GREENHILL ROAD TRAFFIC SIGNAL LINKING

EVALUATION AND OPTIMISATION

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Master of Engineering (Civil)

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Declaration

I certify that the entirety of the work contained does not include any material without acknowledgement. The information presented in the literature review has been aptly referenced and the list of references are provided. The thesis work, in whole or in part, has not been submitted previously in any application of a degree.

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Date:

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Abstract

The regulation of traffic flow along a high-capacity urban road is executed by traffic signals. With the growth of population, there is a constant increase in traffic which leads to congestion on roadways causing the roads to reach their full capacity. Therefore, to reduce the congestion on the road corridor and to minimize stops and delays, coordination of signals proves to improve the efficiency of traffic flow. Signal Coordination is the linking of traffic signals of adjacent intersections to provide a green band progression to the moving traffic. This optimization of traffic signals increases the performance of traffic control system in urban networks. As a consequence of traffic volume upsurge, there is idling of vehicles which generates emissions and fuel consumption, travel delays and fatigue to drivers. Various techniques have been established with high computational complexity to face the challenge of signal coordination of Urban Road networks. This research is conducted to investigate congestion and produce models for better understanding and evaluate the impact on socio, economic and environmental factors. Sidra Software is used to evaluate the performance of intersection Network by signal coordination due to its accuracy of results. Nonetheless, there are limitations for Sidra Network on student license. Moreover, very few studies have scrutinized signal coordination with micro analytical as well as micro simulation software. This study, hence, is conducted on Green hill road in Adelaide consisting of eight signalized intersections. The results are compared with AIMSUN micro simulation. Traffic performance indicators are used to demonstrate the performance of the result. The results are then compared to the literature of the study to indicate the significance of the project.

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1. Introduction, Background and Significance

Traffic Congestion on arterial roads is a global phenomenon and adversely affects the economic productivity and quality of life in metropolitan areas. This in turn increases the travel time of the traveler, consumption of fuel and cost of the freight movements. The reasons of ever-increasing traffic volumes can be attributed to the population growth and hence growth in motorized vehicles (BTRE,2003). Many researches have been conducted to cater the issue of congestion. Intersections act as nodes to transportation Network, a location at which more than one road intersect to form an at grade junction. Traffic Signals are used to control and manage the movement at signalized intersections that experience elevated volumes of traffic (Lin, Zito and Taylor, n.d.).

Intersections play a crucial role in establishing a systematic transport system. It also portrays the congestion that restricts the capacity of the entire network. The significance of analyzing the performance of intersections has always been paramount to the transport researchers and practitioners. A foreign stat shows that intersection traffic congestion caused due to traffic delay observed a total delay of more than a third of urban road traffic and incidents accounted for 50% of traffic accidents (YU, WANG and GONG 2013). Generally, the intersections can be classified into three different types namely Signalized intersection, Unsignalized intersection and Alternative intersections. The traffic signal control of an intersection has been researched over 60 years after Webster published traffic signal setting guidelines for signalized intersections (Webster, 1958). Although traffic signals at intersections allow a safe passage of movement, large volumes of unbalanced flows can cause long queues during peak periods. This can be attributed to lack of coordination of traffic signals between the adjacent intersections. This study evaluates the section of arterial road with large traffic volumes resulting in congestion and no clear peak direction of travel. This research has therefore evaluated the existing traffic conditions and the operations of signal linking of the Network of eight signalized intersections on Green hill road in Adelaide, South Australia.

Figure 1-Greenhill road (8 Signalized Intersections)

To evaluate the performance of the network, a micro analytical software - Sidra intersection and Micro simulation software - AIMSUN was used for comparing the results. The outputs from the software show similar results. However, the analytical models are much easier to develop and calibrate than micro simulation software.

1.1. Aims and Objectives

The objective of this study was to evaluate and optimize the signal linking for the stretch of the study area. There is a research gap identified in this paper that needs to be addressed. By reviewing the literature and analyzing the gap, a research study is vital. The aims of the analysis were established before the undertaken study and are described below –

- Evaluate the efficiency of an interrupted traffic flow along a major arterial road connection with Green hill Road in Adelaide as a case study location.
- Assess a range of performance characteristics in microsimulation environments for varying time periods and traffic flow conditions.
- Propose and test a range of configuration scenarios with a view to optimize efficient operations and propose best practice for the location.

The evaluation of the study area was conducted in terms of key traffic performance indicators with the Micro Analytical and Micro Simulation Optimization.

1.2 Project Scope

The Scope of the project revolves around the objectives of the research study and scrutinizes the network performance in terms of traffic network impacts involving delays, queues, travel times, level of service along with economic (reduces user costs) and environmental (emissions and fuel savings). Different scenarios were developed from the base model and the feasibility of the model was evaluated. The configuration of the optimum scenario was adopted to facilitate the signal linking considering all the aspects.

2. Structure

The structure of the thesis consists of chapters which demonstrates different parts of discussion for the progression of thesis. The chapters are further divided into subsequent sections. Chapter 1 provides Introduction of the research study including the aims and project scope.

Chapter 3 is the method of analysis chosen for this research.

Chapter 4 reviews the literature on Traffic congestion, Environmental impacts in terms of emissions and fuel consumptions, socio economic costs and previous studies along with the research gap.

Chapter 5 indicates the significance of the study.

Chapter 6 discusses the Methodology adopted for conducting the research.

Chapter 8 and 9 presents the creation of analytical and simulation models.

Chapter 10 provides with the results of traffic model and its comparison.

And finally, Chapter 11 provides with the recommendations and future research options.

3. Analysis Method

This thesis represents the modelling of a network of traffic signals for improving the signal coordination of the Network. A number of research have been conducted on improving intersection performance using analytical and microsimulation modelling. Sidra is a micro analytical software which is used for the evaluation of individual intersection performance (DIT, 2021). This specific software was adopted as it is based on the concept of interest and presents with an output that is used for assessment of congestion (Yumlu, Moridpur and Akcelik, 2014). In this research a study was conducted on 8 signalized intersections using Sidra Intersection and a Network of 6 intersections was build using Sidra Network. There is a constraint on student license for Sidra Network and can connect only up-to 6 intersections in a row. Nonetheless, this is compensated by using a micro simulation modelling through AIMSUN.

AIMSUN was used to compare the results with Sidra. The traffic input parameters as well as the traffic volumes used for both Sidra and AIMSUN modelling were similar wherever possible. However, Sidra is an analytical software and micro simulation provides with visualization and results in more intricate detail of the traffic flow. Micro Simulation is comparatively a newer technique which displays the road traffic flow, within which each separate vehicle is evaluated at sub second intervals (Sykes, 2007). The same author states that the vehicles follow the alignment of road and makes decision simultaneously concerning with speed and lane choice. "Each simulation run utilizes a random value which generates a minor variability. A seed value is used to produce random numbers which impacts elements within the model operation" (AECOM Aus, 2019). Hence, for constituting a more comprehensive result, these models are runmultiple times with a separate seed value each time. Each replication produces a different outputand hence 10 replications should be run to reduce a high level of variability (DPTI MATSAM, 2019).

Comparison between Sidra and AIMSUN scenarios was conducted to confirm and validate the findings and to evaluate all the intersections.

4. Literature Review

This section reviews the current literature on Traffic Congestion and the impacts from congestion on arterial roads. Additionally, the Environmental impacts as well as the socio-economic costs associated are reviewed. At the end, previous case studies are reviewed.

4.1 Traffic Congestion

Traffic congestion on the major roads have become an ever-increasing problem for commuters. The congestion can be stated as demand of traffic exceeding the roadway capacity. Extreme levels of congestion are found to be closer to central business district. (Infrastructure Australia, 2019). The same report forecasts about the roads operating over their design capacity which will cause delays to moving traffic. The effects of social, economic and environmental implications on traffic congestion are very significant (Afrin and Yodo, 2020). Congestion is responsible due to plethora of reasons. Congestion can be differentiated as recurrent congestion which is demand induced and mostly occurs due to peak hours during weekdays at specific points in the network and non-recurrent which is induced by incidents of traffic such as accidents, roadworks etc. (Dept. of Transport, Energy and Infrastructure, 2006). Congestion can be attributed to the effect of the interaction between demand and supply factors with the use of cars for peak periods (Victorian competition and efficiency commission, 2006). The same report suggests an increase in recurring congestion induces non-recurring congestion to a greater extent. Non-recurring congestion give rise to greater than 50% of traffic congestion where recurring congestion is 40% (Afrin and Yodo, 2020). The reduction in congestion can however improve travel times, reduce delays as well as lower the environmental and social costs (Victorian competition and efficiency commission, 2006). The significant environmental impacts are associated with considerable increase in the travel times owing to hourly travel times for individualtravelers (Austroads, 2008).

4.2 Environmental Impacts – Emission and fuel consumption

Fuel consumption and Emission is another aspect in traffic signal synchronization. The growth in traffic is directly related to growth in population. Congestion increases the impacts of emissions due to the additional travel time of traffic. Transport is the third largest source of Australia for the emissions of greenhouse gases (Australia climate council, (n.d.)).

The math of traffic increase in Australian cities is rather straightforward (BTRE, 2003). From 2002 to 2020, increased car use per person should result in a 12 percent rise in traffic, with a further 18 percent increase owing to population growth (BTRE, 2003). As a result, global car traffic is expected to increase by roughly 33% during the next few years. When you factor in the rapid rise of LCV traffic (and the considerably lesser growth of heavy vehicle traffic), traffic in Australian cities is expected to increase by more than 40% over the next 18 years (BTRE, 2003).

By improving the fuel efficiency of new vehicles and enhancing traffic control techniques, fuel consumption in traffic systems can be lowered (Liao and Machemehl, 1998). Improved vehicle technology and design can help improve fuel economy (Liao et al. (1998)).

Vehicle types, roadway geometry conditions, traffic management methods, and traffic demand all influence fuel usage (Liao et al. (1998)). Fuel consumption models must account for a wide range of changes in roadway design and traffic regulation (Liao et al. (1998)). Researchers have been working on comprehensive models to better understand the relationship between fuel consumption and traffic management measures as a result of the fuel economy issue (Liao et al. (1998)).

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Figure 2-Delay Stops and fuel consumption as a function of the signal offset (Akcelik, 1981)

The reason why signal coordination is one of the most successful ways of decreasing fuel consumption and enhancing traffic performance and safety in urban areas is shown in the diagram above (Akcelik, 1981).

Implementing ITS applications such as advanced traffic management systems, advanced traveler information systems, and advanced vehicle control systems has been shown in numerous studies to have the potential to reduce negative traffic impacts, such as traffic congestion, as well as fuel consumption and emissions (Kutlimuratov, khakimov, mukhitdinov and Samatov, 2021). To optimize signal times at regulated junctions, several mathematical and simulation-based solutions have been developed. Traffic emissions are influenced by a variety of factors (Kutlimuratov et al. (2021)).

Implementing ITS applications such as advanced traffic management systems, advanced traveler information systems, and advanced vehicle control systems has been shown in numerous studies to have the potential to reduce negative traffic impacts, such as traffic congestion, as well as fuel consumption and emissions (BTRE, 2003). To optimize signal timings at regulated junctions, several mathematical and simulation-based solutions have been developed (BTRE, 2003). Traffic emissions are influenced by a variety of factors like traffic density, road capacity, vehicle operating conditions and technical requirements, and external environmental conditions are the factors to consider (BTRE, 2003). It also suggests that exhausted emissions from traffic on city roadways are mostly determined by the geometry and efficiency characteristics of intersections and traffic signals. Criteria pollutant emissions per unit of distance driven have been greatly lowered by to transportation technology initiatives, the use of new types of fuels in the powertrain system, technological advancements, and optimal engine operation conditions (BTRE 2003).

4.3 Socio Economic costs

High cost is imposed due to time delays, pollution, accidents, driver stress and additional vehicle wear and tear; it also Increases travel time, reduces travel time reliability, increases vehicle operating costs—reductions in accessibility and social involvement, which is the social cost of congestion. Costs of congestion imposed in the broader community include environmental and safety costs (Maunsell Australia, 2006)).

It is seen that when fuel use is converted to consumption per unit time and plotted against speed, the rate progressively eases downwards as speed reduces (Austroads Part 4, 2008). It shows that the engine load per unit distance rises as a vehicle decelerates (accelerates), and fuel consumption depends on how hard the engine is working (Austroads, 2008).

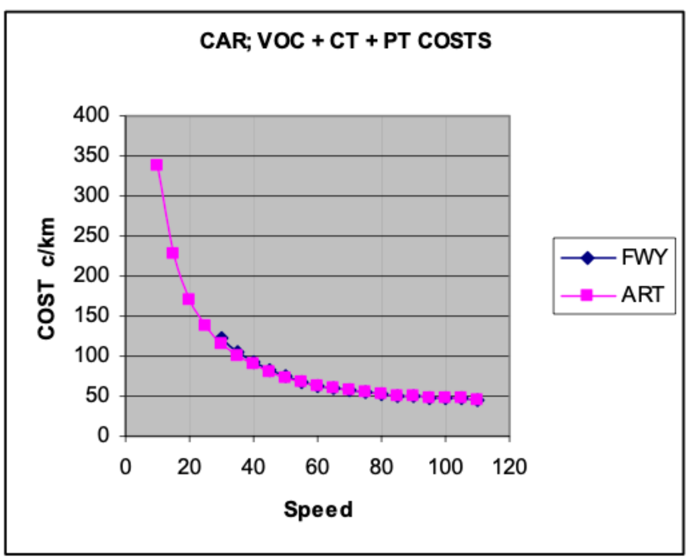

Figure 3-Passenger vehicle operating and time costs as a function of speed for freeways and other roads (Austroads, 2008)

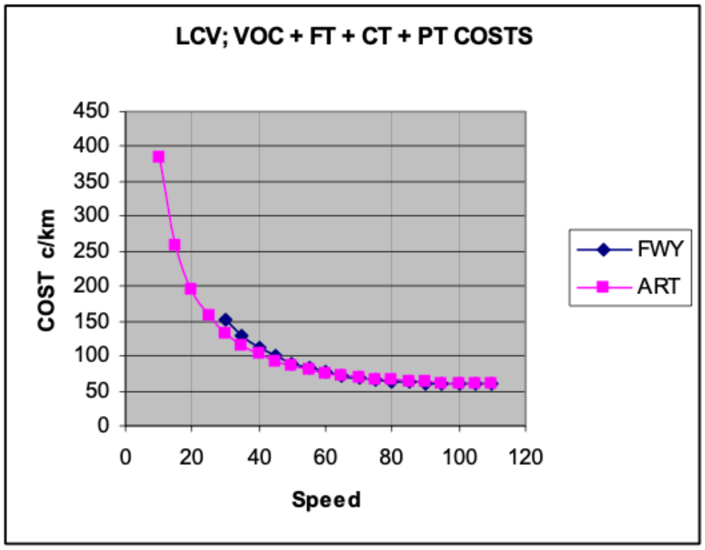

Figure 4 - Light commercial vehicle operating and time costs as a function of speed for freeways and other roads (Austroads, 2008)

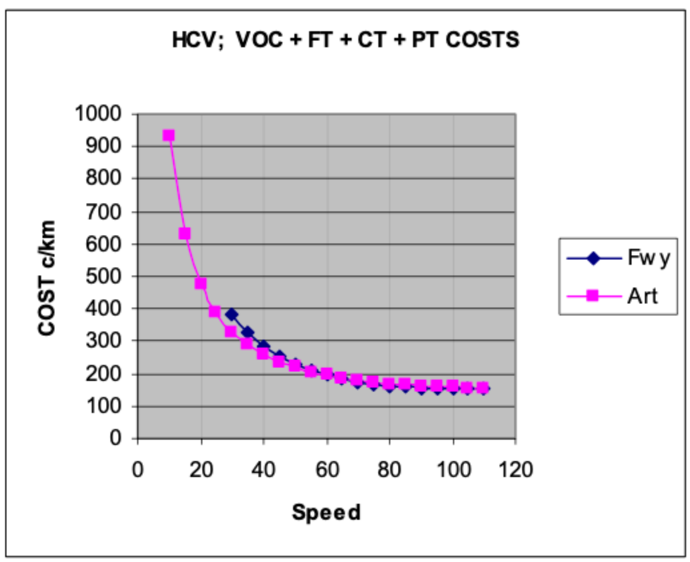

Figure - Heavy commercial vehicle operating and time costs as a function of speed for freeways and other roads (Austroads, 2008)

According to the government's Bureau of Infrastructure, Transport and Regional Economics, traffic congestion costs the national economy $16.5 billion in lost productivity each year. That figure is expected to reach $53 billion a year by 2031 if nothing is done. It is economically sensible to act to reduce these losses (Albanese A., 2017). Congestion raises bus fares and delays their passengers, mainly motorists, who suffer the consequences of their actions (“Traffic congestion: its economic and social consequences”, 2000). The same report suggests that congestion not only delays bus passengers but also, the buses themselves and this generates a need for additional vehicles, plus drivers, to operate them with fares going up consequently.

NCHRP report suggests some economic implications of congestion that costs businesses not just in terms of vehicle and driver delays, but also in terms of inventory costs, logistics costs, reliability costs, just-in-time processing costs, and market area reductions for workers, consumers, and incoming/outgoing deliveries (Weisbrod, Vary and Treyz, 2001). The same report proposes that businesses may respond to increased traffic congestion in several ways, including moving away, going out of business, and adjusting to reduced market regions for workers, suppliers, and customers—all of which result in some productivity loss. Previous studies that surveyed or interviewed business leaders found it difficult to document traffic costs because those who had moved away or gone out of business could not be located, and those who remained had evolved in ways that made it difficult for their staff to assess how the business would have been different in the absence of traffic congestion (Weisbrod et al. 2001). Reduced transportation costs translate into lower labor costs and faster delivery of products/services to clients, lowering total production costs (Weisbrod et al. 2001).

4.4 Previous Studies

Many studies have been conducted with respect to signalized intersections focusing on improving the capacity of the intersections and reducing congestion. However, either micro simulation or micro analytical software is a chosen method of analyses in all the research.

Bhattarai and Marsani (2015) conducted the study on coordination of traffic signals on the basis of time. The purpose of the study was to reduce the delay, number of stops and travel time. Vissim microsimulation software was used to conduct the coordination of signals on two intersections of Nepal. The results obtained were significant reductions in delay and travel time in Eastbound and Westbound directions. These were the results acquired by just coordinating the signals without changing signal and phasing parameters.

Another study found by Akmaz and Çelik (2016) was conducted on two signalized intersections in Turkey using Sidra intersection software in accordance with Australian standards and Highway capacity manual. Optimum cycle times were proposed to reduce the delays and improve level of service and capacity of intersection. The analyzed results proposed a comparison between both the methods and showed similar values. It was observed that by optimizing cycle times, the delay decreased, and the capacity of the intersections increased considerably.

Akçelik (n.d) developed a lane-based signal platoon analytical model for evaluating the signal coordination by Sidra Intersection. The closely spaced intersection with high traffic flow where lane changing for vehicles have limitations is evaluated. The research discusses inferences of utilizing lane-based method for modelling signal platoons and uses special movement classes to allocate a particular movement to different lanes and different signal phases which improves the signal coordination.

4.5 Research Gap

From the findings of the research, it was concluded that traffic signal coordination considerably reduces congestion and its associated environmental impacts and socio - economic costs. However, from the research of previous studies, it is evident that no study conducted has effectively used analytical software in accordance with micro simulation to provide an optimum solution for signal coordination.

For the improvement of road user experience, developing transportation systems have been stresses a lot lately. Traffic signal coordination have long been studied and many effective solutions have been developed for an effective transition of flow. Nonetheless, very little information is available for an optimum method for traffic signal coordination of a route. The question that arises is if there are alternative configuration scenarios to proffer a better road network which can reduce delays and increase the efficiency of traffic performance. In this research, the traffic parameters were assessed to check the efficiency of the existing network. An optimal solution was provided by testing and comparing the alternative scenarios analytically as well as in microsimulation environment.

5. Significance of Study

The growth in entire metropolitan vehicles kilometres travelled was expected to be 37% till 2020 along with lengthening of peak periods (Dept. of Transport, Energy and Infrastructure, 2006). The same study suggests that traffic management is crucial in order to reduce congestion in metropolitan cities. The trips on roads of Adelaide will increase by 24% and the cost of road congestion will double to $7.6 million by 2031 (Infrastructure Australia 2019). The literature findings suggest the significance of optimization of traffic signals which as a result can produce positive impacts on socio-economic and environmental factors.

The benefits of traffic signal coordination are –

- Minimization of Stops and Delays
- Increases traffic handling capacity
- Reduction in fuel consumption and air pollution emissions
- Reduced traffic congestion
- Improvised safety
- Economic Benefits that reduce user costs

As mentioned above, the research on Green hill road is crucial to improvise the signal linking improving the road capacity and mitigating crowding and congestion. The result from this study can also be implemented to other areas in Adelaide and can be used as a fundamental idea for future study. Furthermore, by optimizing the traffic signals, other environmental, economic aspects will also be improved. The different models were built for this study can be additionally improvised to aid research sought to gain the benefits of such changes.

6. Methodology

6.1 Study Area

The study area of the research is Greenhill Road in Adelaide, South Australia. The area stretches from Anzac highway/Greenhill Road intersection to Fullarton Road/Greenhill Road intersection. The scope of the study area consists of eight signalized intersections. The intersection sites lie into two SCATS regions. The region west of King William Road belongs to West Adelaide region whereas the other intersections lying east of King William Road lies in Unley region. The 8 intersections are given intersection numbers and are referred as follows –

TS066 - Greenhill Rd/Anzac highway

TS067 – Greenhill Rd/Goodwood Rd

TS316 - Greenhill Road / Sir lewis Cohen ave

TS181 - Greenhill Road / King William Road

TS068 - Greenhill Road / Unley Road

TS180 - Greenhill Road/ Hutt Road / George St

TS069 - Greenhill Road / Glen Osmond Road

TS070 - Greenhill Road / Fullarton Road

This segment of arterial road experiences large volumes of traffic on both direction of travel. To optimize the direction of travel, two models are used to propose and compare an effective solution

6.2 Sydney Coordinated Adaptive Traffic Signals (SCATS)

SCATS is an adaptive Urban traffic management system that synchronizes traffic signals for the optimization of the traffic flow across networks. SCATS system functions in real time and changes the signal time in accordance with the traffic demand and the capacity of the system (SCATS 6, no date). In lieu of intersection number, SCATS uses subsystems to reference each intersection or group of intersections. A subsystem can contain between oneto 10 signals. The signals in each subsystem is coordinated by SCATS as well as the coordination of one subsystem with another subsystem is also operated by SCATS.

The Data from SCATS is automatically recorded and is utilized for every intersection in Adelaide. The system uses vehicle loop detectors on each lane of an approach that are sensitive to vehicle detection. SCATS records number of vehicles in a traffic flow automatically using these detectors for every signalized intersection.

6.3 Data Collection

The research detailed in this paper obtained the data from a variety of sources. The annual average daily traffic for total volume of vehicles is adopted from Sa Map viewer. The annual average daily traffic is determined by the total volume of traffic over a section of road for a full year divided by number of days in a year (DIT, 2015).

Flinders University has developed a SCATS Database for the students to obtain data from more than 600 traffic signals for conducting traffic analysis. SCATS Data for this research was acquired from Flinders University SCATS database.

SCATS Operation sheet data is the operational design criteria for the traffic signals. The data consists of descriptive signal phasing operation, turning movement operation, phase percentage during peak periods discrete for each intersection which was used for analysing the input parameters used for modelling traffic signals at each intersection.

SCATS vehicle count dataset represents the traffic counts at a 5 minutes interval time for traffic signals at each intersection for the year 2017. The data is collected by detectors in every lane. A detector is a device installed in each lane which gets activated when a vehicle passes over it. See Appendix B for vehicle count analysis.

SCATS images are the graphic images that provides the specific detail of each intersection. The details of location are given in the site graphics. The configuration of the detectors, approaches at the time data was collected and the subsystem linked with the site. Figure 13 represents a typical graphic site image of intersection 070.

SCATS phasing data is obtained and monitored from the Strategic Monitor. The Strategic Monitor is the regional level computer which automatically records data for every intersection in a region. This phasing data from the SM file consists of existing SCATS signal phasing and cycle length timing.

Other data collected includes intersection drawings depicting details of the intersection geometry, lane width etc., google maps, DIT manual turning counts in conjunction with SCATS etc.

6.4 Data Analysis

Detailed Data Analysis of all the signalized intersection was performed. The section of road was studied to identify the busiest intersection and hence the peak hour for modelling on that intersection. Traffic volume counts of each site along with signal phasing was evaluated. This was followed by analyzing the existing signal linking of the Network of 8 intersections. This analyzed data was further used as input parameters for the analytical and simulation model to improve the overall signal linking coordination of the Network.

6.4.1 Busiest Intersection

The busiest Intersection accounts for the site that has the maximum volume of traffic flowing in each specified time period. To accomplish that, the Location SA Map viewer was used to produce annual average daily traffic (AADT) of each approach of the signalized intersection sites. As shown in the figure below, the traffic volume estimates of each road was used to produce the total volume of the site. These volumes can be seen in Table 1.

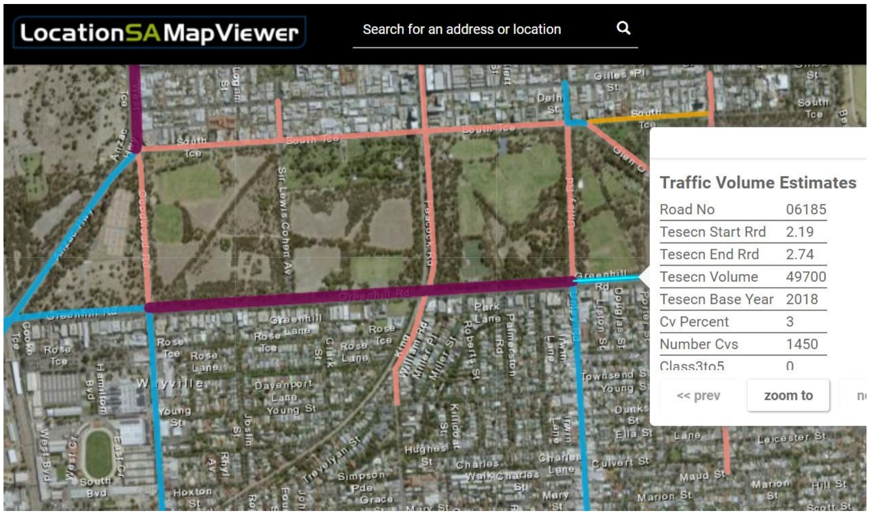

Figure 5-Annual Average daily traffic from SA Map

6.4.1.1 Predicting Traffic Growth

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Figure 6-Car traffic projections (BTRE, 2003)

The growth of traffic is very essential in road system planning (BTRE, 2003). The increase in traffic growth has a direct impact on the economic development. An increase in the income per person leads to increase in personal car travel (BTRE, 2003). Moreover, the population rise in Adelaide due to immigration as well as natural growth has a significant influence on traffic growth. The percentage increase of car travel per person and predictions of population is given as the car traffic projections. The figure 6 above shows car traffic projections for Australian cities for 18 years (2002-2020). There has been an 18% growth in traffic in a span of 18 years in Adelaide. This denotes a 1% traffic growth each year from 2002 to 2020. This 1% traffic growth per year is used to bring the volumes of traffic to current 2021 levels as data of traffic volumes is from previous years.

Table 1-Average annual daily traffic - Sa Map viewer

Map two-way	TS066	TS067	TS181	TS068	TS180	TS069	TS070
Road 1	29600	39400	51200	51700	49700	46200	42900
Road 2	49900	26800	16300	28500	11600	26200	30900
Road 3	39400	51200	51700	49700	46200	42900	34200
Road 4	38700	18600	12300	17700	9200	22600	42900
Total	157600	136000	131500	147600	116700	137900	150900

Table 1 shows the total volume of each site drawn out from the map representing volumes on each road of intersection. Table 2 depicts the respective year of the traffic volume countsobtained for each road of the site. A volume increase table was created to increase the volume by 1% per up to 2021. For instance, if the turning counts were from 2017 the volume was increased by 4% to bring them to the levels of 2021. Similarly, if the counts were from 2018, the volumes were increased by 3%. This is shown in table 3.

Table 2-Traffic Volume year

Year	TS066	TS067	TS181	TS068	TS180	TS069	TS070
Road 1	2020	2019	2019	2018	2018	2018	2017
Road 2	2017	2017	2019	2018	2018	2019	2017
Road 3	2019	2019	2018	2018	2018	2017	2016
Road 4	2018	2018	2019	2018	2018	2019	2014

Table 3-Traffic growth by 1%

2021%	TS066	TS067	TS181	TS068	TS180	TS069	TS070
Road 1	1.01	1.02	1.02	1.03	1.03	1.03	1.04
Road 2	1.04	1.04	1.02	1.03	1.03	1.02	1.04
Road 3	1.02	1.02	1.03	1.03	1.03	1.04	1.05
Road 4	1.03	1.03	1.02	1.03	1.03	1.02	1.07

Table 4 illustrates the final volumes by applying traffic growth to volume obtained in table 1.Total volumes of two sites, TS066 and TS070 were found to be highest. As seen in the table 4 below, site TS066 is observed to be the busiest intersection. However, site TS066 had many SCATS count errors. Hence, site TS070 was chosen to be the busiest intersection as it had more reliable SCATS data. See appendix A.

Table 4-Final Traffic Volumes

2021	TS066	TS067	TS181	TS068	TS180	TS069	TS070
Road 1	14948	20094	26112	26625.5	25595.5	23793	22308
Road 2	25948	13936	8313	14677.5	5974	13362	16068
Road 3	20094	26112	26625.5	25595.5	23793	22308	17955
Road 4	19930.5	9579	6273	9115.5	4738	11526	22951.5
Total	80920.5	69721	67323.5	76014	60100.5	70989	79282.5

The Graph below in figure 7 summarizes the total traffic volume depicting the number of vehicles per day for each intersection. The busiest intersection TS070 (Fullarton Road/Greenhill Road) with a volume count of 79282.5 was selected and the site was further analyzed with volumes from year 2017 to determine the peak hour for the model development.

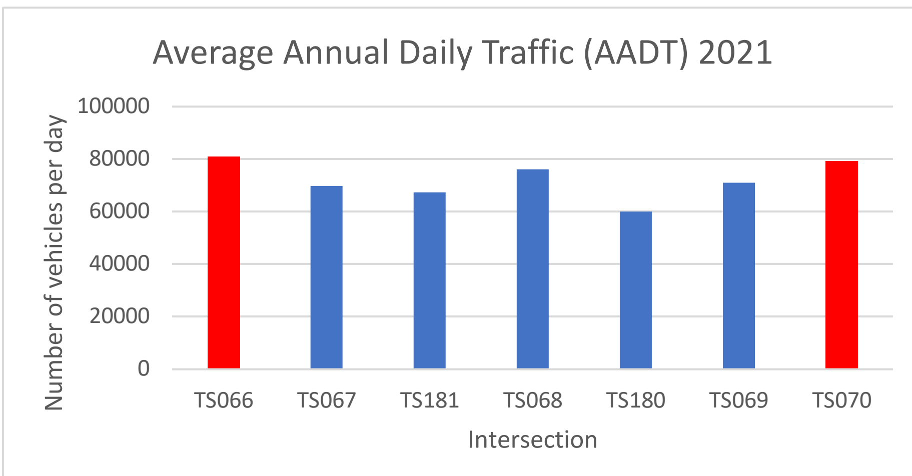


Figure 7-Traffic Volume : Average annual daily traffic

6.4.2 Busiest Month

For the chosen Intersection of TS070 (Fullarton Road/Greenhill Road), SCATS count for the entire year of 2017 were analyzed. This was achieved by evaluating the 5-minute traffic volume counts from each detector in every lane of the intersection. The volume of the individual 5- minute count was summarized to get a total volume of the month. Every month was analyzed discretely to conclude the month with the largest traffic volumes. From the figure 8 below, it is evident that the month of March was observed to be the busiest with a volume of 2372071. See Appendix A for the Volume count and selection of the Month.

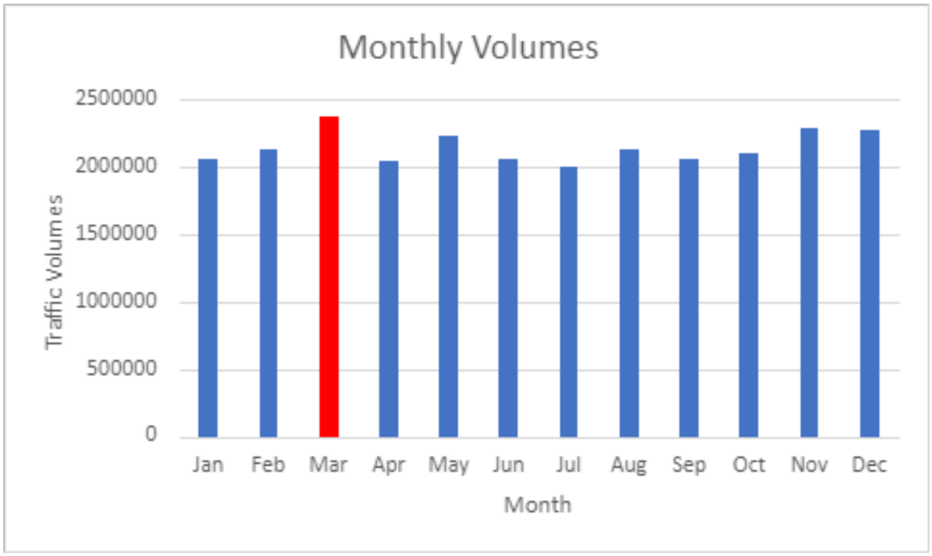


Figure 8-Monthly Traffic Volumes Analyzed

6.4.3 Busiest Week

The assessment of 5-minute Volume count for the entire month of March was performed. Each of the four weeks were calculated discretely for the largest counts. The first week of March was determined to be the busiest with a total traffic count of 418292. The graph below in figure 9 represents the weekly volume which were quite similar. See Appendix A for details.

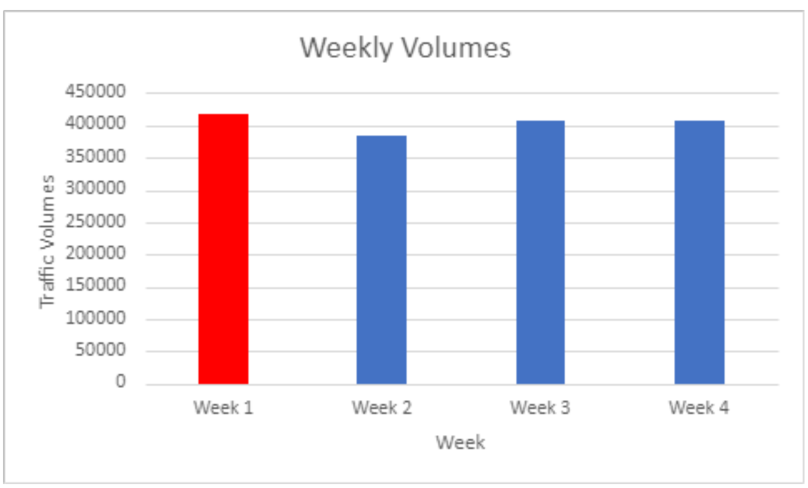


Figure 9-Weekly Traffic Volumes

6.4.4 Busiest Day

The Fig 10 below depicts the daily traffic volumes evaluated for the week days of first week of March. All five days for the first week were analysed for the site TS070. The traffic counts of 5-minute time interval between the hours 00:00 to 23:55 for each day was computed to obtain the busiest day. All the days during the week had approximately similar volumes of traffic. However, Friday showed the highest volume with 84899 vehicles throughout the day.

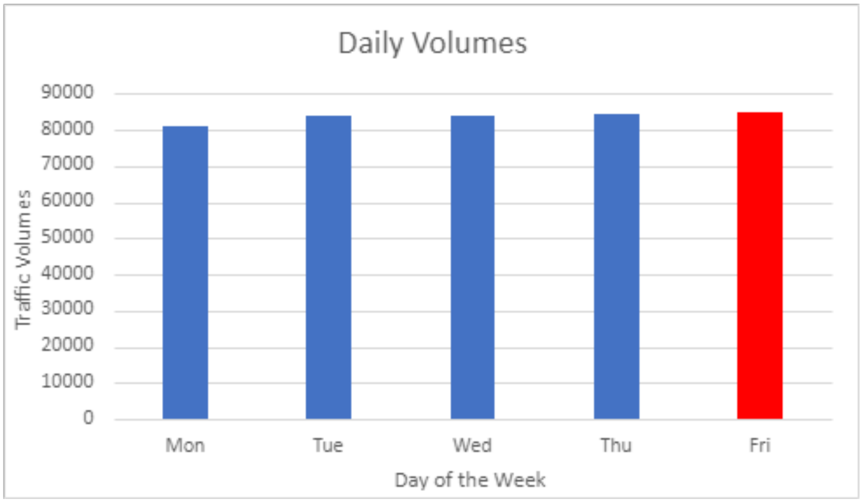


Figure 10-Daily traffic Volumes

6.4.5 Peak Hour

Fig 11 represents the traffic profile of 5-minute interval traffic counts evaluated on the busiest day, Friday March 10 between the hours 00:00 to 23:55. It should be noted that the traffic volumes soared from 6:25 and peaked at 8:15 with 610 vehicles in 5-minute interval of time. However, it plummeted after 8:15 before a steep rise from 14:35 and peaked again between the hours 16:45 to 17:45 with 6786 vehicles crossing the Fullarton intersection 070. Hence, the peak hour proposed was 16:45 to 17:45 i.e. afternoon PM peak as it showed the highest volumes of vehicles during the day. See Appendix A for peak hour analysis.

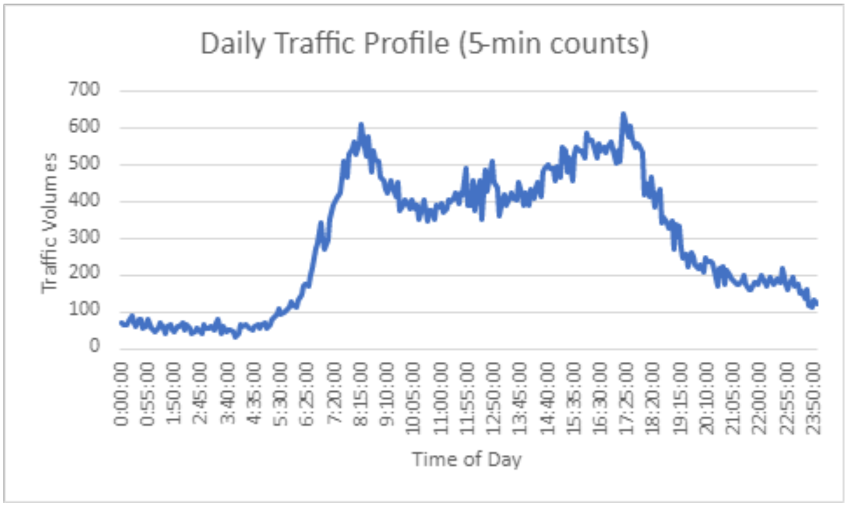


Figure 11-Traffic count of 10th March, Friday

6.4.6 Vehicle Count Analysis

Vehicle count analysis is referred as recording the number of vehicles (light, heavy, bus etc.) passing a particular intersection. Detailed turning count analysis of any intersection is a key to comprehend the performance of a particular signalized intersection (Chaparro, Chitturi, Noyce and Bill, n.d). The traffic volume counts utilized for this project were both automated and manual counts. The automated counts that were obtained from SCATS flinders database were used to analyze individual intersections. Manual counts from vehicle turning movement survey Department of infrastructure and transport were used in addition to SCATS counts to account for the light vehicles, turning movement for shared lanes as well as buses which were not detected by automated detectors. A combination of SCATS data and manual turning count data can give a rich information to validate the existing base case model for each modelling time period (DIT, 2021).

A thorough analysis of the counts was conducted on each intersection for the peak hour i.e. from 16:45 to 17:45. For illustration, the evaluation of one intersection, TS070 (Fullarton road/Greenhill road) is explained below. See appendix B for TS070 analysis.

The total number of left turning vehicles for the North Approach (157 from table 5) is summarized for the peak hour obtained from detector 21 (shown in fig 12) from the SCATS data. Light vehicles were calculated from the manual turning counts. The number of heavy vehicles is the difference between total and light vehicles. Buses were counted manually from the manual counts. Similarly, for the through movement of North approach, the number of vehicles in peak hour for through lanes (detector 2 and 3 in fig 13) is totaled (1001). Whereas for the right turning movement, vehicles passing through detector lanes 3 and 4 are computed (738). Light and heavy vehicles were calculated likewise. Similarly, other approaches were computed. This method is utilized for all approaches to establish precise counts for the intersection. Table 5 demonstrates a summary for intersection TS070.

Table 5-Vehicle turning counts (Intersection 070)

TS070	North			East			South			West		
	Left	Through	Right	Left	Through	Right	Left	Through	Right	Left	Through	Right
Total	157	1001	738	170	991	187	112	940	268	828	1334	60
Light	156	990	730	167	973	181	112	928	268	823	1326	60
Heavy	1	11	8	3	18	6	0	12	0	5	8	0
Buses	0	0	0	0	0	0	0	0	0	0	0	0

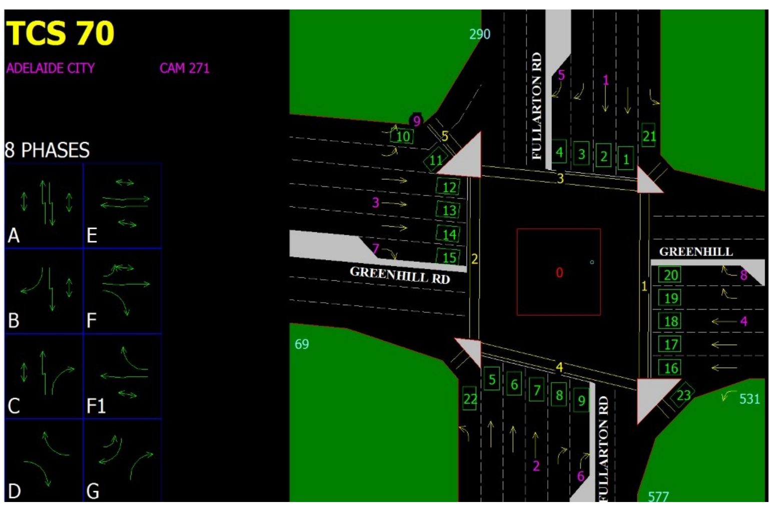


Figure 12-SCATS graphic image (Intersection 070)

6.4.7 Signal Phasing and Timing

A signal phase is defined as the combination of green and red signals that are associated with a single or set of traffic movements (TMR, 2021).

A cycle length constitutes the total time to complete a sequence of phases in a traffic signal.

SCATS SM data was used to acquire the phasing data. For signal coordination, the Signal timing data is of paramount importance. This data contains traffic signal information including phase time, cycle length, phase percentage etcetera. The SM data file was read for each of the eight sites for procuring the phase percentage as well as the cycle length for the respective peak period. Fig 14 indicates SCATS SM data for 066 intersection for the first cycle time of peak period 16:45. The cycle length (CL) is 120 seconds as highlighted in the figure 13.

```
Friday 10-March-2017 16:45 SS   1M+ PL 2.2  PV  29.2 CL  120 +4 RL 118' SA 56  DS 144
 Int   SA/LK   PH  PT!  DS  VO  VK!  DS  VO  VK!  DS  VO  VK!  DS  VO  VK! ADS
   66 S   1  '  C  31!  47   8   7!  43   5   7!  -        -!  -        -!   78
   66 S   2  ' AC  60!   7   2   2!  18   5   5!  64  19  19!  72  20  22!   70
   66 S   3  ' AB  46> 104  24  25> 109  25  27!  92  23  22!  -        -!   90
   66 S 131     B  16!  25   2   2!  28   2   2!  -        -!  -        -!   49
   66 S 206  '  D  40!  95  17  19!  86  16  17!  -        -!  -        -!   94
   66 S 207  '  D  40!  65  14  13!  99  18  20!  -        -!  -        -!   93
   66 S 208  'BDE  56!  50  13  11!  -        -!  -        -!  -        -!   51
   66 S 289 ^' CD  71!  73  14  19!  84  18  20!  -        -!  -        -!   81
  207 L   2  '  A  73!  57  18  19!  86  29  33!  89  31  33!  -        -! 2180
A=<23>  B=15 • C=26  D=34  E=1  F=2
```

Figure 13-SCATS phasing Data

During the peak hour (i.e. from 16.45 to 17.45), 30 cycles run in its entirety. This is shown in phasing analysis fig 14 (C1-C30). For each cycle, the phase percentage of the respective running phases for the intersection were recorded. Fig 14 demonstrates the phase percent of each cycle. The average of these phases was converted into seconds as Sidra input phase parameter requires values in seconds. For instance, average phase A is 25.4 % with a cycle length of 120 so the average phase in seconds will be 25.4 % times CL which is 30.48 seconds. Each of the eight intersections were analyzed respectively to establish an average value. Table 6 shows average phase in seconds for the entire modelling period with the respective cycle length. See Appendix B for Phase calculation.

Phase	A	B	C	D	E	F	G	CL
C1	23	15	26	34		2		120
C2	25	17	22	34		2		120
C3	21	19	22	36		2		120
C4	21	15	24	38		2		120
C5	25	13	24	36		2		120
C6	25	17	22	34		2		120
C7	27	19	22	30		2		120
C8	31	17	20	30		2		120
C9	27	17	22	32		2		120
C10	29	13	24	32		2		120
C11	25	13	26	34		2		120
C12	23	13	30	32		2		120
C13	21	13	30	34		2		120
C14	23	13	26	36		2		120
C15	23	13	26	36		2		120
C16	23	15	22	38		2		120
C17	21	13	22	42		2		120
C18	23	15	22	38		2		120
C19	25	15	24	34		2		120
C20	27	17	24	30		2		120
C21	25	15	28	30		2		120
C22	21	15	30	32		2		120
C23	23	17	26	32		2		120
C24	27	17	24	30		2		120
C25	27	17	26	28		2		120
C26	31	15	26	26		2		120
C27	33	15	22	28		2		120
C28	31	13	26	28		2		120
C29	29	13	28	28		2		120
C30	27	13	28	30		2		120
Average % CL	25.4	15.06667	24.8	32.73333	#DIV/0!	2	#DIV/0!	
Average seconds	**30.48**	**18.08**	**29.76**	**39.28**	**#DIV/0!**	**2.4**	**#DIV/0!**	**120**

Figure 14-Phasing Analysis of TS066

The signal cycle time for one SCATS region differs with the other region. The cycle length for West Adelaide region was 120 sec whilst for Unley region it was 150 sec as seen in table 6. Hence, for achieving coordination of signals, a common optimum cycle length is necessary.

Table 6-Average Phase (seconds)

	A	**B**	**C**	**D**	**E**	**F**	**G**	**CL**
TS066	30.48	18.08	29.76	39.28		2.4		120
TS067	33.04			18	22.48	20.08	26.4	120
TS316	71.64	22.48	25.88					120
TS181	52.3	15.2	15	24	3	60		150
TS068	39.6			28.2	37.5	16.7	28	150
TS180	67.3	15.2	22.2	45.3				150
TS069	27	29.3	58.4	35.3				150
TS070	39.6			18.7	49.2		42.5	150

6.5 SCATS Coordination

Coordination of signals between intersections can be established when the traffic flow volumes are large. The purpose of signal coordination is to flow down a road with all green lights (AITPM, n.d). Traffic signal coordination is to provide a smooth progression of traffic flow on roadways to reduce delay, stops and travel time (DOT - FHWA, 2021) This reduces the pollution and consumption of fuel.

For coordinating traffic signals, two criteria need to be followed -

- A common signal cycle length which runs the sequence of phases of vehicles and pedestrians at a site.
- The offset time between the start of green of one intersection and the start of green of the adjacent intersection in order to maintain a smooth flow of the stream of vehicles. (TMR, 2021)

Image removed due to copyright restriction.

Figure 15-Time Distance graph (DOT – FHWA,2021)

The visual depiction of flowing traffic through coordinated traffic signals can be seen on a time distance graph as seen in the figure 15 above.

Time is demonstrated on x-axis whilst distance on y-axis. Phases are depicted for each intersection with red and green time and the arrows represents the path of traffic flow in both the directions. In the above picture, the signals are coordinated in a two-way progression with effective green time for the platoon of vehicles moving along the corridor. When the signal is coordinated, a car moving from intersection L would reach intersection 2L when the signal turns green. The reason behind an effective coordination is the distance between the intersections along with the speed limit. Other factors that influence signal coordination are cycle length, offset and phase lengths.

SCATS can respond to the varying situations of traffic and the coordination occurs only when its necessary (AITPM, (n.d)). Marriages between intersections can occur when the arterial road experiences higher volumes (AITPM, (n.d)). Since the intersections in west Adelaide region operate on cycle length of 120 sec and intersections in Unley region operate on 150 sec cycle length, a forced marriage can be performed by linking the intersections to form a long group and a single cycle length.

Signals co-ordination is realised in SCATS on two levels: Offset Plans (OP) and Link Plans (LP). Offsets between signal sites belonging to the same sub-system (SS) are set by OP, whereas LP provide offsets between sub-systems, which are dynamically joint “married” by SCATS. (RMS, 2018)

Offset can be defined as the time in seconds of the start of the green phase of an intersection after the start of the green of the linked intersection.

6.5.1 SCATS Existing Linking

For a particular SCATS region, the existing signal linking of the region is adopted from SCATS LX file. “The LX file is a SCATS configuration file that contains signal setting details of all sites in a SCATS region” (RMS, 2018 pp 12). The SCATS regional computer produces the information data every day at 1 am.

The existing signal linking is broken between the two SCATS regions just west of King William Road. The signals in red belongs to West Adelaide whereas the signals in purple belongs to Unley region.

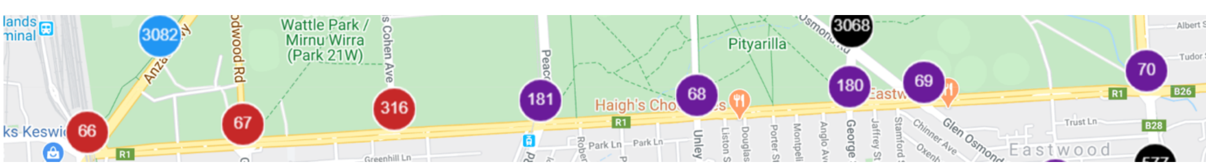


Figure 16-Intersections depicting broken signal linking

SCATS identify each intersection with subsystem numbers (SS) and not traffic signal numbers. A subsystem can consist of a single intersection or a group of intersections. The figure below illustrates the working of subsystem. Subsystem 1 contains 3 intersection sites whilst site 4 and site 5 are in separate subsystem. When the individual sites are in a single subsystem, they are linked by internal offsets as shown in figure 17. Whilst individual sites in seperate subsystems are linked by external offsets. For this study, all the sites are in individual subs ystem so the linking was performed through external offsets.

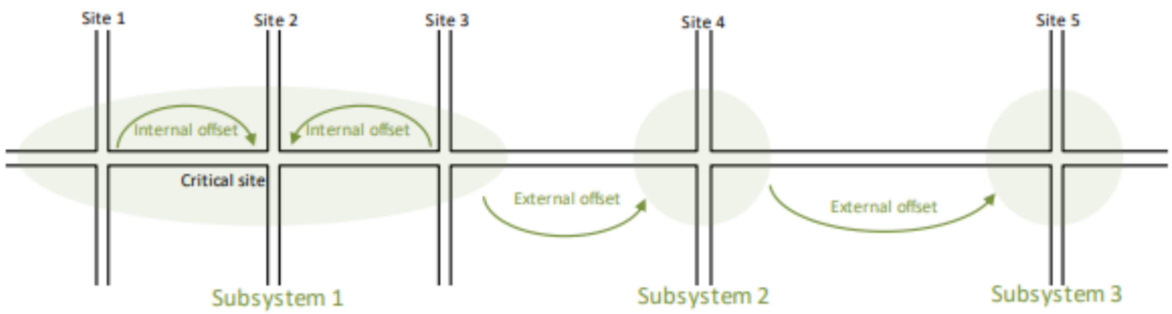


Figure 17-Signal Linking Explanation

For linking the intersection sites within the subsystem two methods are used -

Internal Offsets - These are used to link the sites within the same subsystem. This is identified as Progression Plans (PP) by SCATS. Fig 19 shows the progression plans (PP) as 0. This indicates that every intersection in the proposed area of scope is in a separate subsystem.

External Offsets - This term is referred as Link Plans (LP) by SCATS. External offsets are used to link intersection sites in separate subsystems. A subsystem has four link plans. These link plans are based on different times of the day. The signal linking is through external offsets (link plans) within the entire Network. The four link plans are -

- Link Plan 1: light / night time traffic flow (low cycle time)
- Link Plan 2: afternoon peak
- Link Plan 3: balanced flow between both directions

- Link Plan 4: morning peak (Main roads WA, n.d.)

Looking at the peak hour, the peak period computed was Afternoon peak. Hence, the link plan used was Link plan 2 for signal linking.

Figure 18 below shows a typical LX file of Unley region from SCATS. Therefore, the LX files for West Adelaide region contains 3 sites whereas the file for Unley region contains 5 sites. The data analysed from these files was utilized to create signal linking plan and hence a linking map for the Intersection Network.

```
AT=6!BT=6!CT=6!DT=6S!ET=6!FT=6!GT=6S!
PP1=0,0D!PP2=0,0D!
PP3=0,0D!PP4=0,0D!
SS=8!LCL=42!HCL=150!SCL=60,0!KCL=160!ZSS=
SK=DDGOBF!
XCL=120!SZ=96,100!
FCL=30,40,45,50,60,70,75,80,90,100,110,115,1
PS1=42^,60!PS2=90,108!PS3=90,108!PS4=90,1
LP1=50,50B69!
LP2=50,45B69!
LP3=50,45B69!
LP4=-50,-50C69!
```

Figure 18-LX file data for Unley region

Link Plan Evaluation from SCATS for site TS070.

LP2 = 50,45B69!

LP2 Link plan number 2

50 First offset - This indicates that the subsystem cycle generator will be zero 50 seconds after the end of the nominated phase

45 Second offset - The subsystem cycle generator will be at zero 45 second after the end of nominated phase

B Nominated phase which is referenced for determining the offset link

69! It is the intersection TCS number which is another subsystem to which this subsystem is to link.

This demonstrates the linking between site 69 and 70 so that traffic flows smoothly without stopping. This implies the start of the green time for intersection 070 will begin 45 seconds after intersection 069. The visual depiction of the linking of the intersections is shown in figure 20.

The following data has been analysed from the file for afternoon peak to create the linking map.

Linking Plan for PM Peak

For "West Adelaide Region":

- TS066: SS=1, LP2= -55, -50D207
- TS067: SS=10, LP2=-30,-25B66!
- TS316: SS=41, LP2=30,30F67!

For "Unley Region":

- TS181: SS=16, LP2=-35, -30A68!
- TS068: SS=15, LP2=30,25D180!
- TS180: SS=14, LP2=5,5C69!
- TS069: SS=2, LP2=-50, -30E93!
- TS070: SS=8, LP2=50,45B69

6.5.2 Signal Linking Map

The signal linking map illustrates the linked signals in Unley region and west Adelaide region with a broken link between them. The Red boxes depicts the offsets along with the phase. Negative sign shows the green time will start before the nominated phase. For instance, green time on site 067 will begin 25 second before the start of phase B of intersection 066. This will allow the platoon of vehicles to cover the distance between the intersection before the start of green at site 067. The green box shows subsystem numbers indicating each site in a separate sub system.

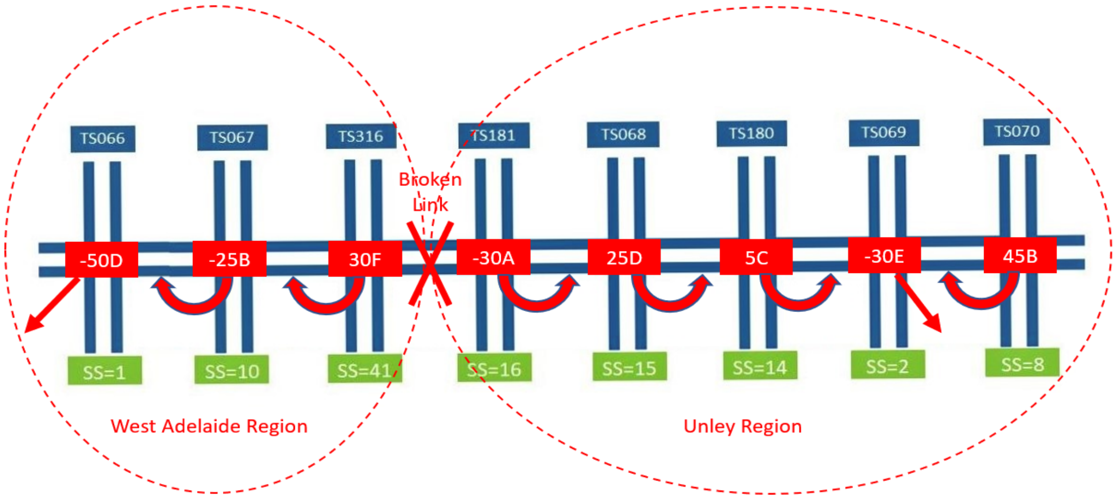


Figure 19-Signal Linking Map

7. Queue Length Survey

Queue length surveys requires counting the number of vehicles positioned in a queue at an intersection at the start of the green signal. Queueing of vehicles suggests that the demand exceeds the road capacity. These are used to calibrate the traffic model and provide evidence of congestion and delay. As the study area is Greenhill road, the survey was conducted on approaches of the Green hill road. Queue surveys are typically measured in metres or number of vehicles. For the purpose of Sidra model calibration, the length measured in metres was considered.

During the peak time of the day, for one-hour period, a 15-minute survey was performed at each intersection. At the start of green of the signal, the back of queue was recorded using a camera as seen in the figure 21 below. For each cycle during an interval of 15 min, the back of queue was recorded at an approach. An aggregated six or seven queue lengths were produced based on the cycle length at the intersection. These lengths were measure in metres. An average of these queue lengths was used for calibrating the model.

The accuracy level of the queue length survey is often less and cannot be clearly defined. It is inconsistent for validation. Nonetheless it is crucial to identify maximum queue lengths for the approaches. (DIT, 2021).

Figure 20-Queue Length survey (Greenhill Road)

8. Sidra Intersection

The model developed for this study in Sidra consisted of eight individual signalized intersections and a Network model of 6 intersections as there is a restriction on student license. The following modelling procedures were followed through for building the Network of Base model. Sidra Network is used to connect the individual sites created and for a network wide performance. Routes were developed for the alternative scenarios to illustrate the direction of signal linking. The output reports of routes demonstrated route travel performance and produced time distance diagrams showing signal coordination of the Network.

8.1 Intersection Configuration

The concept of the creation of individual sites is that the site geometry can be created from the intersection drawings as shown in fig 21 as well as google maps. Different input parameters were modified to build the site. The lane geometry parameter was used to input the number of lanes, lane discipline and lane data. Other input parameters include pedestrian movement indicating full or staged crossing, traffic growth, volumes, priority and phasing times evaluated in this research.

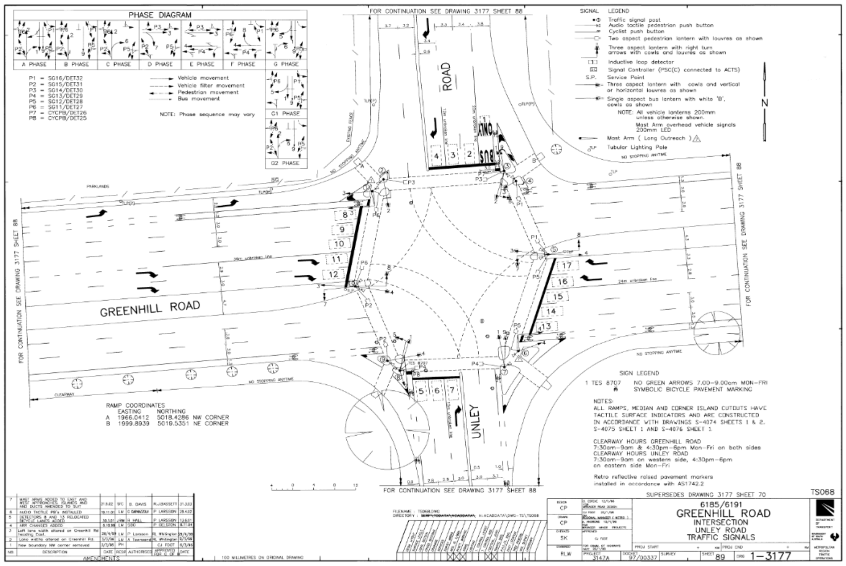


Figure 21-Intersection Drawing

8.2 Traffic Volumes

The traffic volumes analyzed for the afternoon peak hour (16:45 to 17:45) were used as input volumes for each signalized intersection of Greenhill Road. The left, right and through movement of every approach was inputted to duplicate the total volumes of intersection.

8.3 Priority and Phasing time –

The priority parameter is provided to give way to the other movements in an intersection (DIT, 2021). An appropriate priority needs to be provided for a proper functioning of the signals. The phasing and sequence of the intersections is provided according to SCATS phasing. The phase times are input as analyzed above.

8.4 Calibration

Calibration is the process of adjusting a set of parameters within the model according to the observed value. The observed data is based on the queue length survey performed for the study area. The parameter that was adjusted was Basic Saturation flow. The Basic Saturation flow rate

The table shown below illustrates the length of queues in meters for a single approach of green hill road of each intersection. For a 15-minute queue length survey, the back of queue observed during 7 cycles was recorded and calculated in meters and an average value was used to adjust the queue length in Sidra model.

Table 7-Queue Length measure in metres

	CYCLE 1	CYCLE 2	CYCLE 3	CYCLE 4	CYCLE 5	CYCLE 6	CYCLE 7	Average
TS066 (East)	57	75	72	48	53	59	57	60
TS067 (West)	160	149	178	198	198	83	147	159
TS316 (West)	75	75	53	22	31	53	69	54
TS181 (West)	259	268	257	258	258	259	276	262
TS068 (West)	72	155	137	63	153	185	190	136
TS180 (East)	33	26	52	24	53	20	71	40
TS069 (West)	75	52	68	55	55	100	111	74
TS070 (West)	102	105	131	76	75	114	113	102

After attempting to calibrate the queues of the existing model, it was observed that the traffic volumes on green hill road are much lower due to COVID – 19 than it was in 2017. Moreover, according to 1% traffic growth per year the traffic volumes should be 4% higher than 2017. Therefore, the queues could not be decreased to the current observed queues as shown in the table 7 using the realistic Maximum Basic Saturation Flow of 2400 veh/h which is the maximum observed on freeways.

Despite the model not being fully calibrated, the parameters used in the existing model were also applied for all the alternative scenarios and the relative comparison between the model results were still valid.

9. AIMSUN

Microsimulation was used for better visualization and a more detailed analysis of the Network Operation. The reasons for selecting AIMSUN micro simulation modelling was because it is extensively used by department of transport. Several other reasons include

- Due to a limitation in Sidra license i.e., only 6 intersections can be connected to a network. AIMSUN was used to evaluate the network with all eight signalized intersections.

- To confirm the findings obtained from analytical results of Sidra Model.
- Sidra modelling uses average vehicle from each vehicle class while AIMSUN uses different vehicle parameters for each individual vehicle
- AIMSUN network can match the real-life road geometry conditions better than Sidra

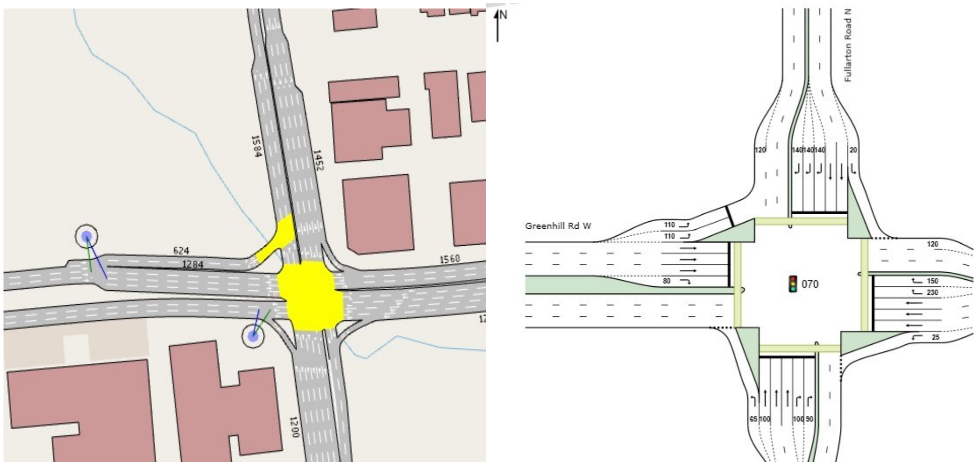


Figure 22-Comparison of AIMSUN and Sidra geometry

- To simulate and observe individual vehicle movements
- To produce simulation movies to be used in seminar presentation

9.1 Creating the Model

Figure 23-AIMSUN Model Geometry

AIMSUN was used to duplicate the entire study area of Green-hill road with eight signalized intersections exactly, hence AIMSUN can demonstrate the real road geometry without the need to create each intersection separately and construct a Network that was used for Sidra. The model is constructed by the available electronic map as the basis for the road system.

The real data sets consist of real-life turning counts of the study area (MATSAM, 2019). The data set for this research covers the afternoon peak period. However, for this study, the real data set file was obtained from the supervisor due to time constraints. The real data set was saved in the real data set folder.

The traffic demand is depicted by a matrix of journeys that links the origin and destination zones, that acts as sources and sinks for vehicles (Sykes, 2007). Traffic demands are split into matrices names cars and trucks (MATSAM, 2019). The vehicles between the zones are obtained from several methods such as manual and automated traffic counts, land use data, interviews etc. The origin and destination matrix for this study was developed manually with 17 zones within the study area. Nearly 21,000 vehicles were observed with 3% commercial vehicles.

For signal phasing of the model, Master control plan was created. Since AIMSUN does not optimize the traffic lights, optimized Sidra phasing was implemented in the model. For the base model, existing signal linking offsets were used. For alternative scenarios, eastbound subpath and westbound subpath were created and the offsets were changed manually for linking the intersection by using the signal offsets obtained from Sidra model. 10 replications were generated, and the average replication was used to produce results.

9.2 Calibration

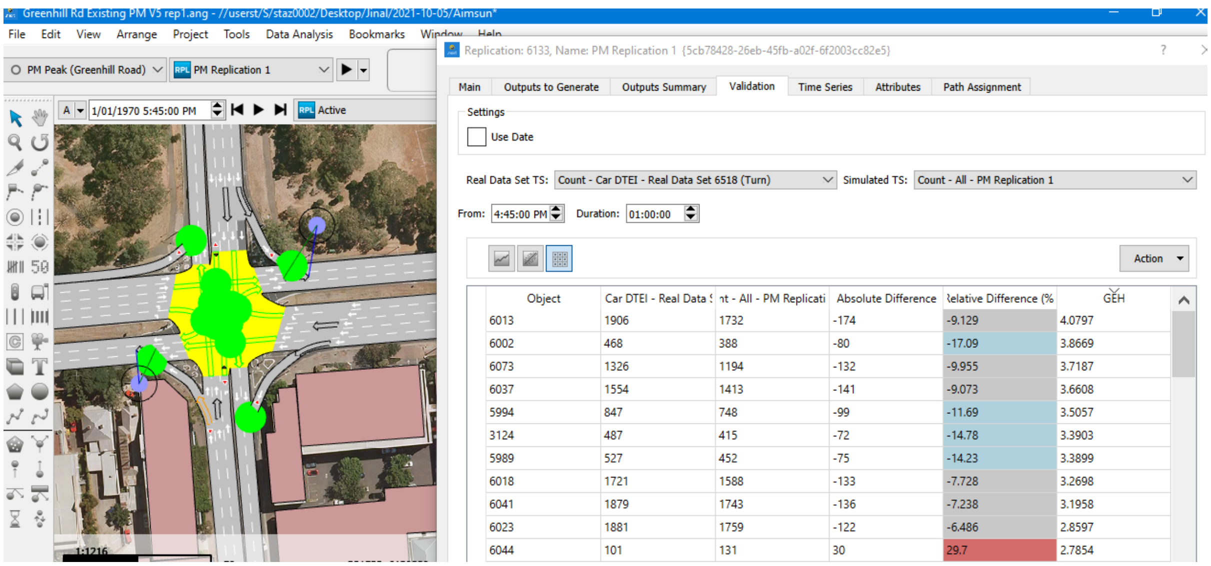
The fundamental step in building the model is calibration. It is known as the adjustment of model parameters to match the real-life traffic movements to the modelled movements. Due to Covid-19 resulting in much lower traffic volumes, the model was not calibrated for queue lengths.

Criteria and Measures – Full Model Period, Warm-Up Period and Peak Hour(s) to be reported	Acceptability Level
Turning Movements	
GEH Statistic for individual flows / movements	
Defined non-critical flows / movements	All <5.0
(Any values >5.0 to be documented)	
All other flows / movements	All <3.0
(Any values >3.0 to be documented)	
Average GEH Statistic for all flows / movements	<1.5
Plot of observed vs modelled individual flows / movements	
Line of Best Fit	
Slope	1.00±0 01
R^2	>0.99
(Slope equation to be included, intercept = 0)	

Figure 24-GEH values: DPTI Standards

However, for model calibration / Validation GEH values were used for comparing the modelled turning movements with observed movements. Figure 24 shows the criteria for acceptable GEH values. GEH values less than 5 in the model illustrates that the counts are close to the observed volumes. The GEH values for calibration of AIMSUN model is shown below.

GEH calibration less than 5



Object	Car DTEI - Real Data	nt - All - PM Replicati	Absolute Difference	Relative Difference (%	GEH
6013	1906	1732	-174	-9.129	4.0797
6002	468	388	-80	-17.09	3.8669
6073	1326	1194	-132	-9.955	3.7187
6037	1554	1413	-141	-9.073	3.6608
5994	847	748	-99	-11.69	3.5057
3124	487	415	-72	-14.78	3.3903
5989	527	452	-75	-14.23	3.3899
6018	1721	1588	-133	-7.728	3.2698
6041	1879	1743	-136	-7.238	3.1958
6023	1881	1759	-122	-6.486	2.8597
6044	101	131	30	29.7	2.7854

Figure 25 GEH values

10. Result and Discussion

This section of the thesis describes the results from the existing as well as alternative scenarios fromSidra and AIMSUN. Comparisons between the analytical and microsimulation model has been made to confirm the findings of the results.

10.1 Sidra Results

Along with the existing model created for the afternoon peak, three alternative scenarios werecreated to improve the overall Network performance by signal linking.

10.1.1 Eastbound Scenario

The Eastbound Scenario was created by linking the signals in east direction. This was developed bycreating travel route towards east direction. The type of vehicles selected for the route was light vehicles. However, a separate scenario was produced with heavy vehicles which showed similar results to light vehicles. The time distance graph illustrated below (fig 26) shows all 6 intersectionslinked towards east direction. The bottom of the graph represents the beginning of the traffic flowfrom site 066. The distance between the intersections along with the time between the start of green of successive intersections is provided in the graph. However, due to difference in the length of phases at adjacent intersections, not all vehicles in the stream passes through. A portion of traffic does experience some delay which can be seen when the green band overlaps red phase. Nonetheless, the eastbound scenario proves to have a better coordination than the westboundscenario which is explained later in this section.

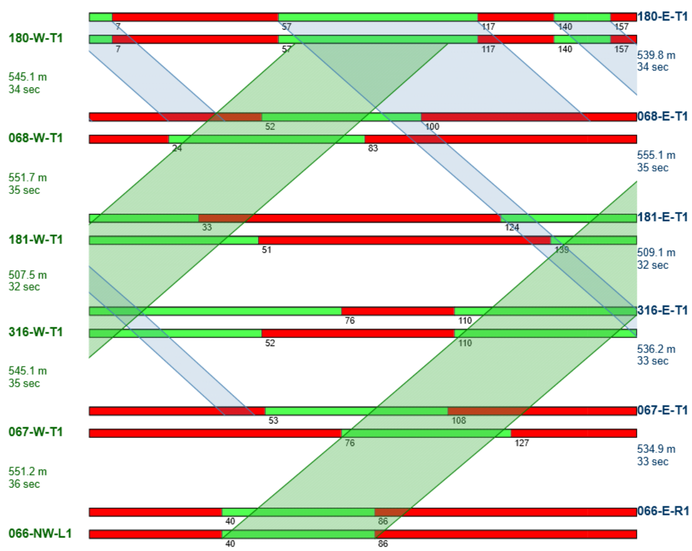


Figure 26-Time - Distance Graph (Eastbound Scenario)

10.1.2 Westbound Scenario

The westbound scenario created is the signal linking with the flow of traffic moving in the west direction. This was produced by developing travel route towards west direction. The flow of traffic as seen in the figure 27

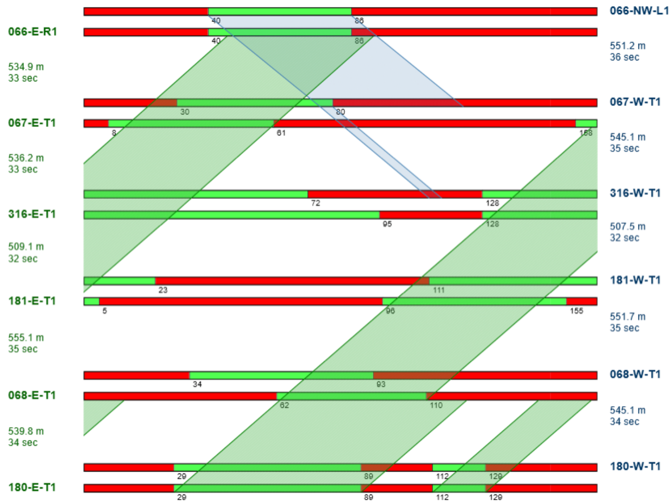


Figure 27-Time - Distance Graph (Westbound Scenario)

begins from site 180 towards the west direction. For westbound scenario as well, two separate routes were developed and attempted to optimize- light and heavy vehicles. However, both showed similar results and the scenario with light vehicles was further optimized. Approximately half portion of traffic volume moving from intersection 180 E experience a red phase at intersection 068. Similarly, the platoon of vehicles passing smoothly with green time at intersections 180 and 068, faces red phase at intersection 181. Hence, at every intersection in the westbound scenario, some vehicles in the platoon need to stop at a red phase which increases the overall delay and travel time. Therefore, when compared between eastbound and westbound direction scenario, eastbound proves to be a better scenario.

10.1.3 Two-way progression

Two-way progression is the movement of traffic volume in both the direction of travel when the signal of both direction is green at the same time and at the same intersection.

Sidra modelling of the signal linking in Eastbound and Westbound direction has shown better network operation than the existing model. This is mainly due to the existing signal linking broken in the middle of the route and individual intersection off-sets not perfectly optimized.

In addition to finding the preferred direction of travel to be linked, an evaluation was done in two-way vehicle progression. Due to the restriction of Sidra student license for interactive offset adjustments, all the changes were made manually.

It was seen that the best performing scenario would be the two-way progression. This means that instead of favoring one direction of travel it would be more beneficial to favortotal number of vehicles travelling, no matter in which direction they travel.

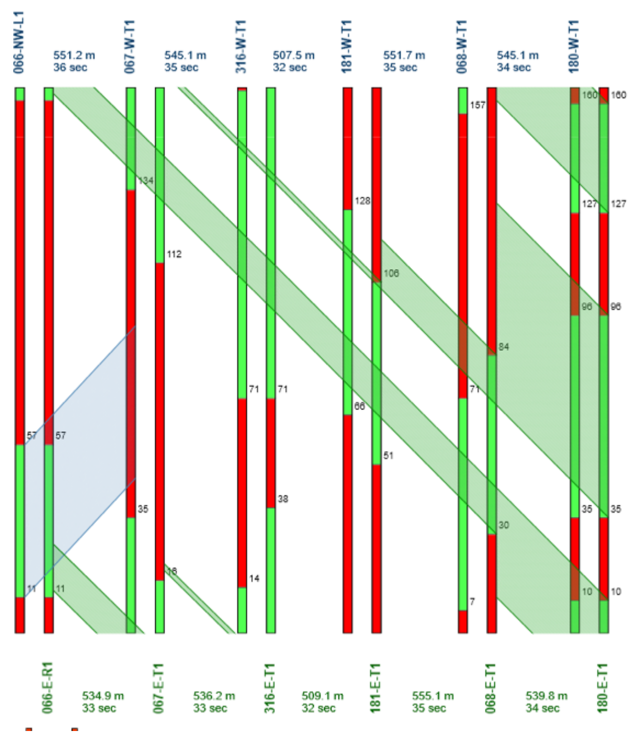


Figure 28-Time - Distance Graph (Two-way progression)

Several other parameters were used to evaluate the improved performance of the Network. The linking of signals showed an improved performance than the existing model which was evaluated by key traffic performance indicators such as level of service, average delay, travel time, fuel consumption, costs etc. Below are the comparisons provided between all the scenarios developed.

10.1.4 Average Control Delays

The average delay time in seconds measured for existing and alternative scenarios as shown in figure 29 below clearly states the efficacy of signal linking in the scenarios. The existing PM model resulted in an average delay of 50.2 seconds. When compared with the Westbound, Eastbound and Two - way progression the delay time dropped to 44.8 sec, 43.9 sec and 42.5 seconds demonstrating the linking of two - way progression to be a better approach.

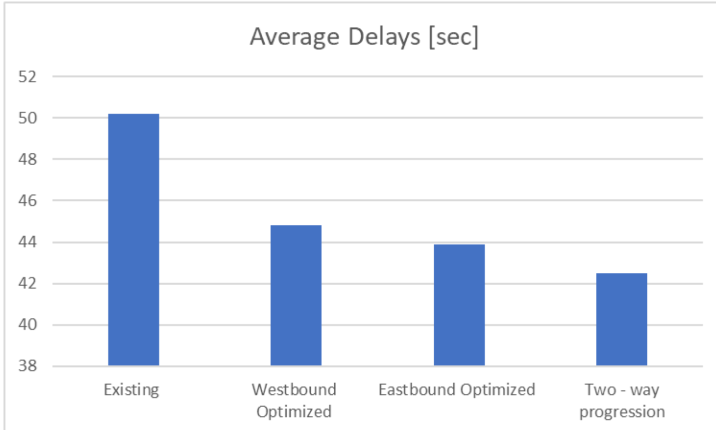


Figure 29- Results - Average delays

10.1.5 Level of Service

Level of service can be stated as the parameter to measure the effectiveness of an intersection. In 1985, the Highway Capacity Manual (HCM) was one of the few first ones to suggest using the level of service (LOS) as an evaluation index of road performance. The table 8 enlists the LOS of the entire Network. LOS is measured from A to F, with A representing the optimum level of service and F indicating the worst service with more delays. Signal linking for the optimized scenarios improved the service from E to D. Table 9 shows level of service of individual optimized intersections. See Appendix for Level of Service.

Table 8-LOS Network

Scenarios	LOS of Network
Existing	E
Westbound Optimized	D
Eastbound Optimized	D
Two - way progression Optimized	D

Table 9-Individual Sites LOS optimized

Individual Intersections	Level of Service Optimized
TS066	D
TS067	D
TS316	B
TS181	E
TS068	E
TS180	D

10.1.6 Environment Impact – Fuel consumption

The environment impact refers to the fuel consumption and emissions that are relevant to the vehicles travel in each model. Another aspect to measure the overall impact of coordinated network performance. Signal Coordination is one of the effective methods to reduce the fuel consumption and improve the overall performance of traffic and safety in an urban area (Akcelik, 1981). The fuel consumption table below depicts that from an existing condition model, over 3219.3 litres of fuel is consumed per hour for a network developed of 6 intersections. However, linking the traffic signals and optimizing for three scenarios, considerable reduction in fuel consumption can be seen. Westbound direction consumes 40425.14 l/h of fuel whereas eastbound scenario shows a fuel consumption of 3047.2 litres/hr. Although, two-way progression was seen to be an optimum linking solution, the fuel consumption in an hour is seen to be more (3080.5 l/h) than optimized eastbound. The reason behind this can be attributed to average speed of some individual intersection increased for eastbound scenario which contributed to overall reduction in fuel consumption than two-way projection. See appendix for route performance.

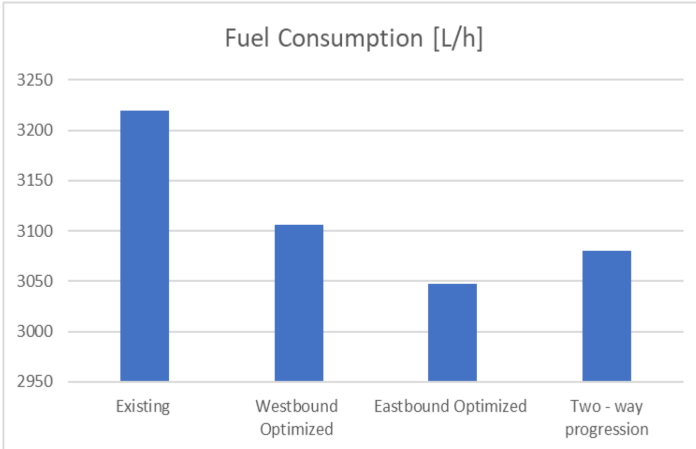


Figure 30- Results - Fuel Consumption

10.1.7 Total Costs

The total costs can be attributed to the direct vehicle operating costs which often includes the cost of fuel, maintenance, and the time cost of vehicles occupants (Sidra Solutions, n.d.). The existing model displays a total cost of 42437.62 $/h which has significantly reduced after signal coordination of the Network. The total cost values of all the three scenarios is quite close as shown in the graph below. Westbound – 40425.14 $/h, Eastbound – 40030.89$/h and Two-way progression – 39743.51 $/h. Reduction in delays and stops has demonstrated of cost savings of up to 7%.

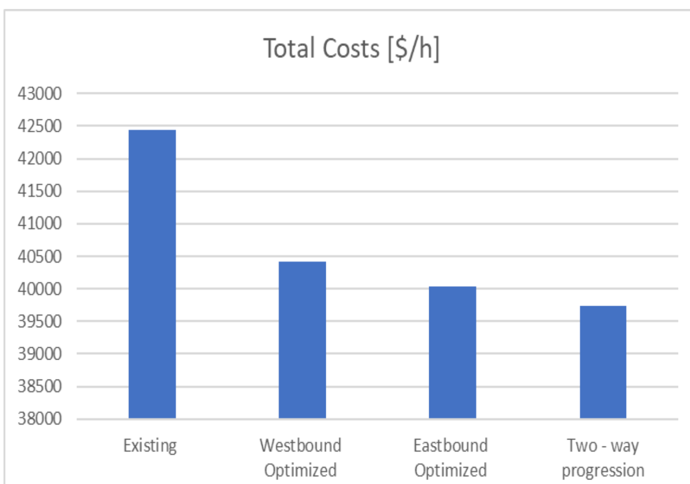


Figure 31- Results - Total Cost

10.2 Comparison of Sidra and AIMSUN

The results obtained from Sidra and AIMSUN show similar results. Table 10 shows that the matching ratio for both the models is approximately 93%. Different parameters are used for showing a detailed comparison between both the models. For comparing the results of Sidra and AIMSUN, the travel distance is same. Although AIMSUN model is used to evaluate all the 8 intersections, yet for comparison purpose only the part with 6 intersections of AIMSUN model is used.

10.2.1 Average Speed

Table 10 shows that the results obtained of Average Speed in Sidra and AIMSUN seem very similar. The average speed of Sidra model for two-way progression is 24.9 km/h whilst the travel speed for AIMSUN model for the same distance of travel is 23.58 km/h. A difference of only 4.3% in travel speed can be seem. However, the travel speed from AIMSUN model must give accurate results than Sidra.

10.2.2 Average Delay Time

The average delay time in Sidra is shorter (284.3 sec) than AIMSUN (303.3 sec). The average delay of the intersection depends on the level of service and is considered as a measure of effectiveness for an intersection. Nonetheless, the difference between both the models has a difference of only 6.7%. As AIMSUN duplicates the road geometry, the delay time should be more precise.

10.2.3 Average Travel Distance

The average travel distance is same for both the models. The reason behind this is that the distance is same in both the models. Although, 8 intersections were modelled in AIMSUN, only 6 intersections were used for comparison. Hence, the distance modelled is similar.

10.2.4 Average Travel Time

Average travel time for Sidra is 488.3 seconds whereas for AIMSUN it is 516.21 seconds. Again, the values show similar results with only 5% difference which confirms and validates the outcomes of the models.

Table 10- Comparison - Sidra and AIMSUN

	Average Speed [km/h]	Average Delay time [sec]	Average Travel Distance [m]	Average Travel Time [sec]
Sidra	24.9	284.3	3373	488.3
AIMSUN	23.58	303.3	3373	516.21
Difference	-4.3 %	6.7 %	0.0 %	5.1

According to the initial literature research of the project, the reduction in travel time and average delays can have significant impacts on reducing traffic congestion. The two-way optimized model of signal linking however has considerably reduced delays and improved travel times as compared to the base model. Sequentially, signal linking has improved the fuel consumption and reduced it to half as compared to the existing base model of the thesis. As stated in the literature, traffic performance has increased decreasing fuel consumption by coordinating the signal. Lastly, the findings of the study have proved to reduce the total costs or operating cost up to 7% which has resulted due to decrease in delay and travel time and hence decrease in congestion. This decreases the socio-economic cost of congestion based on the data of literature reviewed. Thus, this study produces sound results in comparison to the literature reviewed that directly states its significance.

11. Conclusion and Recommendations

In conclusion, this thesis research sought to assess the Network performance of signalized intersections using Sidra Intersection and AIMSUN microsimulation. The objective was to measure the traffic flow conditions on Green hill road with a broken signal linking between two SCATS regions and propose the optimized scenario suitable for the location. It was shown that a detailed analysis was carried out for determining the peak modelling period. The observations from both the analytical and simulation models provides an understanding of different approaches utilized for the study of Network performance.

Results showed that from the three scenarios conducted - Eastbound, Westbound and Two-way progression, the two-way progression was proposed to be a better alternative as compared to the individual direction of travel. The signal linked in both direction produces a smooth green band progression of travel. The different traffic performance indicators – Average delay, level of service, operating cost etcetera were used to assess the efficacy of the alternative scenarios which demonstrated two-way linking as an optimized approach. The model has considerably reduced the traffic congestion which has led to positive implications of decreased environmental impacts and socio – economic costs.

Both the analytical and microsimulation model outputs are not significantly different. For the purpose of this study, AIMSUN microsimulation was used for better visualization of the

Network in addition to cater the limitation of Sidra Intersection. The results of both the models showed similar results in terms of delay, travel time, speed etc. Some results for AIMSUN are a touch higher than Sidra model and the reason behind that can be attributed to the ability of AIMSUN to duplicate the road geometry which can predict accurate results.

Sidra represented the analytical approach for modelling and used lane capacities as an input basis for assessment whereas capacities of road in microsimulation depend on the driver/vehicle/road interaction parameters. Both the models have different capabilities and can be used to obtain rich source of information. The analytical models are much easier to develop and calibrate as compared to microsimulation models. However, microsimulation models can replicate the exact road geometry and can produce a detailed analysis of the Network. Since AIMSUN does not optimize traffic lights, optimized phasing of Sidra model was implemented in AIMSUN. Both the models can be used in conjunction with each other to obtain maximum benefits.

Further research is needed to create more AIMSUN models of fuel consumption and emissions to compare and produce accurate results. The restriction of student license puts a limitation to produce a Network of all the eight intersections in Sidra and hence further research can provide more precise results.

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Appendix A

Vehicle count analysis

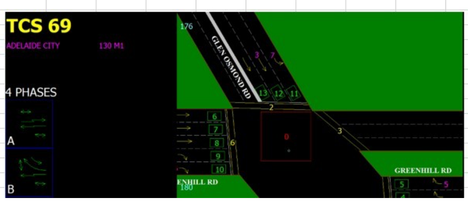
Site 069

datetime	site_no	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2017-03-10T16:50:0(	70	0	44	43	31	26	19	35	31	15	12	28	44	21	41	45	8	24	33	28	2	5
2017-03-10T16:55:0(	70	0	43	54	28	29	17	28	26	13	14	15	36	14	41	43	5	16	27	34	0	8
2017-03-10T17:00:0(	70	0	51	51	30	31	17	23	31	12	12	14	34	14	28	31	6	23	13	28	10	9
2017-03-10T17:05:0(	70	0	27	32	34	29	10	24	23	16	13	35	56	24	39	40	2	18	22	33	11	7
2017-03-10T17:10:0(	70	0	36	41	35	30	12	16	16	9	7	25	37	26	54	50	2	14	22	32	3	1
2017-03-10T17:15:0(	70	0	35	41	28	32	26	39	38	12	12	38	55	18	45	49	8	21	44	45	7	8
2017-03-10T17:20:0(	70	0	49	49	46	39	28	33	33	11	9	22	49	30	36	39	5	22	32	22	12	13
2017-03-10T17:25:0(	70	0	48	45	28	31	27	33	37	10	8	20	48	33	38	41	6	17	28	27	11	11
2017-03-10T17:30:0(	70	0	36	46	29	26	23	38	33	14	11	30	53	30	42	49	3	16	37	37	10	6
2017-03-10T17:35:0(	70	0	40	34	27	27	20	35	36	14	11	22	43	28	45	52	6	18	37	31	10	7
2017-03-10T17:40:0(	70	0	35	41	29	28	12	24	29	7	4	18	46	20	52	52	3	25	39	35	10	11
2017-03-10T17:45:0(	70	0	37	43	35	30	18	23	27	9	13	15	45	18	49	57	6	18	41	32	10	5
		16:45-17:45	481	520	380	358	229	351	360	142	126	282	546	276	510	548	60	232	375	384	96	91
			1001		738		940			268		828		1334				991			187	

TS070	North			East			Le
	Left	Through	Right	Left	Through	Right	
Total	157	1001	738	170	991	187	
Light	156	990	730	167	973	181	
Heavy	1	11	8	3	18	6	
Buses	0	0	0	0	0	0	

Site 069

site_no	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
69	0	28	43	34	14	15	53	49	36	20	23	44	42	45	26	29	33	0	0	0	0
69	0	40	45	43	9	11	43	41	31	20	20	45	47	59	30	26	31	0	0	0	0
69	0	46	57	49	14	14	48	46	40	5	6	30	17	24	19	20	22	0	0	0	0
69	0	35	40	33	10	8	64	54	30	30	28	48	39	44	29	25	33	0	0	0	0
69	0	56	57	55	12	11	63	60	50	15	11	37	36	35	15	16	30	0	0	0	0
69	0	31	30	29	10	9	48	46	24	30	32	46	37	35	26	32	42	0	0	0	0
69	0	47	53	44	19	24	63	54	30	29	31	67	36	42	38	23	42	0	0	0	0
69	0	56	63	56	16	16	61	57	40	22	25	44	35	36	29	28	36	0	0	0	0
69	0	29	46	32	12	11	58	56	44	13	13	40	45	42	28	30	32	0	0	0	0
69	0	36	49	40	15	10	45	43	30	17	17	45	48	56	27	33	51	0	0	0	0
69	0	47	52	44	12	12	51	44	35	14	19	42	27	37	30	28	37	0	0	0	0
69	0	43	57	48	17	15	48	49	35	23	22	34	36	33	25	24	28	0	0	0	0
	16:45-17:45	494	592	507	160	156	645	599	425	238	247	522	445	488	322	314	417	0	0	0	0
		1593			316		1669			485			933			731					



TS069	East			South-East			Left
	Left	Through	Right	Left	Through	Right	
Total	52	1593	316	322	670	61	
Light	52	1583	314	305	637	61	
Heavy	0	10	2	17	33	0	
Buses	0	19	0	0	0	0	

Appendix B

Phasing Analysis

TS067

Clipboard Font

B33 =B32*$I$33/100

	Phase	A	B	C	D	E	F
2	C1	29			15	19	16
3	C2	29			15	19	16
4	C3	29			15	17	16
5	C4	27			15	21	14
6	C5	25			15	21	18
7	C6	23			15	21	16
8	C7	27			15	19	14
9	C8	29			15	19	16
10	C9	27			15	23	16
11	C10	25			15	27	16
12	C11	29			15	25	14
13	C12	31			15	21	14
14	C13	29			15	21	14
15	C14	27			15	21	14
16	C15	25			15	21	14
17	C16	23			15	19	18
18	C17	25			15	15	18
19	C18	29			15	13	18
20	C19	31			15	15	18
21	C20	29			15	19	16
22	C21	33			15	19	14
23	C22	35			15	15	16
24	C23	33			15	19	16
25	C24	31			15	17	20
26	C25	29			15	17	18

TS31

D33 =D32*$I$33/100

	Phase	A	B	C	D	E	F
2	C1	64	14	22			
3	C2	61	17	22			
4	C3	59	16	25			
5	C4	58	18	24			
6	C5	60	16	24			
7	C6	61	16	23			
8	C7	59	19	22			
9	C8	61	20	19			
10	C9	61	17	22			
11	C10	58	20	22			
12	C11	57	23	20			
13	C12	59	23	18			
14	C13	58	25	17			
15	C14	57	23	20			
16	C15	56	21	23			
17	C16	58	21	21			
18	C17	57	21	22			
19	C18	59	22	19			
20	C19	61	21	18			
21	C20	61	24	15			
22	C21	60	22	18			
23	C22	62	21	17			
24	C23	61	19	20			
25	C24	63	16	21			
26	C25	64	13	23			

TS181

G33 =G32*$I$33/100

	A	B	C	D	E	F	G
1	Phase	A	B	C	D	E	F
2	C1	35	10	10	16	2	40
3	C2	32	11	10	18	2	40
4	C3	34	10	10	17	2	40
5	C4	36	9	10	16	2	40
6	C5	39	9	10	13	2	40
7	C6	40	9	10	12	2	40
8	C7	40	10	10	11	2	40
9	C8	37	11	10	13	2	40
10	C9	36	10	10	15	2	40
11	C10	37	10	10	14	2	40
12	C11	38	10	10	13	2	40
13	C12	37	9	10	15	2	40
14	C13	35	9	10	17	2	40
15	C14	33	10	10	18	2	40
16	C15	34	10	10	17	2	40
17	C16	35	11	10	15	2	40
18	C17	33	11	10	17	2	40
19	C18	32	11	10	18	2	40
20	C19	35	9	10	17	2	40
21	C20	33	10	10	18	2	40
22	C21	36	9	10	16	2	40
23	C22	38	9	10	14	2	40
24	C23	36	12	10	13	2	40
25	C24	34	13	10	14	2	40
26	C25	32	12	10	17	2	40
27	C26	31	10	10	20	2	40

TS068

M29

	A	B	C	D	E	F	G
1	Phase	A	B	C	D	E	F
2	C1	26			17	25	11
3	C2	22			19	25	11
4	C3	20			21	25	11
5	C4	22			21	25	13
6	C5	26			19	25	13
7	C6	28			15	25	13
8	C7	26			19	25	13
9	C8	26			23	25	11
10	C9	28			19	25	11
11	C10	28			17	25	13
12	C11	26			17	25	11
13	C12	28			17	25	9
14	C13	30			19	25	9
15	C14	26			21	25	9
16	C15	22			23	25	11
17	C16	24			19	25	13
18	C17	22			19	25	13
19	C18	22			23	25	11
20	C19	20			27	25	11
21	C20	20			27	25	9
22	C21	22			23	25	11
23	C22	26			21	25	11
24	C23	30			19	25	11
25	C24	34			17	25	9
26	C25	34			15	25	9
27	C26	36			13	25	9

TS180

E33 | =E32*$I$33/100

	A	B	C	D	E	F	G
1	Phase	A	B	C	D	E	F
2	C1	42	12	12	34		
3	C2	40	10	12	38		
4	C3	36	12	12	40		
5	C4	38	12	14	36		
6	C5	36	16	14	34		
7	C6	34	20	12	34		
8	C7	32	18	12	38		
9	C8	36	16	12	36		
10	C9	38	16	14	32		
11	C10	40	12	16	32		
12	C11	42	12	18	28		
13	C12	46	10	18	26		
14	C13	48	10	16	26		
15	C14	46	10	14	30		
16	C15	50	8	12	30		
17	C16	50	6	16	28		
18	C17	54	6	14	26		
19	C18	58	6	12	24		
20	C19	56	8	12	24		
21	C20	54	8	16	22		
22	C21	52	6	20	22		
23	C22	50	6	24	20		
24	C23	50	8	20	22		
25	C24	48	8	18	26		
26	C25	46	8	16	30		

TS069

U27

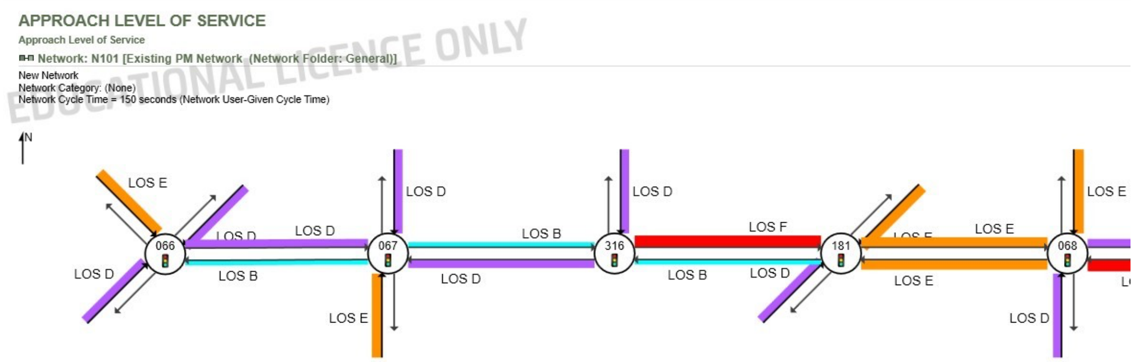
	A	B	C	D	E	F	G
1	Phase	A	B	C	D	E	F
2	C1	23	19	36	22		
3	C2	21	17	40	22		
4	C3	19	15	44	22		
5	C4	15	17	44	24		
6	C5	15	15	46	24		
7	C6	17	17	46	20		
8	C7	15	21	46	18		
9	C8	19	19	44	18		
10	C9	19	17	42	22		
11	C10	19	15	40	26		
12	C11	17	15	38	30		
13	C12	17	15	36	32		
14	C13	21	15	34	30		
15	C14	21	19	32	28		
16	C15	19	23	32	26		
17	C16	17	21	32	30		
18	C17	15	25	30	30		
19	C18	17	27	30	26		
20	C19	19	27	32	22		
21	C20	19	25	36	20		
22	C21	17	25	40	18		
23	C22	19	21	42	18		
24	C23	19	19	46	16		
25	C24	15	21	48	16		
26	C25	13	21	46	20		
27	C26	15	21	42	22		

Appendix C

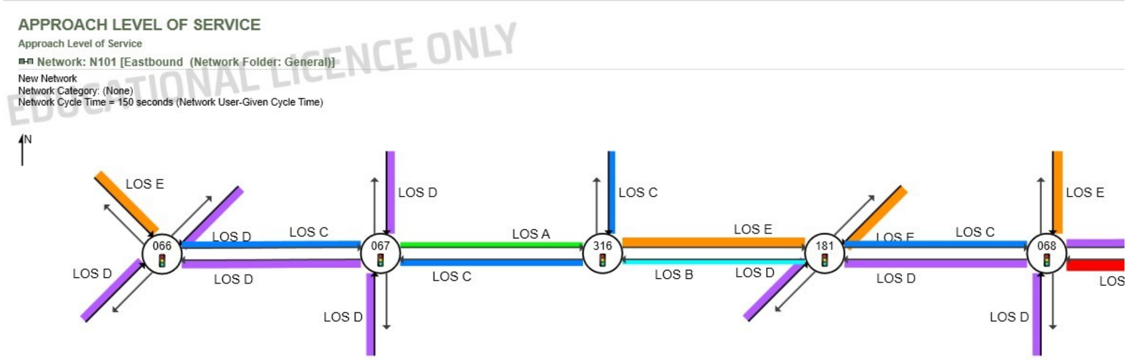
Sidra Results

Level of Service

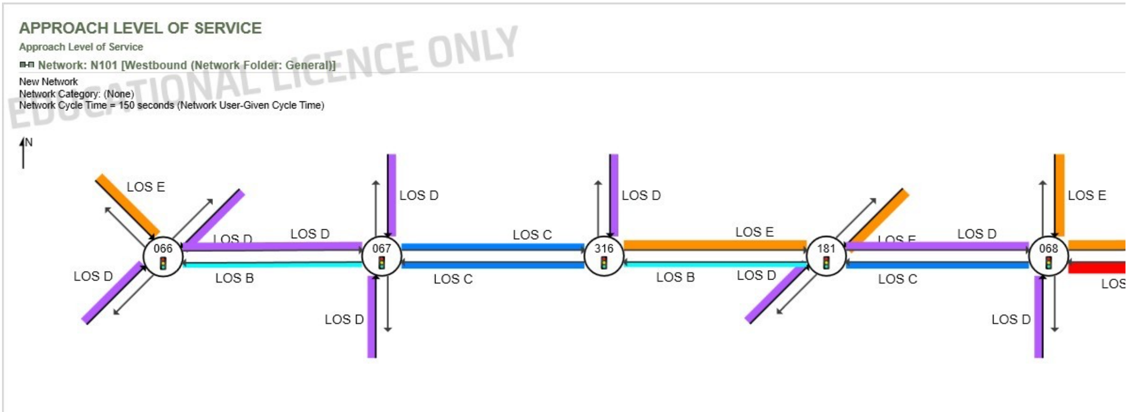
Exisitng PM



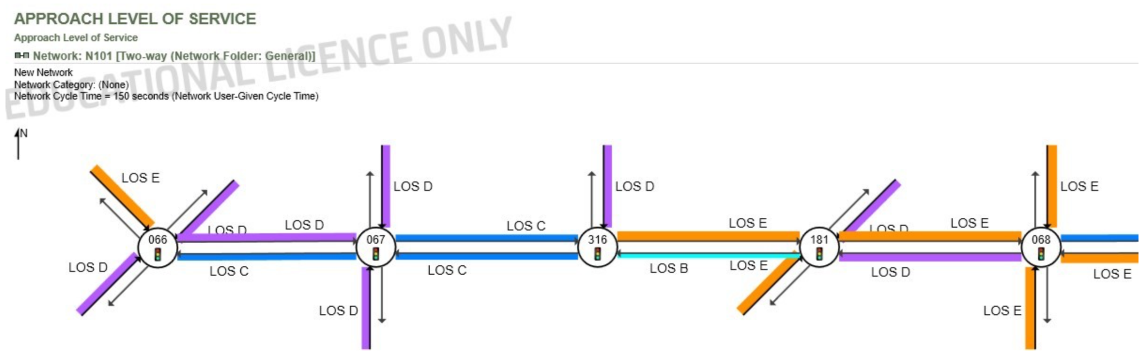
Eastbound Scenario



Westbound Scenario



Two-way progression



Individual Optimized sites

TS066 – Existing and Optimized

Lane Level of Service

Site: 066 [TS066 (Site Folder: General)]

New Site
Site Category: -
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 120 seconds (Site User-Given Phase T

	Approaches				Intersection
	East	Northeast	Northwest	Southwest	
LOS	D	D	F	C	E

Lane Level of Service

Site: 066 [TS066 - Copy (Site Folder: General)]

New Site
Site Category: -
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 150 seconds (Site User-Given Cy

	Approaches				Intersection
	East	Northeast	Northwest	Southwest	
LOS	D	D	F	D	D

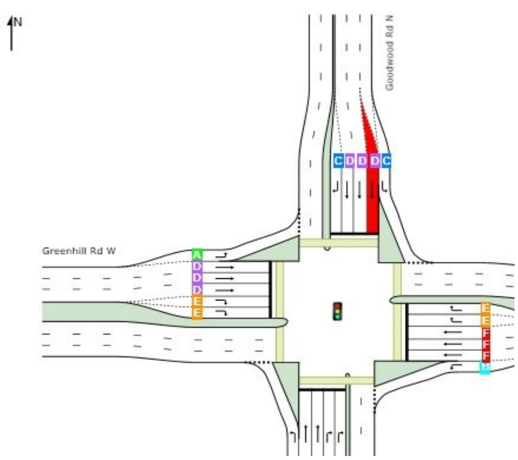
TS067 – Existing and Optimized

Lane Level of Service

Site: 067 [TS067 (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 120 seconds (Site User-Giver

	Approaches				Intersection
	South	East	North	West	
LOS	D	E	D	D	E

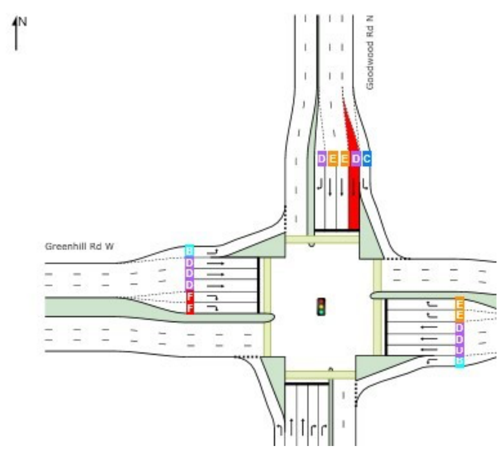


Lane Level of Service

Site: 067 [TS067 - Copy (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated   Cycle Time = 150 seconds (Site User-Given

	Approaches				Intersection
	South	East	North	West	
LOS	E	D	D	D	D



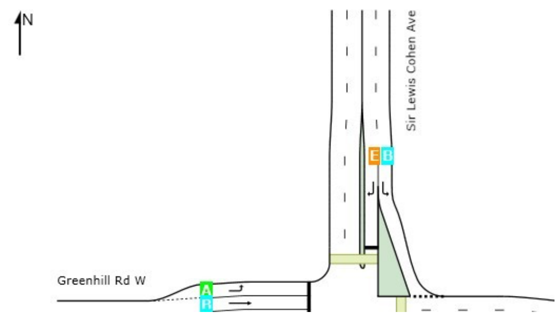
TS316 – Existing and Optimized

Lane Level of Service

Site: 316 [TS316 (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated Cycle Time = 120 seconds (Site User-Given Ph

	Approaches			Intersection
	East	North	West	
LOS	B	C	B	B

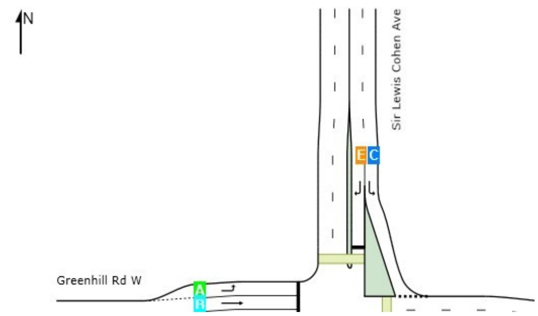


Lane Level of Service

Site: 316 [TS316 - Copy (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated Cycle Time = 150 seconds (Site User-Given Cy

	Approaches			Intersection
	East	North	West	
LOS	B	D	B	B



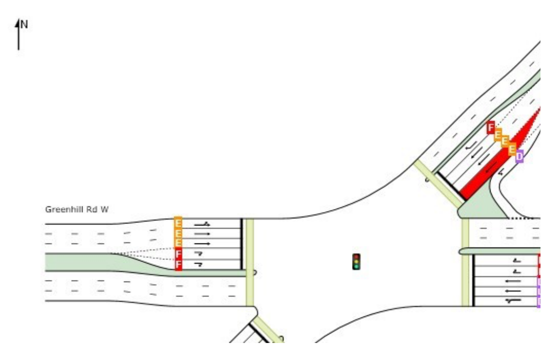
TS181 – Existing and Optimized

Lane Level of Service

Site: 181 [TS181 (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated Cycle Time = 150 seconds (Site User-Given Ph

	Approaches				Intersection
	East	Northeast	West	Southwest	
LOS	D	E	F	D	E



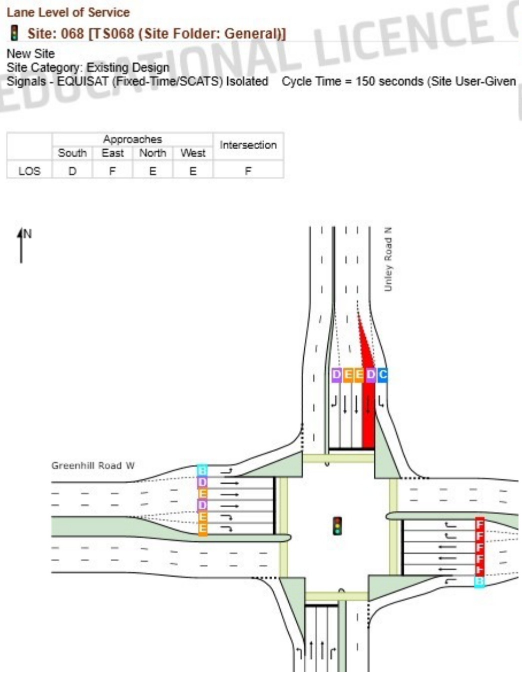
Lane Level of Service

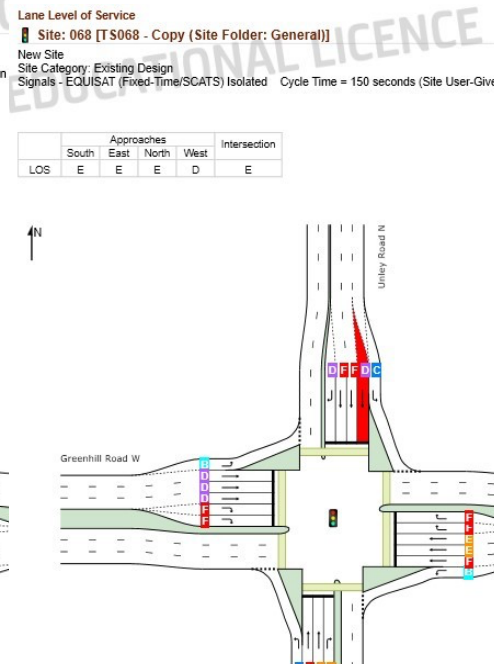
Site: 181 [TS181 - Copy (Site Folder: General)]

New Site
Site Category: Existing Design
Signals - EQUISAT (Fixed-Time/SCATS) Isolated Cycle Time = 150 seconds (Site User-Given Cy

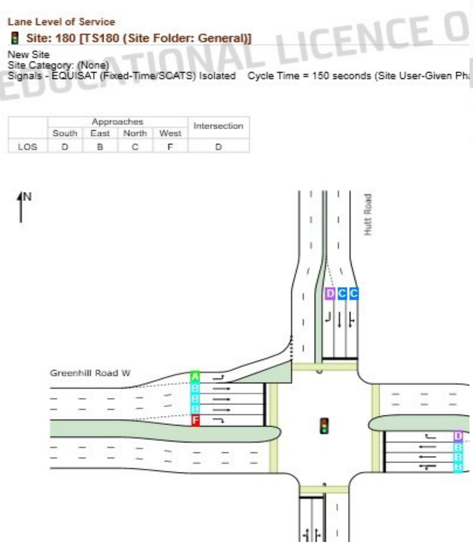
	Approaches				Intersection
	East	Northeast	West	Southwest	
LOS	E	D	E	E	E

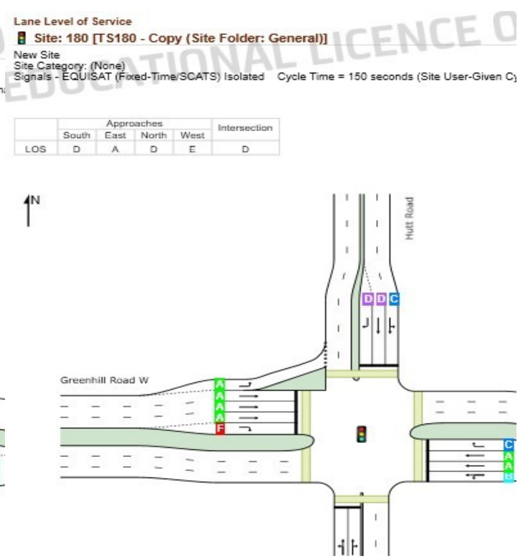
TS068 – Existing and Optimized





TS180 – Existing and Optimized





Network Performance

Existing scenario and Eastbound scenario

NETWORK SUMMARY

Network: N101 [Existing PM Network (Network Folder: General)]

New Network
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Network Performance - Hourly Values			
Performance Measure	**Vehicles**	**Per Unit Distance**	**Pedestrians**
Network Level of Service (LOS)	LOS E		
Speed Efficiency	0.49		
Travel Time Index	4.31		
Congestion Coefficient	2.05		
Travel Speed (Average)	29.3 km/h		1.5 km/h
Travel Distance (Total)	28309.3 veh-km/h		58.4 ped-km/h
Travel Time (Total)	967.6 veh-h/h		39.4 ped-h/h
Desired Speed (Input & Program)	60.0 km/h		
Demand Flows (Total for all Sites)	35535 veh/h		1600 ped/h
Arrival Flows (Total for all Sites)	35286 veh/h		1600 ped/h
Demand Flows (Entry Total)	14831 veh/h		
Midblock Inflows (Total)	415 veh/h		
Midblock Outflows (Total)	-471 veh/h		
Percent Heavy Vehicles (Demand)	1.6 %		
Percent Heavy Vehicles (Arrival)	1.6 %		
Degree of Saturation	1.473		
Control Delay (Total)	491.69 veh-h/h		26.96 ped-h/h
Control Delay (Average)	50.2 sec		60.7 sec
Control Delay (Worst Lane)	482.7 sec		
Control Delay (Worst Movement)	482.7 sec		69.3 sec
Geometric Delay (Average)	1.6 sec		
Stop-Line Delay (Average)	48.5 sec		
Ave. Queue Storage Ratio (Worst Lane)	0.57		
Total Effective Stops	29642 veh/h		1523 ped/h
Effective Stop Rate	0.84	1.05 per km	0.95
Proportion Queued	0.85		0.95
Performance Index	2423.1		47.9
Cost (Total)	42437.62 $/h	1.50 $/km	1088.72 $/h
Fuel Consumption (Total)	3219.3 L/h	113.7 mL/km	
Fuel Economy	11.4 L/100km		
Carbon Dioxide (Total)	7604.0 kg/h	268.6 g/km	
Hydrocarbons (Total)	0.723 kg/h	0.026 g/km	
Carbon Monoxide (Total)	8.060 kg/h	0.285 g/km	
NOx (Total)	7.250 kg/h	0.256 g/km	

Network Model Variability Index (Iterations 3 to N): 1.4 %
Number of Iterations: 7 (Maximum: 10)
Largest change in Lane Degrees of Saturation or Queue Storage Ratios for the last three Network Iterations: 0.0% 0
Network Level of Service (LOS) Method: SIDRA Speed Efficiency.
Software Setup used: Standard Left.

Network Performance - Annual Values			
Performance Measure	**Vehicles**	**Pedestrians**	**Persons**
Demand Flows (Total for all Sites)	1,70,56,80 0 veh/y	7,68,000 ped/y	2,26,46,21 0 pers/y

NETWORK SUMMARY

Network: N101 [Eastbound (Network Folder: General)]

New Network
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Network Performance - Hourly Values			
Performance Measure	**Vehicles**	**Per Unit Distance**	**Pedestrians**
Network Level of Service (LOS)	LOS D		
Speed Efficiency	0.52		
Travel Time Index	4.67		
Congestion Coefficient	1.92		
Travel Speed (Average)	31.2 km/h		1.5 km/h
Travel Distance (Total)	28309.3 veh-km/h		58.4 ped-km/h
Travel Time (Total)	906.7 veh-h/h		39.4 ped-h/h
Desired Speed (Input & Program)	60.0 km/h		
Demand Flows (Total for all Sites)	35535 veh/h		1600 ped/h
Arrival Flows (Total for all Sites)	35286 veh/h		1600 ped/h
Demand Flows (Entry Total)	14831 veh/h		
Midblock Inflows (Total)	415 veh/h		
Midblock Outflows (Total)	-471 veh/h		
Percent Heavy Vehicles (Demand)	1.6 %		
Percent Heavy Vehicles (Arrival)	1.6 %		
Degree of Saturation	1.477		
Control Delay (Total)	430.31 veh-h/h		26.96 ped-h/h
Control Delay (Average)	43.9 sec		60.7 sec
Control Delay (Worst Lane)	485.8 sec		
Control Delay (Worst Movement)	485.8 sec		69.3 sec
Geometric Delay (Average)	1.6 sec		
Stop-Line Delay (Average)	42.3 sec		
Ave. Queue Storage Ratio (Worst Lane)	0.60		
Total Effective Stops	26320 veh/h		1523 ped/h
Effective Stop Rate	0.75	0.93 per km	0.95
Proportion Queued	0.75		0.95
Performance Index	2229.2		47.9
Cost (Total)	40030.89 $/h	1.41 $/km	1088.72 $/h
Fuel Consumption (Total)	3047.2 L/h	107.6 mL/km	
Fuel Economy	10.8 L/100km		
Carbon Dioxide (Total)	7199.2 kg/h	254.3 g/km	
Hydrocarbons (Total)	0.675 kg/h	0.024 g/km	
Carbon Monoxide (Total)	7.734 kg/h	0.273 g/km	
NOx (Total)	6.922 kg/h	0.245 g/km	

Network Model Variability Index (Iterations 3 to N): 26.8 %
Number of Iterations: 10 (Maximum: 10)
Largest change in Lane Degrees of Saturation or Queue Storage Ratios for the last three Network Iterations: 0.0% 0.
Network Level of Service (LOS) Method: SIDRA Speed Efficiency.
Software Setup used: Standard Left.

Network Performance - Annual Values			
Performance Measure	**Vehicles**	**Pedestrians**	**Persons**
Demand Flows (Total for all Sites)	1,70,56,80 0 veh/y	7,68,000 ped/y	2,26,46,21 0 pers/y

Westbound Scenario and Two – Way Progression

NETWORK SUMMARY

Network: N101 [Westbound (Network Folder: General)]

New Network
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Network Performance - Hourly Values

Performance Measure	Vehicles	Per Unit Distance	Pedestrians
Network Level of Service (LOS)	LOS D		
Speed Efficiency	0.52		
Travel Time Index	4.62		
Congestion Coefficient	1.94		
Travel Speed (Average)	30.9 km/h		1.5 km/h
Travel Distance (Total)	28309.3 veh-km/h		58.4 ped-km/h
Travel Time (Total)	914.9 veh-h/h		39.4 ped-h/h
Desired Speed (Input & Program)	60.0 km/h		
Demand Flows (Total for all Sites)	35535 veh/h		1600 ped/h
Arrival Flows (Total for all Sites)	35286 veh/h		1600 ped/h
Demand Flows (Entry Total)	14831 veh/h		
Midblock Inflows (Total)	415 veh/h		
Midblock Outflows (Total)	-471 veh/h		
Percent Heavy Vehicles (Demand)	1.6 %		
Percent Heavy Vehicles (Arrival)	1.6 %		
Degree of Saturation	1.473		
Control Delay (Total)	439.00 veh-h/h		26.96 ped-h/h
Control Delay (Average)	44.8 sec		60.7 sec
Control Delay (Worst Lane)	483.5 sec		
Control Delay (Worst Movement)	483.5 sec		69.3 sec
Geometric Delay (Average)	1.6 sec		
Stop-Line Delay (Average)	43.2 sec		
Ave. Queue Storage Ratio (Worst Lane)	0.57		
Total Effective Stops	27863 veh/h		1523 ped/h
Effective Stop Rate	0.79	0.98 per km	0.95
Proportion Queued	0.79		0.95
Performance Index	2278.7		47.9
Cost (Total)	40425.14 $/h	1.43 $/km	1088.72 $/h
Fuel Consumption (Total)	3105.7 L/h	109.7 mL/km	
Fuel Economy	11.0 L/100km		
Carbon Dioxide (Total)	7336.5 kg/h	259.2 g/km	
Hydrocarbons (Total)	0.690 kg/h	0.024 g/km	
Carbon Monoxide (Total)	7.848 kg/h	0.277 g/km	
NOx (Total)	7.030 kg/h	0.248 g/km	

Network Model Variability Index (Iterations 3 to N): 31.4 %
Number of Iterations: 7 (Maximum: 10)
Largest change in Lane Degrees of Saturation or Queue Storage Ratios for the last three Network Iterations: 0.4%
Network Level of Service (LOS) Method: SIDRA Speed Efficiency.
Software Setup used: Standard Left.

Network Performance - Annual Values

Performance Measure	Vehicles	Pedestrians	Persons
Demand Flows (Total for all Sites)	1,70,56,80 0 veh/y	7,68,000 ped/y	2,26,46,21 0 pers/y

NETWORK SUMMARY

Network: N101 [Two-way (Network Folder: General)]

New Network
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Network Performance - Hourly Values

Performance Measure	Vehicles	Per Unit Distance	Pedestrians
Network Level of Service (LOS)	LOS D		
Speed Efficiency	0.53		
Travel Time Index	4.78		
Congestion Coefficient	1.89		
Travel Speed (Average)	31.8 km/h		1.5 km/h
Travel Distance (Total)	28493.2 veh-km/h		58.4 ped-km/h
Travel Time (Total)	896.2 veh-h/h		39.3 ped-h/h
Desired Speed (Input & Program)	60.0 km/h		
Demand Flows (Total for all Sites)	35535 veh/h		1600 ped/h
Arrival Flows (Total for all Sites)	35535 veh/h		1600 ped/h
Demand Flows (Entry Total)	14831 veh/h		
Midblock Inflows (Total)	415 veh/h		
Midblock Outflows (Total)	-471 veh/h		
Percent Heavy Vehicles (Demand)	1.6 %		
Percent Heavy Vehicles (Arrival)	1.6 %		
Degree of Saturation	1.279		
Control Delay (Total)	419.47 veh-h/h		26.83 ped-h/h
Control Delay (Average)	42.5 sec		60.4 sec
Control Delay (Worst Lane)	322.4 sec		
Control Delay (Worst Movement)	322.4 sec		69.3 sec
Geometric Delay (Average)	1.6 sec		
Stop-Line Delay (Average)	40.9 sec		
Ave. Queue Storage Ratio (Worst Lane)	0.49		
Total Effective Stops	27524 veh/h		1523 ped/h
Effective Stop Rate	0.77	0.97 per km	0.95
Proportion Queued	0.78		0.95
Performance Index	2259.8		47.8
Cost (Total)	39743.51 $/h	1.39 $/km	1085.00 $/h
Fuel Consumption (Total)	3080.5 L/h	108.1 mL/km	
Fuel Economy	10.8 L/100km		
Carbon Dioxide (Total)	7277.3 kg/h	255.4 g/km	
Hydrocarbons (Total)	0.682 kg/h	0.024 g/km	
Carbon Monoxide (Total)	7.824 kg/h	0.275 g/km	
NOx (Total)	7.013 kg/h	0.246 g/km	

Network Model Variability Index (Iterations 3 to N): 13.9 %
Number of Iterations: 8 (Maximum: 10)
Largest change in Lane Degrees of Saturation or Queue Storage Ratios for the last three Network Iterations: 0.0%
Network Level of Service (LOS) Method: SIDRA Speed Efficiency.
Software Setup used: Standard Left.

Network Performance - Annual Values

Performance Measure	Vehicles	Pedestrians	Persons
Demand Flows (Total for all Sites)	1,70,56,80 veh/y	7,68,000 ped/y	2,26,46,21 pers/y

Route Travel Performance

Eastbound direction

ROUTE TRAVEL PERFORMANCE

Route: R101 [Route1]

New Route
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Route Travel Performance

Performance Measure	Vehicles	Per Unit Distance	Persons
Travel Speed (Average)	31.5 km/h		31.5 km/h
Travel Distance (Average)	3381.6 m		3381.6 m
Travel Time (Average)	386.7 sec	114.4 sec/km	386.7 sec
Desired Speed (Input & Program)	60.0 km/h		
Route Delay (Average)	183.5 sec	54.3 sec/km	183.5 sec
Route Stop Rate	3.79	1.12 per km	3.79
Route Level of Service (LOS)	LOS D		
Speed Efficiency	0.52		
Travel Time Index	4.72		
Congestion Coefficient	1.91		

Route Travel Movement Performance

Mov ID	Turn	Trav Dist m	Trav Time sec	Aver. Speed km/h	Aver. Delay sec	Prop. Queued	Eff. Stop Rate	Aver. No. Cycles	De
Site ID: 066 Site Name: TS066									
NorthWest Approach									
27a	L1	482.6	115.2	15.1	86.3	1.00	1.10	1.29	
Site ID: 067 Site Name: TS067									
West Approach									
11	T1	535.2	57.7	33.4	25.6	0.67	0.58	0.67	
Site ID: 316 Site Name: TS316									
West Approach									
11	T1	535.9	37.8	51.0	5.7	0.21	0.19	0.21	
Site ID: 181 Site Name: TS181									
West Approach									

Westbound direction

ROUTE TRAVEL PERFORMANCE

Route: R101 [Route1]

New Route
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Route Travel Performance

Performance Measure	Vehicles	Per Unit Distance	Persons
Travel Speed (Average)	32.0 km/h		32.0 km/h
Travel Distance (Average)	3372.9 m		3372.9 m
Travel Time (Average)	379.1 sec	112.4 sec/km	379.1 sec
Desired Speed (Input & Program)	60.0 km/h		
Route Delay (Average)	175.1 sec	51.9 sec/km	175.1 sec
Route Stop Rate	3.81	1.13 per km	3.81
Route Level of Service (LOS)	LOS D		
Speed Efficiency	0.53		
Travel Time Index	4.82		
Congestion Coefficient	1.87		

Route Travel Movement Performance

Mov ID	Turn	Trav Dist m	Trav Time sec	Aver. Speed km/h	Aver. Delay sec	Prop. Queued	Eff. Stop Rate	Aver. No. Cycles
Site ID: 180 Site Name: TS180								
East Approach								
5	T1	244.5	31.7	27.8	16.6	0.80	0.72	0.80
Site ID: 068 Site Name: TS068								
East Approach								
5	T1	545.1	140.9	13.9	106.4	0.97	1.27	1.50
Site ID: 181 Site Name: TS181								
East Approach								
5	T1	547.7	51.0	38.6	17.8	0.61	0.57	0.62
Site ID: 316 Site Name: TS316								
East Approach								

Two – way

ROUTE TRAVEL PERFORMANCE

Route: R101x [Westbound]

New Route
Network Category: (None)
Network Cycle Time = 150 seconds (Network User-Given Cycle Time)

Route Travel Performance

Performance Measure	Vehicles	Per Unit Distance	Persons
Travel Speed (Average)	32.2 km/h		32.2 km/h
Travel Distance (Average)	3372.9 m		3372.9 m
Travel Time (Average)	376.8 sec	111.7 sec/km	376.8 sec
Desired Speed (Input & Program)	60.0 km/h		
Route Delay (Average)	174.6 sec	51.8 sec/km	174.6 sec
Route Stop Rate	3.98	1.18 per km	3.98
Route Level of Service (LOS)	LOS D		
Speed Efficiency	0.54		
Travel Time Index	4.86		
Congestion Coefficient	1.86		

Route Travel Movement Performance

Mov ID	Turn	Trav Dist m	Trav Time sec	Aver. Speed km/h	Aver. Delay sec	Prop. Queued	Eff. Stop Rate	Aver. No. Cycles
Site ID: 180 Site Name: TS180 - Copy								
East Approach								
5	T1	244.5	23.8	36.9	8.8	0.61	0.57	0.61
Site ID: 068 Site Name: TS068 - Copy								
East Approach								
5	T1	545.1	103.2	19.0	70.5	0.96	1.05	1.21
Site ID: 181 Site Name: TS181 - Copy								
East Approach								
5	T1	547.6	75.9	26.0	42.7	0.94	0.96	1.08
Site ID: 316 Site Name: TS316 - Copy								
East Approach								

Appendix C

AIMSUN

AIMSUN 2D and 3D views