IMPLEMENTATION OF DRIVERLESS VEHICLE AT FLINDERS UNIVERSITY'S BEDFORD PARK CAMPUS

ENGR9700

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Declaration

I certify that this work does not incorporate without acknowledgement 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: ____________________________________

Date: 7 June 2020

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Abstract

The development and implementation of Autonomous vehicles (AVs) have made great progress in recent years. It is expected that they will play an important role in future transport systems as one of the key components in the next transport technology revolution. This paper describes the proposed implementation of driverless vehicles in the Bedford campus of Flinders University. The study includes the planning of the appropriate route for autonomous vehicles in Bedford Park precincts and the provision of the associate shuttle stop locations. It also covers the investigation in the appropriate frequency of driverless shuttle transport services for commuters and residents. The aim of this research is to test the different routes in the campus and recommend the best option that would enable a good connection for students, faculty staff members and visitors to the main campus of Flinders University. The traffic microsimulation approach is adopted in this project that was carried out using the software package tool called AIMSUN. This software is used to evaluate a number of different key traffic performance indicators including travel time, delay, number of bus stops, the direction of travel for specified route etc. The decision to use AIMSUN is made on the basis of this software package being adopted as the main microsimulation tool by the State Transport Agency in South Australia.

The modelling methodology included the development of the existing network conditions and more than a dozen different alternative scenarios covering two different driverless vehicle routes for morning peak modelling period (8:00 AM-10:00 AM). The first route was the main campus Ring Road route and the second one was the current pedestrian path around the Central Campus lake. It was decided to first test the models that do not require any infrastructure upgrades and using current maximum operational speeds of 20 km/h for the driverless vehicles. Following this, the sensitivity analysis using AV speeds in the range of 20-50 km/h was performed. Both directions of travel, clockwise and counterclockwise were assessed on both routes.

Each of the scenarios was run with 5 replications and using the random seed numbers as per the Department of Planning, Transport and Infrastructure (DPTI's) Aimsun Manual specifications. The output of each scenario was recorded for comparison and evaluation of best performing scenario. In total, 18 alternative network scenarios were tested on both routes

for both directions of travel, different number of bus stops and different maximum speeds of driverless vehicles.

Initially, the outer Ring Road route with the length of 2,337.03 m was tested with 12 different scenarios with respect to speed, the direction of travel and indented and non-indented bus stops. A significant increase in vehicle delays of 73 percent was observed if no indented bus stops were provided and the current maximum driverless vehicle speed of 20km/h was adopted. Most of that delay was attributed to bus stop locations which have led to the recommendation to provide indented bus stops.

Further investigation was conducted with the AVs being provided with the indented bus stops and using the current maximum speed of 20 km/h. Although the vehicle delays were reduced slightly, still significant delays were recorded to other vehicles as they were travelling behind the AVs since their speeds were significantly lower than the posted speed limit of 50km/h. An additional AV maximum speed sensitivity analysis was performed to measure the effects they are having on other conventional vehicles. The analysis included testing the speeds in the range of 20-50 km/h with the step of 5 km/h. It was shown that the AVs would cause a significant delay and disruption to other vehicles unless the top speed of the AVs can be increased to at least 40 km/h. This is the reason that the recommendation was made for AVs not be running on Ring Rd until the technology is improved so that the AVs can be run safely with an increased maximum speed of 40-50km/h.

Since both directions of travel were tested for both alternative routes, the modelling results have shown that the counterclockwise direction in both cases performed better when compared with clockwise direction.

Final modelling scenarios involved running the AV service off-road, using the existing pedestrian footpath along the Campus Central Park Lake. Six different scenarios with respect to the direction of travel and options with 3 and 5 stops along the route were developed. The results have shown that the travel time to complete one loop is approximately 8 minutes if the speed limit of 10km/h and 5 stops were used. However, if the 3 stops only were served the run travel time would decrease by 15 percent to around 6.8 minutes. Similarly, the scenario with the footpath speed limit of 20km/h would result in a reduction to travel times of 23.72 percent if only 3 bus stops were used.

Further study was conducted to evaluate the capacity of the Lake route in terms of the maximum number of passengers that it could be served. This study has shown that the minimum travel time of 4.5 (minute/run) can be achieved which means that a maximum of 13 runs per hour is feasible. Using the capacity of the current Flinders Navya shuttle of 15 passengers the entire route capacity would be 195 passengers per hour assuming that only one shuttle was used.

The final recommendation of the study was to implement the AV service around the Central Lake in contraclockwise direction and not use the Ring Road route until the technology is improved and the maximum AV speeds increased to 40-50 km/h.

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List of Abbreviation

AV- Autonomous Vehicle

OD- Origin Destination

FLEX- Flinders Express

MASTEM- Metropolitan Adelaide Strategic Transport Evaluation Model

SCATS- Sydney Coordinated Adaptive Traffic System

DPTI- Department of Planning Transport and Infrastructure

CBD- Central Business District

IMS - Integrated movement Strategies

LOS- Level of Service

1 Introduction

The low speed transit system of transportation is a primary option for the university's campus to tackle the transportation problem among various solutions. Nowadays, campuses are promoting a modal shift from cars to other modes particularly driverless vehicles. Its foremost aim is to reflect on the opportunities to form sustainable campuses from an individual viewpoint (Balsas, 2003, Engwicht, 1995). The main purpose of sustainable transport planning is to provide mobility and access without destroying the qualities of campus. There are a lot of opportunities to explore the low speed transportation on the campuses. The driverless vehicle technology can offer many benefits such as safer roads, travel time reduction, more personalized services, improvement of energy efficiency and parking benefits (Fagnant and Kockelman, 2015). The most important benefits are safety related with the potential to significantly reduce the accident occurrence, with some estimates predicting up to 90% reduction (Waldrop, 2015).

This study uses the Flinders University Campus area in Bedford Park as shown in Figure 1 below:

Figure 1: This image has been removed due to copyright restriction: Flinders Precinct region for Autonomous Vehicle trial (Source: Holmes Dyer Masterplan Report)

The NAVYA autonomous vehicle trial (NAVYA, 2015), the first stage has been completed at Tonsley precinct in 2020. The second stage of the trial is planned to occur at Bedford Park Campus and this report describes the planning process conducted in the selection of the best route for the new service location. The main campus ring route and pedestrian route around the lake of the main campus of Flinders University were developed and evaluated as shown in Figure 2.

1.1 Research Aims and Objectives

According to the review of the literature and research gap analysis, there is a requirement of research to be undertaken. To successfully address the knowledge gaps, a set of aim is targeted for the better direction of outcome.
Aims of this research are listed below: -

- To investigate the performance of new transport technology in the Bedford Park campus.
- Test different routes in the campus
- To check a reliable number of indented bus stops for a trial route to reduce waiting time of other road users
- Try to improve potential AV Rider’s satisfaction
- Develop different modelling scenarios to check the performance of trial route based on the direction of travel, maximum speeds of AVs and of the provision and location of indented bus stops.

The base model network was provided by Flinders University as originally developed by previous students. This model was checked, re-calibrated and further expanded in order to be capable of AV vehicle modelling. The model improvements involved adding the road slopes, new bus stops and new vehicle category that was built based on NAVYA driverless vehicle specifications provided by the vehicle manufacturer.

1.2 Methodology and the Software used

DPTI uses a range of analytical and simulation tools to assess road network performance and to plan the future development of the network. For the detailed intersection performance evaluation, the software package Sidra is most widely used in Australia. This software is not suitable for the detailed network evaluation and it is not capable of simulating and displaying the individual vehicle movements.

Another software package widely used by DPTI and other agencies around the world is CUBE. This software is mostly used for modelling large scale networks and it was not found to be suitable for the Bedford Park network.

The most appropriate modelling tool for the driverless vehicle trial was found to be microsimulation. There were few software packages available for this research, such as Aimsun (Spain), Infraworks (USA), Paramics (UK) and Vissim (Germany). All these tools have similar capabilities and any of them could have been used successfully in this research. Since the Aimsun is the software adopted by DPTI in Adelaide and the Flinders University students have access to free license it was decided to utilise it in this research project.

For the purposes of this study, software package Aimsun was selected (Holyoak et al., 2005, AIMSUN, 2004). Aimsun is the software which was developed in Barcelona (SPAIN). The main reason for the selection is the fact that this software was adopted by the Department of Planning, Transport and Infrastructure (DPTI) in Adelaide and used exclusively for this type of transport network modelling. Aimsun Next is the agencies preferred traffic simulation software, and this manual(Casas et al., 2010) was initially developed to provide broad guidance on the overall process of developing Aimsun microscopic models. The previous version of this manual (released in 2013) was based on Aimsun Version 7.0. Since that time there have been significant changes to the software and also in the way DPTI uses Aimsun software. In terms of changes to the software the capability to create and use mesoscopic models and hybrid models (a combination of the microscopic and mesoscopic approaches) has been enhanced, the capability of creating and using multi-network models has been added, the matrix adjustment capability has been significantly enhanced and path building/checking has also been improved.

This is the only software for traffic simulation supported by DPTI and some of the more key capabilities are listed below:-

- The advanced edition provides a comprehensive and flexible framework for muti resolution transport studies.
- AIMSUN next expert framework is available to analyse and modelling all types and scale of transportation.

- Aimsun includes as standard with every edition a complete set of interfaces with several transportation simulations and signals optimization tools, including:
- GIS importer and exporter
- SYNCHRO importer and exporter

A total of 18 different modelling scenario was performed using Aimsun for two different trial sites as shown in Figure 2. First 12 analysis was tested for the outer ring road and another 6 were performed to check implementation benefits for inner ring route around the lake.

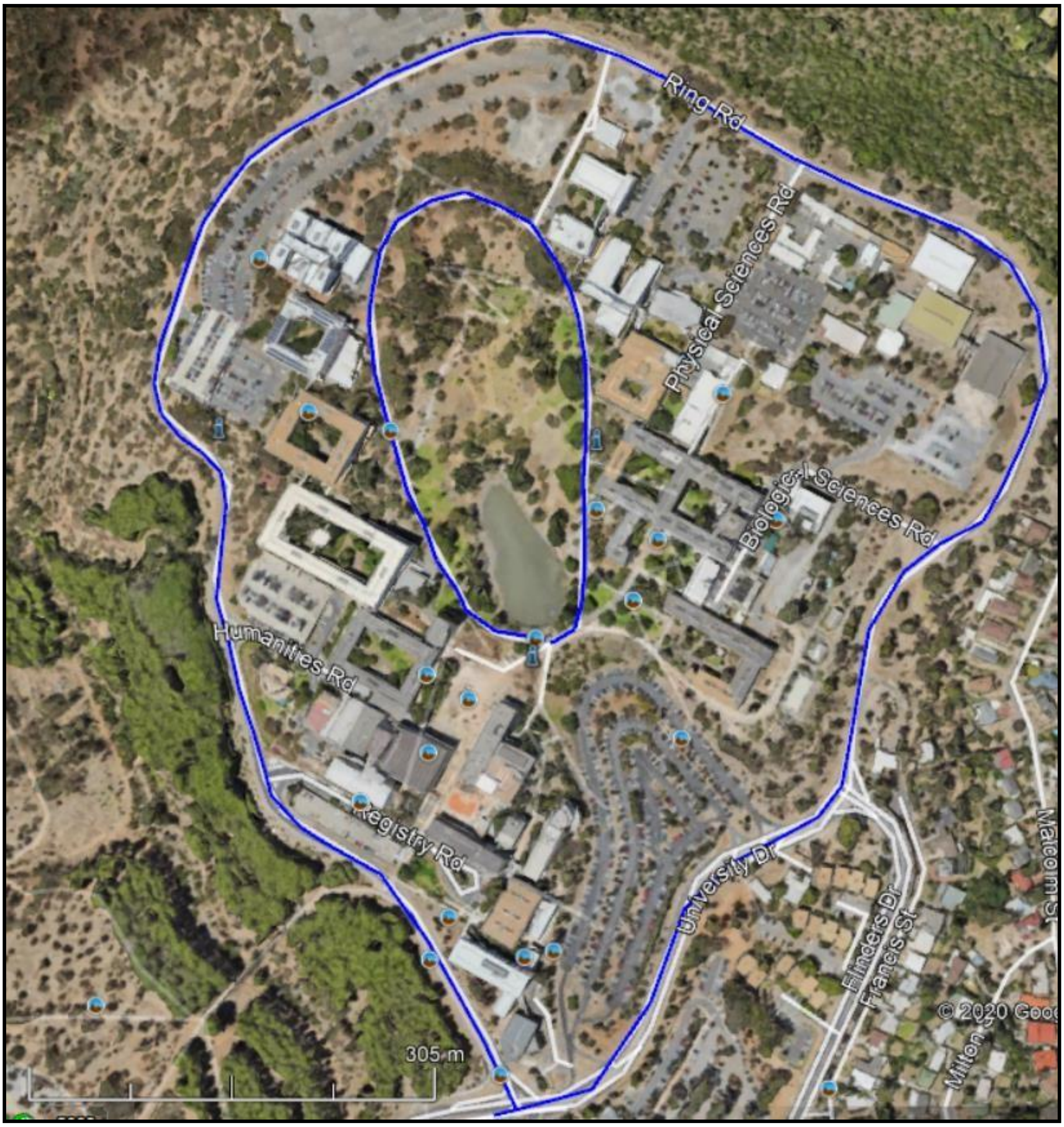


Figure 2: Bedford Precinct Inner and Outer trial route for AV

1.3 Structure of the thesis

This paper is divided into seven chapters, further divided into sections and subsections. The first chapter is a detailed introduction of driverless vehicle technology and proposed aims of this research paper. Chapter 2 will provide a detailed background of implementation of the driverless vehicle and trial stages of Autonomous vehicle atFlinders University. This section also lists other autonomous vehicle trials currently being conducted in Australia. Chapter 3 discusses the significance of driverless shuttle in universities and the operation of an autonomous vehicle in a short distance traffic environment. Chapter 4 describes the microsimulation modelling of trial routes using AIMSUN software package. Aimsun is capable of detailed traffic network modelling on an individual vehicle level. This chapter also includes the extent of the network, driverless vehicle parameters, vehicle profile, traffic data and modelling period and the common assumption that were made during testing of the driverless vehicle.

Chapter 5 discusses the modelling results and includes the sensitivity analysis conducted on the speed of AV varying between 20-50 km/h and including both directions of travel, clockwise and counterclockwise as well as both, the inner and outer ring road.

Chapter 6 presents the modelling results of various alternative Aimsun models. The result includes travel efficiency based on the direction of travel, speed of autonomous vehicles and number, location and type of bus stops.

Chapter 7 provides a discussion drawn from the above results and followed by proposed future research for the advancement of a driverless vehicle. This chapter provides a summary of the modelling results following the recommendations for the proposed implementation of the autonomous vehicles at Bedford Park Campus of Flinders University.

2 Literature Review

2.1 Background

Autonomous vehicle development will essentially change the present pathway of driving by mode of use and riding practice and turn driving into a complex system. An efficient transportation service system is created by an integrated environment, people and vehicles in the system. This system changes the previous “vehicle-road-driver” closed-loop system. Based on the level of road vehicle automation for SAE, the current development of driverless vehicles is at Level 3 (conditional automation) (Balsas, 2003). Level 3 and Level 5 involve vehicles to rely heavily on the driving environment to drive and interact with people. In each case, the low speed traffic environment of the city interacts with people most frequently and deeply.

At the same time, the approaches for creating a low speed transportation service platform founded on autonomous vehicles are diverse in numerous environments (Shi and Ma, 2017). The typical environment includes tram stations, airports, university campuses, parking lots, outdoor gyms, parks, etc.

Flinders University Bedford campus and surrounding precinct are located in a very high trafficked area as this is adjacent to Southern Expressway. During the peak hours, the area surrounded by campus is full of congestion at the intersection and on the roads that impact bus and private vehicle travel time. The campus has a very high demand for parking as the car mode of share in the university is very high that leads to parking issues where site attendance is high (Aitken, 2004).

Flinders Link Project and Gateway South Darlington project has also a big impact on the connectivity of private cars and public transport to the main south road that leads congestion on the road. The ongoing project minimizes the opportunities to commuters for the alternative route. In his media release from 29th April 2019, Minister for Transport, Infrastructure and Local Government Stephan Knoll said the Flinders Link Project will better connect our health, innovation and education precincts. “The extension of the Tonsley line will better enable South Australians to access the Flinders Medical Centre and Flinders University through our public transport network,” said Minister Knoll. Moreover, pedestrian and cyclist access to the main campus from Tonsley and Flinders Medical Centre is also poor.

Hence, planned combined land use and growth on the site is necessary.

2.2 Research Justification

South Australian government's emphasis on Autonomous vehicles and the future of mode split through (Integrated movement Strategies) IMS and 30-year plan for greater Adelaide (DPTI2019b) provides an overwhelming explanation for the base of this research. This paper will examine the feasibility of autonomous vehicles for future transport master-plan vision for the Flinders Precinct. These three stages $4 million Autonomous vehicle projects for which flinders university and DPTI and the Royal automobile association (RAA) have combined with Cohda, SAGE Automation, UPG, Zen Energy and Renewal SA industrial supporter. For all 3 stages, the route is already proposed by the Department of Transport and presently in its very initial stage of implementation. The $10 million from Future Mobility Lab Fund and $1 million from the state government are committed to the planning of transit networks (Government of South Australia, 2019).

Three different stages were given by the subdivision of planning and transport infrastructure and these proposed stages implementation period is different and three different stages to promote the advancement of Autonomous Vehicle are displayed in Figures 3, 4 and 5. Stage 1 of the trial is being conducted in Tonsley area using the public roads as shown in the Figure 3. All the roads that the shuttle will be running along have a posted speed limit of 50 km/h. This indicates that the driverless vehicle will inevitably cause extra delays to other private vehicles until the current maximum speed of the driverless shuttle was increased from initial 15 km/h. During this stage, the maximum shuttle speed was increased safely to 20 km/h together with some other major shuttle operation improvements, such as autonomous intersection turns without a need for chaperone manual inputs. Lessons learnt from the stage 1 and the operational improvements made will be of great importance when planning for the next stage of the trial. Driverless vehicle operation during stage 1 was monitored, analysed and evaluated using several parameters. The analysis included the following:

- The proportion of autonomous versus manual driving travel distance
- Incident report analysis
- Introduction of the autonomous intersection turns
- An increase in shuttle speeds, acceleration, and deceleration performance
- Analysis of the passenger surveys, before and after the run
- Other technical and operational shuttle improvements

Figure 3: Tonsley Precinct (trial stage 1)

Following the completion of stage 1, it was planned to relocate the shuttle service to Bedford Park Campus and conduct the stage 2 at that location as seen in Figure 4. Originally, this was planned to occur in 2020 but due to Covid-19 effects it might need to be postponed for 2021. Since the shuttle route was not predetermined, this study was undertaken to evaluate alternatives and recommend the preferred service operation route. The main difference between this and stage 1 route is the existence of quite large road slopes that will present a challenge and thus needs a careful consideration during the planning stage.

Figure 4: Proposed Flinders Precinct (trial stage 2)

Once the stage 2 is complete, the final stage will look to test the shuttle operation on a route that would connect two Flinders University campuses, Tonsley and Bedford Park. The first two stages were using routes that were exclusively located within one of the campuses but stage 3 will involve the shuttle running on some of the major arterial roads, such as Sturt Rd as shown in Figure 5.

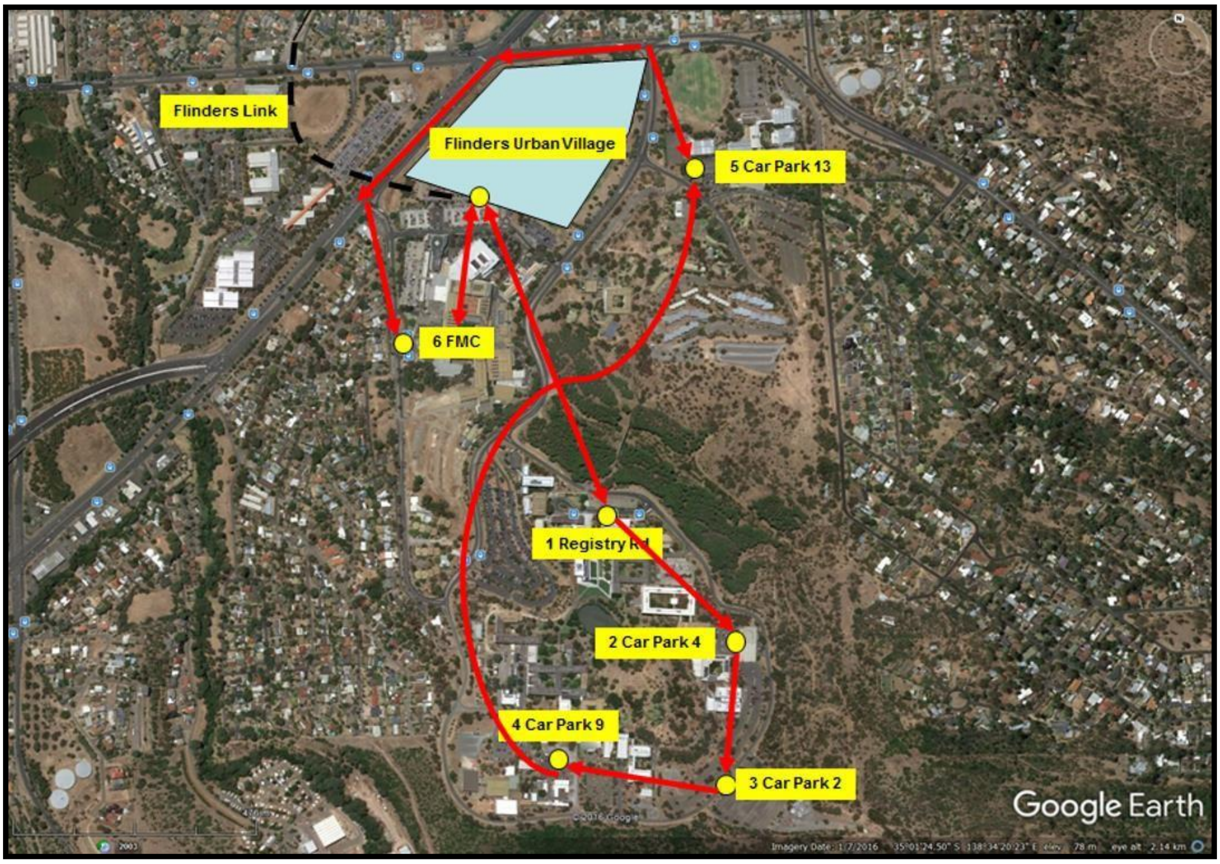


Figure 5: Proposed Flinders Precinct (trail stage 3)

Finally, for trial purpose of stage 1 Autonomous vehicle NAVYA shown in Figure 6 were selected due to some unique technical specifications and operational characteristics. The national guidelines and sets of data used to Analyse stage 1 refer to the Australian Government database and DPTI and South Australian Government on census 2011 and 2016. Some operational characteristics of NAVYA (NAVYA, 2018) is: -

- 3D vision and environment recognition
- Localization and prioritization of object
- Real-time obstacles detection and continues optimization of vehicle
- Configuration of decision-making power using algorithms
- Supervision of operating fleets
- Vehicle and human safety with a high level of data encryption
- No need of manpower
- Less fuel consumption
- Useful for students as it minimizes the travel time within the campus

Figure 6: This image has been removed due to copyright restriction: NAVYA Autonomous Vehicle (NAVYA: minibus et navettes autonomous, 2019)

Figure 7 below shows some other driverless vehicle technologies currently available. Reason for adaption of NAVYA among them is due to more advancement of its technical specification and more seating capacity e.g. the RDM can only seat 2 or 4 people. The proposed trail needed to seek exemptions from most of the elements of the Motors vehicle Act as it bears little resemblance to a normal road vehicle type. This could even result in the need for a separate veh1icle type category.

Figure 7: This image has been removed due to copyright restriction: Driverless vehicle Technology

During the process of driverless vehicle technology selection all four companies that were manufacturing this type of vehicles at the time were invited to submit the applications. Two

of the companies, EasyMile and Navya, are French based. The Local Motors company is from USA, while the RDM is from Great Britain.
It was found that the RDM did not have technology suited for Flinders University trials since they were focusing on off-road customers and providing shuttles with much smaller passenger capacities. The Local Motors technology was found to be a bit behind in its development stages and not ready for the on-road trial for the Stage 1 either. Of the two remaining manufacturers, both from France, it was assessed that they had similar technological and performance characteristics. Although, the Easy Mile had the local office established in Adelaide, the Navya technology was selected as the preferred for the Flinders University trials.

To understand the growth around the flinders precinct and to understand the topography of route suite, the following datasets were used in the analysis:

Table 1 - Datasets used in the microsimulation model development process

Datasets and the Source	**Type of data**
Data SA (data.sa.gov.au).	Road map
	MetroCard validation data
	Public transport stops
	Rail map 2
National Map (nationalmap.gov.au).	SA1-2011 Census data (population, household, mode)
	SA1-2016 Census data (population, household, mode)
	The proportion of the people within walking distance to high-medium frequency public transportation
Australian Bureau of Statistics (www.abs.gov.au).	SA1-2011 Census data (population, household, mode)
	SA1-2016 Census data (population, household, mode)
DPTI	Flinders Link Project – Report and Attachments
	Square Holes Report 2019
	Speed Limit Guideline for South Australia

2.2.1 Relevant National guidelines of Stage 2 route planning

Since the National Guidelines for the driverless vehicle testing and implementation were addressed before the start of the Stage 1 planning and the permission to conduct the trials was already granted, there was no need to repeat the same process for Stage 2 of the trial.

This research project has only involved the author's familiarization with the relevant guidelines. These guidelines are used to insure high level of safety for all road users during the trails. The guidelines are also provided to allow the smooth operation and trial administration and to cover the legal aspects, such as insurance policy.

The National Guidelines have covered certain parts of Autonomous vehicle implementation like Administration of trials, Safety Management Plan (SMP), data, Insurance and information about existing, Heavyweight vehicle and cross-border trials. The guidelines gave information about different countries guidelines as well, but this document mostly focused on DPTI SA guidelines (Bennett et al., 2009). The list of relevant national guidelines compiled after reading the discussion paper.

- According to the South Australian legislation, the notice of specific area of trial testing must be given to the DPTI for stage 2.
- It is required that before trial testing all the aspects about expected performance should be in detail and if any road infrastructure is required, then consult with DPTI.
- For the anticipated tests, including automated vehicle staging; the guidance should be obtained from the DPTI related to Stage 2.
- DPTI required an automated vehicle to meet all existing vehicle standards for trial testing.
- Stage 2 required to ensure the protection of other road users and control of software, including updates should be checked prior to trial testing by DPTI
- Before trial testing, some of the metrics of pre-trial testing need to be calculated before gets the approval of trial testing which are noted below:
    - Pre-trial test hours
    - Pre-trial test kilometres
    - Test in different environments likely to be encountered on public roads
    - Checks and Audits from third-party
    - Access to test results

- The details of operator including licenses, qualifications and experience and also the SWMS (Safe Work Method Statement) should give to DPTI for the trial testing of Stage 2.

2.3 Flinders modal shift for Transportation

Transportation is a primary option for the university's campus to tackle the transportation problem among various solutions. Nowadays, campuses are promoting a modal shift from cars to other modals particularly driverless vehicles. Its foremost aim is to reflect on the opportunities to form sustainable campuses from an individual viewpoint (Balsas, 2003, Engwicht, 1995). The main purpose of sustainable transport planning is to provide mobility and access without destroying the qualities of campus.

2.3.1 Environment Requirement

Speed slower than motorized vehicles is known as slow traffic, and it mostly mentions walking and some other forms of transportation whose speed is lower than 35 km per hour (Adams, 2015). In some urban mobility systems driverless buses are also joined into an urban slow transit system to connect pedestrian and cyclist networks. Slow transit mode boosts commuters to opt for the transport of bicycles and driverless bus, walking and driverless vehicle to save time and congestion. This way of convenience also leads to the protection of the environment.

2.3.2 Object-Oriented Needs

Due to the distinctiveness of campus, the low speed traffic model seems to have an advantage over other modes. Colleges and universities have the opportunity to improve significant social measures of innovation in modern cities and sustainability to become leaders in regional financial growth (Spohrer et al., 2013). Compared with other methods, research and projects on active transportation (also known as non-motorized transportation) planning are still few (Forester, 1994). As a test stage for social advancement, Campus ought to find and advance the forthcoming mobility pattern in the upcoming time. In the meantime, contrasting with urban conditions, the partners and utilizing contexts in the universities are moderately basic, with the goal that most transportation needs could be meet by moderate traffic.

Due to the numerous changes in the road network, vehicle size and flow of people, some of the studies on the urban low speed mobility could not be applied directly into the campuses. There are a lot of opportunities to explore the low speed transportation on the campuses. Thus, there is a need for low speed traffic solutions in urban areas.

2.3.3 Social Demands

"Maybe we don't need service design, but service is everywhere (Stickdorn et al., 2011)". In the present era of the service economy, we must stand on the logic of the service system and integrate the current resources to originate to meet the mutual interests for the stakeholders. The existing society is complex with full of complications and doubts. In the world, interconnections between various aspects are becoming stronger and more difficult to understand. As suggested in section 2.3.2, university campus requires a low speed mode of transportation but how to construct and implement such campus transportation system? Transportation system is not only a single model vehicle, but also a combined network containing interactive and collaborative transportation modes, activities and stakeholders. The idea of service system thinking could help campus low speed traffic products performed more effectively.

2.4 Current Route of NAVYA Shuttle in Tonsley Precinct

Shuttle services at Tonsley Precinct bridge the gap for daily users between bus/train stops and their final destinations. The proposed Flinders University trial projects have three concurrent different stages in which only Stage 1 (Tonsley stage) is the first to be in operation. This stage will be conducted over 24 months at the Tonsley innovation precinct. This stage has also had some possible route variation proposed that would result in the service to be expanded onto the surrounding suburb.

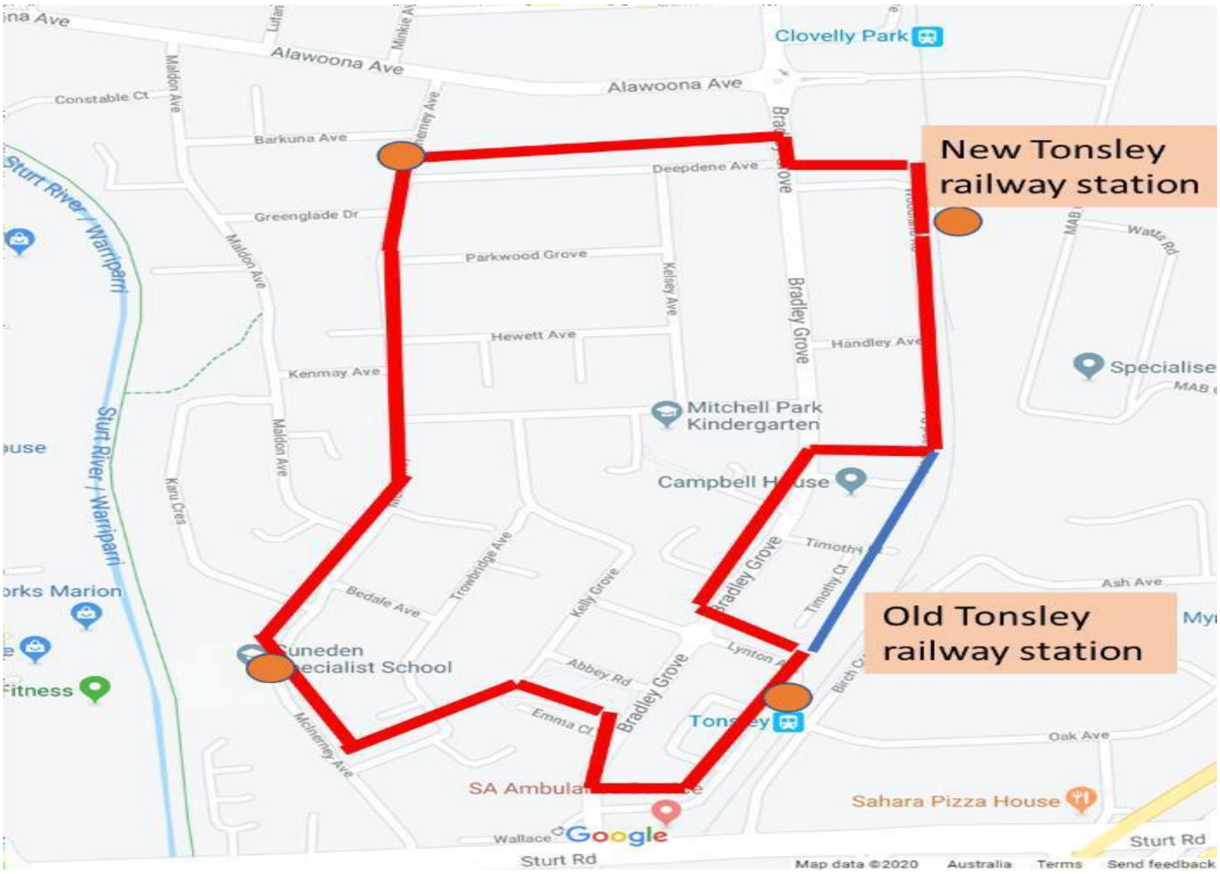


Figure 8: Proposed Flinders trial route in Tonsley 2021

Tonsley precinct first stage of the trial will see the shuttle used on public roads, provide a connection between South Road, the Clovelly Park tram station and all other nearby businesses in the Tonsley. The objective of Stage 1 is to test the driverless vehicle technology in the relatively closed road environment. The entire route, totalling 1.3 km is contained within the Tonsley precinct with only two access point to the surrounding road network. Figure 8 shows the proposed trail route with shuttle stops and proposed initial route speeds. The speeds may be varied for different route parts and time of day and will be tested with a graduated increase. Higher speeds are envisaged for route parts with the lower traffic density.

2.5 Computer Simulation as an Analytical Tool

In recent years, Microsimulation becomes the most useful and commonly adopted tool for simulating traffic models for analysis and to identify the solutions of traffic and transport planning (Austroads, 2006). Proposed models are simulated to determine the outcome of transport facilities, trip generation, model routing, environment impact and travel costs (Currie, Aftabuzzmann, & Sarvi, 2010). Many studies have employed this approach of simulation (Avetisyan et al. 2014; Dia 2011; Dia & Gondwe 2008; Dia, Gondwe & Panwei 2006; Huang, Bird & Bell 2009; Kabit et al. 2014; Koorey, McMillan & Nicholson 2014; Ozbay & Bartin 2004). This has the ability of detailed traffic networks to capture the movement of vehicles and traffic operation and driver to driver interaction using the multi-modal interchange (Holyoak & Stazic 2009). According to Holyoak and Stazic (2009), microsimulation gives better precise results for the measurement of environment implication due to consideration of acceleration and deceleration of individual vehicle on emissions. However, macroscopic simulation leads to an underestimate of emissions. Both Dia (2011) and Kabit et al. (2014) described that this simulation approach is the safest and best to assess the network area-wide impact in a cost-effective manner.

2.6 Summary of research gaps and aims

After reviewing the research and literature of the topic it has been found that there are many potential problems to be encounter during the planning and implementation processes of the Autonomous vehicle routes.

By identifying the key research gap, this study aims to discuss the introduction of Autonomous vehicle at Flinders University Bedford Park campus. The second aim is to investigate the performance of new transport technology through some key objectives such as the reduction in waiting time, provision of a number of indented stops, autonomous vehicle speeds, the direction of travel and the service capacity. Another important aim of this thesis is to construct the best modelling scenario to minimize the potential delay to other vehicles in order to promote the successful introduction of driverless vehicles on the University campus.

3 Driverless vehicles general background and specifications

Autonomous vehicle (also known as a driverless car, self-driving car, robotic car (Breazeal, 2004)) and kind of vehicle is a vehicle that is can navigate, sense the environment without human input (Thrun, 2010). Autonomous vehicles can provide individuals with transportation functions and entertainment value and help to build encouraging relationships between people and the environment (Gehrig and Stein, 1999).

3.1 Operation of Autonomous Vehicle in Short-Distance traffic Environment

Operation of AVs for short-distance traffic environment has numerous benefits like strong flexibility, high traffic frequency, less travel time with more commuters. Moreover, in the low speed-transportation environment, the public has a closer relationship with their surrounding environment. In such a low-speed and relatively narrow environment, driverless low speed transportation vehicles can set up automatic docking and connection, calculate and arrange reasonable paths, also flexibly link people to the environment. As Autonomous Vehicles are controlled by a controlling system, and service platform themselves, deployment and management in a limited space may be more sensitive.

Autonomous vehicle runs continuously on the road by default, except for the charging time. This constant operation can increase the use and release of transportation resources. On one hand, this constant activity can improve vehicle use and accomplish the genuine sharing of assets of public vehicles. Then again, it can spare part of parking spots, which is more important than the past when the low speed transportation spaces were being involved, inevitably amplifying the limit of area for transportation. This also delivers an advantage of external environments for a better process of Autonomous Vehicles.

3.2 Autonomous Vehicle Is Fit for Environments with High-Path Repetition Rate and Simple-Driving Conditions

In low speed traffic environment, campus, airports, industrial parks are far from the city centre and industrial parks are the typical ones. In these typical one environment, the driving path is highly repeatable and driving condition is moderately basic. In universities and industrial parks, the driving path has a specific consistency and repeatability in various periods. Walking is the fundamental method of transportation at the airport and some local locations where vehicles and individuals are isolated(NRMA, 2017). These conditions are closed, don't include in urban transportation regulation and the driving condition is generally simple. Autonomous low speed transportation can expand vehicle usage and serve more individuals in the environment.

3.3 Autonomous Vehicle Can Contribute to the Interaction Between Vehicle and People

Currently, low speed transportation vehicles are the only carrier of transportation services. Vehicles and the users do not recognize, and their intersection is passive with each other. The vehicle does not collect user data, do not learn user data, does not optimize services and benefit other users. Users are unable to respond to their experience in any online format, personal data and schedules to vehicles in time, which doesn't help transportation vehicles to learn more about users' information and the surrounding environment. However, the low speed transit vehicle and an Autonomous service platform should be a university's local information centre. Thus, in this kind of Autonomous Vehicle, an in-vehicle intelligent system was embedded. This smart framework worked like a virtual character, to empower the vehicle to interact with individuals. Through this communication, commuters can enter their information or data, help transportation vehicles infiltrate genuine needs and optimize its benefits in an exceptionally normal way. Furthermore, this service platform stage can give pertinent data to help different clients dependent on recorded information. The dynamic cooperation among clients and vehicles will enable the stage to give on-request benefits that address different needs of the market.

3.4 Driverless Vehicle Can Support Better Function Integration

Numerous environments are getting progressively practical, particularly for various clients. For instance, the campuses are not just an everyday workplace for students and teachers also the assortment and circulation of environmental data around the campuses. Simultaneously, it additionally bears certain social functions, for example, holding some open tests or conferences, and being a visitor's tourist attraction on occasions. Consequently, taking the campuses transportation administration, for instance, we have to address the daily issues, pathfinding, data direction, and campus visits. The autonomous vehicles are controlled directly by the in-vehicle intelligent system and service platforms, not by personnel. Thus, for autonomous vehicles, it is easier to be integrated into the entire system, easier to compound function and dispatch. This advantage helps the autonomous vehicle to provide customized routes based on different users and needs.

4 Methodology

The effects of the proposed driverless vehicle implementation in Flinders University Bedford Park campus were investigated using the traffic microsimulation approach. This approach is capable of detailed traffic network modelling on an individual vehicle level. It is capable of producing and visualising the modelling results in terms of many different traffic key performance indicators (KPIs).

4.1 Microsimulation Modelling network extent and basic description

4.1.1 Network Geometry

Background

The network geometry is based on the trial routes to check the efficiency of the vehicle. These trial routes are designed in order to see the efficiency in the presence of pedestrians and the intersections with no traffic lights. The first trial route is along the lake at the Bedford campus and the second trial route is along the Ring road and the University drive so that staff and students can actually utilize this vehicle for regular commute and it is also important to see the changes in real-life scenarios. The networks are designed accordingly to see all the potential challenges and best service routes.

Network

The Aimsun model of main campus ring route and pedestrian route around the lake was developed. It includes multiple unsignalized intersections and pedestrian crossings. Pedestrian and cyclist track around the lake near the central library hub is trial site 1 for the driverless vehicle. Inner ring route is of 807 m with 80 per cent of path below 10 per cent of the slope. The slope of the route was analysed by physical site walk, Google-earth and advanced GPS run. The observed change in the slope of the route is shown in appendix A. Trial site 1 and 2 is shown in Figure 11 &12.

Figure 9: Scaled Inner Ring Road (trial route 1)

Figure 10 shows the proposed route 2 along the existing Ring Road where AVs would need to share the path with the other conventional vehicles.

Figure 10: Scaled Outer Ring Road (trial route 2)

The length of the outer ring road is of 2,337.03 m having two pedestrian crossings and access connections to car parks 5,3,9. Connection of route to some important parts of a university campus– Oasis at Flinders University, North ridge precinct, university interchange, university drive, the biological science department is also included in the model.

Correct lane widths were modelled as per aerial photographs and intersection drawings available.

Figure 11 shows the possible future extension of the proposed route to include the Flinders Urban village. The consideration of factors at the proposed route is pointed below with a brief description.

The fact that the Bedford Park Campus is located at the hilly area indicates that the route slope is the main factor to consider. The slope of the area was determined using the ArcGIS software loading the data collected by high accuracy GPS data collection equipment as shown in Figure 11. The figure shows that most of the route path is green indicating the slope is below 10%. As mentioned in Operational Design Domain (ODD) of the autonomous vehicle, the slope will affect the operation if in access of 12% which is not the case with the proposed route.

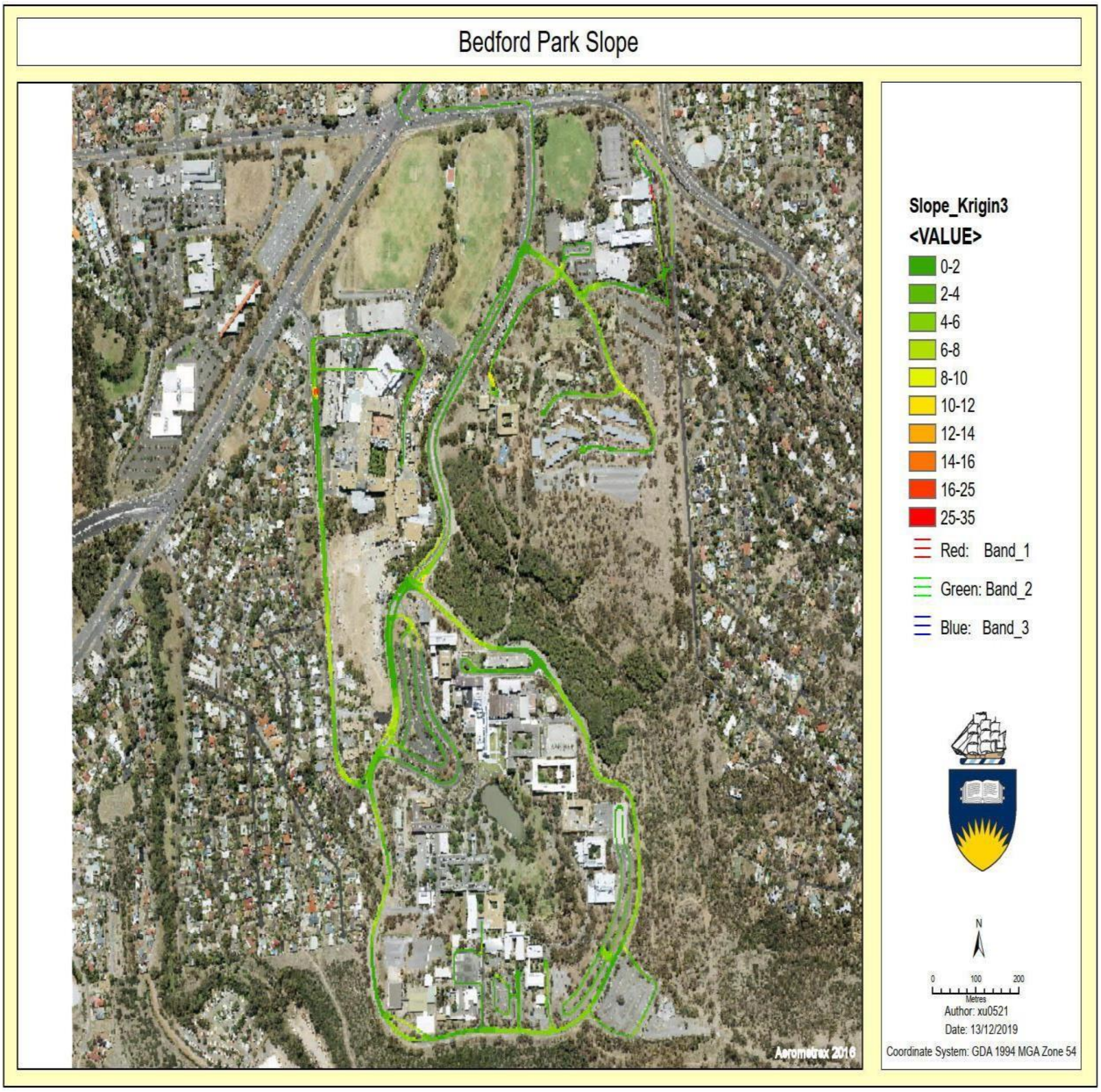


Figure 11: Topographic map of Bedford precinct

The Ring Rd is the single-lane two-way road constructed around the Bedford park where the automated vehicle will potentially operate in the near future. The width of the traffic lane is minimum 3.2m for both lanes for the entire route which should be sufficient enough to allow the driverless vehicle to operate safely with the speeds of above 5m/s. But, for the route around the lake, the road width is 3m so the driverless vehicle cannot exceed speed 5m/s according to Navya manufacturers specifications.

Another issue that needs attention is the existence of numerous trees around the lake which might affect the LiDAR localization. Alternatively, another base system can be located at the nearest building to avoid this situation.

4.2 Driverless vehicle parameters

Since the Aimsun did not have a vehicle type available for driverless vehicles, a new type of vehicle was developed based on manufacturer's specifications. Autonomy shuttle NAVYA also known as NAVYA FLEX (NAVYA, 2018) dimensions are listed below

Table 2: Technical specification of NAVYA(Dimensions)

Length	4.75m
Width	2.11m
Height	2.65m
Clearance	0.21m
Tyres	215/60 R17
Wheel	Steel wheel rims
Empty Weight	2400
Gross Weight	3450

4.3 Vehicle Profile

A separate Vehicle profile was developed in Aimsun as per the specification of NAVYA. A sample of some of the vehicle attribute for AV is given in Figure 12 and Figure 13.

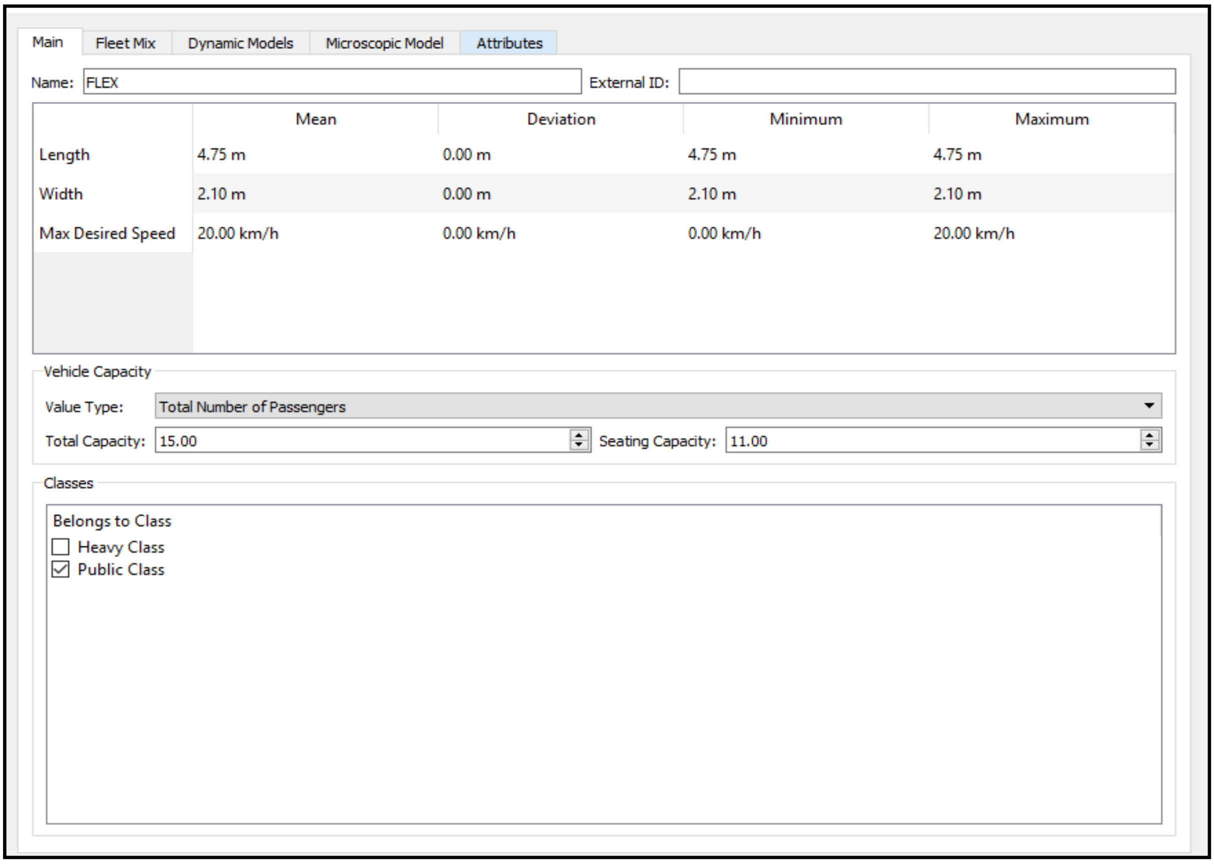


Figure 12: Added vehicle specification in AIMSUN

Driverless vehicle capacity of 15 passengers (11 seated and 4 standing) was used in all models as per manufacturer's specifications. This number includes the seat currently used by a chaperone but it is expected that the AVs will be operated without a need for an on-board controller in near future.

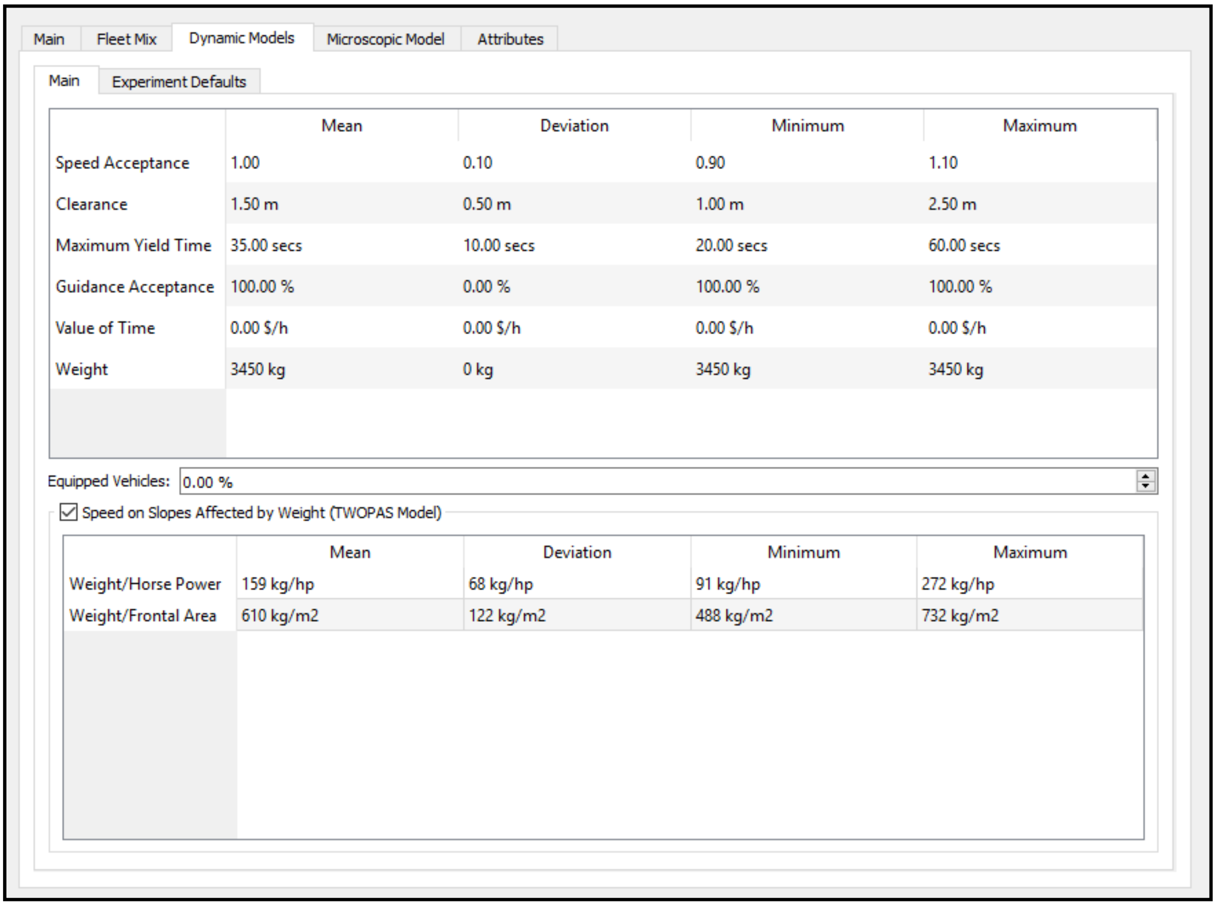


Figure 13: Driverless vehicle attributes

Full set of vehicle attributes is given in appendix C.

4.4 Network Zoning system

Centroid configuration was created in such a way so that all the major origin-destination places were specified as separate zones. All the carparks surrounding the Ring Rd were modelled separately and the traffic was specified based on the car park surveys conducted by Flinders University. Individual local streets were grouped into several zones which means for every midblock location and side of the road, one zone was specified. Local street grouping is shown in Figure 14. Same OD percentage were used for midblock centroids except for a few local roads.

Some of the unsignaled junction was modelled as a distinct zone due to the existence of manual count.

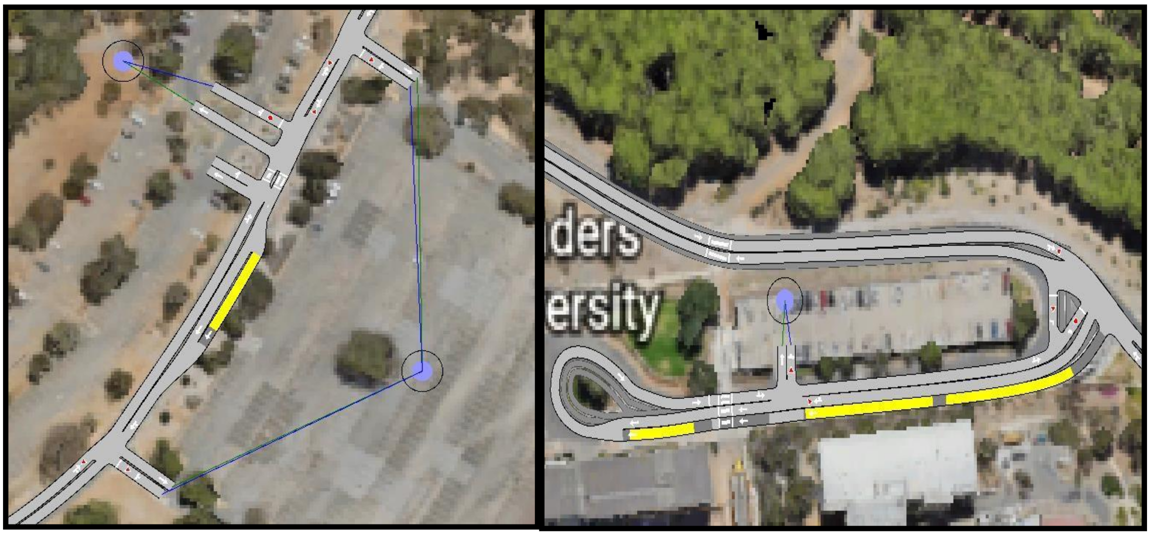


Figure 14: Centroids in AIMSUN model

4.5 Modelling period and traffic data

Modelling period selected was morning peak, 8:00-10:00 as it was expected that the driverless vehicle impact would be the greatest for this period due to higher vehicle volumes than for other time periods.

Traffic data used in the model building and calibration stages were from previous years 2019 provided by Flinders University. It was originally planned to conduct new surveys and update the origin-destination matrix but this was not done due to traffic being affected by COVID-19virus that has resulted in unusual traffic counts. The data used includes manual turning counts, SCATS counts for a signalised intersection, car park usage statistics, GPS data showing the road slopes and supplemented by other data sources such as Google is shown in appendix C.

Any data needed for model development that was not in existence or found to be outdated was originally planned to be collected, analysed and converted in the form that can be inputted into the software. Also, an extensive site investigation was carried out. Additional data that is needed for Aimsun model development include:

- Queue length surveys at signalised intersections
- Lane utilisation at the key intersection
- Travel time surveys (separate for cars and buses)
- GPS runs to determine road slopes

- Public transport stops (bus and train) dwell times
- Unsignalised junction priorities that cannot be determined from aerial photographs or "Google Street View" (GiveWay, Stop, banned turns)
- Kerbside arrangements (e.g. clearways, on-street parking)
- Vehicle classifier data (tube data) and manual turning counts to be collected at some key local streets

Although, not all the planned data collection was conducted and some data might be outdated still the relative comparison between different modelling scenarios may be appropriate.

4.5.1 Traffic Surveys

The survey was conducted for both routes of the driverless vehicle with special focus on the modelled vehicle(private and public transport). Although Some traffic surveys that were planned were not conducted due to Covid-19 effects that have resulted in traffic conditions that were different from normal. Figure 15 car parks volume and SCATS count for the signalised intersection as shown in Figure 16 were considered while modelling with Aimsun.

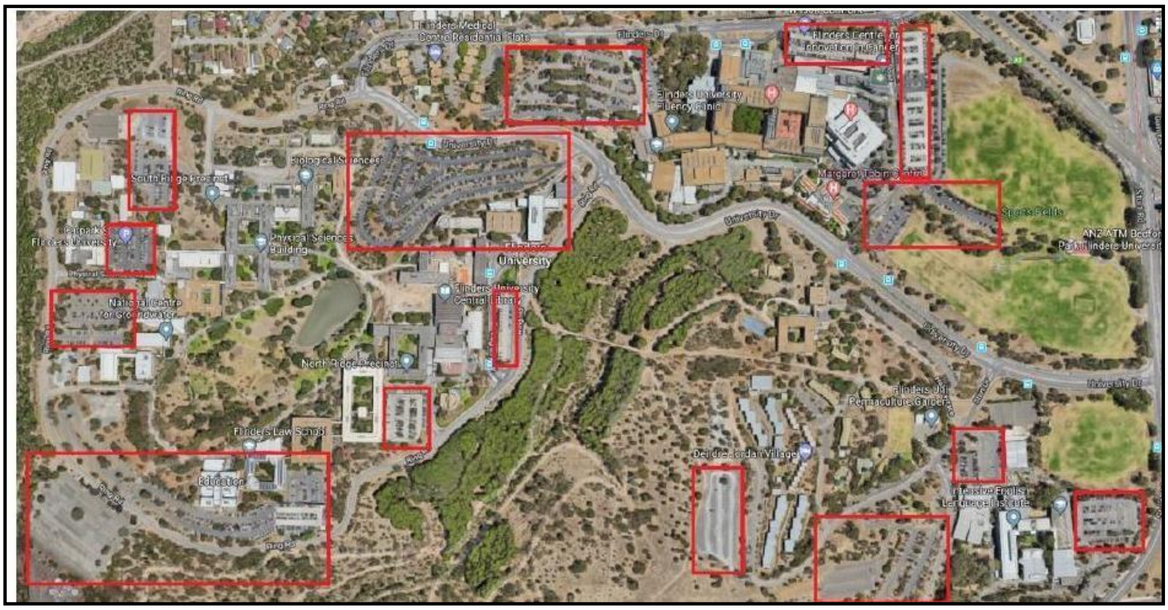


Figure 15: Car park located at Bedford Park

Figure 16: SCATS data locations

Sydney Coordinated Adaptive Traffic System or SCATS is a traffic management system used to manage the real-time phase modulation of traffic signals. Through real-time phasing, the system also includes hardware and software, which means that the SCATS system can adjust the signal time when it detects changes in flow demand (SCATS, 2018).

SCATS uses inductive loop sensors to detect the presence of vehicles in each lane, and it can also detect pedestrians who are waiting to cross the road. In order to detect the vehicle, a loop sensor is installed on the road, close to the stop line.

Inner ring route survey:

Multiple site visits were conducted for a better understanding of the route and also to locate the bus stops and associated characteristics such as the bay length. The selection of the appropriate route will be influenced by multiple factors such as the car park location and size, the main hub of university, library, number of potential students and staff at each University building, etc.. A range of survey sources were used for model development in Aimsun. The surveys that were conducted at the Bedford Park Campus also include a questionnaire that was conducted on students, staff and visitors. Some of the questions asked included:

- The need for Autonomous vehicle on campus
- Believe in technology
- Total number of stops
- Speed of vehicle
- Waiting time on the stop
- Direction of travel
- Rider satisfaction

The questions were designed to produce results which could be directly translated into the model simulation. For example, answers were in the format of either yes/no, multiple-choice or 'mark with x along the line' (representing time/distance). This questioning style was also useful in reducing the time required to complete the quiz, therefore, reaching a larger population and producing more reliable results.

4.6 Aimsun Modelling Scenarios

More than a dozen different scenarios were modelled that included two different driverless vehicle routes. One was the main campus ring route and the other one was the current pedestrian path around the lake as shown in Figure 17 below.

These models were built based on the latest DPTI AIMSUN template and latest Aimsun software version.

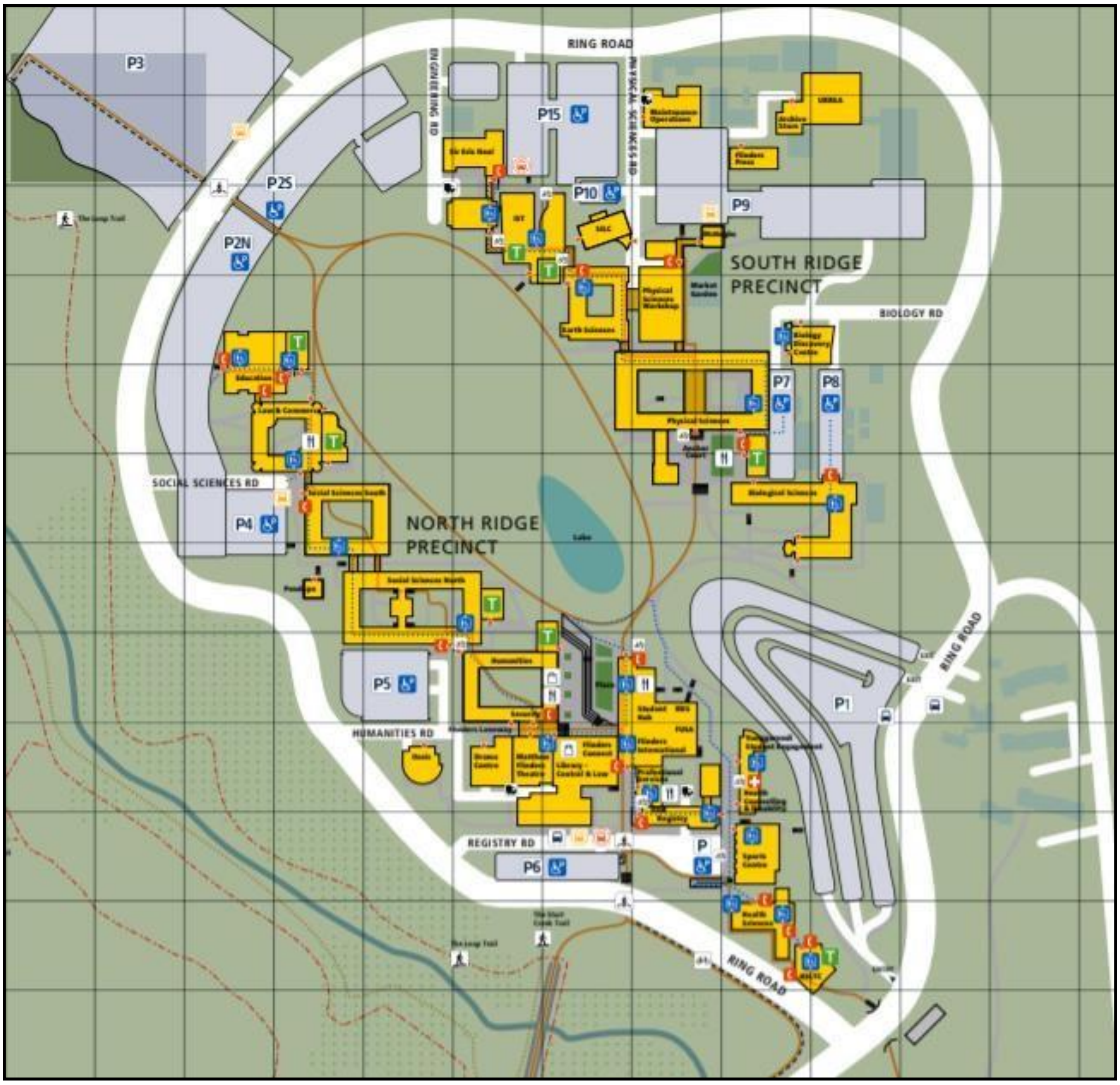


Figure 17: Inner and outer ring road (testing trial sites) sourced Flinders University

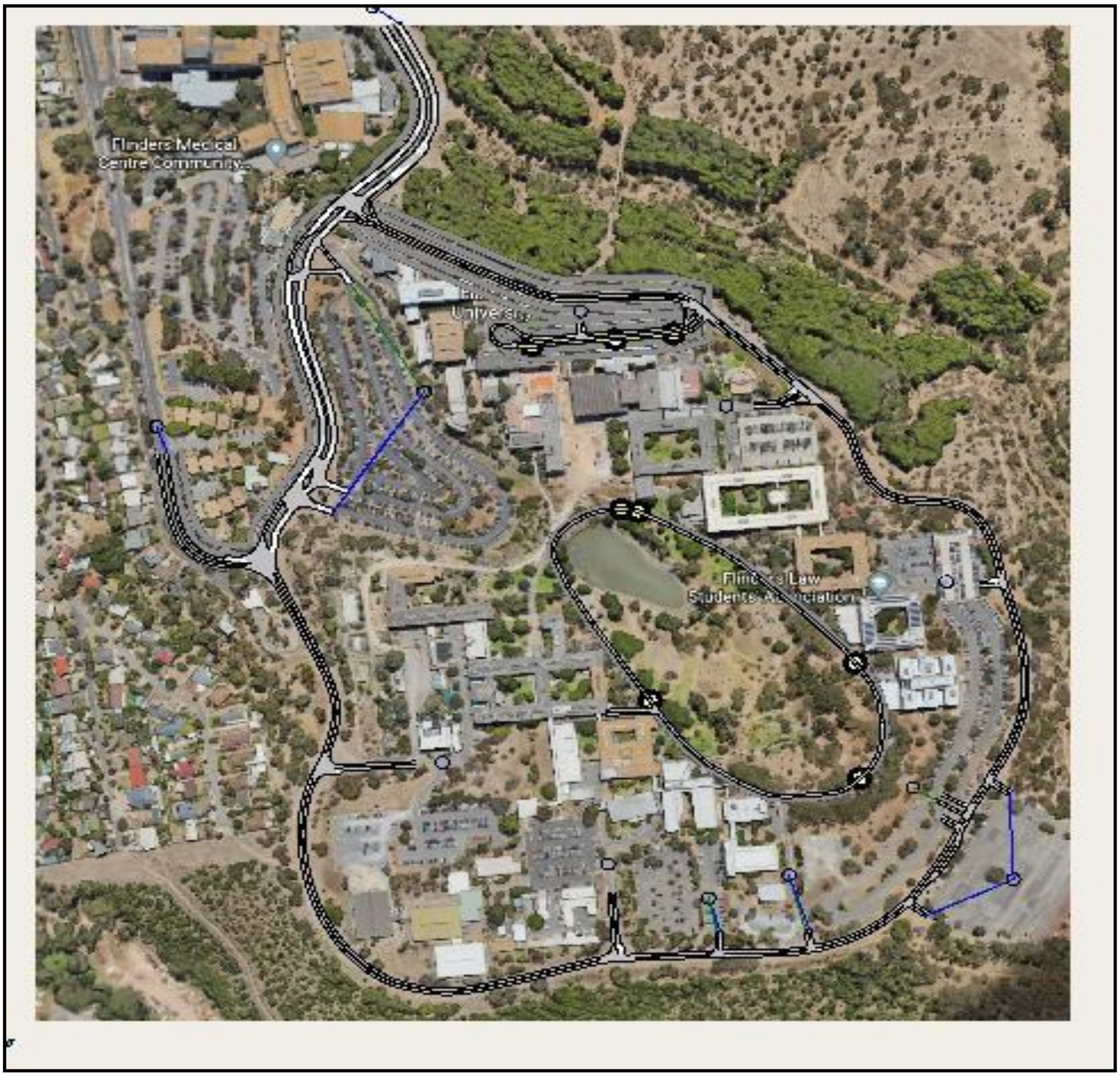


Figure 18: Both trial route with zones in AIMSUN

In addition to the above routes, different bus stops, driverless vehicle maximum speeds and direction of travel (clockwise and counter-clockwise) were investigated for both routes. A detailed Aimsun network extent with centroid is shown in Figure 18.

Since the route around the lake was designated as a shared pedestrian area, the speed limit specified was 10 km/h.

An initial model was provided by Flinders University and no additional model calibration and validation was conducted. This model was used as a starting point and expanded to include the additional route around the lake, new bus stop locations, changed traffic priorities according to current network operation. New driverless vehicle parameters to be used in microsimulation were developed (Appendix F) that matched the AV manufacturer specifications. Also, the road slopes were added which resulted in the full 3D capability of the model as it can be seen in the figure below.

Figure 19 - 3D Model Capabilities

An initial model was given so for further analysis a new type of vehicle was developed based on manufacturers specifications. Initially, the outer ring road was tested in a counter-clockwise direction with a maximum speed of 20 km/h. this scenario was conducted with no indented bus stops. The change in speed for FLEX is easily changeable in Aimsun from public class attributes. Pedestrian movements were not modelled due to licensing restriction for all scenario. The next case involves a maximum speed of 40km/h by keeping the rest parameters same. The output of each scenario was recorded for comparison and evaluation of the best possible scenario. Depending on the direction of travel, several bus stops and speed of the driverless vehicle for ring route a total of 12 scenarios were tested. Similarly, depending on this same parameter for inner ring route around the lake a total of 6 cases were tested for the evaluation of the best scenario.

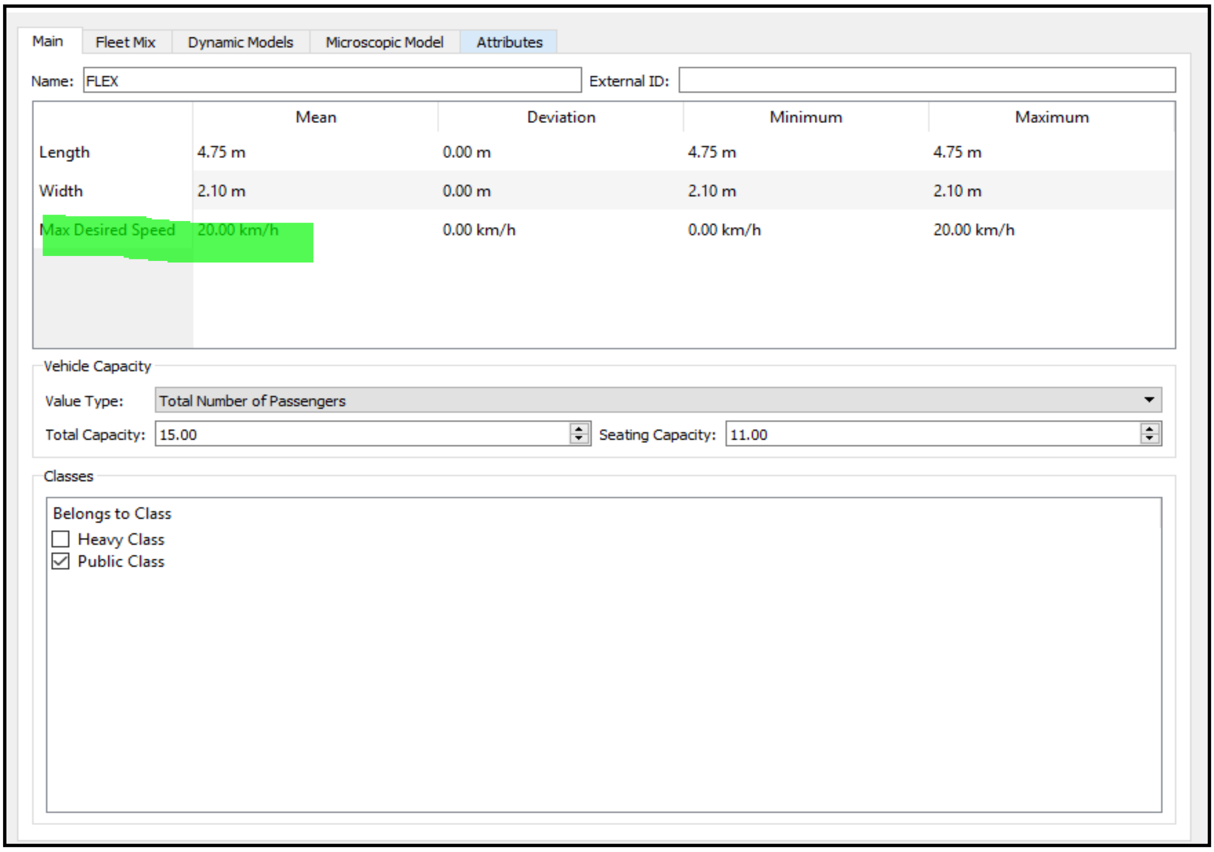


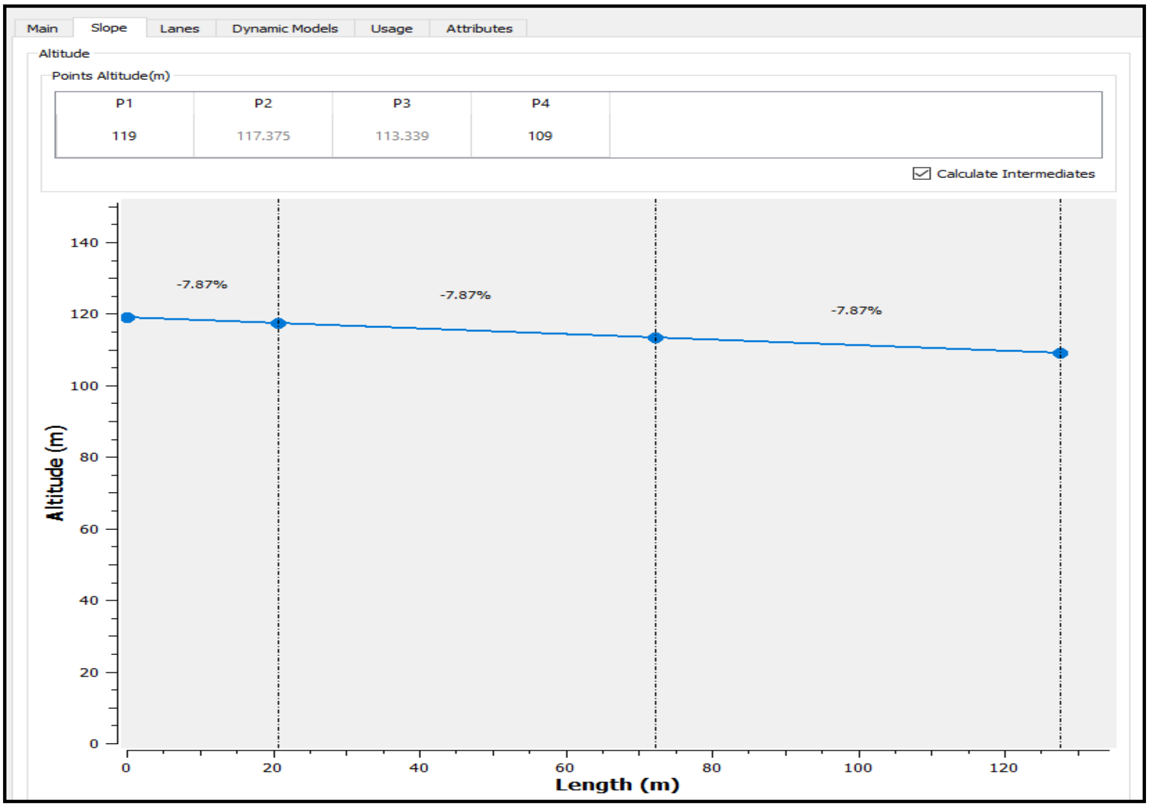
Figure 20: Public class attribute speed change option in Aimsun

The slope is an important factor for the driverless vehicle, the allowable slope for two-drive wheel driverless car is 12%, the allowable slope for four-drive wheel driverless car is 18%.

Internal ring road slopes from AIMSUN

GPS data surveys conducted along the Central Lake route have shown that some parts of the route have slopes in excess of 12% as shown in the Figure below, indicating the need for further investigation before the AV vehicle implementation along this route. The AV currently used by Flinders University can only operate on slopes up to 12% due to having one engine that can be overheated if operated on high slopes for prolonged time periods. This can indicate the need for a different AV version such as four-wheel-drive version capable handling slopes of up to 18% as specified by Navya.

The first figure of figure 21 illustrates the slopes were found of central lake ring road. This is done in the aimsun software and to find the slope, the advanced GPS runs and Google Earth have been used.



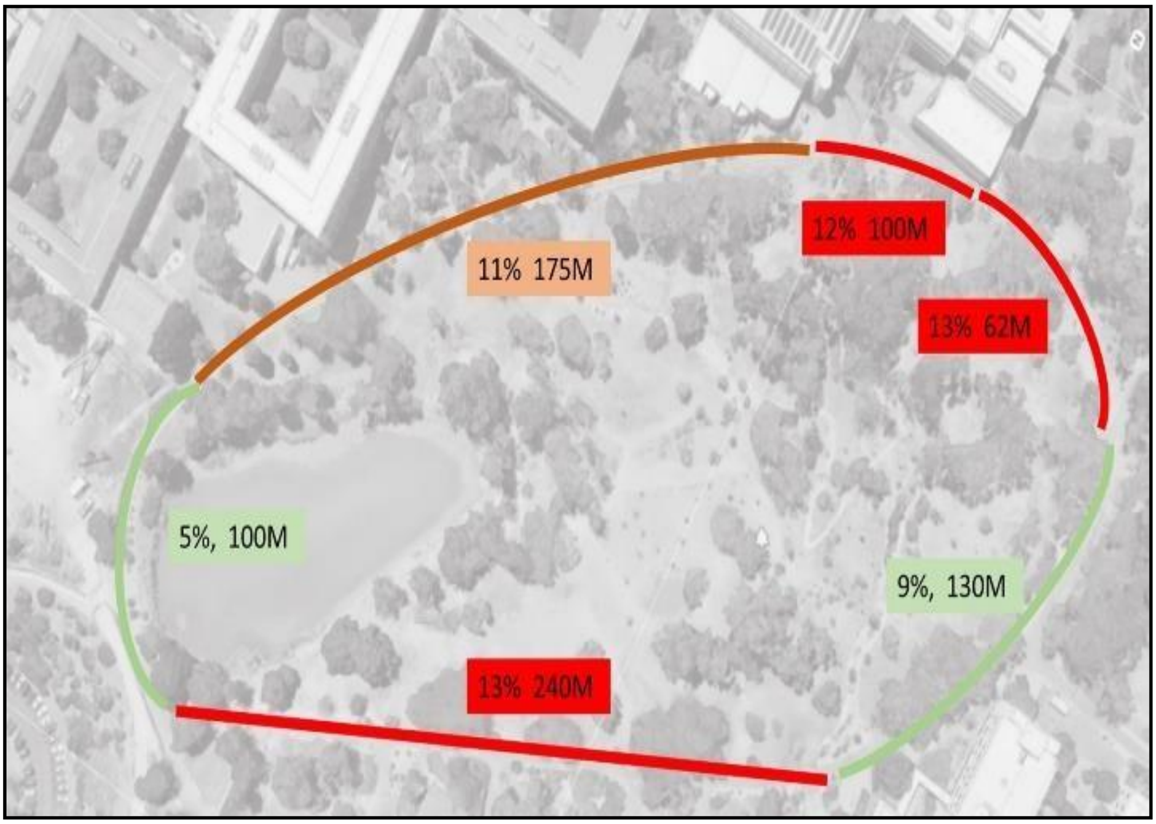


Figure 21 : Internal ring road slopes from Google Earth

External ring road slopes from Aimsun

Advanced GPS runs and Google Earth slope investigation for external Ring Road has shown that this route has slopes below 10% for the entire route. These slopes are significantly lower than the slopes of inner ring route and within the manufacturer's recommendations for safe operation. Slope output from Aimsun is shown in Figure 22.

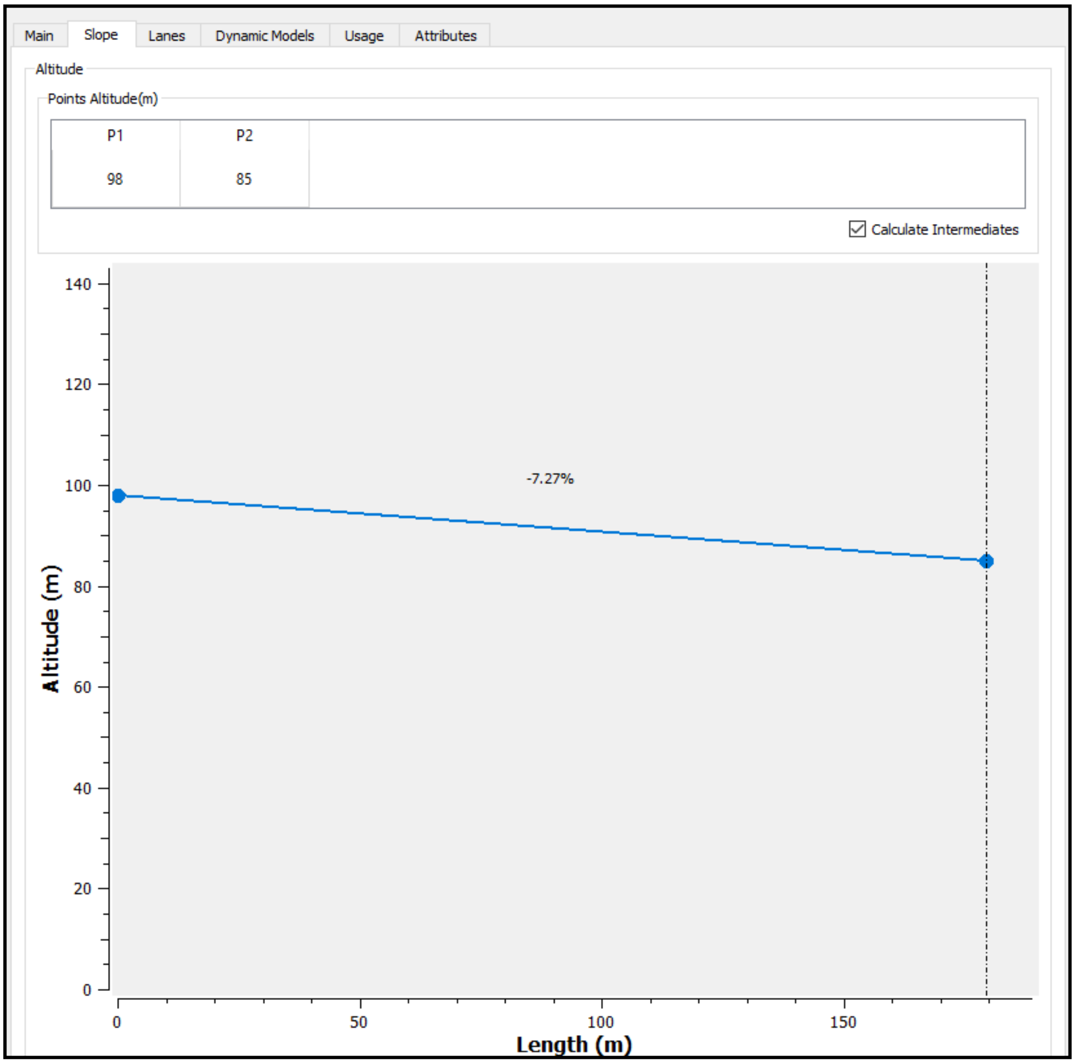


Figure 22: External ring road slope from AIMSUN

5 AIMSUN Models

Two different routes were modelled with respect to the direction of travel, AV top speed and number of the bus stop for morning peak 8:00-10:00. A list of different modelling scenario is labelled below:

Table 3 – List of AIMSUN models

No.	Label	Scheme	Period
1	1	Existing network with no driverless vehicles implemented	AM
2	2	Driverless vehicle implemented along the Ring Route with a current maximum speed of 20 km/h in a counter-clockwise direction and no indented bus stops	AM
3	3	Driverless vehicle implemented along the Ring Route with a maximum speed of 40 km/h in a counter-clockwise direction and no indented bus stops	AM
4	4	Driverless vehicle implemented along the Ring Route with a current maximum speed of 20 km/h in a counter-clockwise direction and indented bus stops	AM
5	4A	Driverless vehicle implemented along the Ring Route with the current maximum speed of 20 km/h in a clockwise direction and indented bus stops	AM
6	5	Driverless vehicle implemented along the Ring Route with a maximum speed of 25 km/h in a counter-clockwise direction and indented bus stops	AM
7	6	Driverless vehicle implemented along the Ring Route with a maximum speed of 30 km/h in a counter-clockwise direction and indented bus stops	AM
8	7	Driverless vehicle implemented along the Ring Route with a maximum speed of 35 km/h in a counter-clockwise direction and indented bus stops	AM
9	8	Driverless vehicle implemented along the Ring Route with a maximum speed of 40 km/h in a counter-clockwise direction and indented bus stops	AM
10	8A	Driverless vehicle implemented along the Ring Route	AM

		with a maximum speed of 40 km/h in a clockwise direction and indented bus stops	
11		Driverless vehicle implemented along the Ring Route with a maximum speed of 45 km/h in a counter-clockwise direction and indented bus stops	AM
12	9	Driverless vehicle implemented along the Ring Route with a maximum speed of 45 km/h in a counter clockwise direction and indented bus stops	AM
13	10	Driverless vehicle implemented along the Ring Route with a maximum speed of 50 km/h in a counter clockwise direction and indented bus stops	AM
14	11	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a counter clockwise direction with 5 bus stops	AM
15	11A	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a counter clockwise direction with 5 bus stops, speed limit 20 km/h	AM
16	12	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a counter clockwise direction with 3 bus stops	AM
17	12A	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a counter clockwise direction with 3 bus stops; speed limit 20 km/h	AM
18	13	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a clockwise direction with 5 bus stops	AM
19	13A	Driverless vehicle implemented around the lake with a current maximum speed of 20 km/h in a clockwise direction with 3 bus stops	AM

Each of the scenarios was run with 5 replications and using the random seed numbers as per DPTI's Aimsun Manual in order to minimise the effects of the randomness built in the model.

This randomness affects many software parameters, such as vehicle release, physical and kinematic parameters, etc. and the results presented in this thesis represent the average values of the multiple runs. The model output produced includes all available types except the environment data, for example, fuel consumption and emission. The database files produced by Aimsun is shown in the appendix.

The location of the bus stops around the lake is shown below. The bus stops are highlighted withyellow in the Figure 23.

Figure 23: Inner ring route with indented bus stops

6 Modelling Results

It was decided to first test the models that do not require any infrastructure upgrades and using current maximum operational speeds of 20 km/h for the driverless vehicles. Following this, the sensitivity analysis using AV speeds in the range of 20-50 km/h was performed. Both directions of travel, clockwise and counterclockwise were assessed. The modelling included options with and without the provision of indented bus stops along the Ring Road. Finally, the models were built with the autonomous vehicle (AV) using the existing Ring Road and the off-road path around the Flinders University Central Park Lake.

First sets of modelling scenarios were performed on the outer ring road. Network delay increase due to the introduction of the autonomous vehicle is given in table 3 along with bar graph representation of 5 different scenarios for the outer ring road. Maximum delay increase observed on this route was 73 percent in case of no indented bus stop provision and with the maximum 20 km/h speed of the autonomous vehicle. When the maximum speed of an autonomous vehicle was increased to 40km/h network delay decreased by approximately 55 percent. However, the vehicle delay increases were much lower in the case the indented bus stops are provided.

Network delay increase relative to the existing scenario is represented in Figure 24.

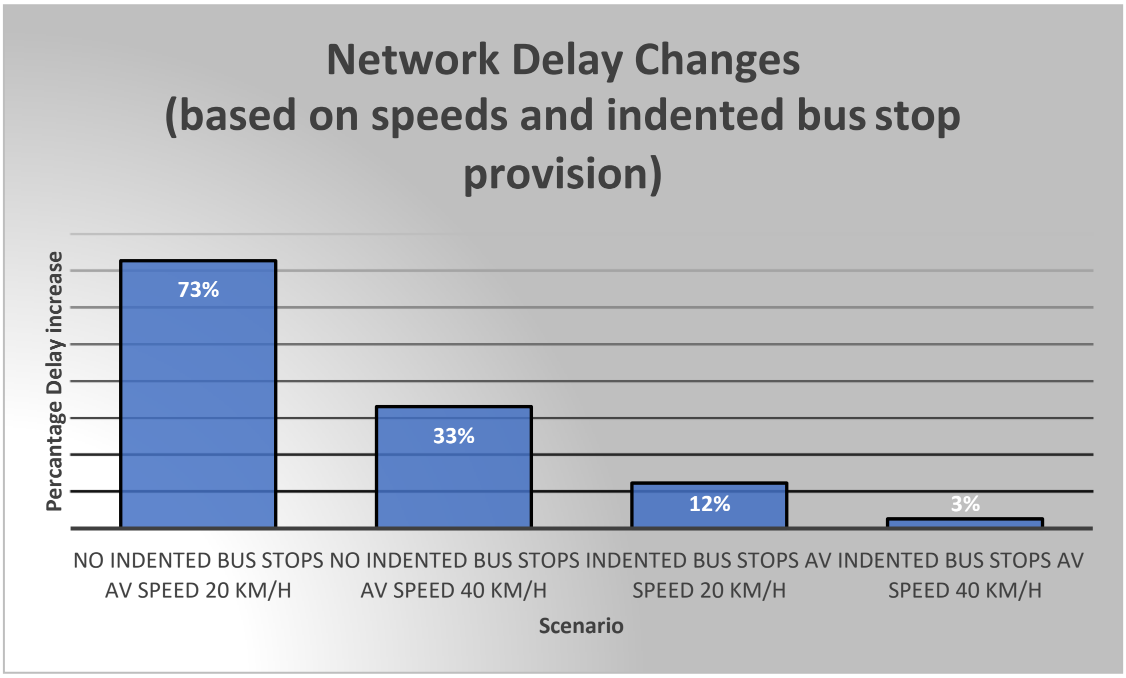


Figure 24 - Network Delay Increase Due to Introduction of AV

Although, the provision of indented bus stops would reduce the delays and obstruction of other vehicles some delays were still present at the midblock locations. Figure 25 illustrates that AV vehicles with the current maximum speed of 20 km/h would delay other vehicles on Ring Rd since the speed limit is 50 km/h. The left picture shows AV vehicle parameters, the right picture shows a vehicle behind the AV whose desired speed is 50 km/h but cannot be reached due to AV being too slow. Picture in the middle shows the queue where Autonomous Vehicle is coloured in red.

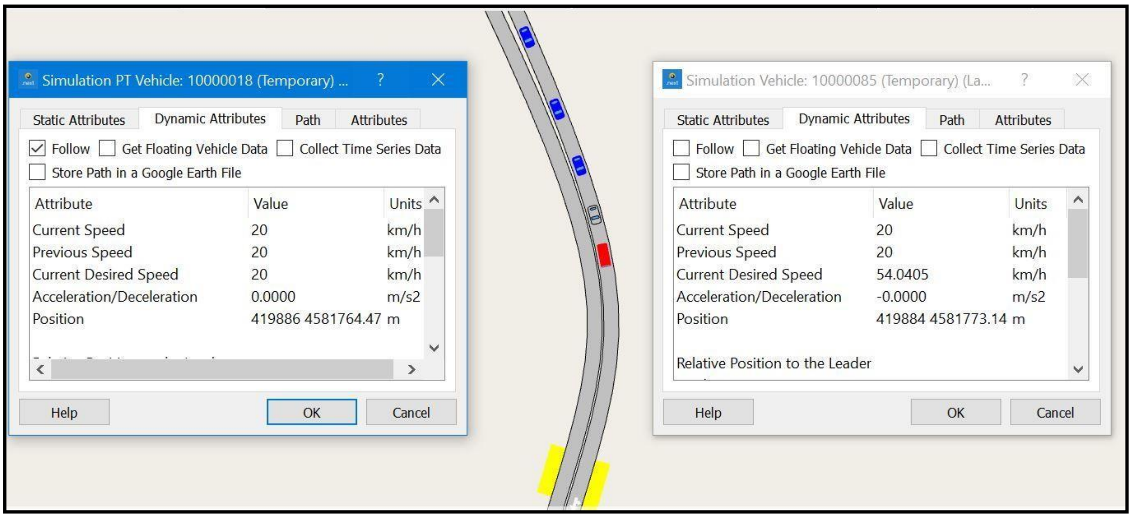


Figure 25 -AV Causing Queues Despite Indented Bus Stops

6.1. Delay and LOS Results

Aimsun output and data analysis (number of stops, delays and LOS based on Highway Capacity Manual (HCM)) (Alexiadis et al., 2004)is given in table 4 and 5. Although the differences between modelling scenario results given in this table are not significant, they only include stopped delay and should be considered in conjunction with the total vehicle delays presented in this report.

Table 4 - Network Delay and LOS results

Modelling Scenario	Modelling period (8:00-10:00)	
	Stopped delay [sec/veh]	LOS [HCM]
20km/h clockwise	13.98	B
20km/h counterclockwise	14.17	B
40km/h clockwise	12.77	B
40km/h counterclockwise	12.81	B

The LOS ranges were adopted from USA HCM and shown in table below. They relate to times that vehicles have been stopped and do not include other delays, such as acceleration/deceleration or geometric delays (delays due to negotiating the road geometry such as curves and turning movements). The LOS values in this table range from A (free flow), through slight (LOS=B) and acceptable (LOS=C) to very congested and intolerable conditions (LOS=F). Since all the models evaluated had stopped delays within the acceptable levels of service there was no need for further investigation and the model evaluations were focused on other evaluation parameters.

Table 5 - LOS based on stopped delay (HCM)

Stopped delay	LOS
<5	A
5-15	B
15-25	C
25-40	D
40-60	E
>60	F

The third set of modelling scenarios has enabled the network delay (sec/km) comparison of different directions of travel for AV.

Figure 26 shows the modelling results of both directions of travel for AVs, clockwise and counterclockwise, along the Ring Road for maximum shuttle speeds of 20 and 40 km/h. It can be seen that the counterclockwise direction of travel performs better for both AV speeds. The reason for this could be the heavy usage of the large car park at the top of the Campus hill by the vehicles entering the Campus from the Sturt Rd direction in the morning peak. This could indicate that the other direction of travel could be the preferred option in the afternoon peak. For all the models described below the counterclockwise direction of travel along the Ring Rd for AVs is selected.

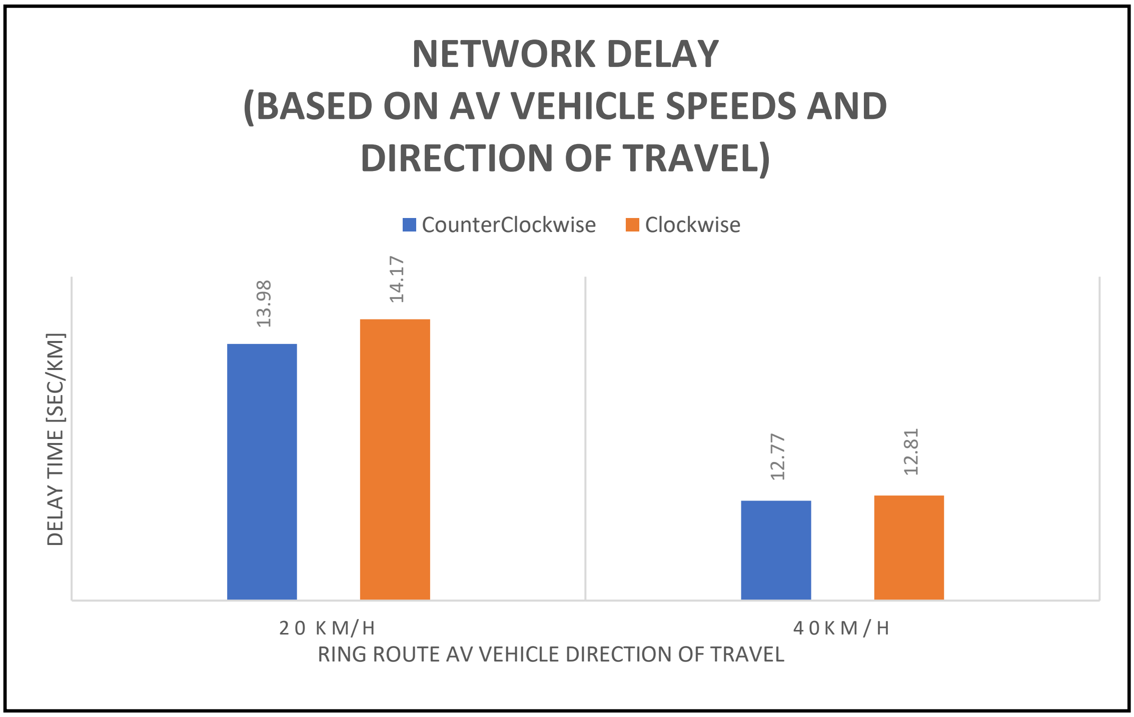


Figure 26 – Network delay of outer ring road based on the direction of travel and speed

Figure 27 shows the results of the sensitivity analysis conducted for different AV maximum speeds, ranging 20-50 km/h. All the models presented in that figure were using the counterclockwise direction of travel and all of the bus stops were indented. Despite this, the models show significant delay increase caused by AV unless the current maximum speed of 20 km/h can be increased.

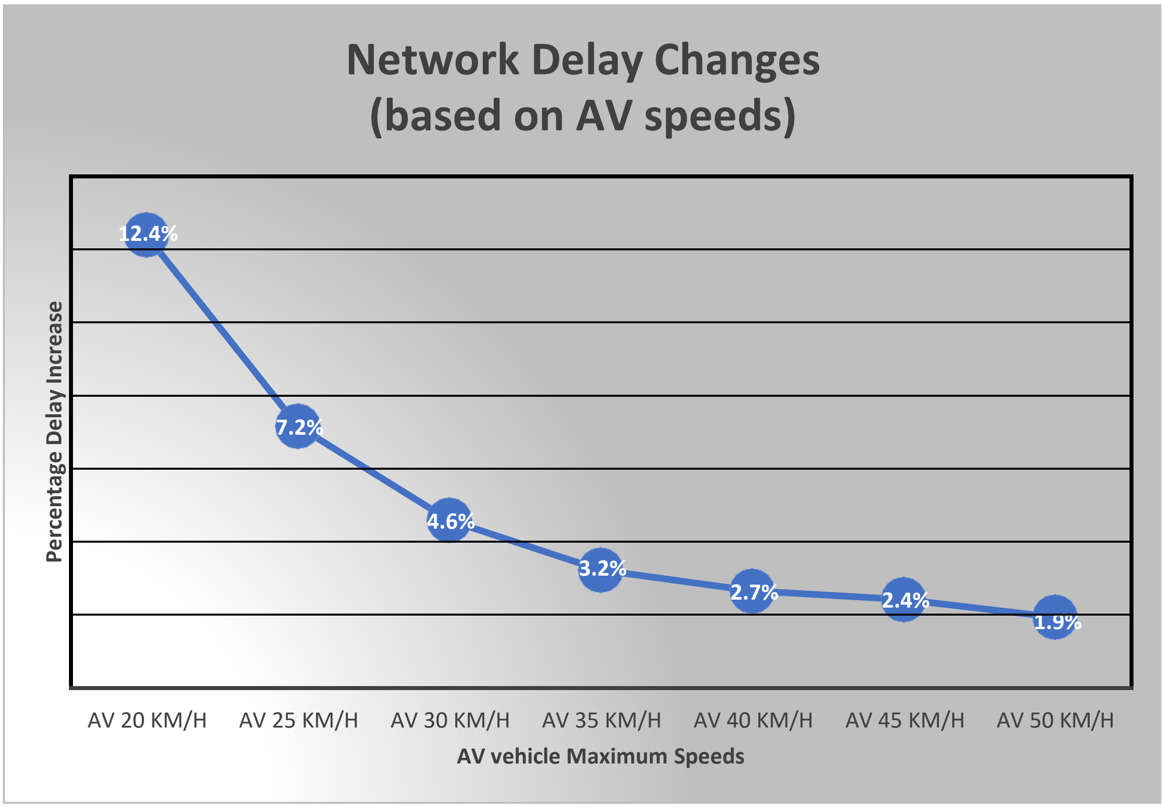


Figure 27 – Delay percentage with a change in AV speed

Since the current maximum operational speed of AVs is around 20 km/h and the results show a significant increase in vehicle delays if the AVs are introduced on the Ring Rd and alternative scenarios were tested. These scenarios involved running the AV service off-the-road, using the existing pedestrian footpath along the Campus Central Park Lake. Modelling scenarios included options with 3 and 5 stops along the route for both directions of travel. Similar to the Ring Rd options, the results in Figure 28 show better traffic performance of the counterclockwise route. The reason for this could be slightly lower road slopes in that direction of travel. Another reason could be less number of stop in the counterclockwise direction of travel for AV.

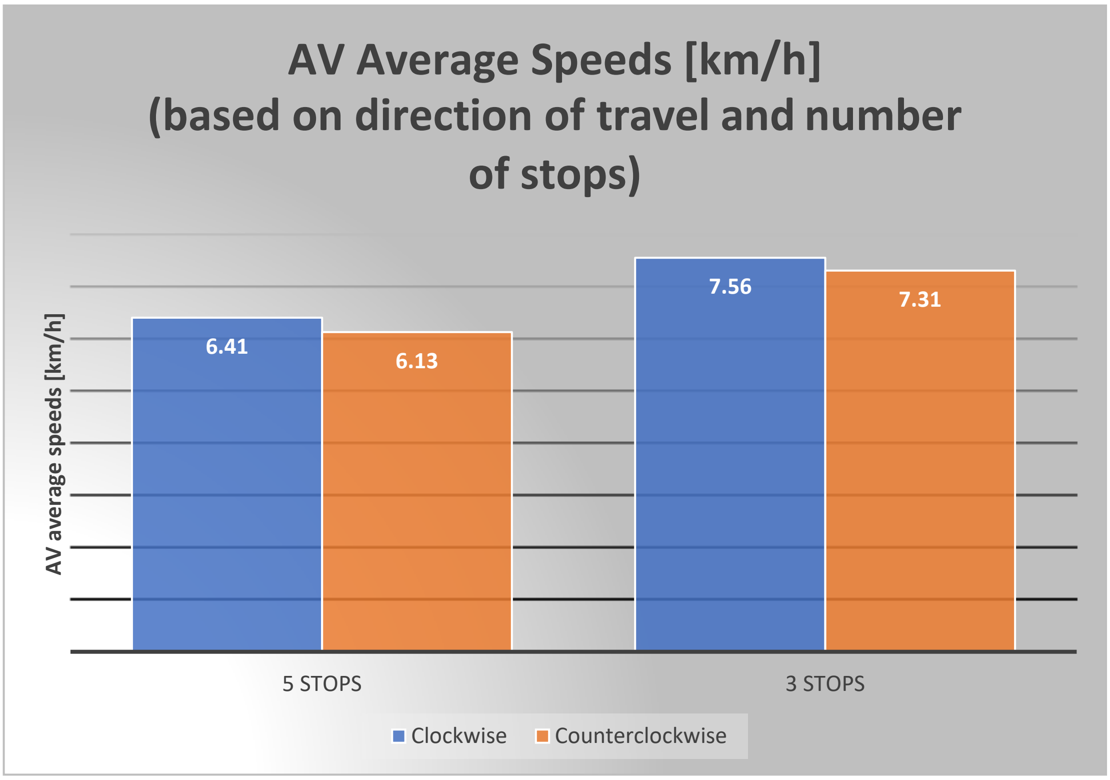


Figure 28 – AV Average speed representation based on the direction of travel and the number of stops

Inner ring road counterclockwise modelling scenarios:

The travel time to complete one full loop is approximately 8 minutes if the speed limit of 10km/h and 5 stops were used. However, if the 3 stops only were served the run travel time would decrease by 15 percent to around 6.8 minutes. Similarly, the scenario with the footpath speed limit of 20km/h would result in a reduction to travel times of 23.72 percent if only 3 bus stops were used.

The travel time per run for different scenarios tested is shown in Figure 29.

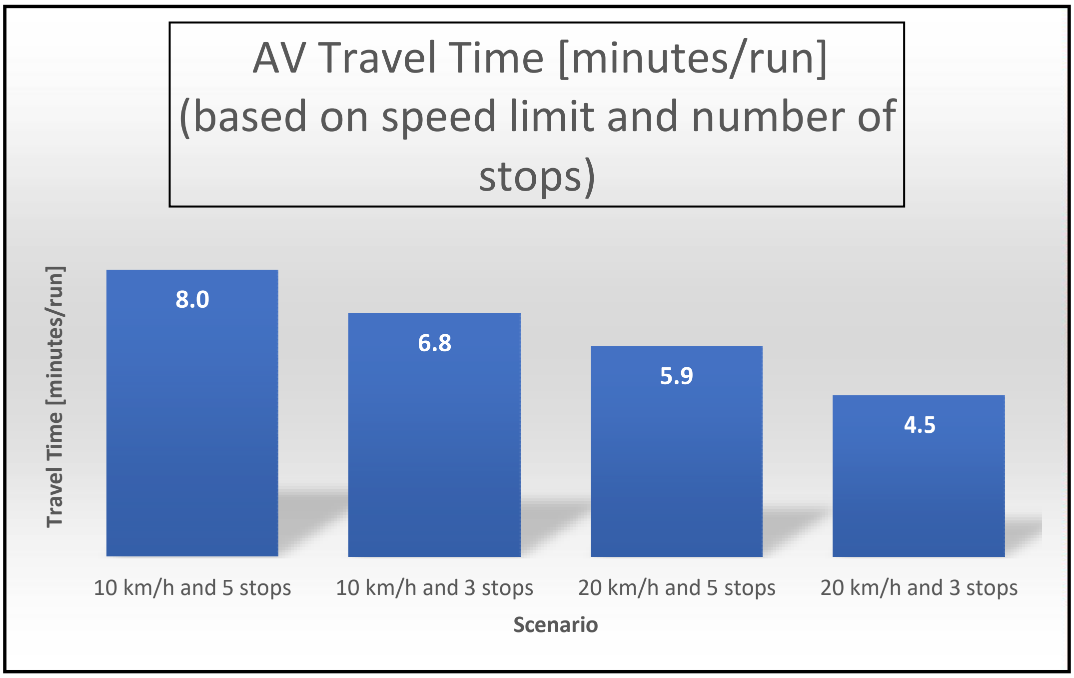


Figure 29 – AV travel time (minute/run) based on speed and number of stops

Further investigation was conducted to evaluate the capacity of the Lake route in terms of the maximum number of passengers that it could be served. This study has shown that the minimum travel time of 4.5 (minute/run) can be achieved which means that a maximum of 13 runs per hour is feasible. Using the capacity of the current Flinders Navya shuttle of 15 passengers the entire route capacity would be 195 passengers per hour assuming that only one shuttle was used.

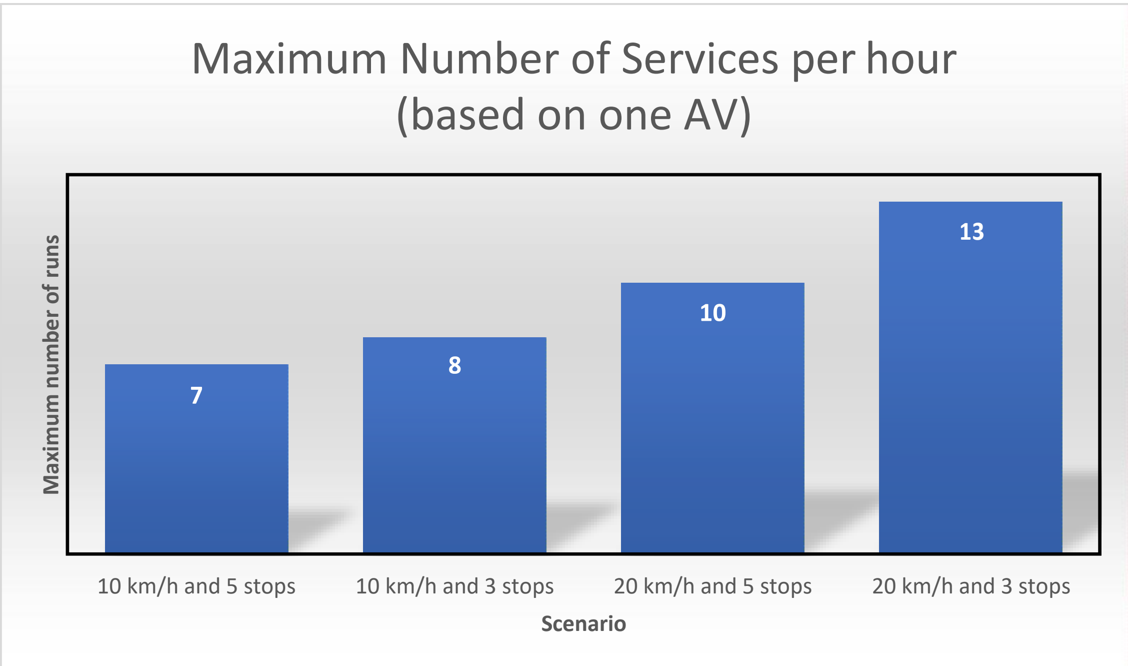


Figure 30 – Service of AV in an hour based on speed and number of stops

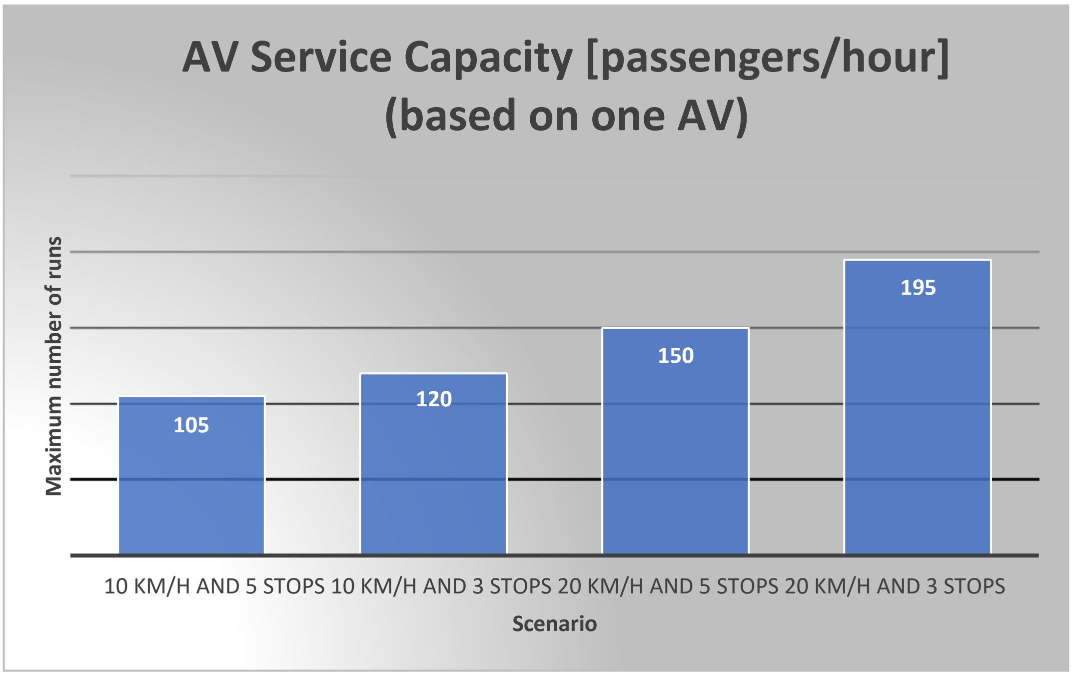


Figure 31 –Maximum number of runs based on service capacity(passengers/hour)

Another Outcome of the modelling involves getting an average speed of the driverless vehicle for different modelling scenario around the lake. This assessment was tested for scenario based on different speed limit and number of stops. The best performing scenario observed with a speed of 20 km/h and involvement of 3 stops in the route. The graphical comparison of different tested cases is shown in Figure 32. Due to the high slope value of inner ring route, a tested scenario has the only speed of 10km/h and 20km/h with multiple stops. It was interpreted that a NAVYA shuttle would only able to achieve an average speed of 11.41 km/h with scenario 13A.

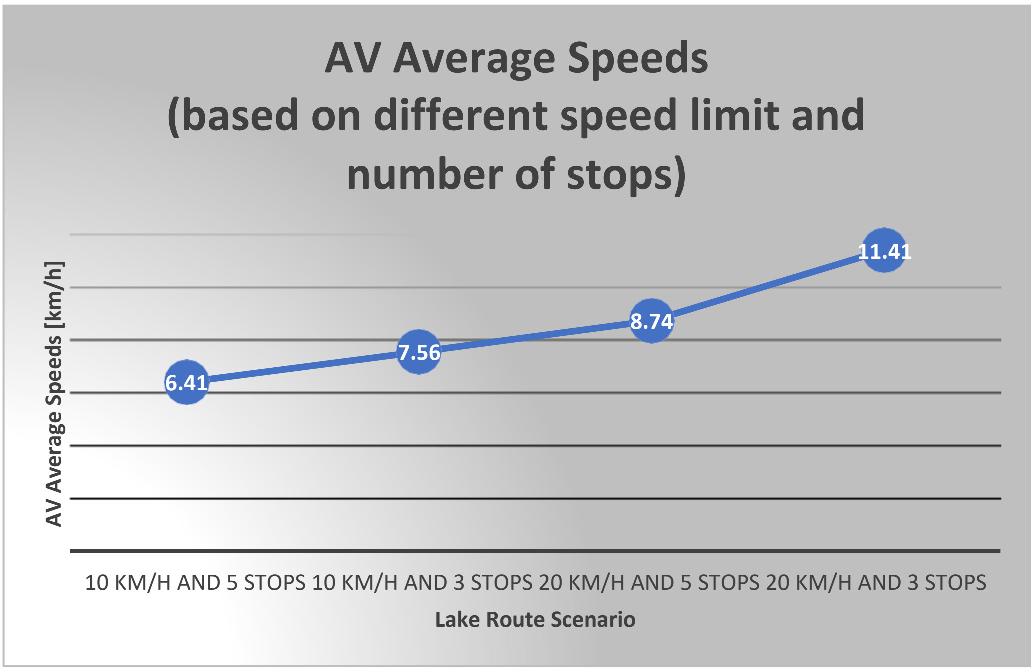


Figure 32 – Average speed of Autonomous Vehicle around the lake for 4 different scenarios

7 Modelling Summary and Conclusions

Traffic microsimulation modelling using AIMSUN software package has been conducted as part of the traffic assessment of the feasibility to introduce autonomous vehicle service at Flinders University Bedford Park Campus. The AIMSUN was used as a tool to help gauge traffic impact on the surrounding road network and compare different access options for the route. Two different driverless vehicle routes with a total of 18 different scenarios were modelled with latest DTEI AIMSUN software. The initial model for further analysis was provided by Flinders University and this model was expanded with the creation of the new vehicle class for NAVYA Driverless vehicle with new vehicle physical and kinematic parameters that matched the vehicle manufacturer specifications. In addition, all the roads were edited to include with the proper road slopes enabling a full capability of 3D modelling. Initially, the outer Ring Road route with the length of 2,337,03 m was tested with 12 different scenarios with the respect to different AV top speeds, the direction of travel and number and type of bus stops. Each of the scenarios was run with 5 replications and using the random seed numbers as per DPTI's AIMSUN Manual. Generated output database files were analysed and the comparison between alternative scenarios conducted in terms of key traffic performance indicators.

A maximum of 73 percent average vehicle delay increase was observed if indented bus stops were not provided and current AV maximum speed of 20km/h is utilised. It was also shown that even if the indented bus stops were provided still the significant delays and obstructions to other vehicles were to be expected unless the top speed of AVs can be increased to 40-50 km/h. The predicted increase in average vehicle delays was the main reason to recommend that the AVs are not be running on Ring Rd until they can increase the maximum speed.

Furthermore, the modelling results have shown that the counterclockwise direction performs better when compared with the clockwise direction in morning peak period with a decrease in network delay of 2.4 percent with top AV speed of 20km/h.

Another modelling scenario involved running the AV service off-the-road, using the existing pedestrian footpath along the Campus Central Park Lake. Six different scenarios that included both directions of travel and options with 3 and 5 stops along the route were modelled. The different performance of the route was analysed with a speed limit of 10km/h and 20km/h with 3 and 5 stops and observed that 20km/h with 3 stops in counterclockwise direction gives the minimum travel time of 4.5 (minute/run). This means that a maximum of

13 runs per hour can be achieved resulting in a maximum passenger service capacity of 195 people.

The final recommendation of the study was to implement the AV service around the Central Lake in contraclockwise direction and not use the Ring Road route until the technology is improved and the maximum AV speeds increased to 40-50 km/h. This will insure the minimum traffic disruption to other vehicles, while providing potential riders with good transport connections within the Bedford Park Campus.

8 Proposed Future Research

For the purposes of this study only one type of driverless vehicle, Navya Arma, was used. It might be beneficial to evaluate different vehicle types with different physical and kinematic parameters and different passenger capacity.

Since the modelling was done only for the morning peak period, other periods could be investigated.

Additional scenarios that capture different driverless vehicle routes can be modelled. For instance, a route that combines parts of the ring route and lake route could be tested.

Furthermore, the lake route could be extended to include some of the car parks in order to achieve better driverless vehicle patronage. This is also important since there are some indications from the manufacturer that the shuttle would require cooling down period after running on a high slope for extended time periods and this could be down by serving the car parks that are on flat terrain.

Due to the effects of COVID-19 on traffic around Bedford Park precinct, some data collections planned were not carried out. It is recommended that these are conducted in the future and the microsimulation models used updated and re-calibrated.

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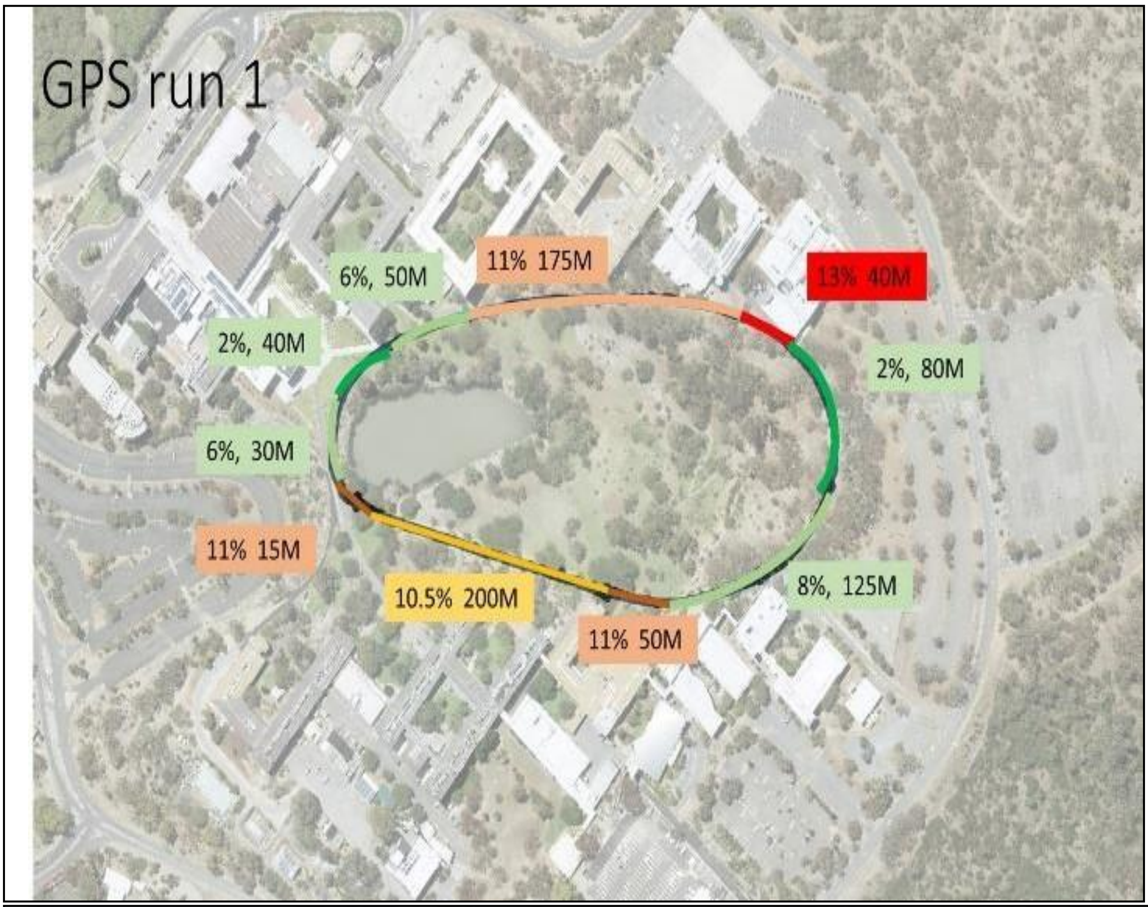
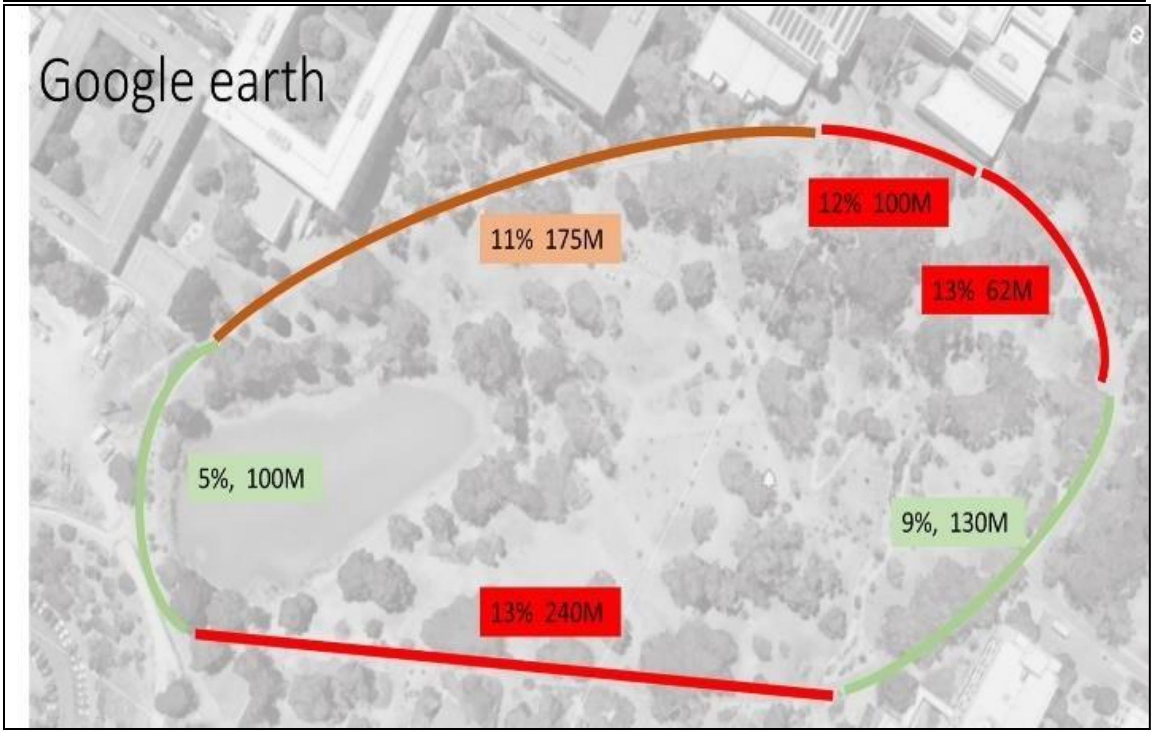
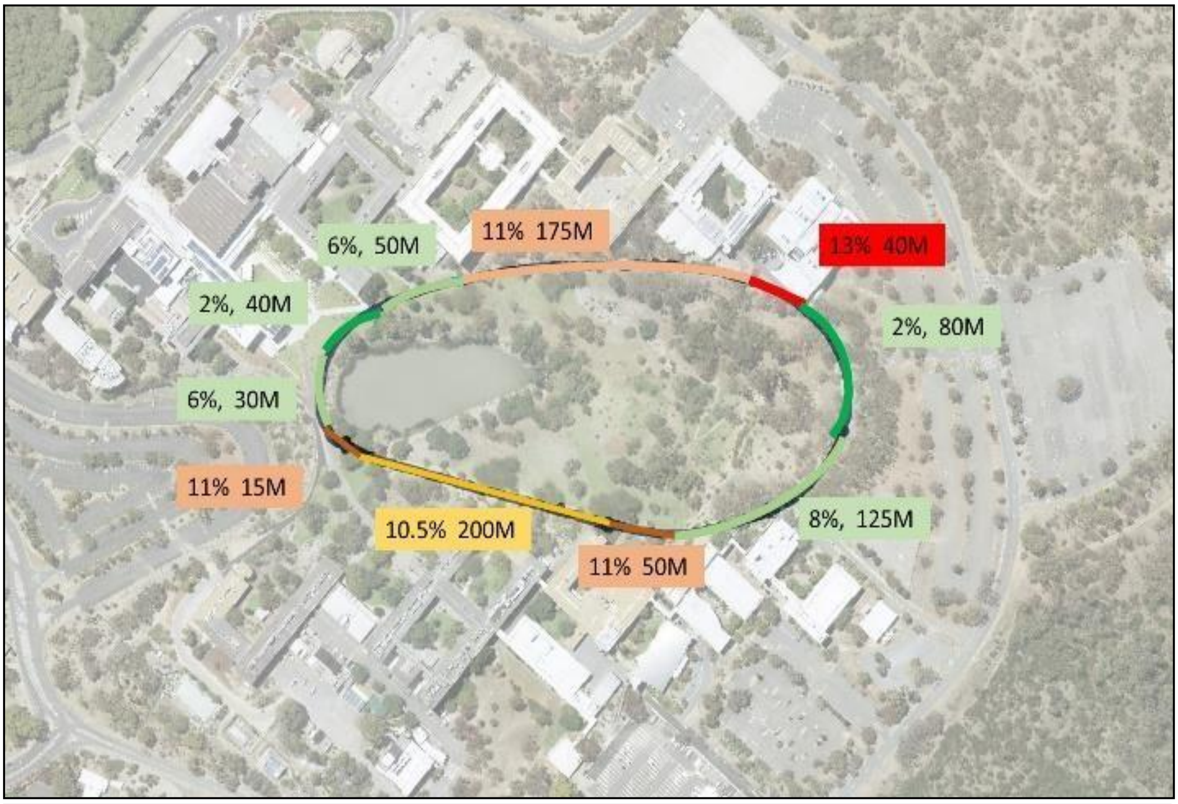
Appendices

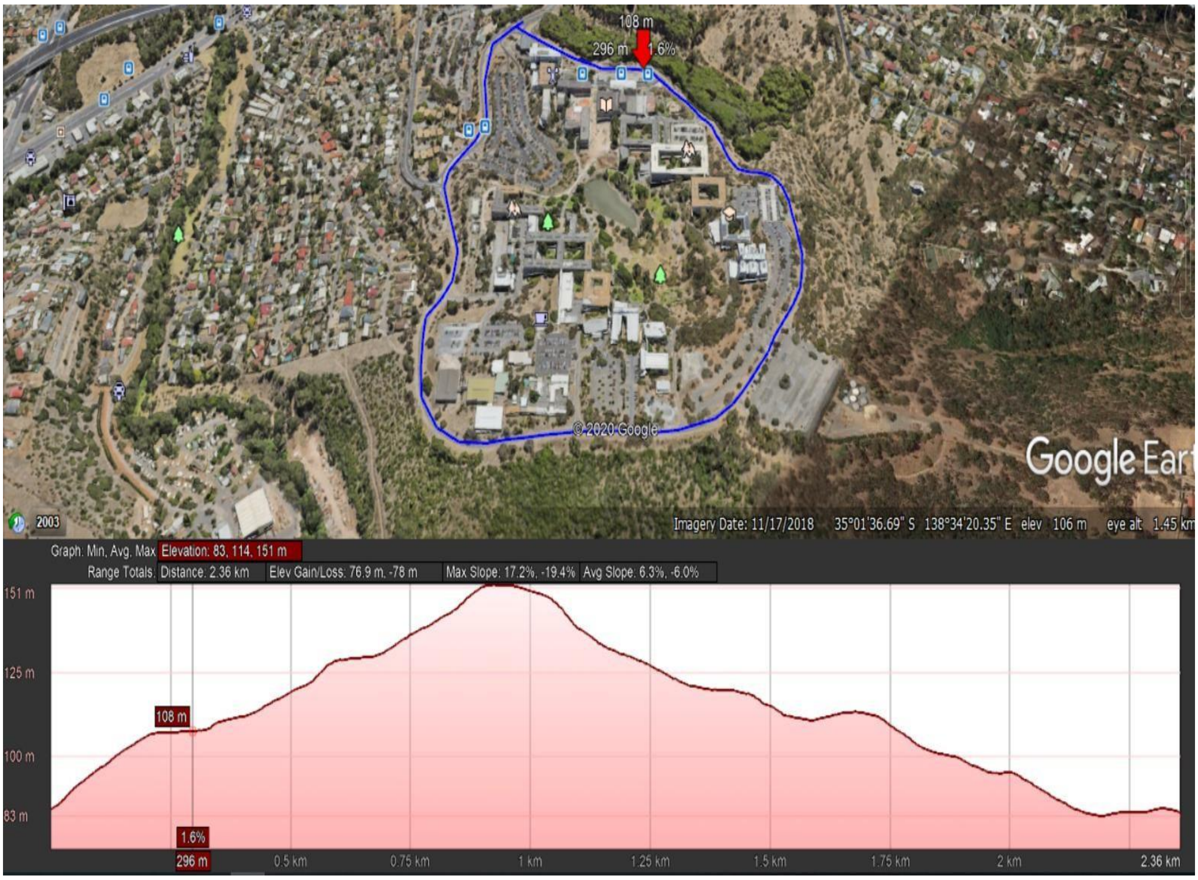
Appendix A: Advance GPS run and Google earth slope measurement of trial routes






11% 175M
13% 40M
6%, 50M
2%, 40M
2%, 80M
6%, 30M
11% 15M
10.5% 200M
8%, 125M
11% 50M


12% 100M
11% 175M
13% 62M
5%, 100M
9%, 130M
13% 240M



Elevation profile of Outer Ring Road

Appendix B: Aimsun time series Summary list

Time Series	S1	S2	S3	S4	S4A	S5	S6	S7	S8	S8A
Delay Time - All	12.44	21.49	16.56	13.98	14.17	13.33	13.01	12.84	12.77	12.81
Delay Time - Car	12.3	21.46	16.48	13.82	14.08	13.19	12.88	12.7	12.62	12.67
Delay Time - Truck	15.47	25.52	18.94	17.7	16.89	15.9	15.78	15.76	15.76	15.86
Delay Time - Bus	17.88	24.47	19.47	24.29	20.68	21.52	20.12	19.58	19.28	17.9
Delay Time - FLEX		0.93	14.58	0.81	2.32	7.43	7.32	9.78	13.29	12.53
Density - All	2.67	3.17	2.92	2.85	2.86	2.81	2.79	2.78	2.77	2.73
Density - Car	2.51	2.87	2.67	2.57	2.58	2.54	2.53	2.52	2.52	2.52
Density - Truck	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Density - Bus	0.1	0.11	0.1	0.11	0.1	0.1	0.1	0.1	0.1	0.1
Density - FLEX		0.12	0.09	0.12	0.12	0.11	0.1	0.09	0.09	0.05
Flow - All	1315.76	1318.64	1321.52	1321.28	1321.36	1321.36	1321.28	1321.36	1321.6	1321.76
Flow - Car	1271.84	1269.2	1271.84	1271.76	1271.84	1271.84	1271.76	1271.84	1271.84	1271.84
Flow - Truck	26.16	26.08	26.16	26.16	26.16	26.16	26.16	26.16	26.16	26.16
Flow - Bus	17.76	17.76	17.76	17.76	17.76	17.76	17.76	17.76	17.76	17.76
Flow - FLEX		5.6	5.76	5.6	5.6	5.6	5.6	5.6	5.84	6
Harmonic Speed - All	44.91	39.97	42.47	43.61	43.55	44.04	44.27	44.4	44.45	44.66
Harmonic Speed - Car	45.22	40.57	42.98	44.39	44.25	44.74	44.91	45.01	45.06	45.03
Harmonic Speed - Truck	42.05	37.64	40.43	41	41.38	41.85	41.91	41.92	41.92	41.88
Harmonic Speed - Bus	32.06	30.28	31.61	30.33	31.28	31.05	31.43	31.58	31.66	32.05
Harmonic Speed - FLEX		13.2	18.22	13.25	14.06	14.84	16.44	17.6	18.41	35.1
Input Count - All	3319	3334	3334	3334	3334	3334	3334	3334	3334	3334
Input Count - Car	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4
Input Count - Truck	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6

Input Count - Bus	45	45	45	45	45	45	45	45	45	45
Input Count - FLEX		15	15	15	15	15	15	15	15	15
Input Flow - All	1327.6	1333.6	1333.6	1333.6	1333.6	1333.6	1333.6	1333.6	1333.6	1333.6
Input Flow - Car	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96
Input Flow - Truck	26.64	26.64	26.64	26.64	26.64	26.64	26.64	26.64	26.64	26.64
Input Flow - Bus	18	18	18	18	18	18	18	18	18	18
Input Flow - FLEX		6	6	6	6	6	6	6	6	6
Max. Virtual Queue - All	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Max. Virtual Queue - Car	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Max. Virtual Queue - Truck	1	1	1	1	1	1	1	1	1	1
Max. Virtual Queue - Bus	1	1	1	1	1	1	1	1	1	1
Max. Virtual Queue - FLEX		0.2	0	0	0	0.2	0	0.2	0	0
Mean Queue - All	0.92	2.93	2.44	1.08	1.13	1.1	1.09	1.09	1.09	0.95
Mean Queue - Car	0.72	2.28	1.81	0.73	0.78	0.73	0.74	0.73	0.74	0.74
Mean Queue - Truck	0.02	0.06	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mean Queue - Bus	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.18
Mean Queue - FLEX		0.41	0.41	0.14	0.15	0.16	0.15	0.14	0.15	0
Mean Virtual Queue - All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mean Virtual Queue - Car	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Mean Virtual Queue - Truck	0	0	0	0	0	0	0	0	0	0
Mean Virtual Queue - Bus	0	0	0	0	0	0	0	0	0	0
Mean Virtual Queue - FLEX		0	0	0	0	0	0	0	0	0
Missed Turns - All	41	42	43	42	40.4	41.2	41.6	40.8	42.6	41.6
Missed Turns - Car	40.2	41.2	42	41.2	39.6	40.2	40.8	40	41.6	40.8
Missed Turns - Truck	0.8	0.8	1	0.8	0.8	1	0.8	0.8	1	0.8
Missed Turns - Bus	0	0	0	0	0	0	0	0	0	0
Missed Turns - FLEX		0	0	0	0	0	0	0	0	0
Number of Lane Changes - All	252.54	255.81	253.18	288.81	281.83	288.75	289.05	287.69	287.41	254.13
Number of Lane Changes - Car	239.28	239.62	239.72	239.4	239.48	239.4	239.38	239.26	239.3	239.7
Number of Lane Changes - Truck	4.51	4.51	4.51	4.51	4.53	4.51	4.51	4.51	4.51	4.51
Number of Lane Changes - Bus	8.75	8.92	8.76	8.92	8.76	8.86	9.21	8.76	8.76	8.76

Number of Lane Changes - FLEX		2.77	0.2	35.99	29.07	35.99	35.95	35.16	34.84	1.17
Number of Stops - All	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of Stops - Car	0.04	0.06	0.06	0.04	0.05	0.04	0.04	0.04	0.04	0.04
Number of Stops - Truck	0.05	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of Stops - Bus	0.13	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13
Number of Stops - FLEX		0.71	0.7	0.71	0.63	0.74	0.7	0.7	0.7	0.07
Speed - All	46.06	43.77	44.76	45.33	45.12	45.56	45.69	45.77	45.81	45.84
Speed - Car	46.32	44.15	45.12	45.73	45.5	45.95	46.08	46.15	46.19	46.15
Speed - Truck	42.97	40.85	42.04	42.28	42.39	42.83	42.87	42.88	42.9	42.81
Speed - Bus	32.14	30.63	31.73	30.68	31.43	31.25	31.57	31.71	31.78	32.13
Speed - FLEX		13.2	18.22	13.25	14.06	14.85	16.45	17.6	18.42	35.16
Stop Time - All	6.27	10.74	9.15	6.33	6.47	6.37	6.37	6.35	6.36	6.37
Stop Time - Car	6.29	10.85	9.25	6.37	6.49	6.4	6.41	6.4	6.4	6.42
Stop Time - Truck	8.16	13.15	10.67	8.33	8.3	8.19	8.18	8.19	8.32	8.31
Stop Time - Bus	1.51	2.66	2.51	2.52	2.43	2.29	2.22	2.24	2.33	1.56
Stop Time - FLEX		0.67	0.25	0.63	5	4.24	0.82	0.12	0.09	2.05
Total Distance Travelled - All	3016.03	3045.88	3055.11	3054.33	3056.44	3054.58	3054.59	3054.69	3055.76	3058.58
Total Distance Travelled - Car	2873.65	2864.94	2872.93	2873.17	2873.81	2873.5	2873.44	2873.55	2873.04	2873.06
Total Distance Travelled - Truck	61.49	61.26	61.42	61.48	61.48	61.42	61.48	61.48	61.42	61.48
Total Distance Travelled - Bus	80.9	80.9	80.9	80.9	80.9	80.9	80.89	80.91	80.9	80.89
Total Distance Travelled - FLEX		38.78	39.86	38.78	40.26	38.78	38.77	38.76	40.41	43.14
Total Distance Travelled (Vehicles Inside) - All	14.58	28.45	17.42	16.37	16.56	16.68	16.97	17.12	16.08	14.55
Total Distance Travelled (Vehicles Inside) - Car	14.16	25.44	14.63	14.04	14.22	14.15	14.12	14.16	14.16	14.13
Total Distance Travelled (Vehicles Inside) - Truck	0.42	1.09	0.37	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Total Distance Travelled (Vehicles Inside) - Bus	0	0	0.36	0	0	0	0	0	0	0
Total Distance Travelled (Vehicles Inside) - FLEX		1.91	2.05	1.91	1.92	2.11	2.43	2.54	1.5	0
Total Number of Lane Changes - All	2555.8	2587.4	2560.8	2921.2	2850.6	2920.6	2923.6	2909.8	2907	2570.4
Total Number of Lane Changes - Car	2421.6	2423.6	2424.6	2421.4	2422.2	2421.4	2421.2	2420	2420.4	2424.4
Total Number of Lane Changes - Truck	45.6	45.6	45.6	45.6	45.8	45.6	45.6	45.6	45.6	45.6

Total Number of Lane Changes - Bus	88.6	90.2	88.6	90.2	88.6	89.6	93.2	88.6	88.6	88.6
Total Number of Lane Changes - FLEX		28	2	364	294	364	363.6	355.6	352.4	11.8
Total Number of Stops - All	1510.6	2140.8	1999.4	1623	1634.8	1628.8	1621.4	1620.6	1625.8	1526.4
Total Number of Stops - Car	1418.4	1930.8	1794.2	1425.6	1449.8	1429	1427.6	1427.8	1426.8	1424.4
Total Number of Stops - Truck	32.4	44.4	38.6	32.6	31.8	31.8	32	32	32.2	31.8
Total Number of Stops - Bus	59.8	65.2	65	64.4	64.2	63.6	62.4	62.2	64	60.2
Total Number of Stops - FLEX		100.4	101.6	100.4	89	104.4	99.4	98.6	102.8	10
Total Travel Time - All	67.13	79.24	73.49	71.65	71.88	70.64	70.05	69.71	69.61	68.69
Total Travel Time - Car	63.15	71.96	67.21	64.56	64.94	63.96	63.65	63.48	63.39	63.46
Total Travel Time - Truck	1.46	1.67	1.53	1.5	1.49	1.47	1.47	1.47	1.46	1.47
Total Travel Time - Bus	2.52	2.67	2.56	2.67	2.59	2.61	2.57	2.56	2.55	2.52
Total Travel Time - FLEX		2.94	2.19	2.93	2.86	2.61	2.36	2.2	2.2	1.23
Total Travel Time (Vehicles Inside) - All	0.46	1.01	0.55	0.61	0.67	0.6	0.61	0.61	0.52	0.46
Total Travel Time (Vehicles Inside) - Car	0.42	0.81	0.42	0.42	0.48	0.41	0.42	0.42	0.42	0.42
Total Travel Time (Vehicles Inside) - Truck	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Travel Time (Vehicles Inside) - Bus	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total Travel Time (Vehicles Inside) - FLEX		0.15	0.09	0.15	0.15	0.15	0.15	0.15	0.06	0
Total Travel Time (Waiting Out) - All	0	0	0	0	0	0	0	0	0	0
Total Travel Time (Waiting Out) - Car	0	0	0	0	0	0	0	0	0	0
Total Travel Time (Waiting Out) - Truck	0	0	0	0	0	0	0	0	0	0
Total Travel Time (Waiting Out) - Bus	0	0	0	0	0	0	0	0	0	0
Total Travel Time (Waiting Out) - FLEX		0	0	0	0	0	0	0	0	0
Travel Time - All	80.17	90.06	84.76	82.55	82.67	81.74	81.32	81.09	80.98	80.61
Travel Time - Car	79.61	88.74	83.76	81.1	81.36	80.47	80.16	79.99	79.9	79.95
Travel Time - Truck	85.61	95.63	89.05	87.81	87	86.01	85.89	85.87	85.87	85.97
Travel Time - Bus	112.29	118.88	113.88	118.7	115.09	115.94	114.53	113.98	113.69	112.31
Travel Time - FLEX		272.75	197.62	271.62	256.13	242.59	218.96	204.59	195.54	102.57
Vehicles Inside - All	29.6	37.4	30.2	30.8	30.6	30.6	30.8	30.6	30	29.6
Vehicles Inside - Car	27.8	34.4	27.8	28	27.8	27.8	28	27.8	27.8	27.8
Vehicles Inside - Truck	1.2	1.4	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Vehicles Inside - Bus	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Vehicles Inside - FLEX		1	0.6	1	1	1	1	1	0.4	0
Vehicles Lost Inside - All	0	0	0	0	0	0	0	0	0	0
Vehicles Lost Inside - Car	0	0	0	0	0	0	0	0	0	0
Vehicles Lost Inside - Truck	0	0	0	0	0	0	0	0	0	0
Vehicles Lost Inside - Bus	0	0	0	0	0	0	0	0	0	0
Vehicles Lost Inside - FLEX		0	0	0	0	0	0	0	0	0
Vehicles Lost Outside - All	36.6	37.6	38.4	37.2	36	36.8	37	36.4	38.2	37.2
Vehicles Lost Outside - Car	36.6	37.6	38.2	37.2	36	36.6	37	36.4	38	37.2
Vehicles Lost Outside - Truck	0	0	0.2	0	0	0.2	0	0	0.2	0
Vehicles Lost Outside - Bus	0	0	0	0	0	0	0	0	0	0
Vehicles Lost Outside - FLEX		0	0	0	0	0	0	0	0	0
Vehicles Outside - All	3289.4	3296.6	3303.8	3303.2	3303.4	3303.4	3303.2	3303.4	3304	3304.4
Vehicles Outside - Car	3179.6	3173	3179.6	3179.4	3179.6	3179.6	3179.4	3179.6	3179.6	3179.6
Vehicles Outside - Truck	65.4	65.2	65.4	65.4	65.4	65.4	65.4	65.4	65.4	65.4
Vehicles Outside - Bus	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4	44.4
Vehicles Outside - FLEX		14	14.4	14	14	14	14	14	14.6	15
Vehicles Waiting to Enter - All	0	0	0	0	0	0	0	0	0	0
Vehicles Waiting to Enter - Car	0	0	0	0	0	0	0	0	0	0
Vehicles Waiting to Enter - Truck	0	0	0	0	0	0	0	0	0	0
Vehicles Waiting to Enter - Bus	0	0	0	0	0	0	0	0	0	0
Vehicles Waiting to Enter - FLEX		0	0	0	0	0	0	0	0	0
Waiting Time in Virtual Queue - All	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Waiting Time in Virtual Queue - Car	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Waiting Time in Virtual Queue - Truck	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Waiting Time in Virtual Queue - Bus	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Waiting Time in Virtual Queue - FLEX		0.01	0	0	0	0.08	0.02	0.01	0	0

Time Series	S9	S10	S11	S12	S13	S14	S11A	S12A	Units
Delay Time - All	12.74	12.68	12.38	12.38	12.38	12.38	12.42	12.42	sec/km

Delay Time - Car	12.57	12.51	12.3	12.3	12.3	12.3	12.3	12.3	sec/km
Delay Time - Truck	15.66	15.14	15.47	15.46	15.46	15.46	15.47	15.46	sec/km
Delay Time - Bus	19.04	19.06	17.88	17.88	17.88	17.88	17.88	17.88	sec/km
Delay Time - FLEX	17.09	20.1	0	0	0	0	9.06	8.38	sec/km
Density - All	2.78	2.78	2.75	2.73	2.75	2.74	2.73	2.71	veh/km
Density - Car	2.54	2.54	2.51	2.51	2.51	2.51	2.51	2.51	veh/km
Density - Truck	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	veh/km
Density - Bus	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	veh/km
Density - FLEX	0.09	0.09	0.08	0.07	0.08	0.07	0.06	0.04	veh/km
Flow - All	1328.6	1333.52	1321.68	1321.76	1321.68	1321.76	1321.76	1321.76	veh/h
Flow - Car	1278.93	1283.76	1271.84	1271.84	1271.84	1271.84	1271.84	1271.84	veh/h
Flow - Truck	26	26.16	26.16	26.16	26.16	26.16	26.16	26.16	veh/h
Flow - Bus	17.73	17.68	17.76	17.76	17.76	17.76	17.76	17.76	veh/h
Flow - FLEX	5.93	5.92	5.92	6	5.92	6	6	6	veh/h
Harmonic Speed - All	44.49	44.54	43.73	43.92	43.67	43.88	44.08	44.31	km/h
Harmonic Speed - Car	45.08	45.11	45.22	45.22	45.22	45.22	45.22	45.22	km/h
Harmonic Speed - Truck	41.97	42.24	42.05	42.06	42.06	42.06	42.05	42.06	km/h
Harmonic Speed - Bus	31.71	31.67	32.06	32.06	32.06	32.06	32.06	32.06	km/h
Harmonic Speed - FLEX	18.99	19.31	6.4	7.55	6.11	7.3	8.73	11.4	km/h
Input Count - All	3352.17	3364.6	3334	3334	3334	3334	3334	3334	veh
Input Count - Car	3226.17	3238.2	3207.4	3207.4	3207.4	3207.4	3207.4	3207.4	veh
Input Count - Truck	66	66.4	66.6	66.6	66.6	66.6	66.6	66.6	veh
Input Count - Bus	45	45	45	45	45	45	45	45	veh
Input Count - FLEX	15	15	15	15	15	15	15	15	veh
Input Flow - All	1340.87	1345.84	1333.6	1333.6	1333.6	1333.6	1333.6	1333.6	veh/h
Input Flow - Car	1290.47	1295.28	1282.96	1282.96	1282.96	1282.96	1282.96	1282.96	veh/h
Input Flow - Truck	26.4	26.56	26.64	26.64	26.64	26.64	26.64	26.64	veh/h
Input Flow - Bus	18	18	18	18	18	18	18	18	veh/h

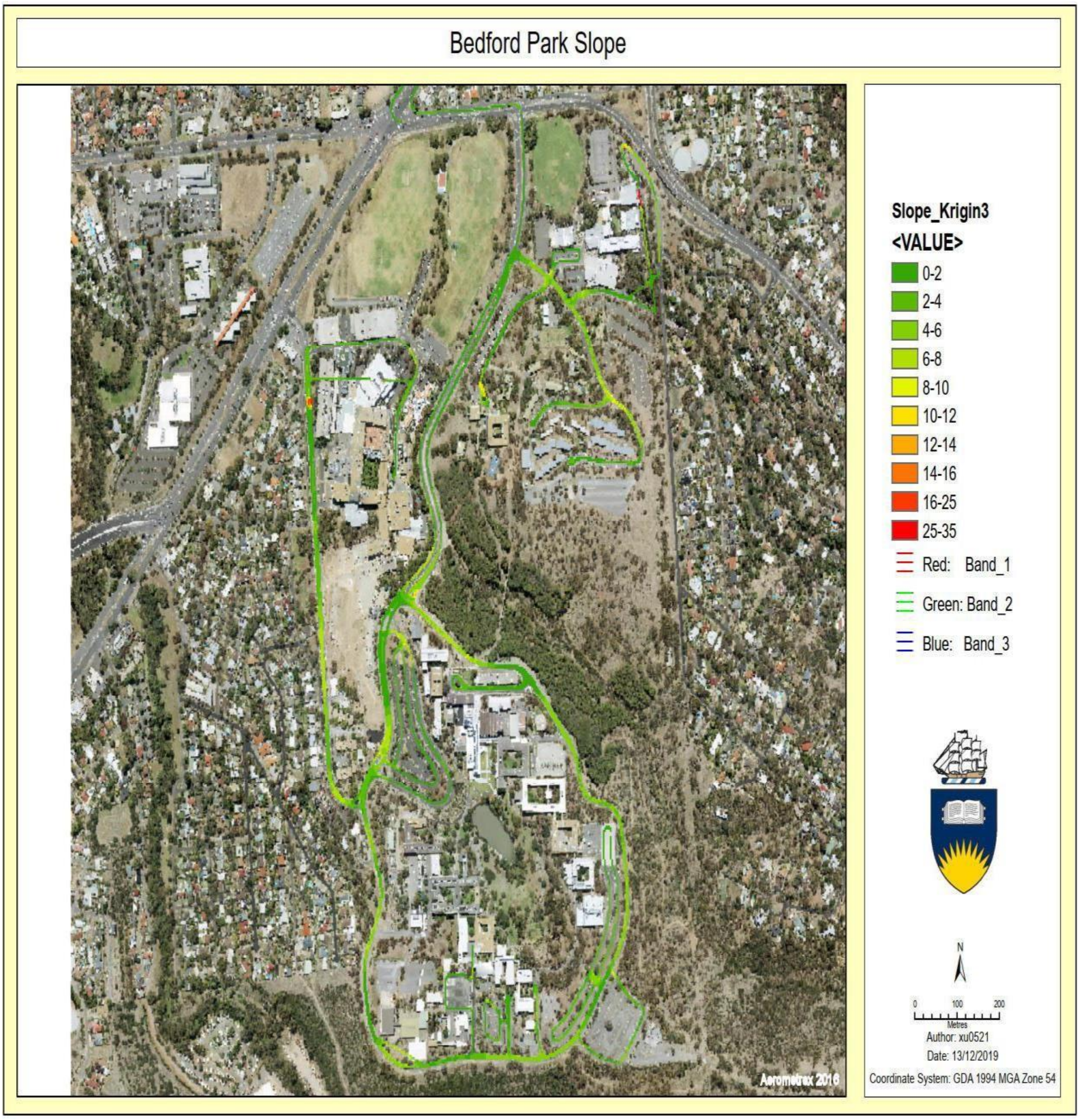
Input Flow - FLEX	6	6	6	6	6	6	6	6	veh/h
Max. Virtual Queue - All	3.33	3.2	3.2	3.2	3.2	3.2	3.2	3.2	veh
Max. Virtual Queue - Car	3.33	3.2	3.2	3.2	3.2	3.2	3.2	3.2	veh
Max. Virtual Queue - Truck	1	1	1	1	1	1	1	1	veh
Max. Virtual Queue - Bus	1	1	1	1	1	1	1	1	veh
Max. Virtual Queue - FLEX	0.17	0.2	0	0	0	0	0	0	veh
Mean Queue - All	1.09	1.07	1.71	1.59	1.75	1.62	1.23	1.09	veh
Mean Queue - Car	0.74	0.72	0.72	0.72	0.72	0.72	0.72	0.72	veh
Mean Queue - Truck	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	veh
Mean Queue - Bus	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	veh
Mean Queue - FLEX	0.15	0.15	0.79	0.67	0.84	0.7	0.31	0.17	veh
Mean Virtual Queue - All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	veh
Mean Virtual Queue - Car	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	veh
Mean Virtual Queue - Truck	0	0	0	0	0	0	0	0	veh
Mean Virtual Queue - Bus	0	0	0	0	0	0	0	0	veh
Mean Virtual Queue - FLEX	0	0	0	0	0	0	0	0	veh
Missed Turns - All	41	42.4	41	41	41	41	41	41	
Missed Turns - Car	39.83	41.2	40.2	40.2	40.2	40.2	40.2	40.2	
Missed Turns - Truck	1.17	1.2	0.8	0.8	0.8	0.8	0.8	0.8	
Missed Turns - Bus	0	0	0	0	0	0	0	0	
Missed Turns - FLEX	0	0	0	0	0	0	0	0	
Number of Lane Changes - All	290.46	291.19	252.54	252.53	252.58	252.57	252.54	252.53	#/km
Number of Lane Changes - Car	241.75	242.62	239.28	239.27	239.32	239.3	239.28	239.27	#/km
Number of Lane Changes - Truck	4.66	4.69	4.51	4.51	4.51	4.51	4.51	4.51	#/km
Number of Lane Changes - Bus	8.75	8.72	8.75	8.75	8.76	8.76	8.75	8.75	#/km
Number of Lane Changes - FLEX	35.3	35.16	0	0	0	0	0	0	#/km
Number of Stops - All	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	#/veh/km
Number of Stops - Car	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	#/veh/km
Number of Stops - Truck	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	#/veh/k

									m
Number of Stops - Bus	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	#/veh/km
Number of Stops - FLEX	0.7	0.7	0.1	0.1	0.1	0.1	0.49	0.3	#/veh/km
Speed - All	45.81	45.84	45.88	45.88	45.88	45.88	45.89	45.9	km/h
Speed - Car	46.19	46.21	46.32	46.32	46.32	46.32	46.32	46.32	km/h
Speed - Truck	42.93	43.14	42.97	42.98	42.98	42.98	42.97	42.98	km/h
Speed - Bus	31.83	31.78	32.14	32.14	32.14	32.14	32.14	32.14	km/h
Speed - FLEX	18.99	19.32	6.41	7.56	6.13	7.31	8.74	11.41	km/h
Stop Time - All	6.36	6.31	6.24	6.24	6.24	6.24	6.24	6.24	sec/km
Stop Time - Car	6.41	6.37	6.29	6.3	6.29	6.3	6.29	6.3	sec/km
Stop Time - Truck	7.96	7.37	8.16	8.15	8.15	8.15	8.16	8.15	sec/km
Stop Time - Bus	2.42	2.42	1.51	1.51	1.51	1.51	1.51	1.51	sec/km
Stop Time - FLEX	0.1	0.14	0	0	0	0	0.01	0.01	sec/km
Total Distance Travelled - All	3075.06	3082.56	3028.73	3029.02	3028.79	3028.97	3028.9	3029.02	km
Total Distance Travelled - Car	2892.62	2900.32	2873.65	2873.76	2873.67	2873.67	2873.65	2873.76	km
Total Distance Travelled - Truck	60.61	60.75	61.49	61.49	61.49	61.49	61.49	61.49	km
Total Distance Travelled - Bus	80.78	80.53	80.9	80.9	80.9	80.9	80.9	80.9	km
Total Distance Travelled - FLEX	41.06	40.97	12.7	12.87	12.74	12.91	12.87	12.87	km
Total Distance Travelled (Vehicles Inside) - All	16.01	15.47	14.75	14.58	15.09	14.58	14.58	14.58	km
Total Distance Travelled (Vehicles Inside) - Car	14.11	13.91	14.16	14.16	14.16	14.16	14.16	14.16	km
Total Distance Travelled (Vehicles Inside) - Truck	0.36	0.19	0.42	0.42	0.42	0.42	0.42	0.42	km
Total Distance Travelled (Vehicles Inside) - Bus	0.22	0.27	0	0	0	0	0	0	km
Total Distance Travelled (Vehicles Inside) - FLEX	1.32	1.1	0.17	0	0.51	0	0	0	km
Total Number of Lane Changes - All	2937.83	2945.2	2555.8	2555.8	2555.8	2555.8	2555.8	2555.8	
Total Number of Lane Changes - Car	2445.17	2454	2421.6	2421.6	2421.6	2421.6	2421.6	2421.6	
Total Number of Lane Changes - Truck	47.17	47.4	45.6	45.6	45.6	45.6	45.6	45.6	

Total Number of Lane Changes - Bus	88.5	88.2	88.6	88.6	88.6	88.6	88.6	88.6	
Total Number of Lane Changes - FLEX	357	355.6	0	0	0	0	0	0	
Total Number of Stops - All	1641.33	1642.4	1525.4	1526.8	1525.6	1526	1585.6	1556.8	
Total Number of Stops - Car	1443	1445	1418.4	1419.8	1418.8	1419	1418.4	1419.8	
Total Number of Stops - Truck	30.33	29.4	32.4	32.2	32.2	32.2	32.4	32.2	
Total Number of Stops - Bus	63.5	63.4	59.8	59.8	59.8	59.8	59.8	59.8	
Total Number of Stops - FLEX	104.5	104.6	14.8	15	14.8	15	75	45	
Total Travel Time - All	69.93	69.98	69.12	68.84	69.22	68.9	68.61	68.27	h
Total Travel Time - Car	63.78	63.88	63.15	63.15	63.15	63.15	63.15	63.15	h
Total Travel Time - Truck	1.44	1.43	1.46	1.46	1.46	1.46	1.46	1.46	h
Total Travel Time - Bus	2.55	2.54	2.52	2.52	2.52	2.52	2.52	2.52	h
Total Travel Time - FLEX	2.16	2.12	1.98	1.7	2.08	1.77	1.47	1.13	h
Total Travel Time (Vehicles Inside) - All	0.5	0.53	0.49	0.46	0.49	0.46	0.46	0.46	h
Total Travel Time (Vehicles Inside) - Car	0.43	0.45	0.42	0.42	0.42	0.42	0.42	0.42	h
Total Travel Time (Vehicles Inside) - Truck	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	h
Total Travel Time (Vehicles Inside) - Bus	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	h
Total Travel Time (Vehicles Inside) - FLEX	0.02	0.03	0.03	0	0.03	0	0	0	h
Total Travel Time (Waiting Out) - All	0	0	0	0	0	0	0	0	h
Total Travel Time (Waiting Out) - Car	0	0	0	0	0	0	0	0	h
Total Travel Time (Waiting Out) - Truck	0	0	0	0	0	0	0	0	h
Total Travel Time (Waiting Out) - Bus	0	0	0	0	0	0	0	0	h
Total Travel Time (Waiting Out) - FLEX	0	0	0	0	0	0	0	0	h
Travel Time - All	80.92	80.83	82.33	81.97	82.45	82.04	81.67	81.24	sec/km
Travel Time - Car	79.86	79.8	79.61	79.61	79.61	79.61	79.61	79.61	sec/km
Travel Time - Truck	85.78	85.22	85.61	85.6	85.6	85.6	85.61	85.6	sec/km
Travel Time - Bus	113.52	113.67	112.29	112.29	112.29	112.29	112.29	112.29	sec/km
Travel Time - FLEX	189.61	186.43	562.08	476.79	588.81	493.36	412.29	315.77	sec/km
Vehicles Inside - All	30.67	30.8	29.8	29.6	29.8	29.6	29.6	29.6	veh
Vehicles Inside - Car	28.83	28.8	27.8	27.8	27.8	27.8	27.8	27.8	veh
Vehicles Inside - Truck	1	1	1.2	1.2	1.2	1.2	1.2	1.2	veh
Vehicles Inside - Bus	0.67	0.8	0.6	0.6	0.6	0.6	0.6	0.6	veh

Vehicles Inside - FLEX	0.17	0.2	0.2	0	0.2	0	0	0	veh
Vehicles Lost Inside - All	0	0	0	0	0	0	0	0	veh
Vehicles Lost Inside - Car	0	0	0	0	0	0	0	0	veh
Vehicles Lost Inside - Truck	0	0	0	0	0	0	0	0	veh
Vehicles Lost Inside - Bus	0	0	0	0	0	0	0	0	veh
Vehicles Lost Inside - FLEX	0	0	0	0	0	0	0	0	veh
Vehicles Lost Outside - All	36.83	38	36.6	36.6	36.6	36.6	36.6	36.6	veh
Vehicles Lost Outside - Car	36.33	37.4	36.6	36.6	36.6	36.6	36.6	36.6	veh
Vehicles Lost Outside - Truck	0.5	0.6	0	0	0	0	0	0	veh
Vehicles Lost Outside - Bus	0	0	0	0	0	0	0	0	veh
Vehicles Lost Outside - FLEX	0	0	0	0	0	0	0	0	veh
Vehicles Outside - All	3321.5	3333.8	3304.2	3304.4	3304.2	3304.4	3304.4	3304.4	veh
Vehicles Outside - Car	3197.33	3209.4	3179.6	3179.6	3179.6	3179.6	3179.6	3179.6	veh
Vehicles Outside - Truck	65	65.4	65.4	65.4	65.4	65.4	65.4	65.4	veh
Vehicles Outside - Bus	44.33	44.2	44.4	44.4	44.4	44.4	44.4	44.4	veh
Vehicles Outside - FLEX	14.83	14.8	14.8	15	14.8	15	15	15	veh
Vehicles Waiting to Enter - All	0	0	0	0	0	0	0	0	veh
Vehicles Waiting to Enter - Car	0	0	0	0	0	0	0	0	veh
Vehicles Waiting to Enter - Truck	0	0	0	0	0	0	0	0	veh
Vehicles Waiting to Enter - Bus	0	0	0	0	0	0	0	0	veh
Vehicles Waiting to Enter - FLEX	0	0	0	0	0	0	0	0	veh
Waiting Time in Virtual Queue - All	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	sec
Waiting Time in Virtual Queue - Car	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	sec
Waiting Time in Virtual Queue - Truck	0.15	0.16	0.13	0.13	0.13	0.13	0.13	0.13	sec
Waiting Time in Virtual Queue - Bus	0.31	0.33	0.33	0.33	0.33	0.33	0.33	0.33	sec
Waiting Time in Virtual Queue - FLEX	0.01	0.01	0	0	0	0	0	0	sec

Appendix C: Topographic slope map of Flinders University


Bedford Park Slope
Slope_Krigin3
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4-6
6-8
8-10
10-12
12-14
14-16
16-25
25-35
Red: Band_1
Green: Band_2
Blue: Band_3
N
0
100
200
Metres
Author: xu0521
Date: 13/12/2019
Coordinate System: GDA 1994 MGA Zone 54
Aerometrex 2016


Slope
<VALUE>
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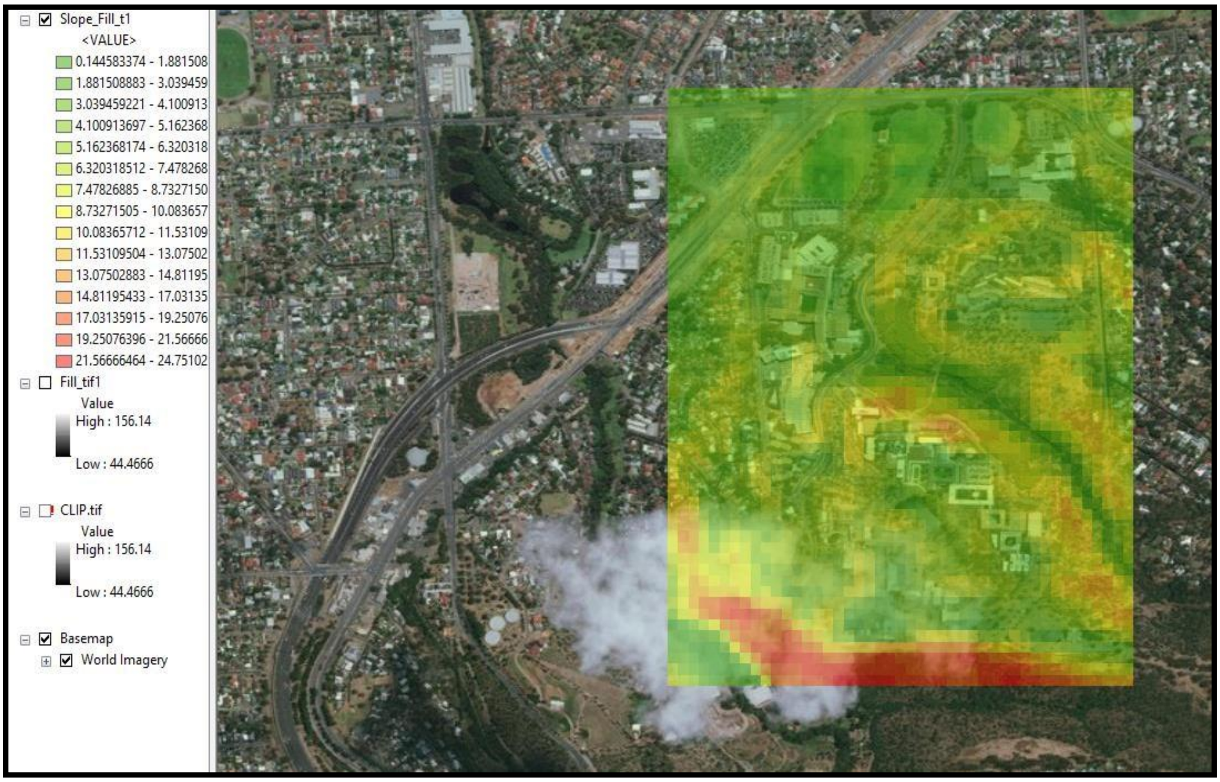
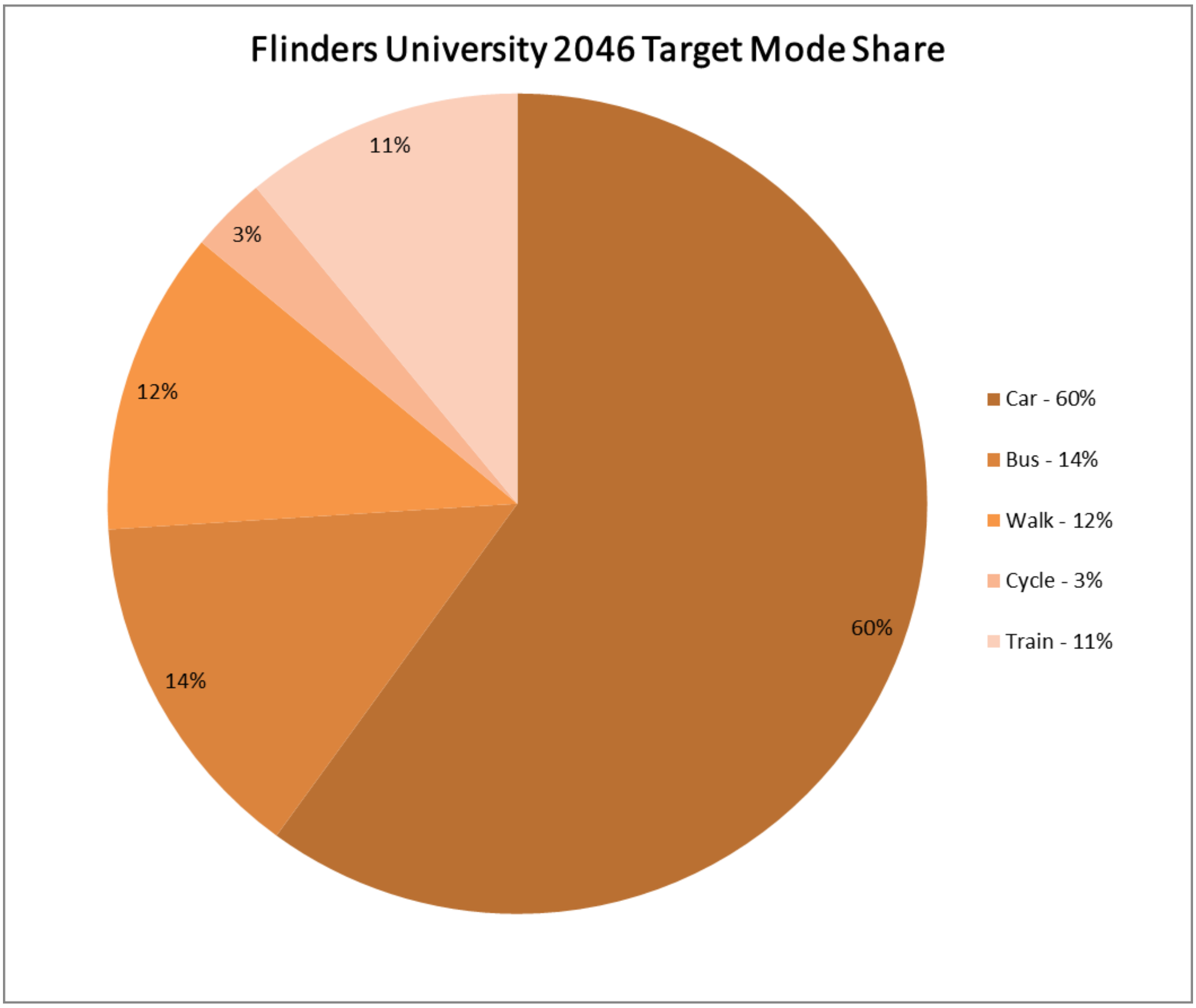
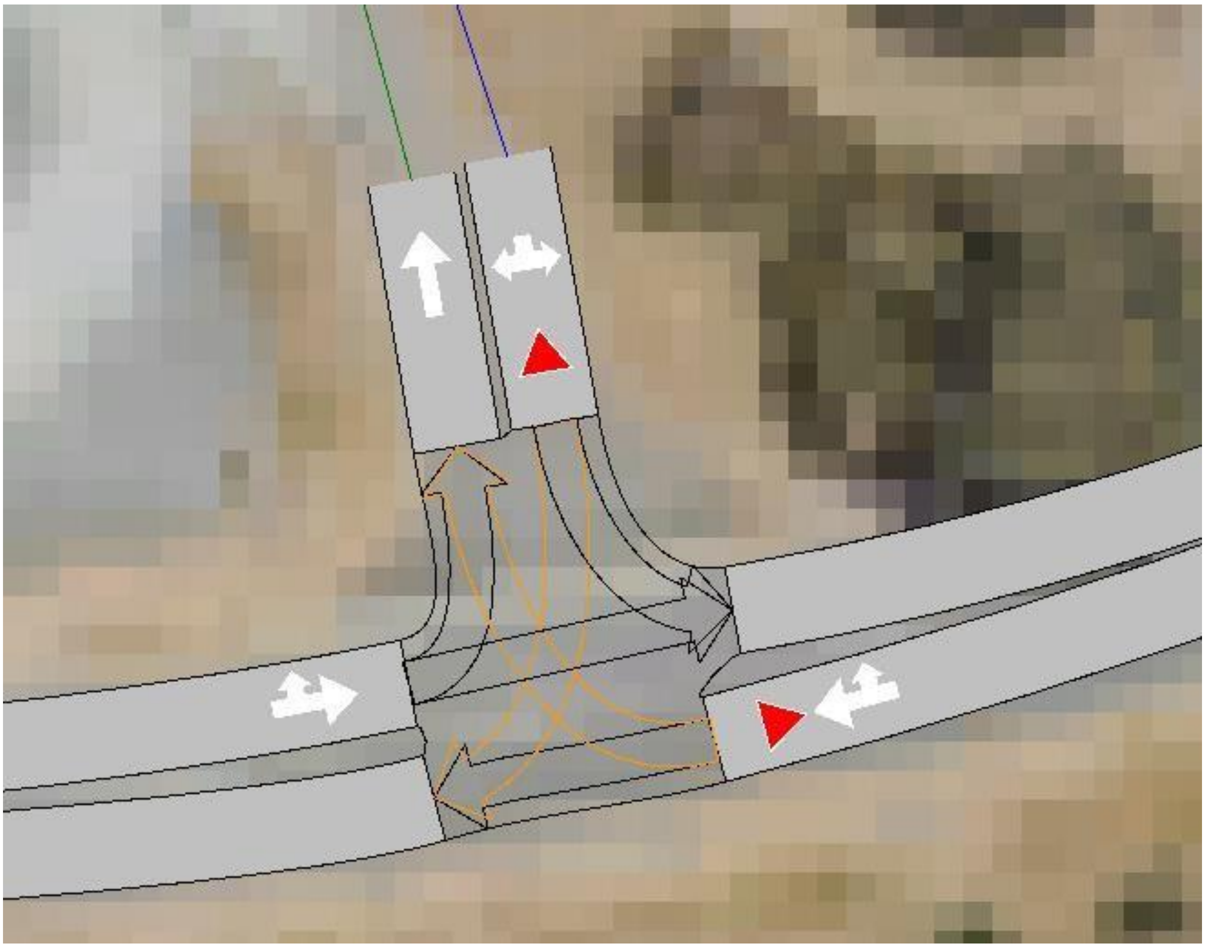
2 - 4
4 - 6
6 - 8
8 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30+

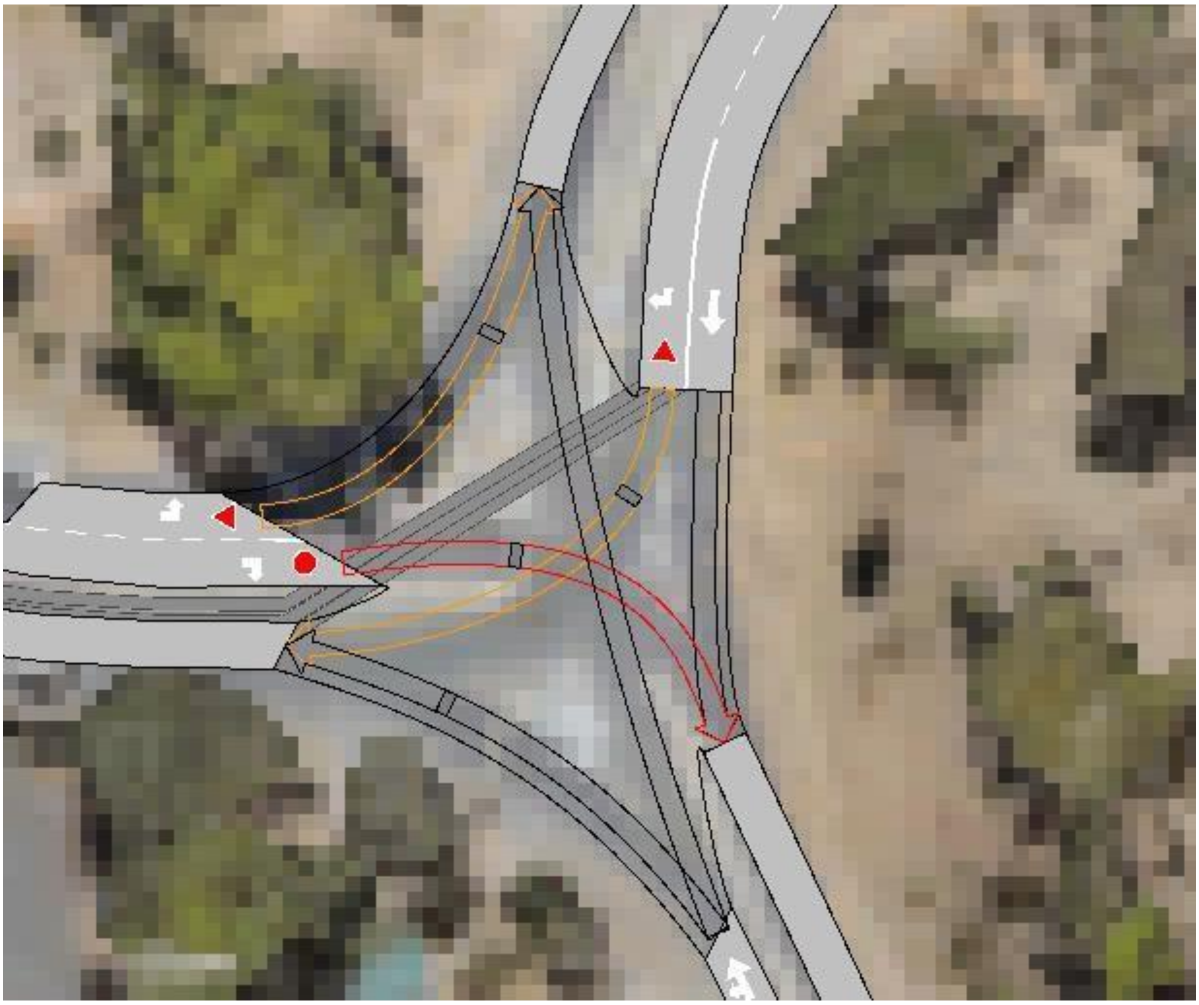


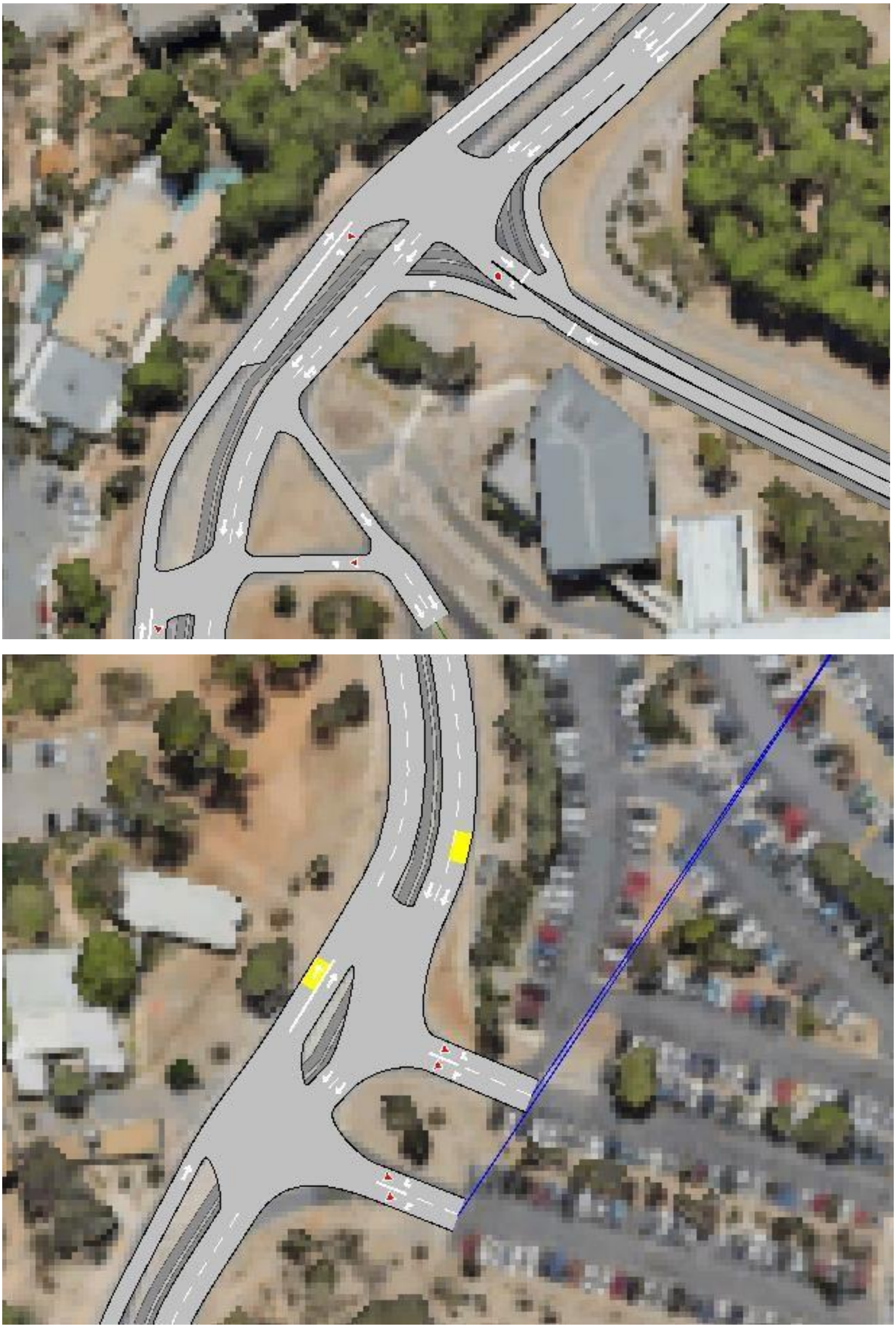


2046 Target Mode Share (4,576 vehicles for AM peak & 4,042 vehicles in PM peak)

Appendix D: AIMSUN model intersections







Outer ring road network with bus stops location

Appendix E: Indented bus stops network delay changes

Time Series	S1	S2	S3	S4	S8
Delay Time - All	12.44	21.49	16.56	13.98	12.77
Delay Time - Car	12.3	21.46	16.48	13.82	12.62

Scenario	Existing	No indented bus stops AV speed 20 km/h	No indented bus stops AV speed 40 km/h	Indented bus stops AV speed 20 km/h	Indented bus stops AV speed 40 km/h
Delay Time - All	12.44	73%	33%	12%	3%

Time Series	S4	S4A	S8	S8A
Delay Time - All	13.98	14.17	12.77	12.81
Delay Time - Car	13.82	14.08	12.62	12.67

	20 km/h	40 km/h
CounterClockwise	13.98	12.77
Clockwise	14.17	12.81

Inner ring route Average speed with direction of travel

Time Series	S11	S13	S12	S14
Speed - FLEX	6.41	6.13	7.56	7.31

	5 stops	3 stops
CounterClockwise	6.41	7.56
Clockwise	6.13	7.31

AV Travel time (Based on speed and number of stops)

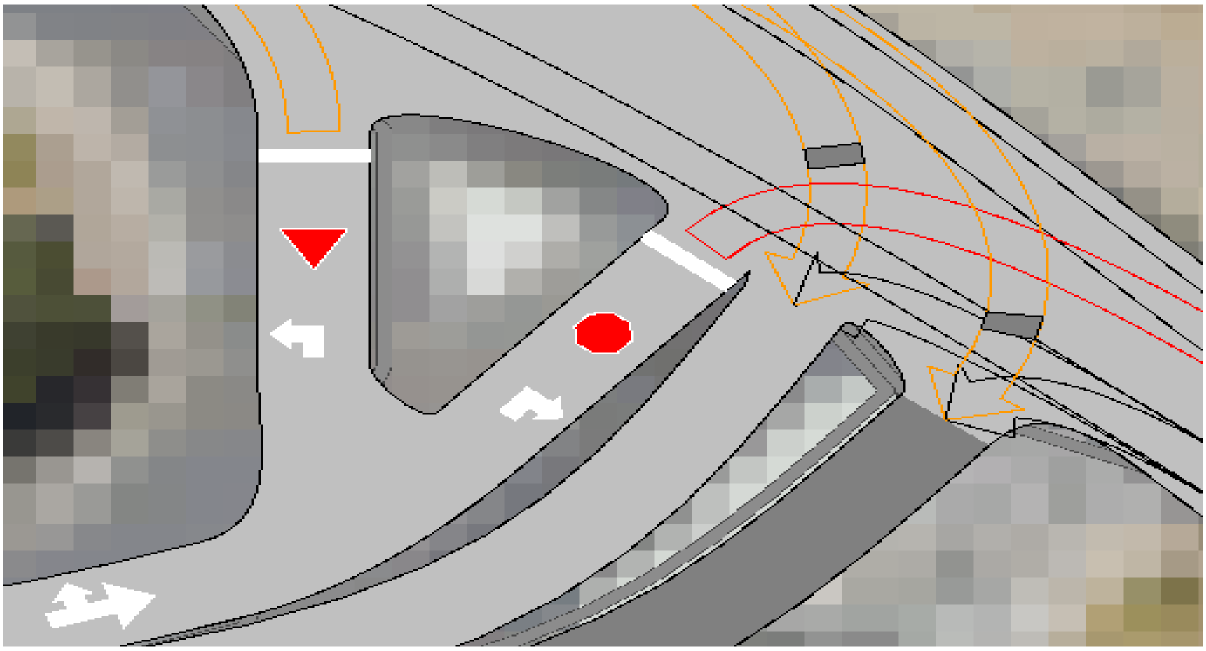
Time Series	10 km/h and 5 stops	10 km/h and 3 stops	20 km/h and 5 stops	20 km/h and 3 stops	Units
Travel Time - FLEX	562.08	476.79	412.29	315.77	sec/km
Travel Time - FLEX	482	409	354	271	sec/run

Time Series	10 km/h and 5 stops	10 km/h and 3 stops	20 km/h and 5 stops	20 km/h and 3 stops	Units
Travel Time - FLEX	9.4	7.9	6.9	5.3	min/km
Travel Time - FLEX	8.0	6.8	5.9	4.5	min/run

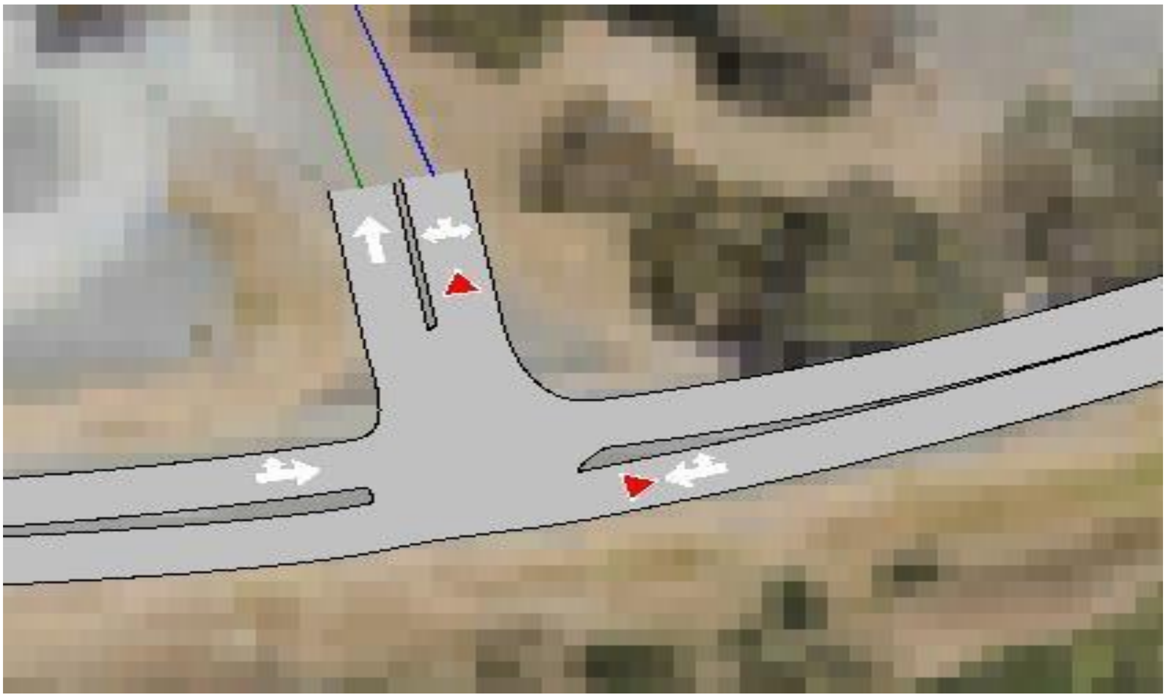
Passenger capacity				
Runs per hour	7	8	10	13
Passengers per hour	105	120	150	195

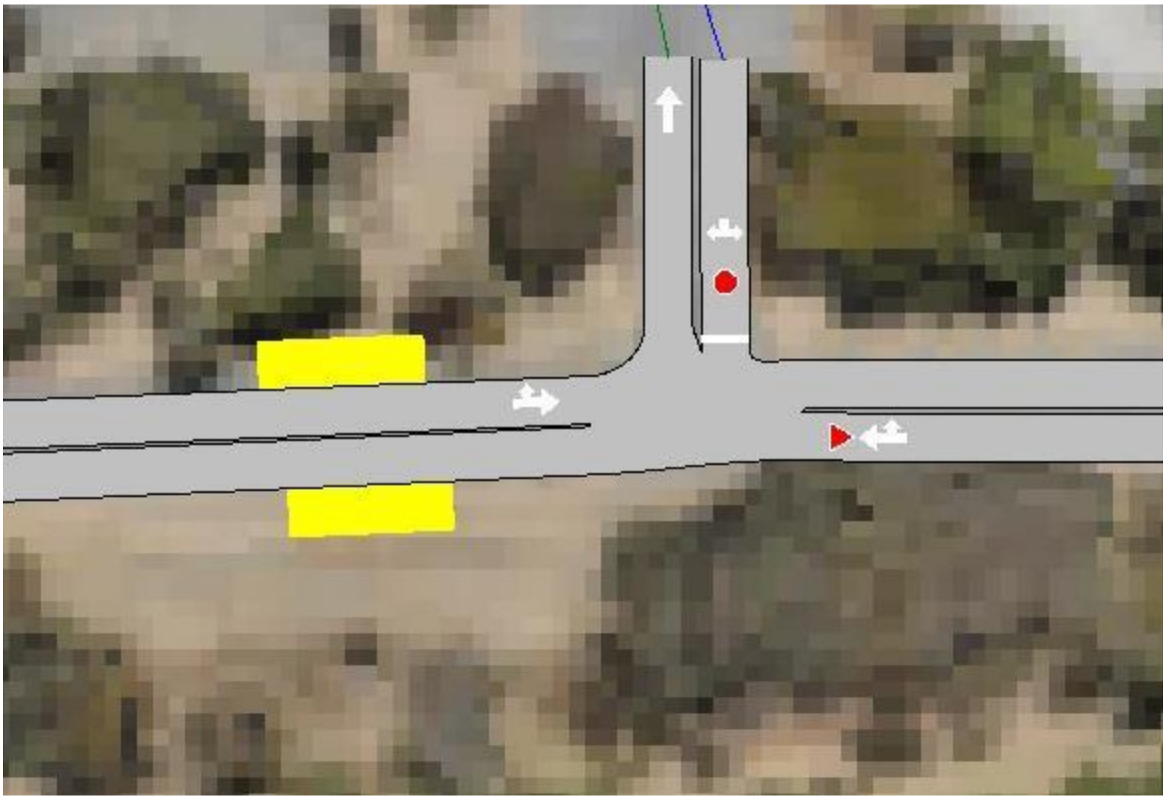
Appendix F: Changes from Initial model In Aimsun

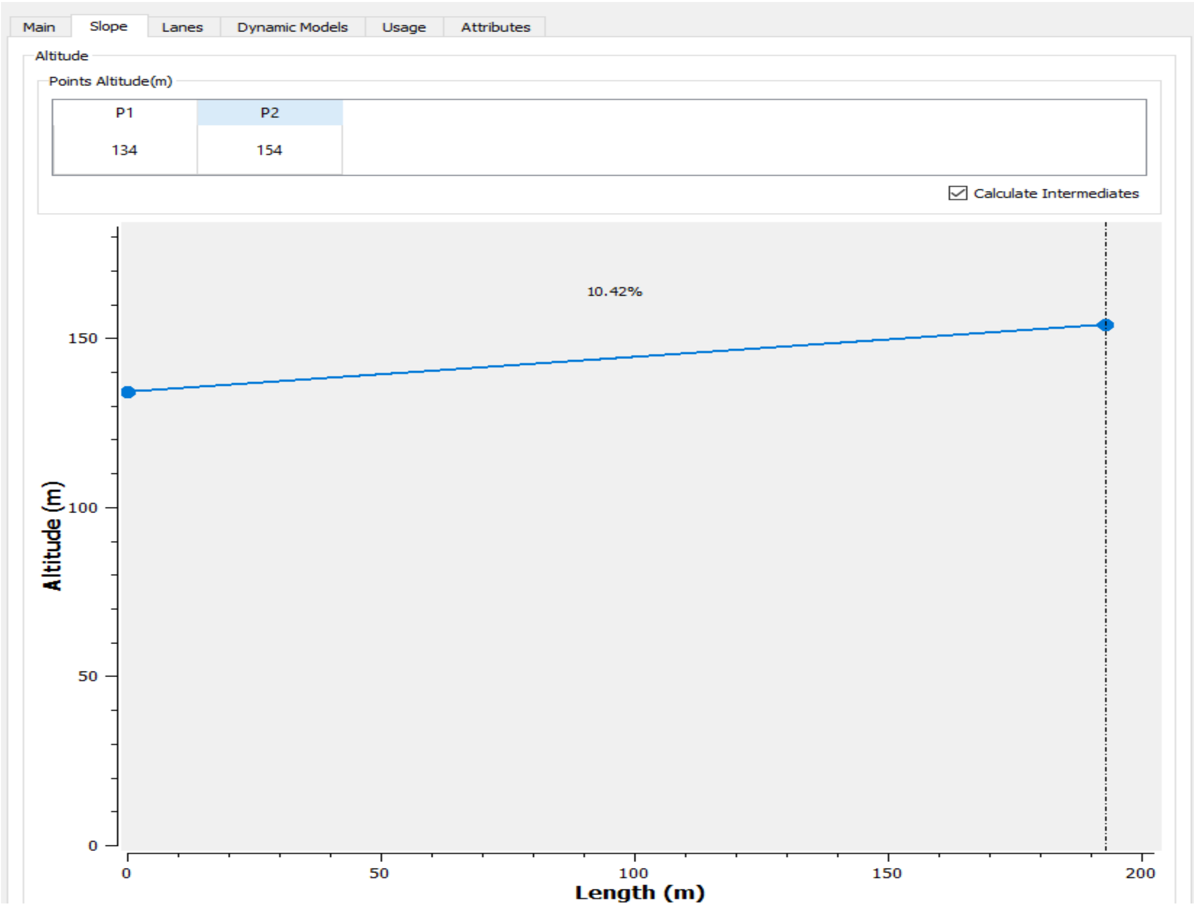
Built a new Internal Ring Rd around the lake



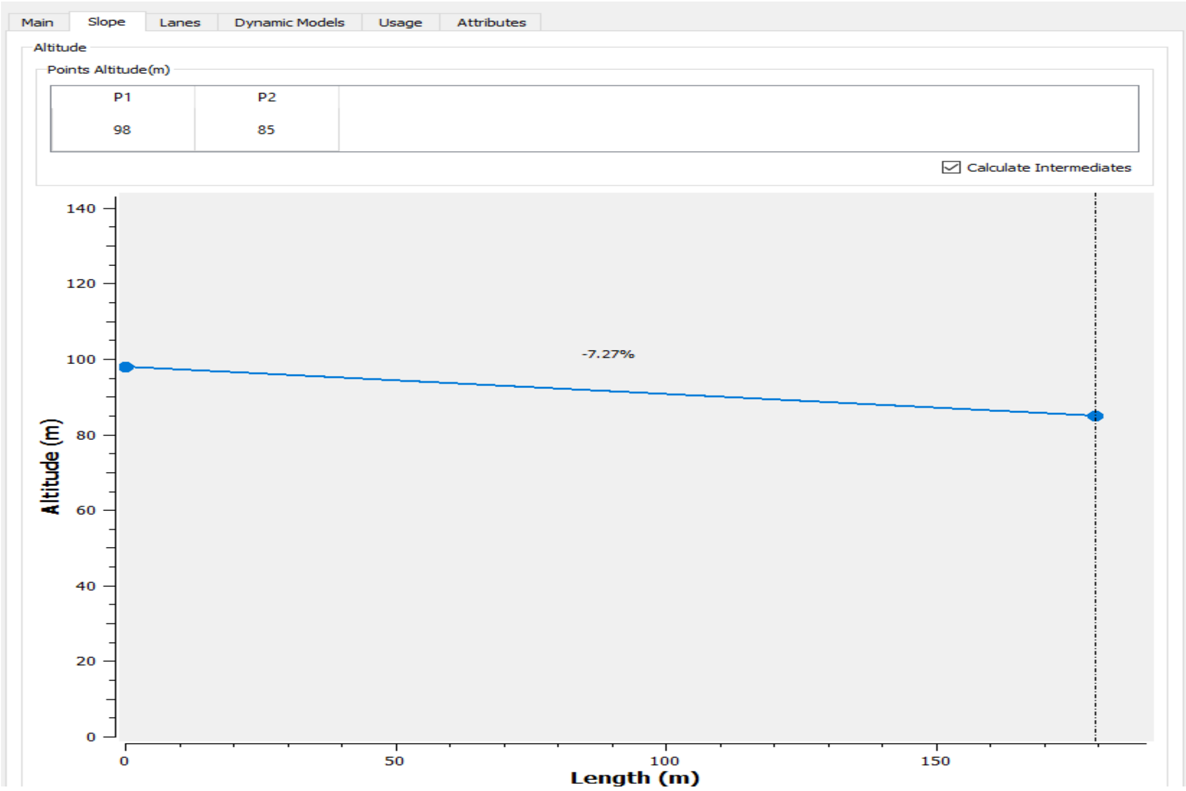
Changed Traffic Signs


Built an Engineering Road

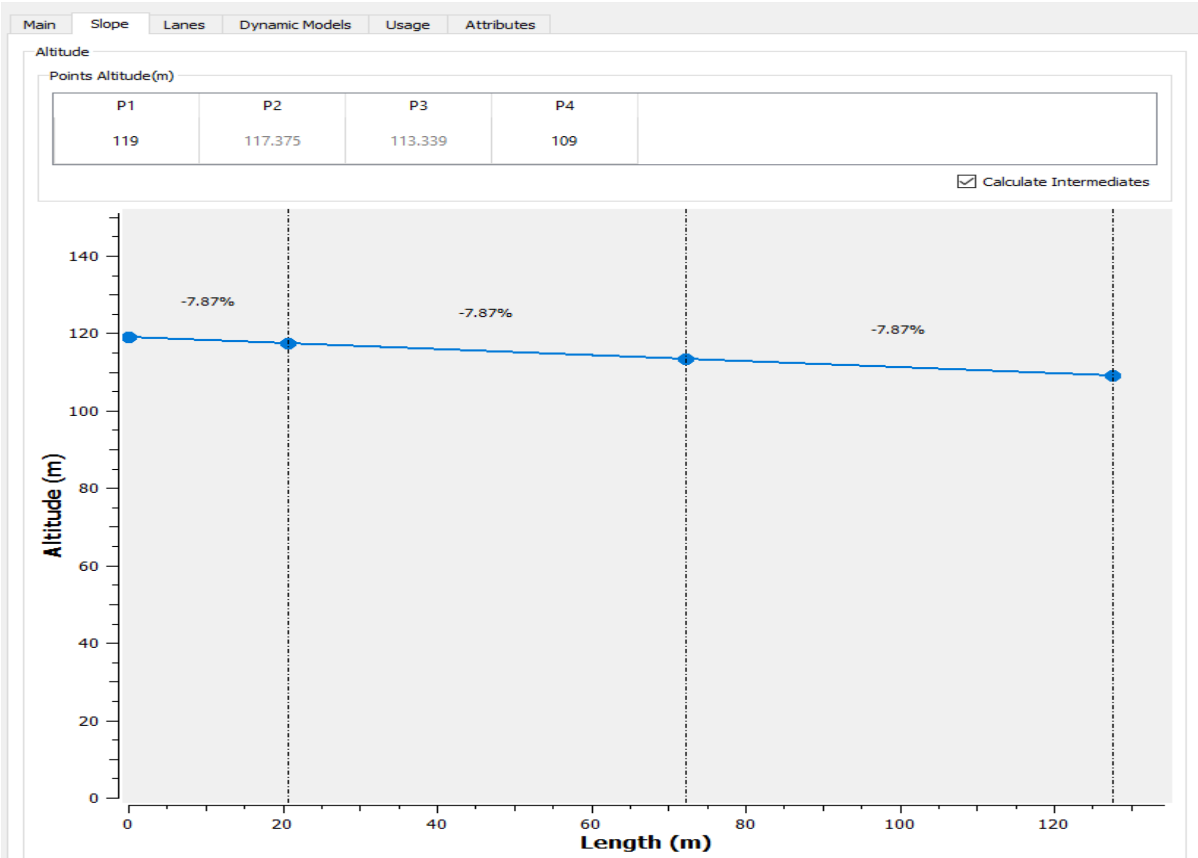

Fixed a Bus Stop Locations



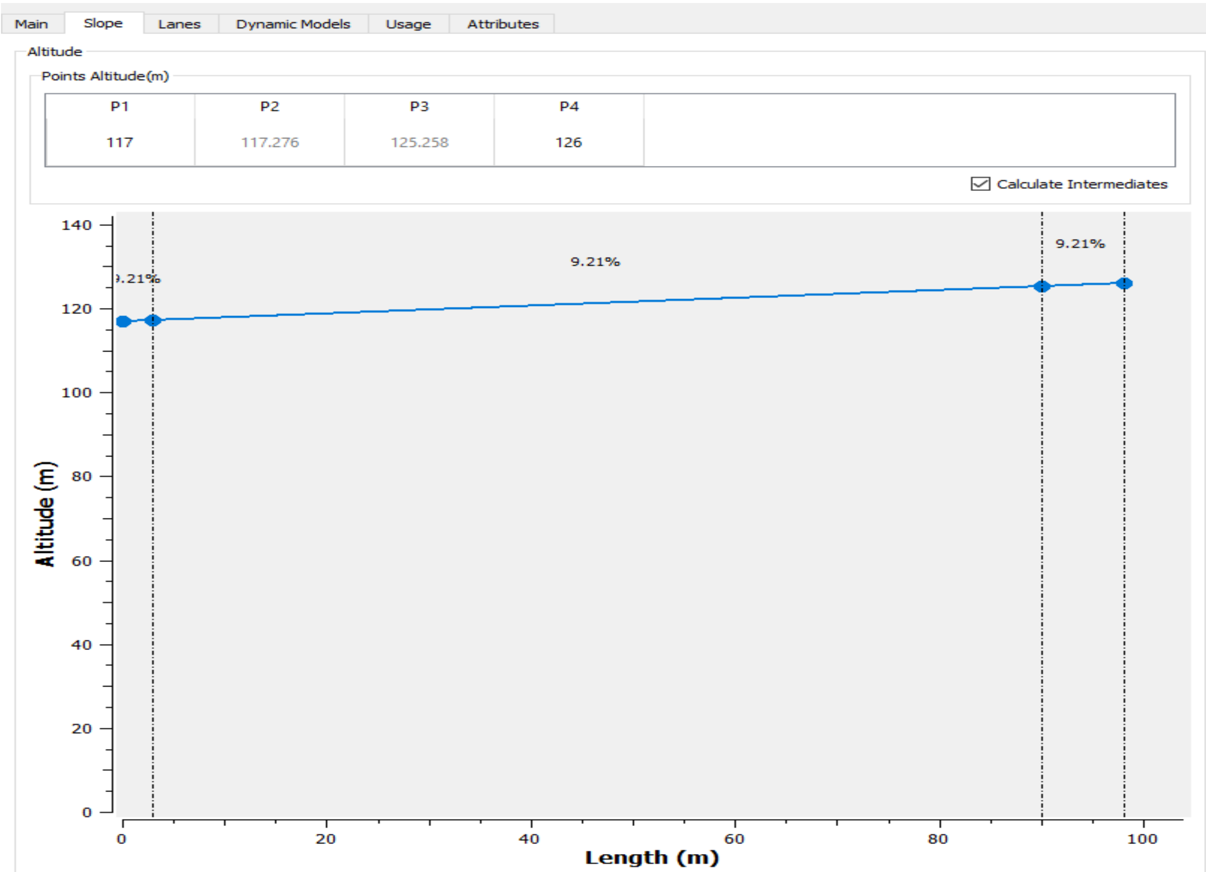
Ring Rd Slope in Aimsun Modelling



Ring Rd Slope in Aimsun Modelling



Internal Ring Rd Slope in Aimsun



Internal Ring Rd Slope in Aimsun