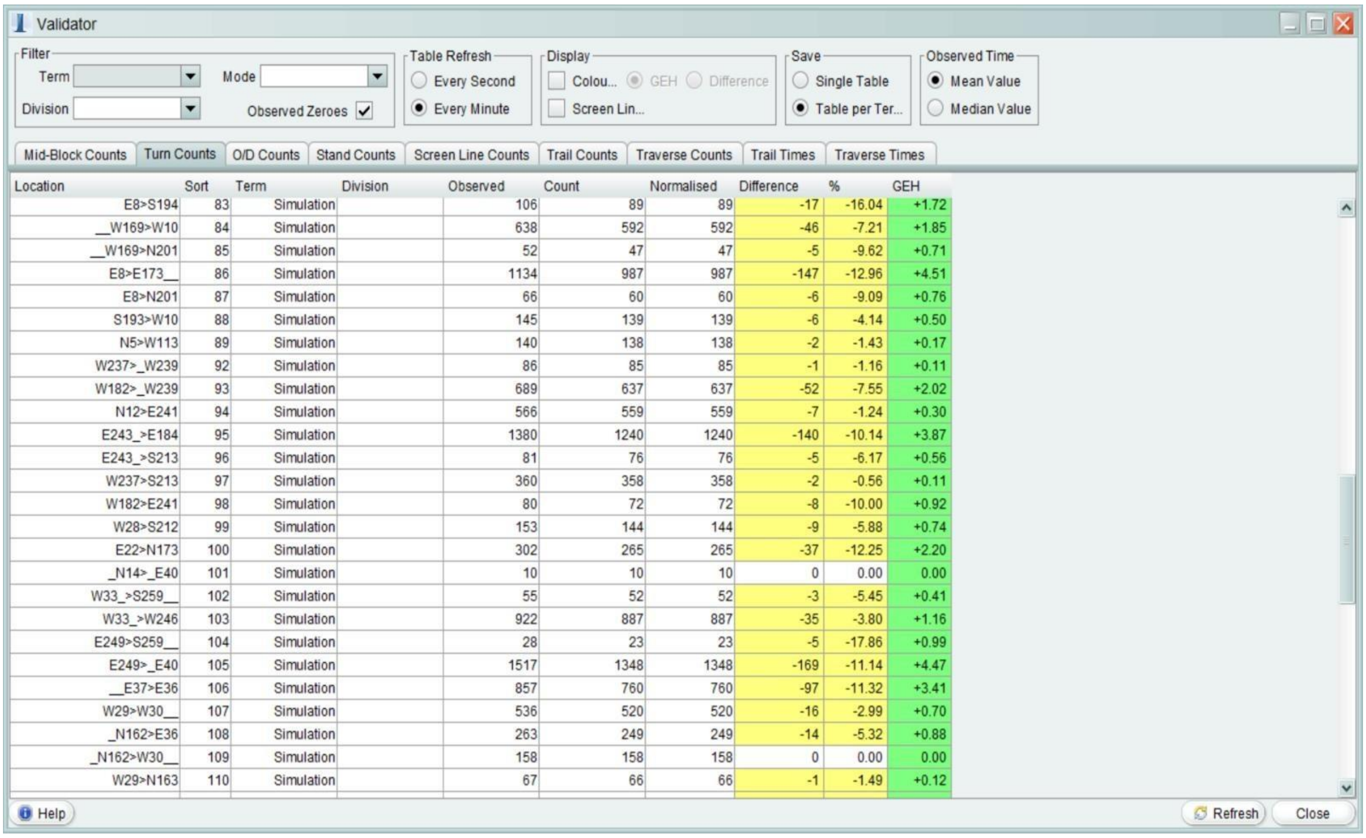
| Location | Sort | Term | Division | Observed | Count | Normalised | Difference | % | GEH |
|---|---|---|---|---|---|---|---|---|---|
| N166>E9_ | 120 | Simulation | | 262 | 236 | 236 | -26 | -9.92 | +1.65 |
| S226>E9_ | 121 | Simulation | | 540 | 519 | 519 | -21 | -3.89 | +0.91 |
| _W11>S164 | 122 | Simulation | | 367 | 367 | 367 | 0 | 0.00 | 0.00 |
| _W11>N235_ | 123 | Simulation | | 156 | 153 | 153 | -3 | -1.92 | +0.24 |
| _N235>N234 | 124 | Simulation | | 2009 | 1999 | 1999 | -10 | -0.50 | +0.22 |
| _W142>S226 | 125 | Simulation | | 40 | 40 | 40 | 0 | 0.00 | 0.00 |
| _N235>E149_ | 127 | Simulation | | 248 | 223 | 223 | -25 | -10.08 | +1.63 |
| S225>S226 | 128 | Simulation | | 2101 | 2068 | 2068 | -33 | -1.57 | +0.72 |
| S225>E149_ | 129 | Simulation | | 17 | 17 | 17 | 0 | 0.00 | 0.00 |
| _S132>S131 | 130 | Simulation | | 1350 | 1330 | 1330 | -20 | -1.48 | +0.55 |
| N133>N134_ | 131 | Simulation | | 1520 | 1510 | 1510 | -10 | -0.66 | +0.26 |
| E205>N134_ | 132 | Simulation | | 155 | 155 | 155 | 0 | 0.00 | 0.00 |
| W202>W201 | 133 | Simulation | | 345 | 332 | 332 | -13 | -3.77 | +0.71 |
| E205>E206 | 134 | Simulation | | 629 | 629 | 629 | 0 | 0.00 | 0.00 |
| W202>N134_ | 135 | Simulation | | 163 | 161 | 161 | -2 | -1.23 | +0.16 |
| E205>S131 | 136 | Simulation | | 568 | 566 | 566 | -2 | -0.35 | +0.08 |
| N133>E206 | 137 | Simulation | | 277 | 266 | 266 | -11 | -3.97 | +0.67 |
| N133>W201 | 138 | Simulation | | 232 | 227 | 227 | -5 | -2.16 | +0.33 |
| S13>E131 | 139 | Simulation | | 75 | 74 | 74 | -1 | -1.33 | +0.12 |
| S133>S132_ | 140 | Simulation | | 1275 | 1268 | 1268 | -7 | -0.55 | +0.20 |
| S133>E130 | 141 | Simulation | | 200 | 198 | 198 | -2 | -1.00 | +0.14 |
| _N134>E130 | 142 | Simulation | | 258 | 251 | 251 | -7 | -2.71 | +0.44 |
| _N134>N135 | 143 | Simulation | | 1580 | 1575 | 1575 | -5 | -0.32 | +0.13 |
| W123>N135 | 144 | Simulation | | 50 | 47 | 47 | -3 | -6.00 | +0.43 |
| W123>S132_ | 145 | Simulation | | 150 | 149 | 149 | -1 | -0.67 | +0.08 |
| Total | | | | 54971 | 52726 | 52726 | -2245 | -4.08 | +9.67 |

***Figure 10. 16 Validator Turn count for intersections***



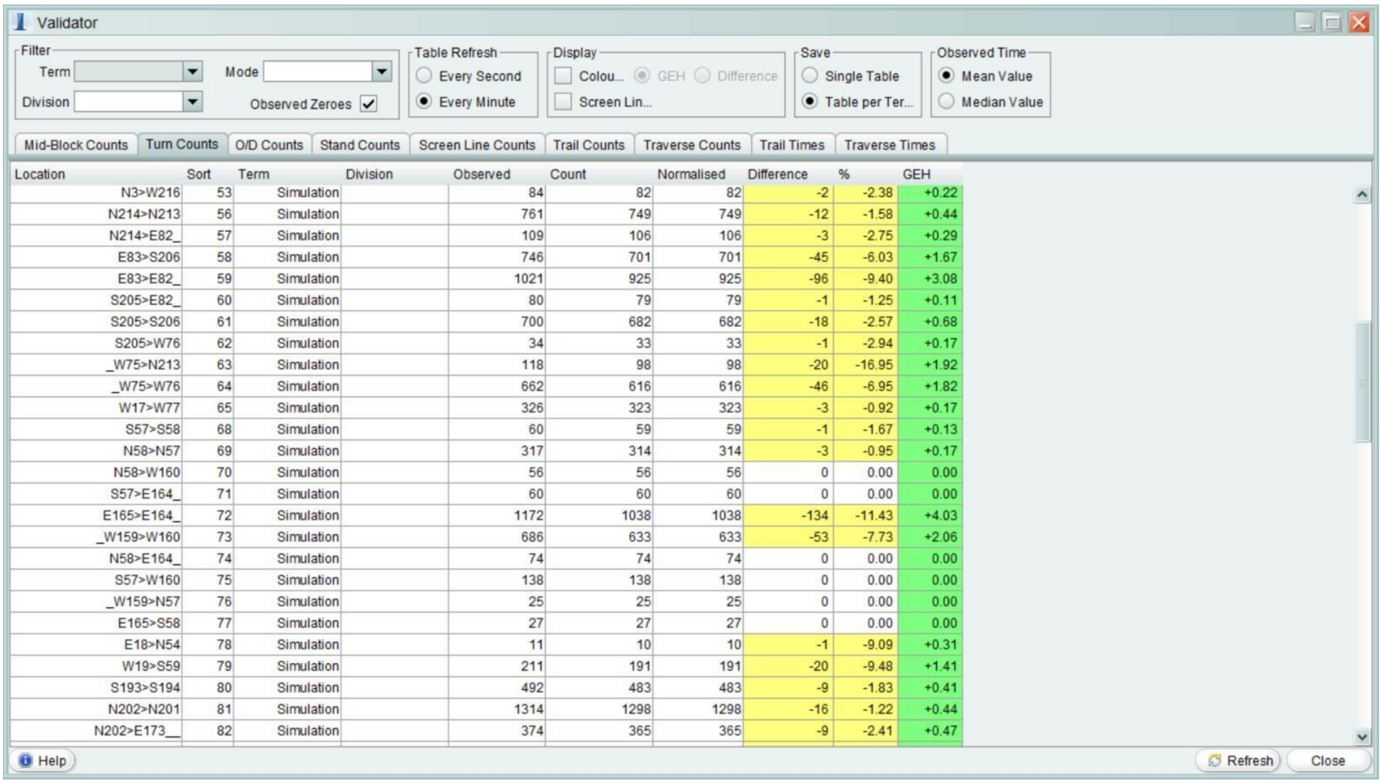

| Location | Sort | Term | Division | Observed | Count | Normalised | Difference | % | GEH |
|---|---|---|---|---|---|---|---|---|---|
| W29>N163 | 110 | Simulation | | 67 | 66 | 66 | -1 | -1.49 | +0.12 |
| _N162>N163 | 111 | Simulation | | 1998 | 1933 | 1933 | -65 | -3.25 | +1.47 |
| __E37>S160_ | 112 | Simulation | | 206 | 181 | 181 | -25 | -12.14 | +1.80 |
| S161>W30__ | 113 | Simulation | | 281 | 273 | 273 | -8 | -2.85 | +0.48 |
| S161>S160_ | 114 | Simulation | | 1400 | 1376 | 1376 | -24 | -1.71 | +0.64 |
| S161>E36 | 115 | Simulation | | 287 | 285 | 285 | -2 | -0.70 | +0.12 |
| W30>_S160 | 116 | Simulation | | 60 | 60 | 60 | 0 | 0.00 | 0.00 |
| E24>N164 | 117 | Simulation | | 396 | 348 | 348 | -48 | -12.12 | +2.49 |
| N166>N235_ | 118 | Simulation | | 2101 | 2091 | 2091 | -10 | -0.48 | +0.22 |
| S226>S164 | 119 | Simulation | | 1601 | 1576 | 1576 | -25 | -1.56 | +0.63 |
| N166>E9_ | 120 | Simulation | | 262 | 236 | 236 | -26 | -9.92 | +1.65 |
| S226>E9_ | 121 | Simulation | | 540 | 519 | 519 | -21 | -3.89 | +0.91 |
| _W11>S164 | 122 | Simulation | | 367 | 367 | 367 | 0 | 0.00 | 0.00 |
| _W11>N235_ | 123 | Simulation | | 156 | 153 | 153 | -3 | -1.92 | +0.24 |
| _N235>N234 | 124 | Simulation | | 2009 | 1999 | 1999 | -10 | -0.50 | +0.22 |
| _W142>S226 | 125 | Simulation | | 40 | 40 | 40 | 0 | 0.00 | 0.00 |
| _N235>E149_ | 127 | Simulation | | 248 | 223 | 223 | -25 | -10.08 | +1.63 |
| S225>S226 | 128 | Simulation | | 2101 | 2068 | 2068 | -33 | -1.57 | +0.72 |
| S225>E149_ | 129 | Simulation | | 17 | 17 | 17 | 0 | 0.00 | 0.00 |
| _S132>S131 | 130 | Simulation | | 1350 | 1330 | 1330 | -20 | -1.48 | +0.55 |
| N133>N134_ | 131 | Simulation | | 1520 | 1510 | 1510 | -10 | -0.66 | +0.26 |
| E205>N134_ | 132 | Simulation | | 155 | 155 | 155 | 0 | 0.00 | 0.00 |
| W202>W201 | 133 | Simulation | | 345 | 332 | 332 | -13 | -3.77 | +0.71 |
| E205>E206 | 134 | Simulation | | 629 | 629 | 629 | 0 | 0.00 | 0.00 |
| W202>N134_ | 135 | Simulation | | 163 | 161 | 161 | -2 | -1.23 | +0.16 |
| E205>S131 | 136 | Simulation | | 568 | 566 | 566 | -2 | -0.35 | +0.08 |

*Figure 10. 17 Validator Turn count for the third intersection*




| Location | Sort | Term | Division | Observed | Count | Normalised | Difference | % | GEH |
|---|---|---|---|---|---|---|---|---|---|
| E8>S194 | 83 | Simulation | | 106 | 89 | 89 | -17 | -16.04 | +1.72 |
| __W169>W10 | 84 | Simulation | | 638 | 592 | 592 | -46 | -7.21 | +1.85 |
| __W169>N201 | 85 | Simulation | | 52 | 47 | 47 | -5 | -9.62 | +0.71 |
| E8>E173__ | 86 | Simulation | | 1134 | 987 | 987 | -147 | -12.96 | +4.51 |
| E8>N201 | 87 | Simulation | | 66 | 60 | 60 | -6 | -9.09 | +0.76 |
| S193>W10 | 88 | Simulation | | 145 | 139 | 139 | -6 | -4.14 | +0.50 |
| N5>W113 | 89 | Simulation | | 140 | 138 | 138 | -2 | -1.43 | +0.17 |
| W237>_W239 | 92 | Simulation | | 86 | 85 | 85 | -1 | -1.16 | +0.11 |
| W182>_W239 | 93 | Simulation | | 689 | 637 | 637 | -52 | -7.55 | +2.02 |
| N12>E241 | 94 | Simulation | | 566 | 559 | 559 | -7 | -1.24 | +0.30 |
| E243_>E184 | 95 | Simulation | | 1380 | 1240 | 1240 | -140 | -10.14 | +3.87 |
| E243_>S213 | 96 | Simulation | | 81 | 76 | 76 | -5 | -6.17 | +0.56 |
| W237>S213 | 97 | Simulation | | 360 | 358 | 358 | -2 | -0.56 | +0.11 |
| W182>E241 | 98 | Simulation | | 80 | 72 | 72 | -8 | -10.00 | +0.92 |
| W28>S212 | 99 | Simulation | | 153 | 144 | 144 | -9 | -5.88 | +0.74 |
| E22>N173 | 100 | Simulation | | 302 | 265 | 265 | -37 | -12.25 | +2.20 |
| _N14>_E40 | 101 | Simulation | | 10 | 10 | 10 | 0 | 0.00 | 0.00 |
| W33_>S259__ | 102 | Simulation | | 55 | 52 | 52 | -3 | -5.45 | +0.41 |
| W33_>W246 | 103 | Simulation | | 922 | 887 | 887 | -35 | -3.80 | +1.16 |
| E249>S259__ | 104 | Simulation | | 28 | 23 | 23 | -5 | -17.86 | +0.99 |
| E249>_E40 | 105 | Simulation | | 1517 | 1348 | 1348 | -169 | -11.14 | +4.47 |
| __E37>E36 | 106 | Simulation | | 857 | 760 | 760 | -97 | -11.32 | +3.41 |
| W29>W30__ | 107 | Simulation | | 536 | 520 | 520 | -16 | -2.99 | +0.70 |
| _N162>E36 | 108 | Simulation | | 263 | 249 | 249 | -14 | -5.32 | +0.88 |
| _N162>W30__ | 109 | Simulation | | 158 | 158 | 158 | 0 | 0.00 | 0.00 |
| W29>N163 | 110 | Simulation | | 67 | 66 | 66 | -1 | -1.49 | +0.12 |

*Figure 10. 18 Validator Turn count for the fourth intersection*




| Location | Sort | Term | Division | Observed | Count | Normalised | Difference | % | GEH |
|---|---|---|---|---|---|---|---|---|---|
| N3>W216 | 53 | Simulation | | 84 | 82 | 82 | -2 | -2.38 | +0.22 |
| N214>N213 | 56 | Simulation | | 761 | 749 | 749 | -12 | -1.58 | +0.44 |
| N214>E82_ | 57 | Simulation | | 109 | 106 | 106 | -3 | -2.75 | +0.29 |
| E83>S206 | 58 | Simulation | | 746 | 701 | 701 | -45 | -6.03 | +1.67 |
| E83>E82_ | 59 | Simulation | | 1021 | 925 | 925 | -96 | -9.40 | +3.08 |
| S205>E82_ | 60 | Simulation | | 80 | 79 | 79 | -1 | -1.25 | +0.11 |
| S205>S206 | 61 | Simulation | | 700 | 682 | 682 | -18 | -2.57 | +0.68 |
| S205>W76 | 62 | Simulation | | 34 | 33 | 33 | -1 | -2.94 | +0.17 |
| _W75>N213 | 63 | Simulation | | 118 | 98 | 98 | -20 | -16.95 | +1.92 |
| _W75>W76 | 64 | Simulation | | 662 | 616 | 616 | -46 | -6.95 | +1.82 |
| W17>W77 | 65 | Simulation | | 326 | 323 | 323 | -3 | -0.92 | +0.17 |
| S57>S58 | 68 | Simulation | | 60 | 59 | 59 | -1 | -1.67 | +0.13 |
| N58>N57 | 69 | Simulation | | 317 | 314 | 314 | -3 | -0.95 | +0.17 |
| N58>W160 | 70 | Simulation | | 56 | 56 | 56 | 0 | 0.00 | 0.00 |
| S57>E164_ | 71 | Simulation | | 60 | 60 | 60 | 0 | 0.00 | 0.00 |
| E165>E164_ | 72 | Simulation | | 1172 | 1038 | 1038 | -134 | -11.43 | +4.03 |
| _W159>W160 | 73 | Simulation | | 686 | 633 | 633 | -53 | -7.73 | +2.06 |
| N58>E164_ | 74 | Simulation | | 74 | 74 | 74 | 0 | 0.00 | 0.00 |
| S57>W160 | 75 | Simulation | | 138 | 138 | 138 | 0 | 0.00 | 0.00 |
| _W159>N57 | 76 | Simulation | | 25 | 25 | 25 | 0 | 0.00 | 0.00 |
| E165>S58 | 77 | Simulation | | 27 | 27 | 27 | 0 | 0.00 | 0.00 |
| E18>N54 | 78 | Simulation | | 11 | 10 | 10 | -1 | -9.09 | +0.31 |
| W19>S59 | 79 | Simulation | | 211 | 191 | 191 | -20 | -9.48 | +1.41 |
| S193>S194 | 80 | Simulation | | 492 | 483 | 483 | -9 | -1.83 | +0.41 |
| N202>N201 | 81 | Simulation | | 1314 | 1298 | 1298 | -16 | -1.22 | +0.44 |
| N202>E173__ | 82 | Simulation | | 374 | 365 | 365 | -9 | -2.41 | +0.47 |

*Figure 10. 19 Validator Turn count for the fifth intersection*

| Level | From | To |
|---|---|---|
| A | 0 | 14.5 |
| B | 14.5 | 28.5 |
| C | 28.5 | 42.5 |
| D | 42.5 | 56.5 |
| E | 56.5 | 70.5 |
| F | 70.5 | |

*Table 10. 5 LOS chart*

| Name | Description | Time ($/hour) | Distance ($/km) | Stop |
|---|---|---|---|---|
| A | Private | 25 | 0 | 0 |
| B | Business | 25 | 0.25 | 0.125 |
| C | Commercial | 25 | 0.25 | 0.125 |

*Table 10. 6 Time, Distance and stop cost factors*

## Appendix C: ECONOMIC EVALUATION REPORT

| Title | | | | | Economic Evaluation Report for Existing Model | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / Date / Time | | | | | | | | | | |
| Simulation file | W:/Master of Civil Engg/Thesis/m | | | | | | | | | | |
| Model run at | Wed Oct 09 21:10:21 ACDT 2019 | | | | | | | | | | |
| Simulation date | 25 / 06 / 2016 | | | | Last Clear: | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 20768 | 23924.58 | 817.309 | 29.276 | 28985 | 461.714 | 5981.144 | 20430.232 | 3623.125 | 30034.501 |
| | Mean | | 1.152 | 00:02:21 | | 1.396 | 00:01:20 | 0.288 | 0.984 | 0.174 | 1.446 |
| | Std Dev | | 1.232 | 00:02:10 | | 1.252 | 00:01:12 | 0.308 | 0.909 | 0.157 | 1.331 |
| All Trips | Total | 21645 | 25996.5 | 849.697 | 30.595 | 31277.3 | 479.05 | 6499.124 | 21242.435 | 3909.65 | 31651.208 |
| | Mean | | 1.201 | 00:02:21 | | 1.445 | 00:01:19 | 0.3 | 0.981 | 0.181 | 1.462 |
| | Std Dev | | 1.276 | 00:02:10 | | 1.291 | 00:01:12 | 0.319 | 0.909 | 0.161 | 1.334 |
| All (Normalised) | Total | 1000 | 1201.039 | 39.256 | 30.595 | 1445.008 | 22.132 | 300.26 | 981.401 | 180.626 | 1462.287 |

***Table 10. 7 Economic evaluation for Existing model***

| Title | | | Economic Evaluation Report for Future model 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / Date / Tim | | | | | | | | | | |
| Simulation | W:/Master of Civil Engg/T | | | | | | | | | | |
| Model ru | Fri Oct 11 11:47:57 ACDT 2 | | | | | | | | | | |
| Simulatio | 22 / 09 / 2017 | | | | Last Clear: | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete | Total | 18729 | 22266.471 | 761.537 | 29.539 | 26021 | 429.941 | 5566.618 | 19038.435 | 3252.625 | 27749.5767 |
| | Mean | | 1.189 | 00:02:26 | | 1.389 | 00:01:22 | 0.297 | 1.017 | 0.174 | 1.487 |
| | Std Dev | | 1.338 | 00:02:37 | | 1.323 | 00:01:33 | 0.335 | 1.096 | 0.165 | 1.526 |
| All Trips | Total | 19579 | 24219.288 | 800.759 | 30.245 | 28206.73 | 1921285.639 | 6054.822 | 20018.977 | 3525.841 | 29599.64 |
| | Mean | | 1.237 | 00:02:27 | | 1.441 | 02:07:47 +4 | 0.309 | 1.022 | 0.18 | 1.512 |
| | Std Dev | | 1.373 | 00:02:40 | | 1.372 | 06:29:22 +113 | 0.343 | 1.114 | 0.171 | 1.538 |
| All(Norm | Total | 1000 | 1237.003 | 40.899 | 30.245 | 1440.662 | 98129.917 | 309.251 | 1022.472 | 180.083 | 1511.805 |

***Table 10. 8 Economic evaluation for Future Model 1***

| Title | Economic Evaluatior | | Economic Evaluation Report for Model 1a | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / Dat | | | | | | | | | | |
| Simulation file | W:/Master of Civil E | | | | | | | | | | |
| Model run at | Fri Oct 11 13:02:55 A | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear: | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 19752 | 23470.353 | 819.727 | 28.632 | 28091 | 470.352 | 5867.588 | 20493.179 | 3511.375 | 29872.143 |
| | Mean | | 1.188 | 00:02:29 | | 1.422 | 00:01:25 | 0.297 | 1.038 | 0.178 | 1.512 |
| | Std Dev | | 1.334 | 00:02:40 | | 1.352 | 00:01:36 | 0.333 | 1.117 | 0.169 | 1.551 |
| All Trips | Total | 20644 | 25467.414 | 860.028 | 29.612 | 30353.313 | 1537447.841 | 6366.853 | 21500.709 | 3794.164 | 31661.727 |
| | Mean | | 1.234 | 00:02:29 | | 1.47 | 02:28:27 +3 | 0.308 | 1.041 | 0.184 | 1.534 |
| | Std Dev | | 1.365 | 00:02:42 | | 1.393 | 04:04:38 +90 | 0.341 | 1.131 | 0.174 | 1.559 |
| All (Normalised) | Total | 1000 | 1233.647 | 41.66 | 29.612 | 1470.321 | 74474.319 | 308.412 | 1041.499 | 183.79 | 1533.701 |

***Table 10. 9Economic evaluation for Future Model 1(a)***

| Title | | Economic Evaluation Report for Model 1b | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Optio | | | | | | | | | | |
| Simulation file | W:/Master of | | | | | | | | | | |
| Model run at | FriOct1113: | | | | | | | | | | |
| Simulation date | 22/09/2017 | | | | Last Clear | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30to08:3 | | | | This Save | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance | TimeCos | Stops Cos | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 17684 | 21026.2 | 709.51 | 29.635 | 24313 | 396.37 | 5256.549 | 17737.75 | 3039.125 | 26033.427 |
| | Mean | | 1.189 | 00:02:24 | | 1.375 | 00:01:20 | 0.297 | 1.003 | 0.172 | 1.472 |
| | Std Dev | | 1.337 | 00:02:32 | | 1.296 | 00:01:28 | 0.334 | 1.059 | 0.162 | 1.486 |
| All Trips | Total | 18486 | 22845.72 | 748.179 | 30.535 | 26333.8 | 1641794.586 | 5711.43 | 18704.49 | 3291.725 | 27707.641 |
| | Mean | | 1.236 | 00:02:25 | | 1.425 | 16:48:46 +3 | 0.309 | 1.012 | 0.178 | 1.499 |
| | Std Dev | | 1.37 | 00:02:35 | | 1.346 | 12:53:04 +90 | 0.342 | 1.082 | 0.168 | 1.501 |
| All (Normalised) | Total | 1000 | 1235.839 | 40.473 | 30.535 | 1424.527 | 88812.863 | 308.96 | 1011.819 | 178.066 | 1498.845 |

***Table 10. 10 Economic evaluation for Future Model 1(b)***

| Title | | Economic Evaluation of Future Model 1c | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / D | | | | | | | | | | |
| Simulation file | W:/Master of Civ | | | | | | | | | | |
| Model run at | Fri Oct 11 13:50:1 | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear | | 07:30:00.0 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save | | 08:30:00.0 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | DistanceCost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 19947 | 23697.34 | 829.461 | 28.57 | 28553 | 476.657 | 5924.485 | 20736.51 | 3569.125 | 30230.122 |
| | Mean | | 1.188 | 00:02:29 | | 1.431 | 00:01:26 | 0.297 | 1.04 | 0.179 | 1.516 |
| | Std Dev | | 1.335 | 00:02:42 | | 1.38 | 00:01:38 | 0.334 | 1.127 | 0.172 | 1.562 |
| All Trips | Total | 20855 | 25738.72 | 870.522 | 29.567 | 30843.13 | 1336865.8 | 6434.68 | 21763.05 | 3855.391 | 32053.122 |
| | Mean | | 1.234 | 00:02:30 | | 1.479 | 16:06:10 +: | 0.309 | 1.044 | 0.185 | 1.537 |
| | Std Dev | | 1.366 | 00:02:44 | | 1.416 | 08:49:24 +' | 0.342 | 1.141 | 0.177 | 1.569 |
| All (Normalised) | Total | 1000 | 1234.175 | 41.742 | 29.567 | 1478.932 | 64102.891 | 308.544 | 1043.541 | 184.866 | 1536.951 |

***Table 10. 11 Economic evaluation for Future model 1(c)***

| Title | | Economic Evaluation for Future Model 1d | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / | | | | | | | | | | |
| Simulation file | W:/Master of Civ | | | | | | | | | | |
| Model run at | Fri Oct 11 13:57:3 | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance | Time Cos | Stops Cos | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 20810 | 24499.37 | 878.53 | 27.887 | 30563 | 513.879 | 6124.842 | 21963.26 | 3820.375 | 31908.472 |
| | Mean | | 1.177 | 00:02:31 | | 1.469 | 00:01:28 | 0.294 | 1.055 | 0.184 | 1.533 |
| | Std Dev | | 1.312 | 00:02:43 | | 1.412 | 00:01:40 | 0.328 | 1.134 | 0.177 | 1.574 |
| All Trips | Total | 21795 | 26838.2 | 930.595 | 28.84 | 33317.76 | 1619187.613 | 6709.549 | 23264.88 | 4164.72 | 34139.152 |
| | Mean | | 1.231 | 00:02:33 | | 1.529 | 02:17:30 +3 | 0.308 | 1.067 | 0.191 | 1.566 |
| | Std Dev | | 1.352 | 00:02:47 | | 1.474 | 08:48:37 +73 | 0.338 | 1.163 | 0.184 | 1.596 |
| All (Normalised) | Total | 1000 | 1231.392 | 42.698 | 28.84 | 1528.688 | 74291.701 | 307.848 | 1067.441 | 191.086 | 1566.375 |

***Table 10. 12 Economic evaluation for Future Model 1(d)***

| Title | | Economic Evaluation for Future model 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / Da | | | | | | | | | | |
| Simulation file | W:/Master of Civil | | | | | | | | | | |
| Model run at | Fri Oct 11 14:01:29 | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear: | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance | Time Cos | Stops Cos | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 18734 | 22242.47 | 761.279 | 29.217 | 25690 | 430.107 | 5560.618 | 19031.99 | 3211.25 | 27803.855 |
| | Mean | | 1.187 | 00:02:26 | | 1.371 | 00:01:22 | 0.297 | 1.016 | 0.171 | 1.484 |
| | Std Dev | | 1.329 | 00:02:43 | | 1.28 | 00:01:40 | 0.332 | 1.133 | 0.16 | 1.548 |
| All Trips | Total | 19579 | 24148.61 | 802.682 | 30.085 | 27725.85 | 1421119.593 | 6037.152 | 20067.05 | 3465.732 | 29569.931 |
| | Mean | | 1.233 | 00:02:27 | | 1.416 | 00:35:01 +3 | 0.308 | 1.025 | 0.177 | 1.51 |
| | Std Dev | | 1.362 | 00:02:48 | | 1.322 | 13:48:31 +72 | 0.341 | 1.167 | 0.165 | 1.57 |
| All (Normalised) | Total | 1000 | 1233.393 | 40.997 | 30.085 | 1416.102 | 72583.87 | 308.348 | 1024.927 | 177.013 | 1510.288 |

*Table 10. 13 Economic evaluation for Future Model 2*

| Title | Economic Evaluation | Economic Evaluation of Future Model 3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | DesignOption / Date | | | | | | | | | | |
| Simulation file | W:/Master of Civil Er | | | | | | | | | | |
| Model run at | FriOct 11 14:05:27 A | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear | | 07:30:00. | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | ThisSave | | 08:30:00. | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance | TimeCost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 18642 | 21457.19 | 717.368 | 29.915 | 25354 | 398.456 | 5364.297 | 17931.7 | 3169.25 | 26465.251 |
| | Mean | | 1.151 | 00:02:18 | | 1.36 | 00:01:16 | 0.288 | 0.962 | 0.17 | 1.42 |
| | Std Dev | | 1.23 | 00:02:09 | | 1.259 | 00:01:11 | 0.308 | 0.896 | 0.157 | 1.317 |
| All Trips | Total | 19429 | 23290.86 | 745.743 | 31.232 | 27411.37 | 413.736 | 5822.715 | 18643.59 | 3426.421 | 27892.722 |
| | Mean | | 1.199 | 00:02:18 | | 1.411 | 00:01:16 | 0.3 | 0.96 | 0.176 | 1.436 |
| | Std Dev | | 1.275 | 00:02:09 | | 1.302 | 00:01:11 | 0.319 | 0.897 | 0.163 | 1.321 |
| All (Normalised) | Total | 1000 | 1198.768 | 38.383 | 31.232 | 1410.848 | 21.295 | 299.692 | 959.575 | 176.356 | 1435.623 |

*Table 10. 14 Economic evaluation for Future Model 3*

| Title | Economic Evalua | Economic Evaluation for future model 4 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subtitle | Design Option / | | | | | | | | | | |
| Simulation file | W:/Master of Civ | | | | | | | | | | |
| Model run at | FriOct1114:12:5 | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear: | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 17416 | 18838.19 | 855.75 | 22.014 | 26609 | 575.584 | 4709.548 | 21393.742 | 3326.125 | 29429.414 |
| | Mean | | 1.082 | 00:02:56 | | 1.528 | 00:01:58 | 0.27 | 1.228 | 0.191 | 1.69 |
| | Std Dev | | 1.263 | 00:03:56 | | 1.617 | 00:02:58 | 0.316 | 1.644 | 0.202 | 2.09 |
| All Trips | Total | 19097 | 23477.15 | 999.533 | 23.488 | 33120.1 | 525397.834 | 5869.288 | 24988.332 | 4140.012 | 34997.632 |
| | Mean | | 1.229 | 00:03:08 | | 1.734 | 03:30:43 +1 | 0.307 | 1.308 | 0.217 | 1.833 |
| | Std Dev | | 1.386 | 00:04:15 | | 1.845 | 07:06:25 +36 | 0.346 | 1.775 | 0.231 | 2.246 |
| All (Normalised) | Total | 1000 | 1229.363 | 52.34 | 23.488 | 1734.309 | 27512.061 | 307.341 | 1308.495 | 216.789 | 1832.625 |

*Table 10. 15 Economic evaluation for Future Model 4*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | Economic Evaluation | Economic Evaluation of Future model 5 | | | | | | | | | |
| Subtitle | Design Option / Dat | | | | | | | | | | |
| Simulation file | W:/Master of Civil E | | | | | | | | | | |
| Model run at | Fri Oct 11 14:17:39A | | | | | | | | | | |
| Simulation date | 22 / 09 / 2017 | | | | Last Clear | | 07:30:00.000 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save | | 08:30:00.000 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 18663 | 21981.48 | 783.509 | 28.055 | 29800 | 430.661 | 5495.369 | 19587.721 | 3725 | 28808.09 |
| | Mean | | 1.178 | 00:02:31 | | 1.597 | 00:01:23 | 0.294 | 1.05 | 0.2 | 1.544 |
| | Std Dev | | 1.322 | 00:02:50 | | 1.743 | 00:01:24 | 0.33 | 1.183 | 0.218 | 1.653 |
| All Trips | Total | 19579 | 24174.58 | 834.089 | 28.983 | 32619.06 | 453.322 | 6043.644 | 20852.214 | 4077.382 | 30973.24 |
| | Mean | | 1.235 | 00:02:33 | | 1.666 | 00:01:23 | 0.309 | 1.065 | 0.208 | 1.582 |
| | Std Dev | | 1.366 | 00:02:55 | | 1.806 | 00:01:25 | 0.341 | 1.217 | 0.226 | 1.683 |
| All (Normalised) | Total | 1000 | 1234.72 | 42.601 | 28.983 | 1666.023 | 23.153 | 308.68 | 1065.03 | 208.253 | 1581.962 |

***Table 10. 16 Economic evaluation for Future Model 5***

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Title | | Economic Evaluation of Future model 6 | | | | | | | | | |
| Subtitle | DesignOption/D | | | | | | | | | | |
| Simulation file | W:/Master of Civil | | | | | | | | | | |
| Model run at | FriOct1114:36:3 | | | | | | | | | | |
| Simulation date | 25 / 06 / 2016 | | | | Last Clear: | | 07:30:00.0 | | Version: | | 6.00.006 |
| Simulation duration | 07:30 to 08:30 | | | | This Save: | | 08:30:00.0 | | | | |
| | | Count | Distance | Time | Speed | Stops | Delay | Distance Cost | Time Cost | Stops Cost | Total Cost |
| | | | (km) | (h:m:s) | (km/h) | | (h:m:s) | ($) | ($) | ($) | ($) |
| Complete Trips | Total | 18636 | 21498.51 | 731.786 | 29.378 | 25857 | 413.316 | 5374.627 | 18294.661 | 3232.125 | 26901.414 |
| | Mean | | 1.154 | 00:02:21 | | 1.387 | 00:01:19 | 0.288 | 0.982 | 0.173 | 1.444 |
| | Std Dev | | 1.233 | 00:02:09 | | 1.262 | 00:01:12 | 0.308 | 0.897 | 0.158 | 1.317 |
| All Trips | Total | 19429 | 23294.72 | 759.27 | 30.68 | 27920.09 | 428.067 | 5823.679 | 18981.743 | 3490.012 | 28295.434 |
| | Mean | | 1.199 | 00:02:20 | | 1.437 | 00:01:19 | 0.3 | 0.977 | 0.18 | 1.456 |
| | Std Dev | | 1.275 | 00:02:08 | | 1.302 | 00:01:11 | 0.319 | 0.894 | 0.163 | 1.316 |
| All (Normalised) | Total | 1000 | 1198.966 | 39.079 | 30.68 | 1437.032 | 22.032 | 299.742 | 976.98 | 179.629 | 1456.35 |

***Table 10. 17 Economic evaluation for Future Model 6***