DYNAMIC SIGNAL TIMING AND PHASING OPTIMIZATION AT TRAFFIC INTERSECTIONS USING WIRELESS TECHNOLOGY

By

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EXECUTIVE SUMMARY

This research thesis investigates the intersection traffic signal control problem (ITCP) extensively. The research conducts an extensive and detailed literature review on the current state of traffic management systems at traffic intersections, and highlights the key findings. The research literature review looks at the history of the development of traffic management systems, and their advancement over the years. The review also highlights the research gap on this topic.

The research also takes an innovative approach by modelling the two most popular traffic management systems, that's is; the Fixed control system and the SCATS system. The research looks intensively into these two systems and highlights their strengths, their weaknesses and their performance. The highlight of this thesis is the addition of a third design system that is fully dynamic and actuated, here referred to as the "Dynamic traffic control system". The research models all three systems and then compares their performance as they battle to manage a real-life scenario of rush hour traffic using a data sample from Adelaide CBD.

The research then pushed the modeled systems further with more tests, and one such test is the "what-if" scenario, in which the systems were introduced to an extremely high traffic demand scenario, and the goal was to examine their individual behaviors and determine which system was the best performing in terms of vehicle delays. The results showed that all three systems eventually become overwhelmed when the demand gets extremely high, however, the SCATS and Dynamic systems perform slightly better than the Fixed-timed system.

The research was limited to the functions and features available in the two softwares used in this study, which were SIDRA INTERSECTION and AIMSUN NEXT software.
The research then concludes the study with a series of recommendations based on the research findings, and highlights key areas that need further research and effort in order to advance the current situation with the intersection traffic signal control problem (ITSCP) currently experienced in major cities around the world.

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INTRODUCTION

The intersection traffic signal control problem (ITSCP) is a topic that has existed in the space of transport engineering since the advancement of modern vehicles, and in recent decades, has gained a lot of attention due to the growing need to find tangible solutions to managing traffic in busy cities around the world. Vehicle traffic congestion, particularly at busy intersections, presents a persistent challenge even in the most developed countries worldwide. The issue of congestion is a common frustration during peak periods of travel, including morning rush hours, mid-day lunch breaks, and evening commutes (Jiao et al., 2018). Traditional solutions to relieve traffic congestion, such as expanding roadways by adding extra lanes, have demonstrated only temporary effectiveness. Ironically, these expansions often lead to increased traffic volume, worsening congestion at intersections over time.(Fajardo et al., 2011).

https://www.ghd.com/en-ca/insights/are-you-ready-planning-forunplanned-events-in-an-age-of-uncertainty

Figure 1: showing traffic signal lights, and a congested intersection with no traffic control

Despite advancements in intersection management techniques, including the use of pressure sensors to optimize signal timings, many intersections still struggle with heavy congestion beyond the capabilities of existing management strategies. This congestion results in significant delays for vehicles passing through intersections and diminishes the overall level of service (Eom & Kim, 2020). In numerous countries, particularly in the developing world, inefficient signal timing during peak hours often calls for manual intervention by transport officers to regulate traffic flow, often disregarding automated signal lights (Tang, K, 2019). In some cases, intersections are equipped with CCTV cameras monitored remotely by transport officers, who manually adjust signal timings to ease congestion more effectively. This human intervention highlights the critical role of human intelligence in dynamically controlling traffic flow through intersections, underscoring the correlation between intersection intelligence and efficiency (Han et al, 2019). This raises the pivotal question: What if intersections could autonomously see and understand traffic situations, and hence make decisions (calculations) to efficiently manage high traffic demand at intersections? This question formed the cornerstone of this thesis project, whose goal was to answer the following key questions:

1) What is the current level of intelligence in traffic management systems at intersections, with main reference to intersections in Adelaide?
2) How can existing intersection technology be improved in order to enhance their intelligence and efficiency?
3) What wireless technologies can be integrated into intersection systems to utilize artificial thinking or autonomy and improve decision-making in signal timing and phasing on these intersections?
4) What are the most common systems currently in use around the world and how do they compare against each other?

A Fixed signalized intersection is an intersection that uses fixed timed signals to control traffic at an intersection. This system has been around for decades and is the most popular among countries in the world (Ye et al., 2019; Abbas, 2013). This system works well for lower traffic demands, but over the years has shown to be inefficient with increased traffic demand (Liu H, 2014). Unsurprisingly, some more developed countries around the world have migrated to more adaptive actuated systems, and one such system is the Sydney Coordinated Adaptive Traffic System SCATS, which was developed in Sydney, Australia and is used in Australia and some parts of Europe (Sims & Dobinson, 1980). This system is an actuated system, which means that the system responds to vehicle demand using sensors installed on the roads. These sensors are detectors placed at the intersection stoplines. The detectors are induction loop detectors which detect the presence of a vehicle due its heavy metal body. This research was aimed at targeting these two main systems and comparing them to a proposed fully dynamic actuated system with an algorithm that allows the system to respond to traffic demand in real-time (Grant-Muller & Laird, 2007; Amini et al., 2016). Looking back in history, the Intersection Traffic Signal Control Problem (ITSCP) has been the subject of study for over six decades, since the publication of guidelines by Webster in 1958. This complex problem is influenced by various factors, including human behaviour, vehicle interactions, traffic accidents, and stochastic road demand. A decade later, Robertson developed TRANSYT, a software tool for calculating signal network performance and determining optimal signal settings, although it had fixed configurations. With increasing transportation demands, fixed-time signals have become unworkable, necessitating dynamic solutions to adapt to evolving road network demands. (Ye et al., 2019; Abbas, 2013; Liu H, 2014). Four main concepts define traffic signal sequence settings:

- Cycle: The total time required to complete one signalization sequence for all movements at an intersection.

- Phase: The controller timing unit associated with one or more movements.
- Duration: The time the signal spends in each phase without changing.
- Traffic flow group: Comprising one or more compatible movements of road users, each phase has specific timings for traffic flow groups. (Agerholm, N, 2013)

The primary challenge in addressing traffic congestion at intersections lies in determining an optimal traffic signal configuration to maximize traffic flow. This entails minimizing vehicle delays or maximizing network throughput. (Sims & Dobinson, 1980).

In the 21st century, advanced hardware, wireless technologies, and artificial intelligence (AI) have revolutionized various engineering fields, including robotics and mechanical engineering. However, the full potential of these technologies in transportation remains largely untapped, primarily due to financial constraints. Further research is essential to leverage these technologies effectively in mitigating traffic congestion on road networks and intersections. Dynamic signal adjustment, emphasised by pilot studies in Los Angeles, demonstrates significant reductions in travel times and waiting periods at intersections (Zhao et al, 2011). Economically, the benefits of Dynamic traffic systems outweigh the costs, as evidenced by the substantial return on investment reported in pilot programs (Sutandi, 2020). Manual operation has proven more effective than automatic, programmed traffic signal operation in alleviating congestion at signalized intersections during extreme heavy peak hours, events, detours and the like. The goal of this thesis study was to investigate whether such a system can be designed, and if so, to compare its effectiveness with the other existing common traffic management systems. In order to do so, the research focused on studying the currently existing systems and modelling them on a worse case scenario, followed by designing a fully dynamic system in a model, and finally comparing the performance of the systems to understand the significance of an intelligent traffic management system at traffic intersections. (Mahalel, 1991)

RESEARCH AIMS AND OBJECTIVES

This research had the following aims and objectives:

Aims and objectives:

- To evaluate and compare the current state of the most popular traffic signal control systems which are in use today, and identify opportunities for improvement using advanced wireless technology and an advanced control algorithm, focusing on available technologies and approaches.

- Propose a system with an algorithm which will enable traffic intersections to autonomously adjust signal timings and phase sequences, thereby enhancing the level of service. Envision the future of intersection control by developing a conceptual framework for optimizing traffic flow across linked intersections.
- Investigate the effect on the performance of an intersection when multiple intersections are linked into a network, working in sync to produce a combined result.

Comparative studies have been conducted to evaluate the performance of different intersection control systems. Research has shown that adaptive control systems like SCATS outperform fixed-time signals in terms of overall intersection efficiency and travel time savings (Stavanovic, 2017). Adaptive systems can dynamically adjust signal timings in response to changing traffic patterns, leading to more effective traffic flow management (Zhou et al., 2010). Despite the advantages of dynamic signal control however, challenges remain in implementing these systems effectively. One such challenge is the integration of various traffic data sources and communication technologies to enable real-time decision-making (Kevey, 2022). Moreover, ensuring the reliability and accuracy of sensor data is crucial for the successful operation of dynamic signal control systems (Traffic Tech. Today, 2022). In recent years, advancements in artificial intelligence (AI) have enabled more sophisticated approaches to intersection traffic control. AI-based systems can analyze large volumes of data to identify traffic patterns and optimize signal timings accordingly (Cosmomagazine, 2022). These systems offer the potential to further enhance intersection efficiency and adaptability in complex urban environments

The outcomes and conclusions of this project aimed to formulate a viable dynamic system capable of significantly enhancing the functionality and efficiency of traffic intersections. Furthermore, this research contributes to the collective knowledge in transportation on the intersection traffic signal control problem (ITSCP), fostering advancements in the field and facilitating the development of more efficient traffic signal control systems.

LITERATURE REVIEW

Research on the Intersection Traffic control problem has grown to be a very important issue due to the increasing traffic congestion in places with increasing urban population. Traffic congestion has become a threatening social, environmental, and economic issue in major urban cities around the world, with severe negative consequences. For example, in Australia, $16.6 billion in travel delays is lost every year. Also, in 2014 in the USA alone, an estimated $160 billion was lost due to congestion, while in the EU, 1% of a 160 billion GDP annually is lost, arising from increased fuel consumption, an increase in travel time, and emission costs (560 billion pounds of CO2 gas emitted). It is also known to cause excessive fatigue, mental illness, and problems related to the cardiovascular, respiratory, and nervous systems in the human body. (Agerholm,N, 2013; Qadri, Gokce & Oner, 2020; Jamal et al. 2020).

In 2016, researchers predicted that 'intelligent control of traffic will become a very important issue in the future as the number of road users rapidly increases' (Jadhav et al., 2016). Traffic congestion has always been an important aspect of urban planning, but has in recent years become an increasingly concerning issue due to the rapid annual vehicle growth rate and the increase in transportation demand due to rapid urbanization as well as growing economies. Other causes include poor planning at the early stages of development and reduction in financing for infrastructure (World Bank, 2020). The majority of this congestion occurs on main roads at intersections, where different streams of traffic flow cross paths.

Expansion of roads is necessary as it does increase the volume capacity of roads, but only for a while. It also has its limitations such as large capital as well as land availability. Researchers have clearly noted that the main reason for the congestion experienced today is the poor techniques that are being used for traffic management. Today's traffic management systems have little emphasis on "Live" traffic scenarios which leads to the inefficiencies observed and discussed further below. Hence, engineers and transport professionals are required to go beyond the expansion of roads and explore novel strategies in order to solve the issue of traffic congestion. (Pandit et al., 2014; Han et al., 2019)

"Traffic signal control" is an integral part of Intelligent transport systems (ITS), which involves the application of advanced technologies, computers, information processing, and control systems to optimize traffic operations. ITS is considered to be one of the (if not the most) important tools to reduce traffic congestion at intersections. This can be achieved by determining the most effective/optimal signal timings and phase sequences that are right for every changing situation on an intersection using intelligent traffic control methods (Sutandi, 2020; Jamal et al., 2016; Eom & Kim, 2020)

Due to the increase in available technology to date (hardware and software), the size of a network which is computationally affordable has increased and more dynamic and complex problems can be solved for efficiently than in the past. There are a number of ITS currently in use all over the world, and the major ones will be discussed in the following chapters of this review. (Eom & Kim, 2020)

THE USE OF FIXED-TIME SIGNALS FOR TRAFFIC CONTROL

Commonly used in Traffic Signal Control is the "Fixed-time strategy" for traffic signal timing and sequencing, which establishes fixed durations for each phase and cycle of movements (Tang et al., 2019). Fixed traffic signal systems, characterized by predetermined signal timings, have been integral to traffic control for decades since their inception in the early 20th century. The installation of the first electric traffic signal system in Cleveland, Ohio, in 1914 marked the genesis of modern traffic control systems (Webster, 1958). Fixed signal systems operate on pre-set signal cycles, with timings typically derived from historical traffic patterns and engineering guidelines (Tang et al., 2019). Fixed traffic signal systems offer si`mplicity and predictability in signal operation, rendering them suitable for intersections with stable traffic patterns. These systems entail cost-effective installation and maintenance compared to adaptive systems like SCATS. Moreover, fixed signal systems ensure orderly vehicle movement through intersections, providing a fundamental level of traffic control (Amini et al., 2016; Stevanovic, Kergaye & Martin, 2009).

A primary drawback of fixed traffic signal systems lies in their limited adaptability to fluctuating traffic conditions. Signal timings remain static irrespective of traffic volume variations, potentially leading to inefficiencies and congestion during peak periods. Fixed systems may struggle to accommodate unforeseen events or disruptions, such as accidents or road closures, without manual intervention (Sutandi, 2020). The problem with this kind of sequencing is that it assumes that the traffic situation will stay the same as when calibrated (using historical traffic data) which is far from the dynamics of reality. On the other hand, an "Actuated system" collects real-time data from the on-site sensors and then applies an algorithm to determine optimal traffic signal settings for the particular situation (Chai et al. 2017). Some agencies deploy these 'Actuated Traffic control systems' (ATCS) to deal with day to day traffic, which has shown to be more effective than conventional "Time of Day" (TOD) or fixed-timed systems (Taale, 2002). However, it is also worth noting that for some situations and locations, signalization is not always the best option for a given intersection. Yield or Stop control may be preferred on intersections which are on local or residential streets, as noted by researchers Grant-Muller & Laird (2007).

The common reason for traffic congestion is poor efficiency in terms of prioritization of traffic flow timings. With a fixed-timed system, we experience situations where one lane has less traffic saturation than the other but both lanes get equal green time, which is highly inefficient, not to mention stressful to drivers. However, depending on the programmed timing plan, some streets on an intersection may be programmed to have more green-time than others during peak-hours, and change back to default during non-peak hours (Sims & Dobinson, 1980; Han et al., 2019).

Nevertheless, fixed traffic signal systems persist worldwide, especially in regions characterized by consistent traffic patterns and constrained resources for advanced traffic management solutions (Abbas, 2013). While adaptive systems like SCATS have gained traction in certain areas (McCann, 2014), fixed signal systems continue to be prevalent due to their simplicity and affordability. In general, most urban areas will choose to use fixed-timed signals due to easy regularity, predictability, and network organization (Patel, 2020). Another noted advantage of the fixed-time system is that it makes pedestrians an equal part of the system, offering consistent times and intervals with each phase cycle of signals (Taale, 2002). Interestingly, some researchers have argued that a fixed-time system should be preferred so as to avoid confusing road users, while others argue that for the sake of performance requirements, a fixed-timed system is not preferred (Amini et al., 2016).

Further arguments come in again when the agencies begin to consider the cost of “re-timing” these fixed-timed signals. These systems, even though fixed, are supposed to be re-timed at regular intervals (e.g., once a year) to keep up with the changing situations (Patel, 2020). However, this operation is very labor-intensive and hence costly because each intersection has to be re-timed manually (Abbas, 2013). As a result of this cost, most agencies in the USA for example will only re-time their intersections after 2 to 3 years (Abbas, 2013). As a result, it has been shown that traffic congestion increases by 3% to 5% every year simply because the timing plans are not kept up to date (Taale, 2002).

In spite of all this, fixed-time signals are still found in many locations around the world, particularly in downtown areas. In North America (USA, Canada), fixed-time controls, after over a century of development represent only a small portion of the signals, which are mostly seen in the city downtown areas (Grant-Muller & Laird, 2007). The majority of signals are either fully actuated, or semi-actuated under a time of day (TOD) signal plan (Taale, 2002).

In Germany and Austria, there are no clear statistics of exactly how many signals are fixed or actuated, but it is clearly seen that medium-sized cities (with 250,000 to 500,000 inhabitants) have the highest share of actuated signals due to the public transport priority (Agerholm et al., 2013). Still, the control logic of these actuated signals is based on fixed-time signal settings, usually in stages or individual signal groups, in other words, Time of day settings (TOD) (Saiyed, 2010).

Fixed-time traffic intersections are unable to cope with the dynamic changes in traffic situations, leading to extreme congestion, fuel wastage, crashes, exhaust emissions, and major delays (Abbas, 2013). This is because the vehicles are bound to make frequent stops which restrains the overall throughput capacity of the intersection and network (Sims & Dobinson, 1980). Research based on microsimulations has also shown that actuated (or adaptive) systems outperform the 'Time of Day' (TOD-Fixed) system models (Chai et al., 2017). Other studies have also shown that manual operation (signals determined by a human operator) performs way better than a fixed-timed signal system during high-demand periods (Taale, 2002). It is for these reasons that real-time traffic control was introduced to overcome the difficulties of the fixed system (Zhao et al., 2011).

Advanced Traffic Control systems (ATCS)

"With the increasing complexity of traffic patterns and the growing demand for efficient transportation systems, the need for effective intersection control systems has become more pronounced (Jiao et al., 2018). One of the key challenges in managing signalised intersections is the dynamic nature of traffic conditions, which necessitates adaptive control strategies to respond to changing demands (Fajardo et al., 2011). Dynamic signal control systems have emerged as a promising approach to address the complexities of intersection traffic management. These systems employ real-time data and advanced algorithms to dynamically adjust signal timings based on traffic volumes, vehicle speeds, and other relevant factors (Eom & Kim, 2020). By continuously optimizing signal phasing and timing, dynamic signal control systems can improve intersection efficiency and reduce congestion (Tang et al., 2019).

There are a couple of developed advanced traffic systems that are currently in use around the world. These systems include SCATS (Sydney Coordinated Adaptive Traffic System), SCOOT (Split Cycle Offset Optimization Technique), OPAC, MOTION, UTOPIA, and RHODES. SCOOT and SCATS are the most widely deployed Adaptive Traffic Control Systems worldwide. SCOOT and

SCATS were found to reduce overall network delays and stops by at least 14% and 9%, respectively, though SCATS caused fewer stops than SCOOT (Stevanovic et al., 2009).

Unlike fixed-time control strategies, the main aim of these adaptive control systems is to optimize the Traffic Signal Timing (TST) plan according to the present-time traffic situations in every phase. Hence the reason why these systems are built upon the use of sensor technologies mounted on or around the traffic lanes. These are intelligent transport systems, but not AI or machine learning. The systems may be thought of as calculators, and the values being input are cars and pedestrian volumes.

In today's age, we have more computational power and richer data to drive the development of intelligent transport systems. However, our current systems still rely heavily on simplified data and rules. Most of the existing traffic control schemes are based on historical traffic information without considering real-time traffic information. This is because the prediction of vehicle traffic dynamics is limited due to the fixed locations of the detectors on the road, which provide point data. This means the input data is based on vehicles passing or occupying the loops which are installed at a single point on the road lanes (Jadhav et al., 2016). This means that the main flaw of these current systems is that they are unable to "see" cars coming – only registering them once they've arrived on the detector. And the systems are also not particularly good at including other modes of transport such as trams, cyclists, and pedestrians (Zhao et al., 2011).

The preferred primary location for SCATS detectors is at the stop line in each lane, carried out by 'figure of eight' loops, typically 4.5m long and set back from the stop line about 1.5m – 2m. For the Rhodes system, detectors have to be placed on each lane of the approaches, typically 30 to 40 m upstream of the intersection. For OPAC, detectors are typically placed 8 to 15 seconds upstream from the intersection (120-200 m upstream of stop bar) but there are some field implementations where detectors were placed at stop bars. In addition, left turn count detector should be placed as far as possible. SCOOT and SCATS have the greatest number of installations, with OPAC having the smallest. Some systems were installed as early as 1992, showing that ATCS are systems used for over two decades.

The Sydney Coordinated Adaptive Traffic System (SCATS) emerges as a groundbreaking adaptive traffic control system conceived in the late 20th century. Initially developed by the Roads and Traffic Authority (RTA) of New South Wales in Sydney, Australia, during the 1970s, SCATS aimed to dynamically adjust signal timings at intersections based on real-time traffic conditions, thereby enhancing traffic flow efficiency and curbing congestion. SCATS boasts adaptability to shifting traffic demands, setting it apart from fixed-time signal systems. Its dynamic adjustment of signal timings in response to traffic volume, queues, and congestion fosters optimized traffic flow and reduced delays. SCATS enables coordination between adjacent intersections, facilitating synchronized signal operation across extensive road networks. Furthermore, SCATS' durability and dependability have been validated through extensive operational success across diverse urban landscapes. However, despite its merits, SCATS entails substantial initial setup and implementation costs, necessitating investment in infrastructure, sensors, and software. Its efficacy may fluctuate depending on variables like traffic volume variations and sensor precision. Regular maintenance and calibration are imperative to sustain SCATS performance at an optimal level over time. SCATS has garnered widespread adoption not only in Australia but also internationally. Nations such as the United Kingdom, Singapore, China, and India have embraced SCATS or similar adaptive traffic control systems to manage urban traffic efficiently. The system's flexibility and adaptability render it a preferred choice for municipalities seeking effective traffic management solutions (Stevanovic et al., 2009). Research by Abbas, M.M (2013). took a survey of 11 agencies who had installed ATCS systems, and weighted their satisfaction on performance. The compiled results showed that agencies acknowledged the improvements which the systems made regarding performance, but the improvements were still lacking to impress, hence the average satisfaction weighting. This is primarily because ATCS do not usually perform well in oversaturated networks since their algorithms were designed for undersaturated conditions, where traffic patterns are more predictable. In addition, the lack of the capacity for these systems to have real-time adaptation plays a huge role in the performance during high demand periods.

An important feature of SCATS is that it uses the number of spaces and the total space-time between vehicles to determine the level of congestion, rather than the actual volumes and occupancy. Scats uses this max flow value to determine if an approach is over or under saturated. Also, because the loop sensors are activated only when a vehicle passes through them, the signal cannot perceive and react in real-time to traffic situations. When the system detects a traffic condition, it varies NEXT cycle timing by few seconds. It can take several minutes to completely implement the 'improved' timing. The trigger event may have dissipated by the time the newly optimized timing has been implemented. The fact that these systems rely on previous cycle data to estimate the best settings for optimizing the next cycles makes the systems one step behind (or rather one cycle behind) the actual traffic situation.

Advanced Transport Control Systems (ATCS) hence require a problem (trigger) to exist before it takes action, which results in time inefficiencies. Also, while ATCS can reduce the need for manually updating timing plans, they require oversight to ensure efficient operation (trained professional labour). On the plus side, ATCS collect a variety of data that transportation agencies can use to measure and monitor performance. A research project carried out by Gandhi, M. and Mind, A.I showed the improvements that ATCS made to the performance of the studies roads, as well as a comparison of their costs. The tabulated results of this research showed an overall positive improvement caused by the use of any one of the ATCS. Overall ATCS reduces transportation time, and the effect is most clear when the transportation time is highest. Buses, trams, and passengers are slightly delayed, but despite this, the tentative conclusion is that the prospective increase in traffic volume is handled better with ATCS than without.

SOME INCORPORATED TECHNOLOGIES FOR REAL-TIME ADAPTATION

In addition to added features using wireless technology, it is ingenious to consider the incorporation of image processing on intelligent transport systems due to their ability to actually 'see' and process the real-time traffic situations. For instance, street-facing surveillance cameras used for security purposes can also provide a more detailed depiction of the traffic situation on nearby roads, specifically on how many cars are waiting in the lane, how many cars are taking turns, where they are located, and how fast they are traveling, etc. One such technology is called InSync, which uses video image processing information to make traffic signal decisions (Jadhav et al., 2016). In simulations, researchers found that InSync outperforms current ATCS by 5% to 24% due to its real-time adaptability. The InSync trail system was installed and tested on a 12-intersection corridor along SR-421 in Volusia County, Florida, US (Stevanovic et al., 2017). The prospect with such a system is that it would give the ATCS the ability to have 'Artificial vision' to make better real-time decisions. Video processing technology is already accurately being used on highways for identifying vehicles by their number plates, especially by law enforcement for security reasons. Another benefit of video processing is that unlike ATCS equipment, Video processing hardware and software are easier to set up and are way less costly. Image tracking of vehicles will give us quantitative parameters, which then gives us complete traffic flow information, which in turn completes traffic theory.

COSTS AND LIMITATIONS ASSOCIATED TO THE USE OF ATCS

ATCS obviously are not cheap systems, as discussed previously. They each come with costs which are all similar in nature but not in magnitude. For the SCOOT system, literature suggests that the average cost for implementation is $49,300 per intersection, with the average number of hours of training for engineers (per location) to use the system approximately 400 hours, and about 180 hours for maintenance training. For SCATS, the cost is a bit more, with literature suggesting the average cost per intersection to be between $80,000 to $130,000. Comparing these figures, we can see that ATCS require significant financial outlay. However, these costs must be weighed against the potential benefits in terms of reduced congestion, improved traffic flow, and enhanced overall urban mobility. The long-term cost-effectiveness of ATCS hinges on factors such as system reliability, maintenance requirements, and the magnitude of congestion reduction achieved (Sims & Dobinson, 1980).

In summary, the effective management of traffic at intersections is critical for urban mobility, safety, and environmental sustainability. While fixed, adaptive, and dynamic actuated traffic signal systems each offer distinct advantages and drawbacks, the selection of a system should align with specific urban transportation needs, infrastructure constraints, and budget considerations. As cities continue to grapple with escalating traffic congestion and transportation challenges, investments in innovative traffic management solutions, informed by robust research and technological advancements, are imperative for fostering sustainable urban development and enhancing the quality of life for residents (Saiyed, 2010).

RESEARCH GAP AND FUTURE RESEARCH

The challenge of the Intersection Traffic Control Problem (ITSCP) is to find an optimal traffic signal configuration system that maximizes the traffic flow in a network. However, it remains necessary to develop an approach that can handle a network consisting of variously shaped intersections (Fajardo et al., 2011). Further research regarding traffic signal control in accident scenarios is mandatory to prepare for the coming age of autonomous vehicles.

As stated above, current ATCS in use still rely heavily on oversimplified information and rule-based despite this age having richer data, more computing power and advanced methods to drive the development of intelligent transportation. Several researchers agree that further research needs to be carried out to take advantage of this new age's current technology advancements. Although some signalized intersections in urban metropolitans are operating under actuated traffic control, heuristic-based traffic control has not been thoroughly studied so far. As a result, heuristic-based intersection traffic control is minimal because of the lack of research in local conditions (Jamal et al., 2020). Further research needs to be carried out to better optimize signal systems (Grant-Muller & Laird, 2007).

As noted by researchers, 'there is a lack of a good literature review paper that should cover the literature published in these years regarding signal timing and control settings' (Qadri, Gokce & Oner, 2020). Also, noted by researchers Han, E., Lee, H.P. & Park, (2019), 'despite many literature reviews by other researchers about real-time traffic control, many of research efforts did not define exactly which type of data and contents will be used in their development' (Han et al., 2019). Contrary to this finding, this research specifies that 'wireless technology and associated data' will be used in the development of the proposed intelligent traffic system. The researchers Qadri, S.S.S.M., Gökçe, M.A., and Öner, E. (2020), further conclude 'We believe that fixed-time controllers will have a less practical impact and therefore more research effort can be expected on real-time control strategies'.

In Melbourne Australia, the university of Melbourne and the Victoria department of transport have embarked on a $2 million dollar pioneer project to install a super intelligent traffic corridor that will use sensors, cloud-based AI, machine learning algorithms, predictive models and real-time data capture to improve traffic management (cosmosmagazine, 2022). The 2.5km corridor section will run along Nicholson Street, in Carlton. Using 180-degree high-definition cameras, as well as a range of detectors (including the normal SCATS detectors), the team of researchers are currently testing the AI system using this real-world data in a computer simulation (Gökçe et al., 2020). "Our Intelligent Corridor will use the latest technology to better manage traffic and make our roads safer for everyone," Professor Sarvi said. AIMES Director and Professor of Transport Engineering at the University of Melbourne, Professor Majid Sarvi said the Intelligent Corridor will provide a model for cities around the world (cosmosmagazine, 2022). . This technology is laying the groundwork for a sustainable and congestion-free future, utilizing the very best in multi-modal demand management technologies such as the Kapsch EcoTrafix platform (Gökçe et al., 2020). AI-based traffic optimization will happen at the intersection or "node" rather than at a central system (Jiao et al., 2018). With the sensors taking and analyzing the data almost instantly, the lights might change if there are more pedestrians waiting, or a tram might get right of way if it's running behind schedule (Gökçe et al., 2020).

METHODOLOGY

SITE SELECTION (STUDY AREA)

In order to pick the best study area for this research, the objective was to pick sites with significant traffic flow behavior. In order to analyse the traffic flow behavior, SA Map viewer, a data tool from DATA.SA website, was used to analyse the peak traffic flow behavior as shown figure 2 and 3 below:

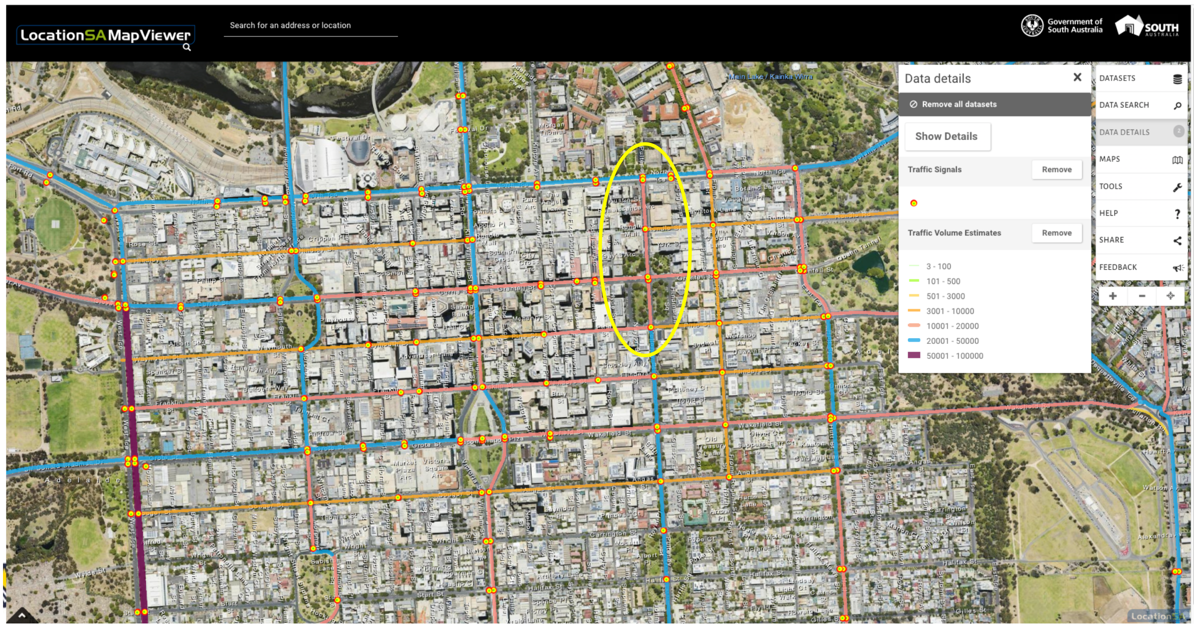


Figure 2: Site Selection using DataSA's Location Map Viewer

Figure 3: Location of Sites (Map and street views) (Google imaging, 2023)

The CBD is known to have the highest traffic flows, and hence was the location of choice. For the selection of intersections, careful analysis was done using the data maps in figure 2 above. The data maps show the distribution of traffic flows in the Adelaide CBD roads. From the legend, we can see that the roads with red highlight have the highest traffic flows at peak time. The selected study area is shown by the red circle on the figures, and this area has some of the highest traffic flow volumes in the Adelaide CBD. The study area has three busy intersections which are shown in figure 3 above: The intersection ID's for the chosen intersections are show in figure 3 as **3018, 3019** and **3020**. These codes will be used to refer to each respective intersection in this thesis. These three chosen intersections in the study area accommodate some of the highest traffic flow volumes during morning peak hour, and were the most ideal to model and carry out experiments. Also, owing to their CBD location, it was assured that traffic flow data such as SCATS data counts would be up-to-date and readily available for the purpose of analysis and modeling.

DATA COLLECTION

Traffic volume counts are recorded by the SCATS detector system and stored in a Volume database, and these counts are considered to be 100%+/- accurate. In Adelaide, the intersections are under the control of the Adelaide city council (not the department of infrastructure) together with all the traffic volume data. In order to analyse the actual on-site traffic behaviour of the chosen intersections, it was necessary to obtain the traffic counts data, which is conveniently stored in the council database which my supervisors have access to. The SCATS operation diagrams for each intersection are shown in figure 4 below:

Figure 4. SCATS operation schematic diagrams of intersections 3018, 3019, 3020

SCATS operation data for each intersection was obtained which provided detailed information on the operation of the intersection, such as the historical calibrations and changes, the right turn rules, amount of intergreen time, maximum cycle time, site details, phasing operation etc, and all this information was necessary for the modelling of these intersections in both SIDRA and AIMSUN. This is shown in Appendix 1. In addition to the operational site data, SCATS vehicle turning count data was also obtained for each intersection. This data is a record of each intersections vehicle counts for each approach, recorded by the SCATS detectors and compiled every 5 Minutes. This data is in csv. This data is shown in Appendix 2. For the purpose of daily traffic volume analysis, two weeks worth of data was obtained, for the month of March, 2024. The month of March (nicknamed “Mad March”) in Adelaide is known as one of the active months due to the festivals that happen each year. The data collected was from **11th March to 24th March**, which are the two middle weeks of march. This data is a record of all the vehicle movement counts for each intersection, on each approach, for every 5 minutes during the peak hour (8am to 9am), for Monday to Sunday for two weeks.

DATA ANALYSIS

	WEEK 1	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3018	EAST	272	925	952	849	875	602	396
	WEST	151	848	789	836	838	339	165
	SOUTH	106	440	431	433	428	196	136
	SUM	529	2213	2172	2118	2141	1137	697

	WEEK 2	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3018	EAST	911	794	872	942	989	530	348
	WEST	853	898	827	867	838	304	184
	SOUTH	401	443	438	463	469	167	132
	SUM	2165	2135	2137	2272	2296	1001	664

			1	2	3	4	5	6
	WEEK 1	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3019	EAST	54	291	270	303	316	70	41
	NORTH	82	642	574	611	605	214	127
	SOUTH	149	761	805	777	768	323	164
	SUM	285	1694	1649	1691	1689	607	332

	WEEK 2	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3019	EAST	311	309	317	292	256	79	43
	NORTH	642	594	624	649	656	198	123
	SOUTH	720	819	815	843	845	290	175
	SUM	1673	1722	1756	1784	1757	567	341

	WEEK 1	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3020	EAST	104	777	847	822	808	227	176
	NORTH	116	738	665	707	703	250	169
	WEST	130	637	668	643	660	261	174
	SOUTH	145	924	948	946	962	319	178
	SUM	495	3076	3128	3118	3133	1057	697

	WEEK 2	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3020	EAST	797	827	841	772	755	217	159
	NORTH	735	693	741	757	712	225	158
	WEST	689	720	667	696	642	256	143
	SOUTH	782	943	970	921	979	360	184
	SUM	3003	3183	3219	3146	3088	1058	644

Figure 5: Compiled Volume data for each day on each intersection, for each approach

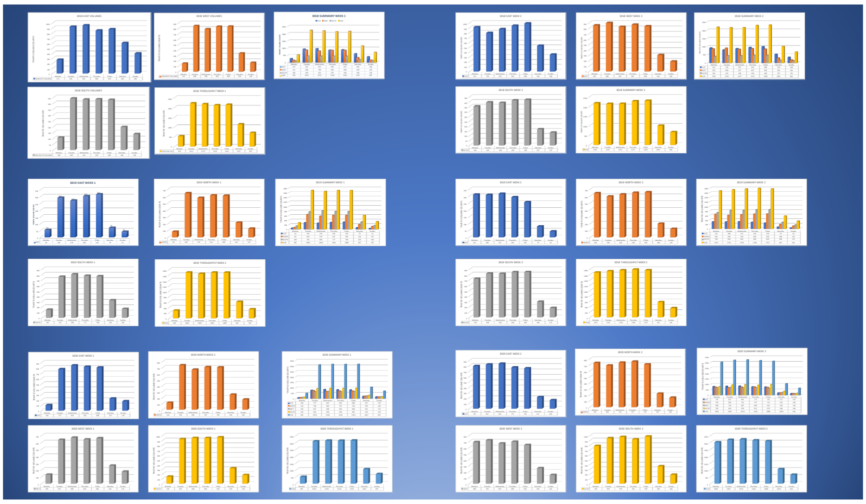


Figure 6: Resulting graphs produced from volume data

The data was then cleaned up and filtered, and a series of tables was created which showed the total volume counts for each approach, for each intersection, on each day (Monday to Sunday), for two weeks. This data allowed for the analysis of traffic behaviour from Monday to Sunday, and this was a significant part of the project for the purpose of modelling because it gave a means to select a day and time for modelling of the Level of Service (LOS) of the Network and of the intersections. These tables are shown in figure 5 above. Also, as shown in figure 6 above, the volume data compiled in the tables was used to generate the cluster of volume graphs, which reflect the volume counts and patterns for each approach of each intersection, for each day of the week, for two weeks. This volume behaviour was analysed using the graphs to determine which day of the week had the highest occurring traffic count volumes during peak time compared to the other days. From the cluster of graphs, a few key graphs are discussed below. These graphs are attached in Appendix 3.

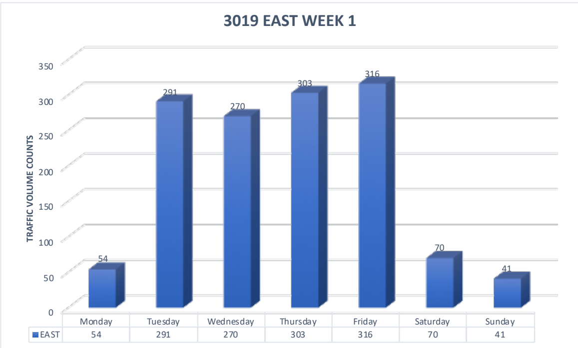


Figure 7: Volumes for 3019 East approach in week 1

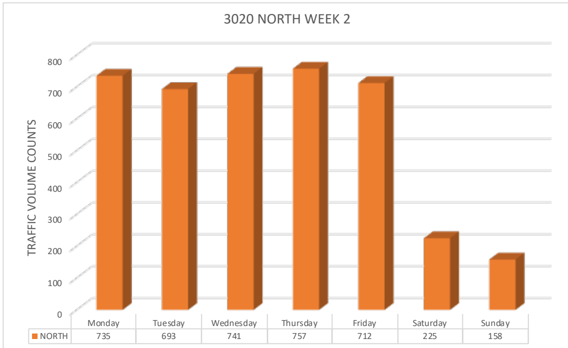


Figure 8: Volumes for 3020 North approach in week 2

The volume graphs were able to show the traffic volume pattern for each approach of each intersection, as seen in figure 7 and figure 8 above. From these graphs, it was possible to see which approaches experienced the highest volume of vehicles at peak hour compared to the other approaches, on each day of the week, which was useful later in the research when picking which sections to check for improvement/delays after running the traffic model simulations, as will be shown.

The graphs were also able to clearly show the throughput of each intersection, which is the number of vehicles that travelled through the intersection during the peak hour, for each day of the week. Figure 9 and 10 show and example of this.

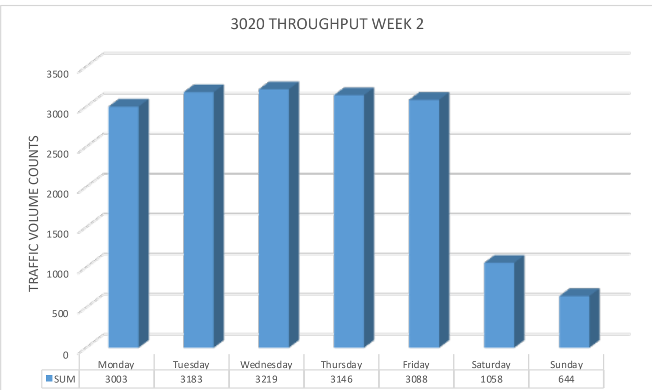


Figure 9:Throughput Volumes for intersection 3020 in week 2,

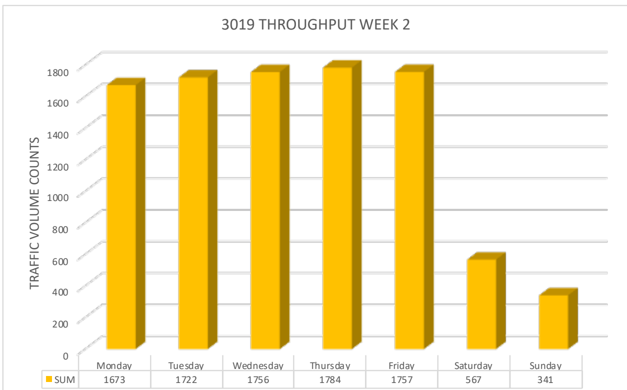
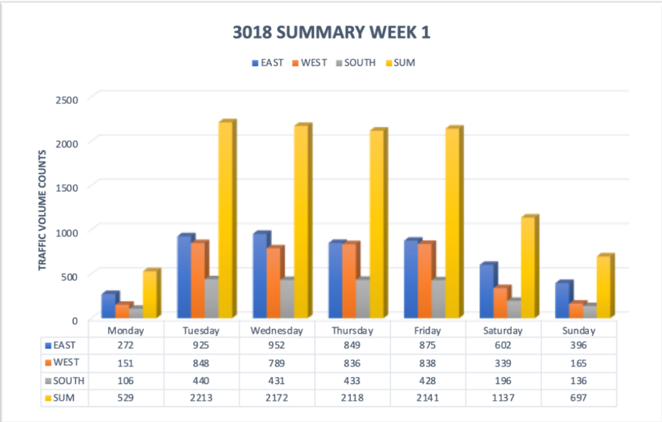


Figure 10: Throughput Volumes for intersection 3019 in week 2

From the figures, it was possible to analyse and determine which day had the largest volumes in the 14 days analysed. Taking figure 9 above as an example, it can be seen that the highest number of vehicles passing through intersection 3020 was recorded on Wednesday in week 2, which was 3219 vehicles, while the lowest number of vehicles through the intersection was recorded on Sunday, with a count of 644 vehicles.

Lastly, another significant visualisation obtained from the volume data was the compiled summary graphs for each intersection, as shown in figure 11 and figure 12 below:



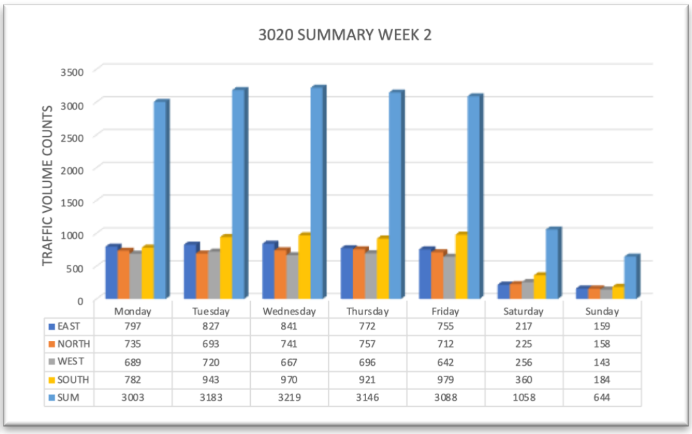


Figure 11: Throughput Volumes for intersection 3020 in week 2

Figure 12: Throughput Volumes for intersection 3019 in week 2

From the summary graphs, was easy to see the comparison of traffic volumes for each approach on an intersection, as well as compare the throughputs throughout the week. The summary graphs make it easy to determine which day of the week experienced the highest number of vehicle demand during peak hour. Determining this special day gives guidance on which day to model in the microsimulation models, in order to know the performance of the intersection and the network on this day.

Finally, after all the volume analysis using the graphs and the volume tables, it was possible to select the modelling day to represent the work case (highest demand) currently being experienced in this section of the Adelaide CBD at the time of this research.

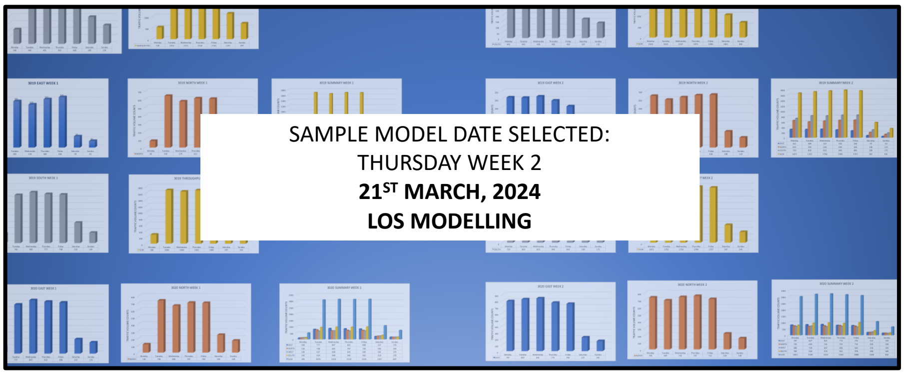


Figure 13: Representative day selected for LOS modelling

Figure 13 above shows that finally a date was selected for modelling, that date being the 21st March, 2024. The peak hour traffic data for this day was used for analysis in the microsimulation models of SIDRA and AIMSUN to determine the current serviceability of the Adelaide intersections under their highest recorded traffic volumes within these two weeks.

SIDRA INTERSECTION was used to analyse the current state of the network, focusing on parameters such as Level of service (LOS), Delays and ques. AIMSUN NEXT was used to model the network and compare the three traffic systems, FIXED, SCATS and DYNAMIC systems, to see how they compare in handling the traffic demands for the selected day, in terms of delays, ques and other traffic parameters.

SIDRA MODELLING

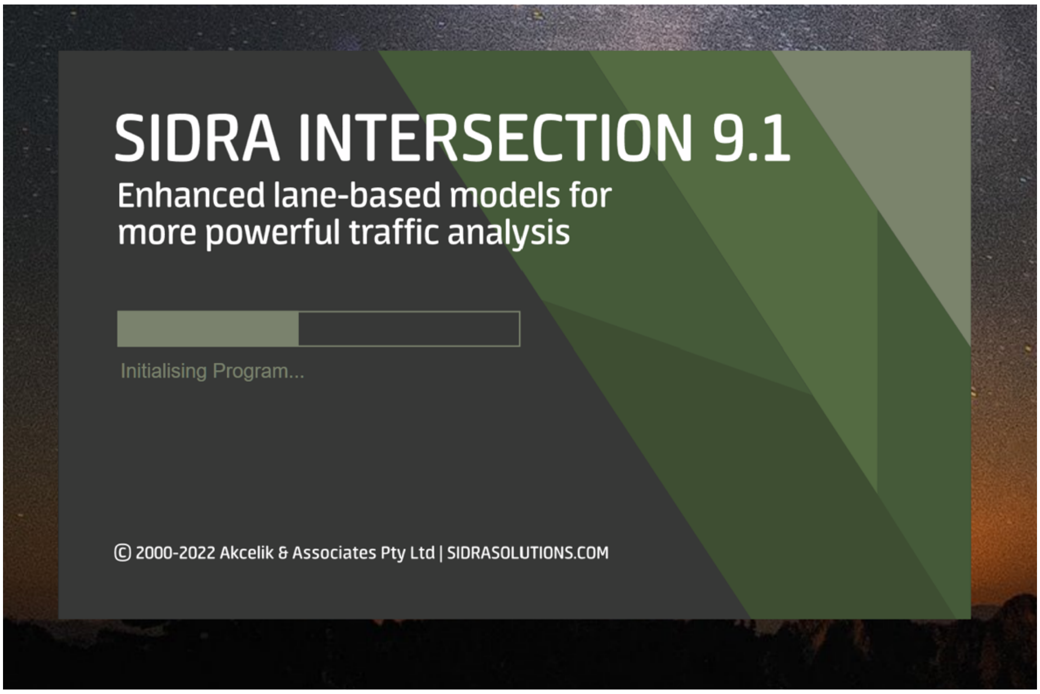


Figure 14: SIDRA INTERSECTION

Using the data from the SCATS traffic volume counts for the date chosen, together with the SCATS intersection operation data obtained from Adelaide city council for the intersections, the network of intersections was modelled in SIDRA INTERSECTION software from SIDRA SOLUTIONS, shown in figure 14 above.

SIDRA INTERSECTION is powerful software used as an aid for design and evaluation of individual intersections and networks of intersections (*Sidra.com)*. SIDRA INTERSECTION uses lane-based second-by-second arrival and departure flow patterns to accurately analyse coordinated signal systems and Common Control Groups. SIDRA INTERSECTION can model simple to complex road traffic facilities with ease and efficiency. (*Sidra.com)*.

SIDRA software was chosen because it is a powerful microsimulation software which can analyse the current traffic situation of the study area using the intersection data and traffic

counts, and

determine accurately the current level of service (LOS) for the intersection and the network. This was important to understand the current level of operation of the CDB intersections which are using the SCATS system to manage traffic in the city. The Level of Service gives an insight on whether the traffic management system performance currently being used is adequate/satisfactory, or whether the performance of the traffic network is unsatisfactory or worsening, hence indicating that improvements need to be made. This helps with future traffic and transportation planning.

MODEL BUILDING (NETWORK)

MODELLING STEPS

The modelling process followed the standard SIDRA model building process. The modelling steps taken in building the models for this study are as shown in figure 15 below:

1. Intersection	7. Priorities
2. Movement definitions	8. Gap acceptance data
3. Lane geometry	9. Vehicle movement
4. Lane movements	10. Phasing and timing
5. Pedestrians	11. Demand and sensitivity
6. Volumes	12. Parameter settings

Figure 15: SIDRA Modelling Steps

GEOMETRY BUILDING

The main steps and parameters used when building the model are shown in the paragraphs below. The first step was importing site data from open street maps into SIDRA. Data for the three intersections was imported, and the geometry of each intersection was modelled to represent the onsite geometry, as required.

Figure 16 below shows the 3 intersections modelled in SIDRA intersection.

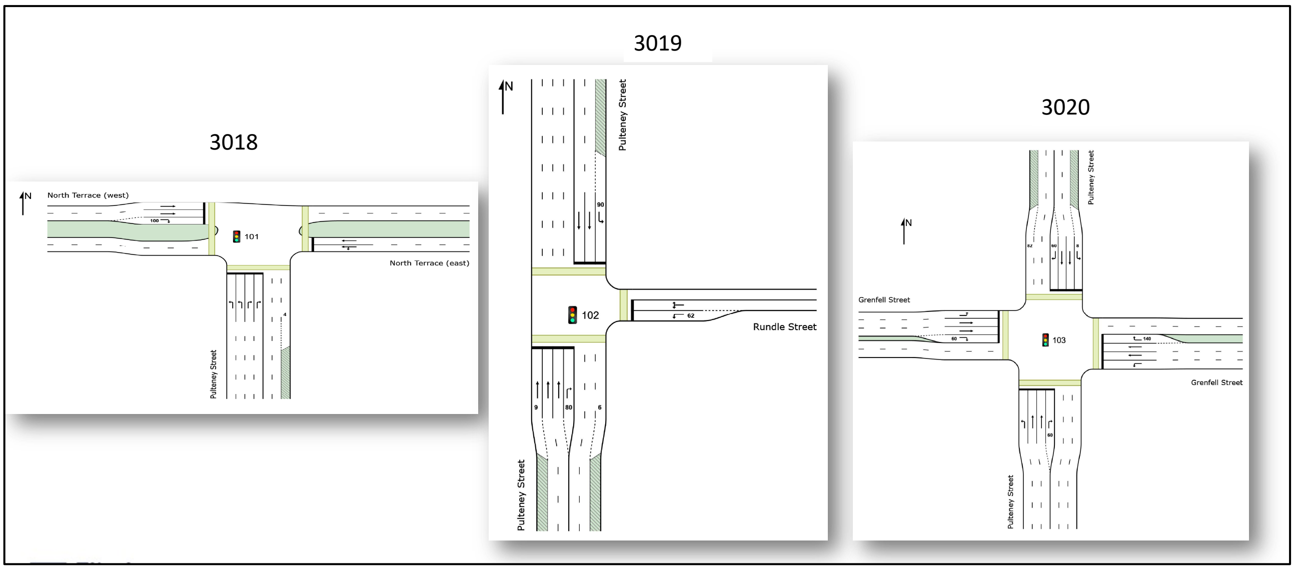


Figure 16: Geometry modelling of 3 intersections

Another the ‘intersection’ tab, the approach distances for each approach on each intersection was above 100 meters, hence bunching factor of 20% was used for each approach. Also, Area factor of 0.9 was used for all intersections because the study area is in the CBD. Under the ‘Volume factors’ tab, an annual growth rate of 1% was used to represent the current annual traffic growth rate of Adelaide, also used by the Department of Transport (DPTI). These calibrations are shown in figure 17 below:

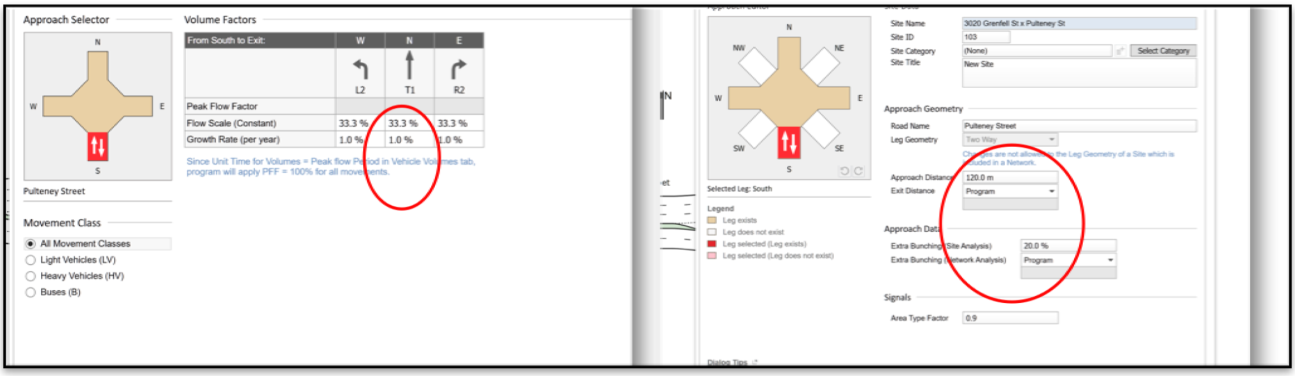


Figure 17: Volume factors and Approach calibrations

VOLUMES INPUT

The vehicle counts from the SCATS volume data were used in the model under ‘vehicle volumes’. The modelling period was also set to 60 minutes (1 hour). These calibrations are shown in figure 18 below. These volumes can also be referenced to the volume data in Appendix 3.

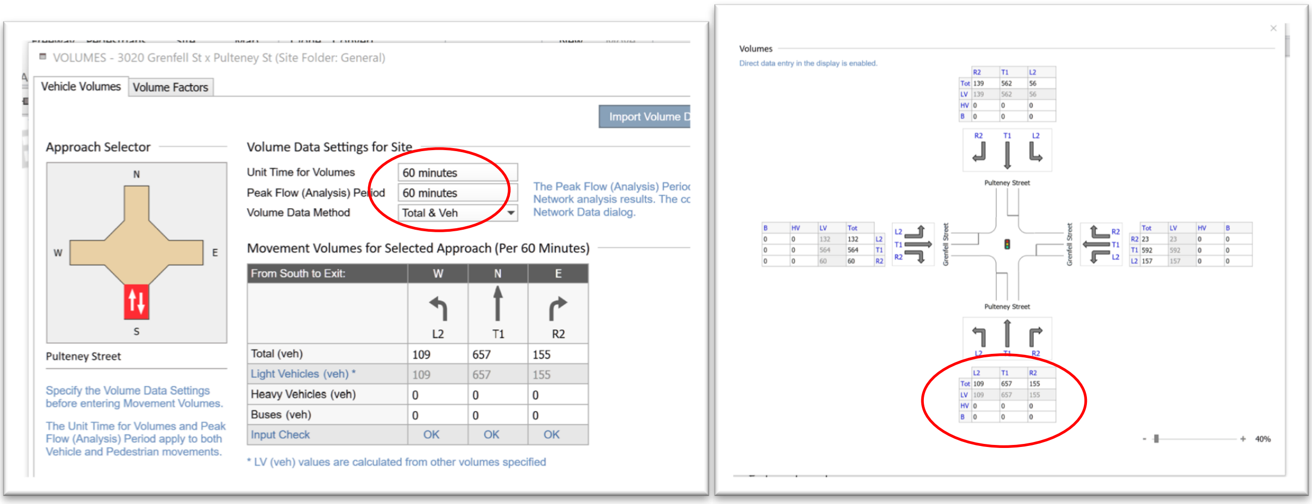


Figure 18: Vehicle volume input

The example above is for intersection 3020, south approach. The same was done for all other approaches on each intersection.

PHASE TIMING AND SEQUENCE

Using the information from the SCATS operation data, the phase sequencing for each intersection was modelled. The signal analysis method was also set to “SCATS”, a feature in SIDRA software that allows for the model to behave as it does with the SCATS system being used on the traffic intersections. These calibrations are shown in figure 19 below:

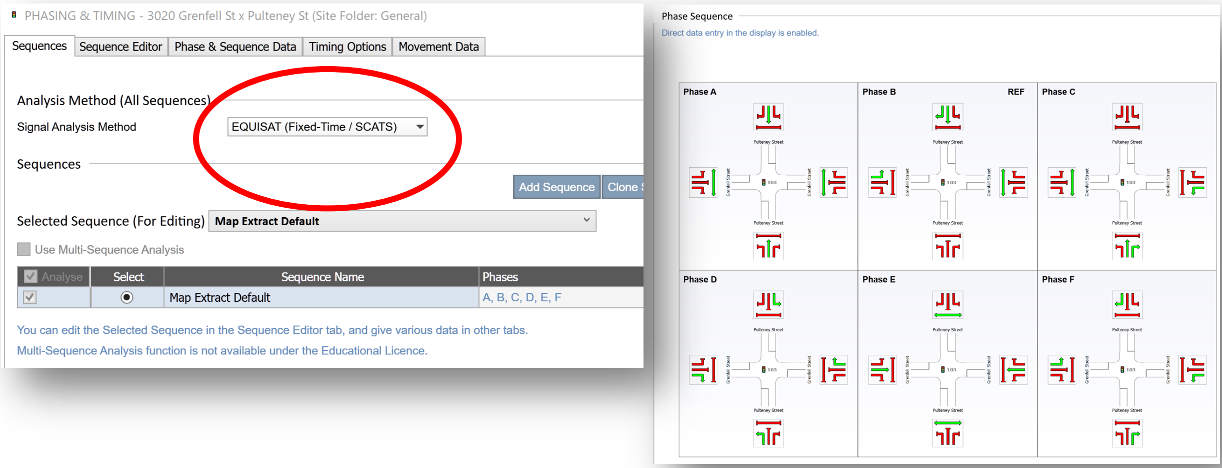


Figure 19: Phase sequencing and Signal analysis method calibration

NETWORK CALIBRATION

After all the modelling parameters had been set for each intersection according their respective features and characteristics, the final step was to create a network with the three intersections, in readiness for the processing of the whole project site.

The three intersections where joined into a network as shown in figure 20 below.

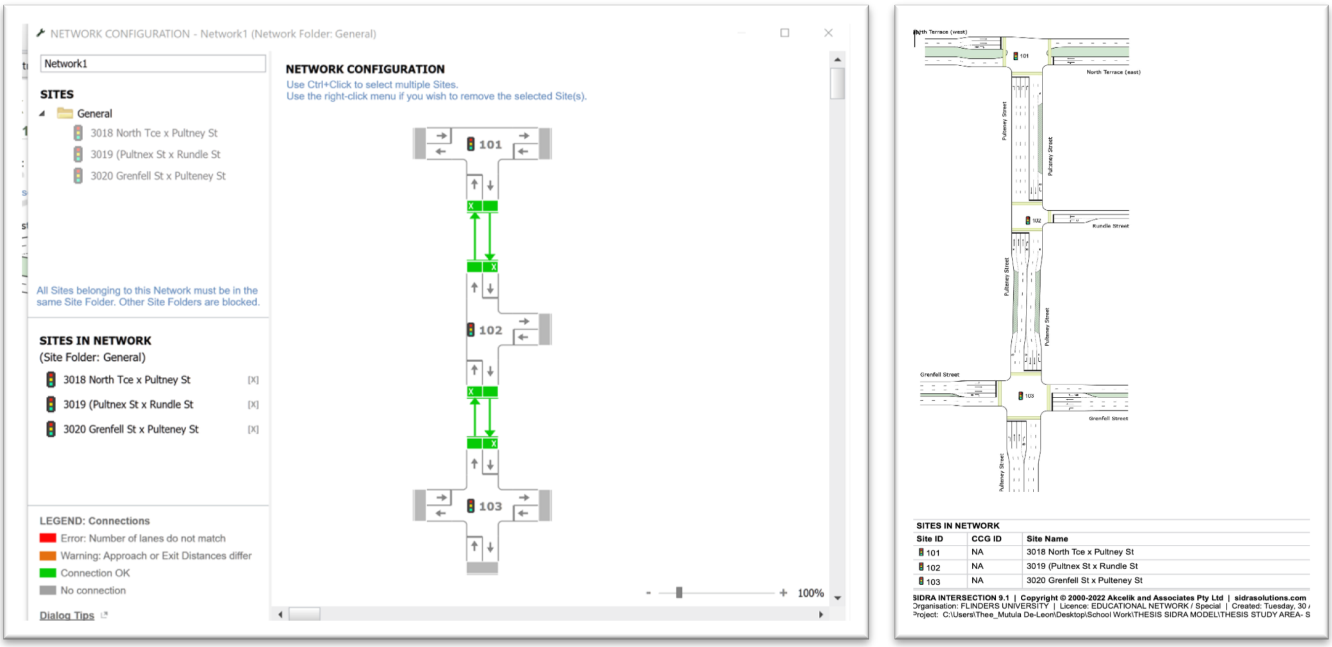


Figure 20: Network Building and Calibration

Once the network was created and properly calibrated, the site was ready for processing. The results from the analysis of the network, and of the individual intersections, are discussed under 'SIDRA Results'.

AIMSUN MODELLING

Before discussing the SIDRA analysis results for the network, the modelling carried out in AIMSUN NEXT software is discussed in this section.

Figure 21: AIMSUN NEXT SOFTWARE

Aimsun Next is a multi-resolution modelling platform that simulates mobility in networks of all sizes, from a single intersection to an entire region (aimsun.com). Aimsun Next is an all-in-one approach to mobility modelling, providing a single, united network representation of how people move in any mode, on any scale. Aimsun's simulation and predictive data analytics help customers to understand transportation network performance, to predict its future evolution, and to support decision making. At its core, AIMSUN Next utilizes advanced algorithms and modelling techniques to replicate real-world traffic scenarios, enabling transportation engineers and urban planners to evaluate the performance of various infrastructure designs, traffic management strategies, and mobility solutions. Whether assessing the impact of new road layouts, optimizing signal timings, or simulating the integration of autonomous vehicles, AIMSUN Next provides a versatile platform for exploring the dynamics of urban transportation systems in diverse contexts.

In this study thesis, three transport management systems were modelled, studied and compared in performance. These systems were the FIXED signal system, the SCATS signal system, and the DYNAMIC traffic signal system which this thesis is trying to investigate to determine how these systems perform when compared to one another. The main focus of this thesis was to investigate the efficiency of a Dynamic traffic management system compared to the other two systems.
AIMSUN NEXT software was ideal for this purpose because of its ability to simulate different systems with different configurations. The most useful feature of AIMSUN NEXT software for this thesis was the detector feature. This feature allows for detectors to be placed at points in the roads of the model, allowing for an actuated system to be configured. This allows for systems such as SCATS which are actuated systems to be modelled, but most importantly, it allows for a dynamic system

to be imagined and created by simply playing around with the detectors. Dynamic system is a system which has enough input data to allow the traffic management system to think dynamically. By using the detectors in AIMSUN in the correct way and with proper calibration, AIMSUN software gives the opportunity to model a dynamic system as far as possible, with its own limitation. This system can be thought of as a “super actuated system”.

MODEL BUILDING

The first step in the modelling process was to import data from the open street maps website using the “OSM Import” tool in AIMSUN, for the Adelaide CBD, focusing on the three main intersections for this case study. The figure 22 below shows the case study area with an imported background image of the Adelaide CBD, with the geometry of the network of the three intersections.

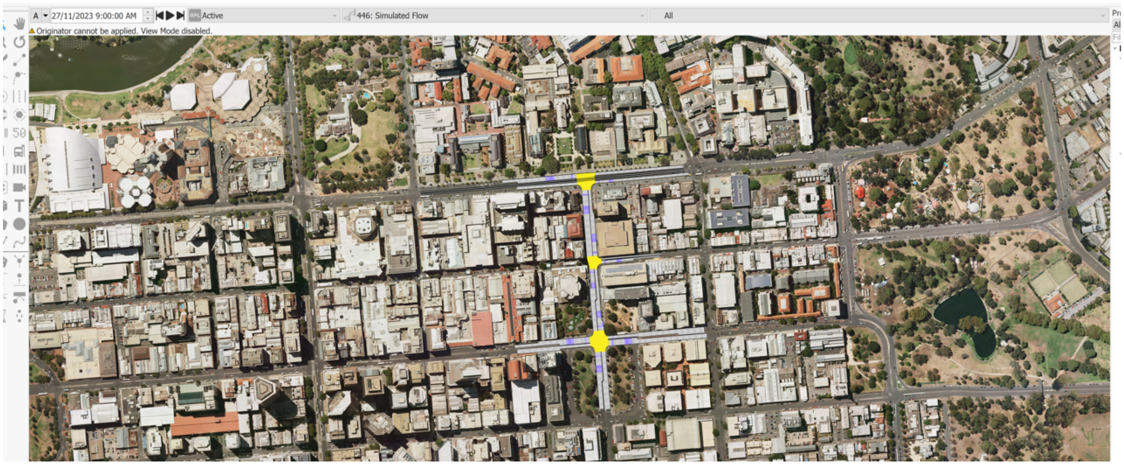


Figure 22: Network Data import in AIMSUN

Building on from the imported geometry data, the network or intersections were fixed by adjusting their geometry, number of lanes, intersection alignment, turning movements, Lane disciplines, stop lines, and turn priorities. Figure 23 below shows the final intersection models.

Figure 23: Modelling of intersections 3018, 3019, 3020

The remainder of the steps in the Aimsun modelling process followed the common AIMSUN standard modelling procedure and will not be highlighted here. However, the main steps in the building and calibration of the models is highlighted in this section.

DEMAND DATA (VEHICLE VOLUME DATA)

The SCATS vehicle turning counts that were used in the Sidra modelling process were also in the AIMSUN model as demand data. This step ensures accuracy and consistency in the models for comparing results. AIMSUN vehicle demand data can be entered in two ways; as an "O-D Matrix", and as a "Traffic state" which represents actual turning movement counts, similar to those used in SIDRA modelling. For this model, the vehicle data was entered as a "Traffic State", which is also consistent with the vehicle count data provided for the intersections. Using this data directly allows for high level of model accuracy. Figure 24 below shows the demand data being entered as a "Traffic State".

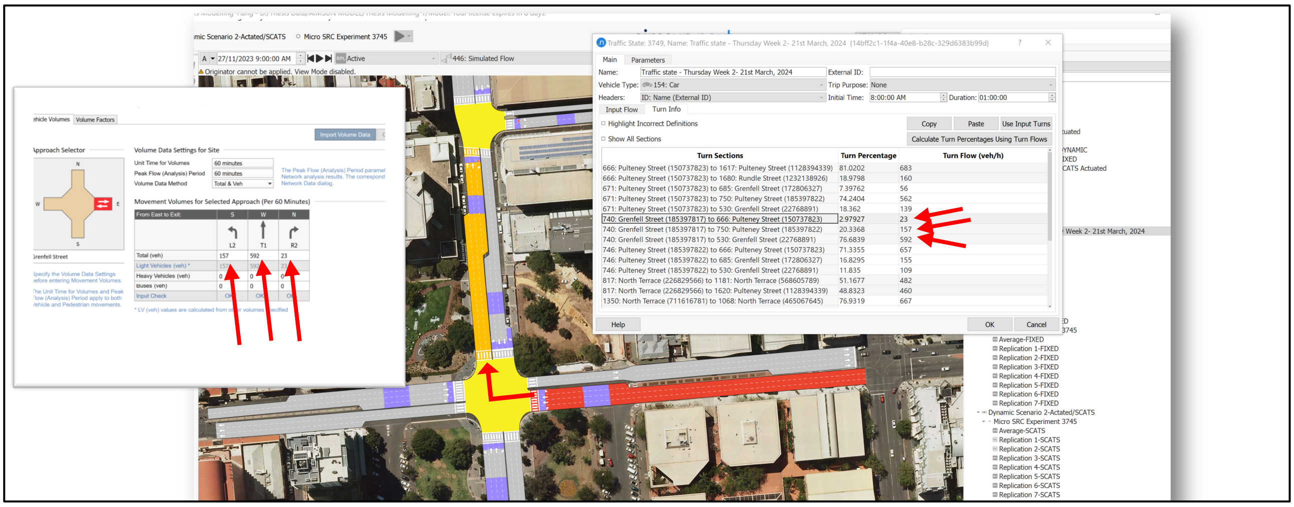


Figure 24: Demand Modelling in AIMSUN & comparison with SIDRA volume data

Figure 24 above shows the creation of a traffic state which represents the vehicle demand on Thursday 21st March, 2024. The figure also shows that the vehicle data is consistent with the vehicle counts entered when modelling in SIDRA. From the geometry on the image, the red section of the road highlighted represents the section in which volume data is being entered. The exact same data was entered when modelling in Sidra as is shown in the figure above.

The red arrows in the figure above, on the two diagrams, emphasize that the data entered for the highlighted section (and every other section) is exactly the same. This ensures maximum consistency in the models and in the data entered when creating the models in the two softwares. This is the advantage of entering vehicle data as a Traffic state when OD data is not available. The red section on the diagram is the road section with the entered turning counts, while the orange section represents the turning movement. This visualization in ancient assist to prevent errors in data entry while creating the traffic states.

After all the traffic demand volume data was entered in the traffic state, one of the key features of Aimsun Next is the ability to visualize this data on the network. Figure 25 shows the network with the road sections color-coded according to the volume saturation, as recorded in the traffic state created. The legend on the top-right corner shows the number of vehicles as a range relating to the colour code on the figure. Using this visualization, it is clearly seen which road sections had the highest saturation (volumes) compared to the other sections in the network and peak hour. This also serves as a guide to check important sections in the network for delays and LOS.

Figure 25: Vehicle volume (saturation) colour coded visualisation of network at peak hour for the created Traffic State.

The next step in the AIMSUN modelling process, after the creation of a traffic state, was the creation of a Traffic Demand. A new 'Traffic Demand' was created and the previously created 'traffic state' was loaded into the 'traffic demand'. This traffic demand represented the vehicle turning counts for each intersection, and it is this traffic demand that is used later when creating the scenarios and running the experiments in AIMSUN.

The figure 26 below shows the creation of the new traffic demand, with the traffic state loaded into it as input. The peak hour of this traffic state is also Shown on the traffic demand as 8:00 AM to 9:00 AM.

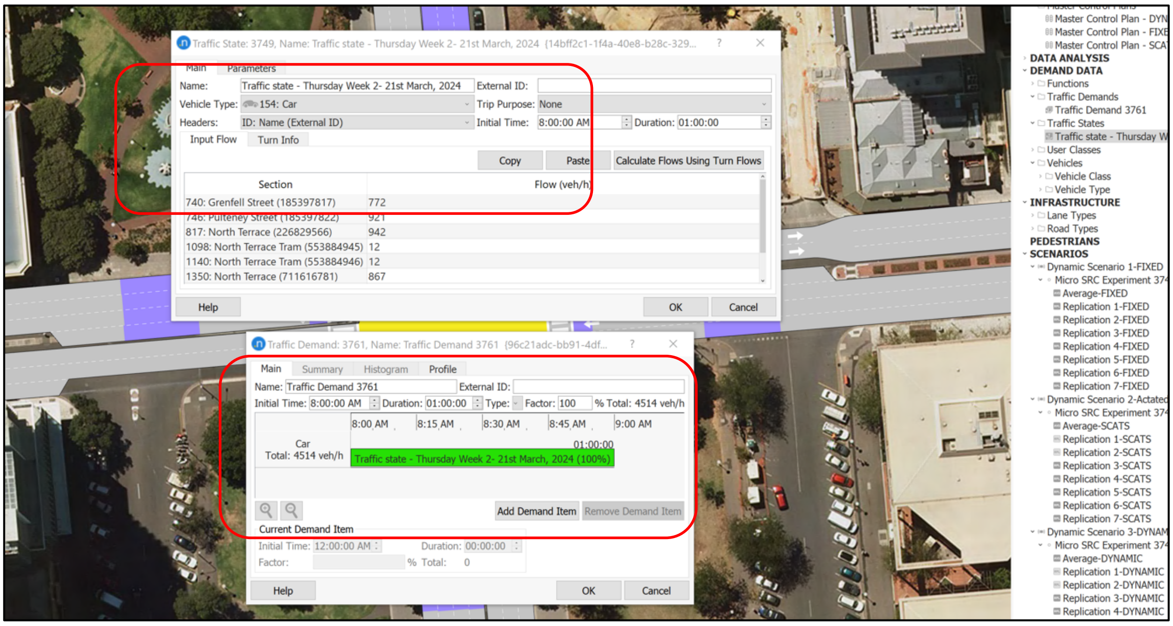


Figure 26: Creating a Traffic Demand and Loading the traffic state into the new traffic demand

CONTROL PLANS AND MASTER CONTROL PLANS

The next significant step in the modelling process was is the creation of three different control plans. A control plan in Aimsun Next is an ALGORITHM (or set of rules) which control the behaviour of the signal timings and phases on a signalized intersection. As previously stated three different traffic management systems were compared and analysed for performance, these were; the FIXED

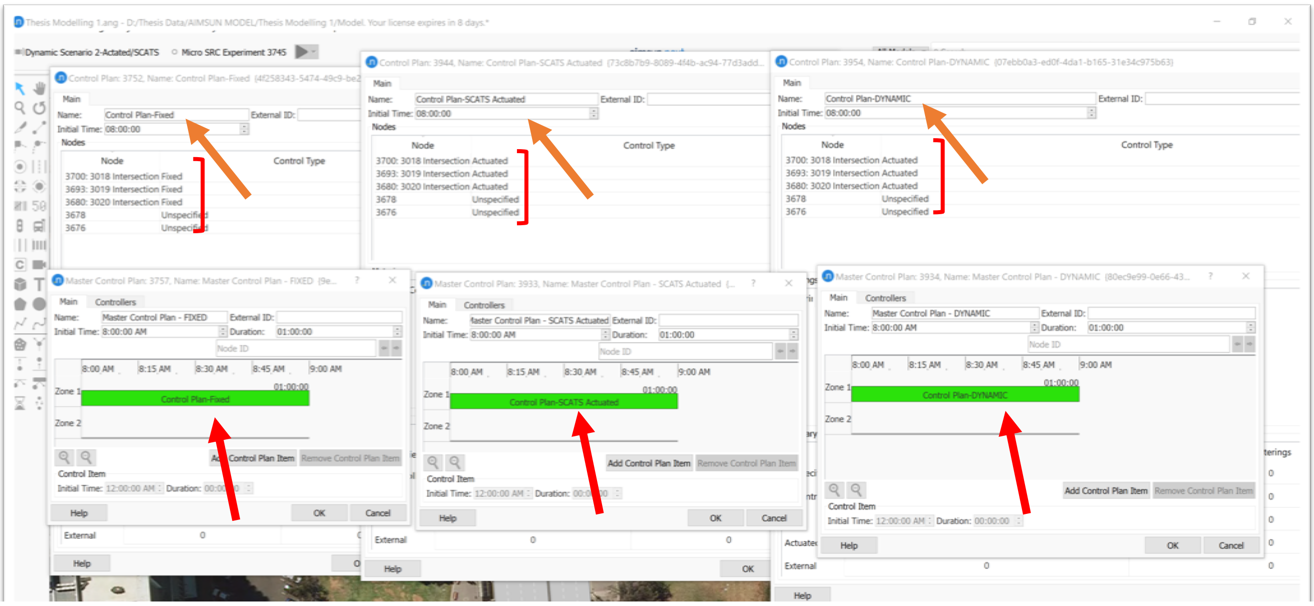


Figure 27: Creating 3 Control plans and loading them into 3 Master control plans

SYSTEM, the SCATS system, and the DYNAMIC system. Because three different systems were to be modelled, three different control plans with three different ALGORITHMS also had to be modelled (or designed, in the case of the dynamic system). The main comparison in this thesis was between the SCATS system and the proposed Dynamic system. For the purpose of control, the fixed system was also introduced and added to the group of systems to be modelled and compared, which allowed for a broader set of results to be produced (despite the increased work load). The Fixed Traffic Management System is the most popular system currently being used around the world, the SCATS system is an actuated system currently being used in Australia and some parts of Europe, while the Dynamic system is the main focus of this research(all in Figure 27). As such, it proved to be very logical to have the three systems compared, and not just the former two. The difference between these systems is their way of operation, their mentality, in other words; their ALGORITHM. The differences in the ALGORITHMS is discussed in the next section.

After all three 'control plans' and their respective algorithms we are created, each 'control plan' was loaded into a 'Master control plan'. It is the 'master control plan' that was then used in the creation of 'dynamic scenarios' before running experiments in Aimsun Next software. Figure 31 above shows how to control plans were created and later loaded into the master control plans. Also, from figure 31, we can also see that for the fixed control plan, the 'control type' for each intersection is set to "FIXED", while for the other two control plans, the control type for each intersection is set to "ACTUATED" because both the SCATS System and the proposed DYNAMIC system are considered to be actuated traffic management systems due to the use of detectors.

ALGORITHMS (SET OF RULES FOR EACH CONTROL TYPE)

As previously mentioned, the main difference between the three traffic management systems is the use of detectors and their configuration. Unlike the FIXED system, the SCATS system and the Dynamic system are actuated systems, meaning they make use of detectors to trigger (or actuate) traffic signal timings and phases according to predetermined ALGORITHMS or sets of rules.

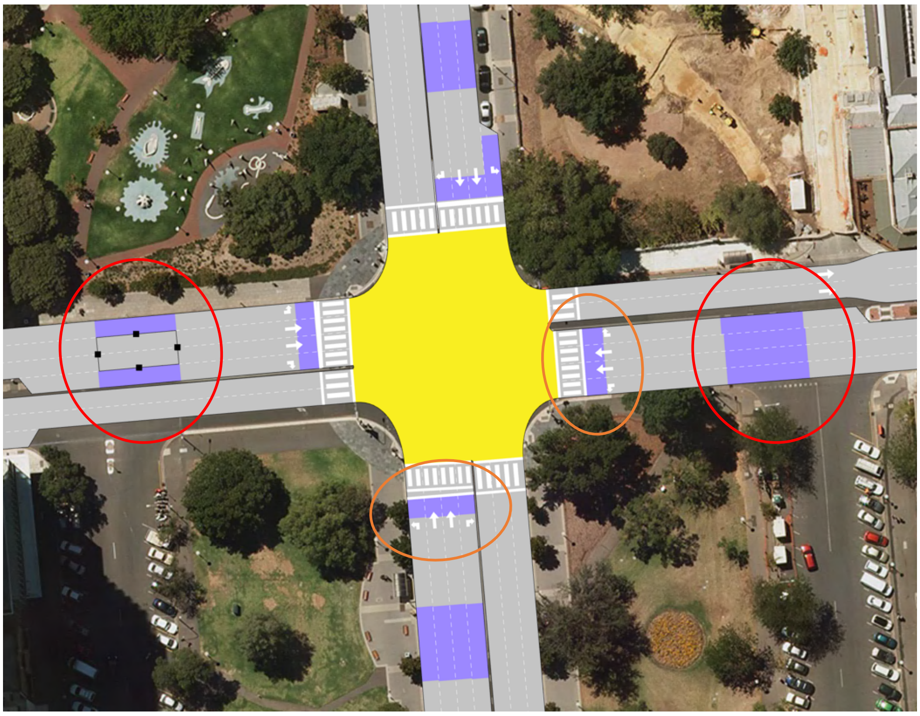


Figure 28: Position of Vehicle Detectors on the intersection Models

Therefore, in order to discuss the three different types of ALGORITHMS, it is important to note the arrangement of the detectors in the model. The purple rectangular bars in figure 28 above represent detectors placed at strategic locations. As a standard, the SCATS system uses detectors that are placed at the stop lines of each approach, for each intersection. The detectors placed away from the stop lines, as seen in the figure above, are part of the design of the DYNAMIC system which will be discussed in the next sections.

FIXED SYSTEM ALGORITHM

The first and simplest system to discuss is the fixed traffic management system which uses a fixed control plan. The algorithm of the fixed control plan is easy and simple because it is set in such a way that every phase or vehicle movement is allocated a fixed amount of time and this is not changed or affected by any actuators or detectors.

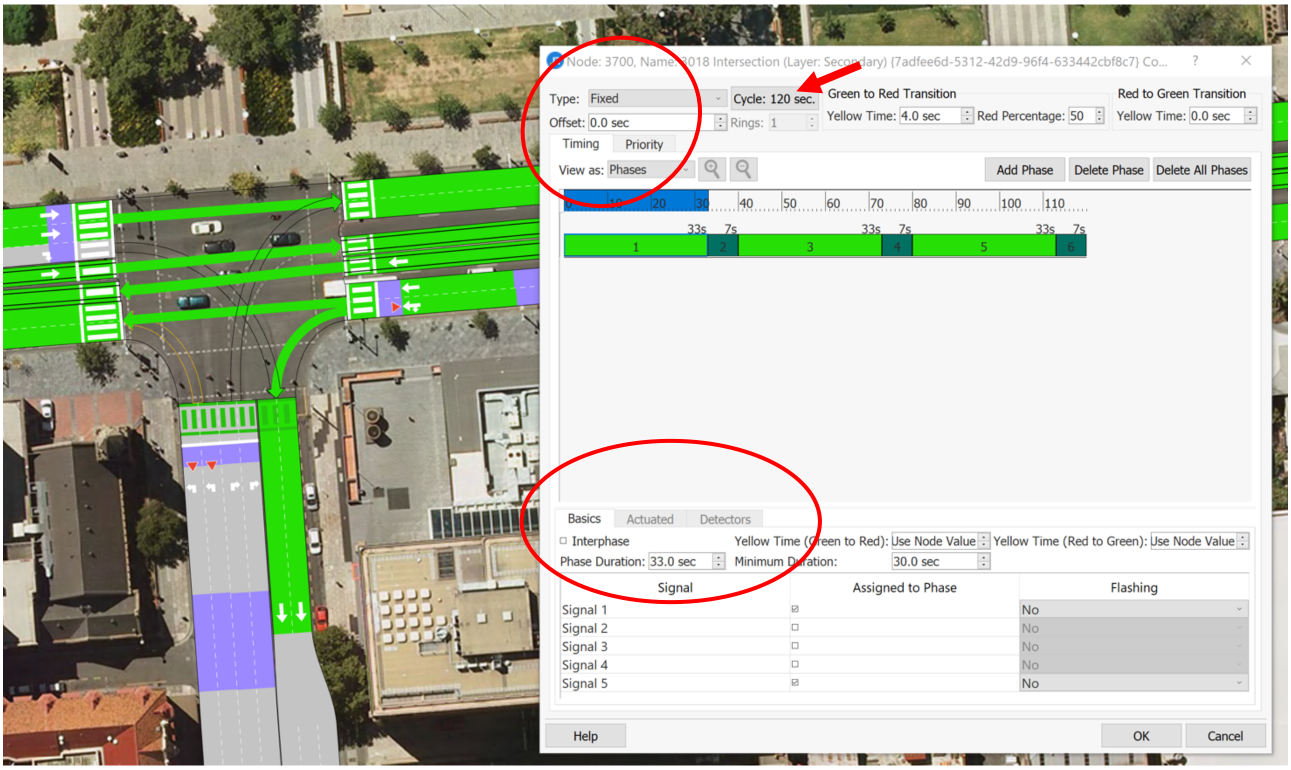


Figure 29: ALGORITHM settings for the FIXED traffic control plan for the fixed system.

Figure 29 above shows the calibration settings for the FIXED control plan. As seen in the figure, the “actuated” and “detector” tabs are deactivated (greyed out) for the FIXED system and only the basic tab is active. The total cycle time used was 120 seconds which is the standard for all the intersections. After configuring each interphase to 7 seconds (which is the standard for this particular intersection according to the Adelaide City Council intersection data), the remaining cycle time is allocated to each of the three phases equally, and these phase timings are expected to repeat in each cycle during peak time. This is currently the most popular and most used traffic management system/algorithm around the world as many countries are yet to upgrade to actuated systems. Some FIXED control systems will be set to give more green time to selected traffic phases and less green time to others. However, in order to prevent unjustified bias in the model, the green time is divided equally among all the three phases in the cycle (excluding the intergreen time of 7 seconds for each interphase).

SCATS SYSTEM ALGORITHM

In order to model the SCATS system algorithm, careful attention was paid to the 'SCATS operation data' (shown in the data collection section) that was provided for each intersection. Therefore, the set of rules (algorithm) configured for the SCATS control system was configured according to the data provided in the SCATS operation data provided by the Adelaide City Council (through the thesis supervisors), also provided in Appendix 1. This means that the algorithm represents (as close as possible) the actual working configuration of the SCATS system currently being used on the three intersections in the CBD, at the time of this research thesis.

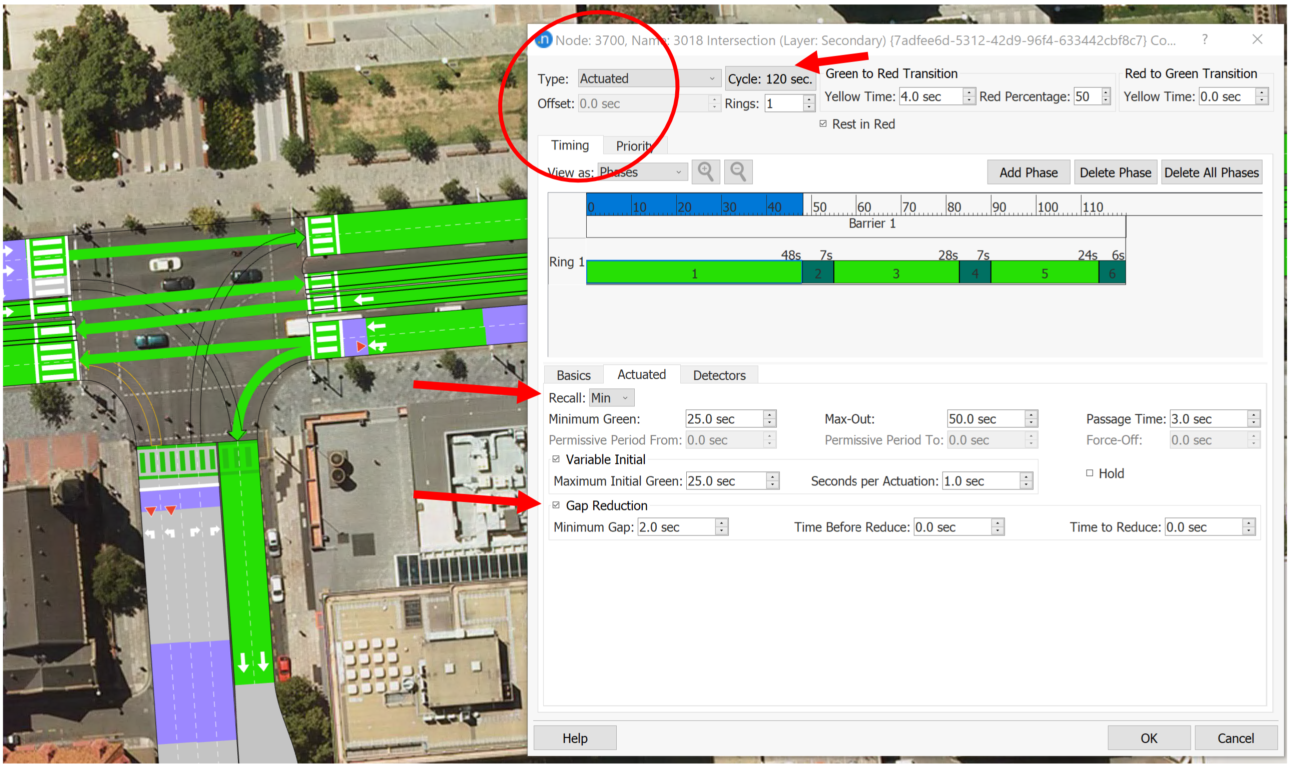


Figure 30: ALGORITHM settings for the SCATS traffic control plan.

As seen in the calibration in figure 30 above, the SCATS control type was set to "Actuated", with a circle time of 120 seconds. Also, it is important to note that the "Recall" for all the phases in the SCATS control system was set to minimum (or "min") as shown in the figure above. This is important to note because the SCATS control system, according to the operation data, requires that each of the main phases in a cycle at peak time must run for at least a minimum of its allocated time, regardless of the number of calls for the phase from the detectors. For phases with pedestrian movements, a minimum phase time of 25 seconds is set. Another important setting that is part of the SCATS control system is the "Gap Reduction". The SCATS system relies on detectors that are placed at the stoplines of each approach, on each intersection, in order to calculate vehicle demand and predict the traffic situation in order to adjust signal timings and phases. However, because the system cannot actually "see" the intersection and the real-time traffic situation (due to limited input data), the system relies on other parameters such as 'vehicle headway' and 'vehicle speed' to do its calculations. The 'passage time' is set to three seconds, which means that vehicles moving through the intersection are expected to be a maximum of three seconds apart. This rule or Parameter is measured by measuring the vehicle headway. Hence, if the vehicle headway increases to more than 3 seconds, the allowable gap or "passage time" is reduced to a new lower value set by the "minimum gap". So, the "gap reduction" function will reduce the maximum allowed headway to a minimum value, because the system interprets an increase in headway as a reduction in lane saturation, vehicle demand and traffic volume(congestion). Therefore, by comparing these parameters for all the approaches on an intersection, the SCATS control system will allocate green time to each phrase according to the interpretation of the traffic demand. Hence, for the SCATS system, the "Gap Reduction" function is activated at all times.

Thereafter, the next calibration to set for the SCATS control system model was the calibration of the Detectors. Figure 31 below shows the configuration settings for the detectors of the SCATS control system model.

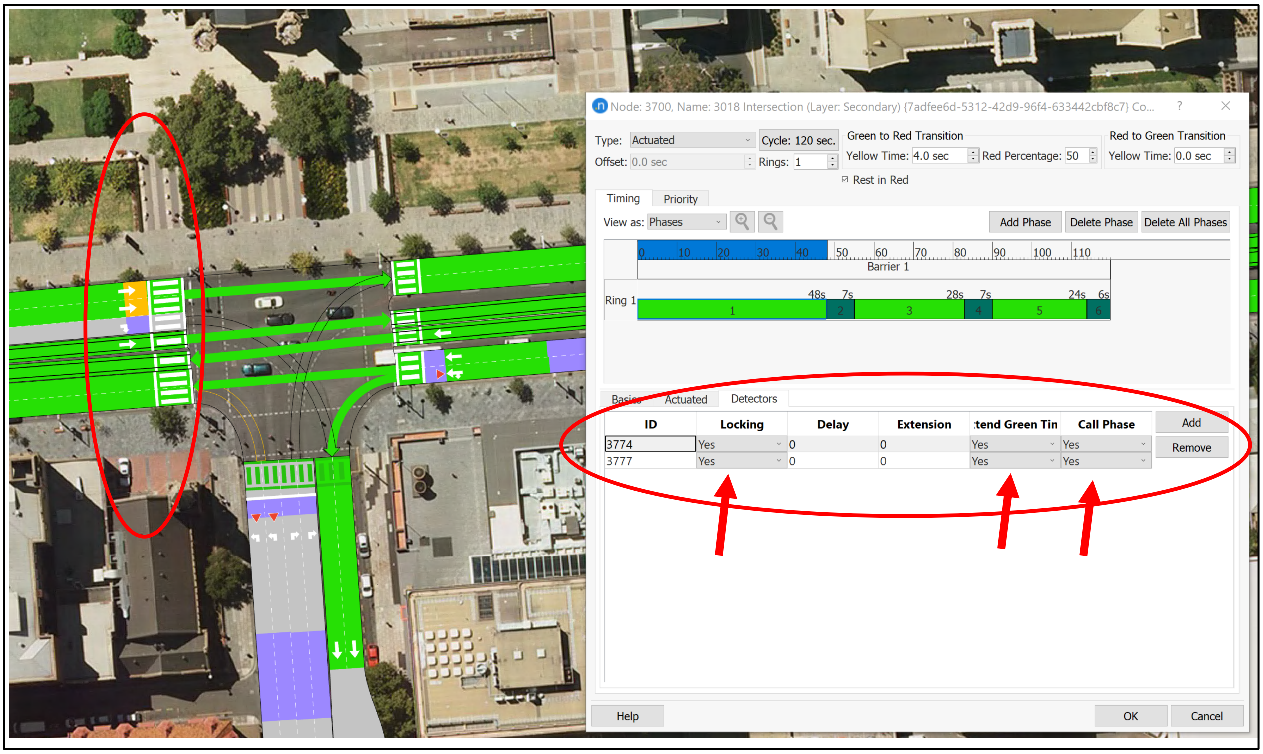


Figure 31: Configuration of the SCATS control model detectors.

For each intersection, every approach movement is linked to its respective stopline detectors, as shown in the figure above. Each of the movements associated with each phase in a cycle was assigned a vehicle detector, located at the stopline of that approach, and the purpose of this detector was to monitor vehicle presence, vehicle passage, vehicle speed, and vehicle headway as vehicles passed through the stopline of that approach. These parameters are what form the input data to enable the SCATS control system ALGORITHM to make its calculations for optimising signal phase timings in each cycle. The example in figure 35 above shows that, for the selected 'phase 1', only two detectors are linked to the phase, and these detectors are 'stopline detectors'. Detectors that are not at the stopline of each approach should be ignored in the figure above when discussing the SCATS system because the SCATS system only uses detectors at the stopline. The remaining detectors, whose location is away from the stopline of an approach, are part of the dynamic system which will be discussed in the next section.

As seen in figure 35 above, three main configurations have been set to "YES". The first configuration, 'Locking', refers to the detectors ability to record the 'count' of vehicles that passes over the detector. This feature was set to "YES" for all the detectors because vehicle count was necessary for data analysis such as vehicle flow calculations and graphs. The second feature, "Extend Green Time", was also set to "YES", which enables the detectors to request for extended green time during an active phase if vehicle headway is less than the 'passage time'. This is how the system is able to adjust green time in active phases according to demand (vehicle flow). The last feature, "Call Phase", was also set to "YES", which means that the detectors were used to call their respective phases when a vehicle was detected at the stopline of the approach during a red signal, while other phases are running. This tells the system that there is a vehicle or vehicles waiting to cross on that approach, which helps the system calculate demand for the next cycle. Other features such as "delay" or "extension" which further alter the functioning of the detectors were not tampered with because we do not have the freedom to alter/manipulate the functionality the system, but rather, the aim was to model the true nature of the SCATS control system as close as possible. This restriction did not apply to the dynamic system because the dynamic system is a proposed design, and therefore the freedom of calibration of any parameters was to the liking and discretion of the researcher (system designer). The design of the dynamic control system is presented in the next section and will discuss how all these and other parameters where utilized and calibrated.

DYNAMIC SYSTEM ALGORITHM

The dynamic control system in this thesis, as previously stated, is a proposed traffic control system whose aim manage the flow of traffic through an intersection by actively adjusting the phase timings and phase sequences according to the real time traffic scenario. In order to actively manage the traffic situation in real-time, the system would require enough input data to be able to "SEE" the real time situation on a traffic intersection. The aim of this part of the thesis was to design this system to behave in such a way as would one that can actually "see" the real-time traffic situation on an intersection, and use this information to make real time calculations and decisions for traffic flow. By systematically and strategically using the detector function in Aimsun Next software, a dynamic system was modelled and calibrated, and experiments were carried out to examine how this dynamic system managed the traffic situation. Hence, ultimately, the goal was to compare the performance of the DYNAMIC system to the performance of the FIXED system (basecase) and the SCATS system when managing the same exact traffic demand scenario.

Because the dynamic system is a proposed design, the actuated control function in AIMSUN Next software, which involves the use of detectors, was utilized to its full potential without any limitations in order to reflect a true dynamic nature as far as possible. This meant that every key parameter in the configuration of the system was freely set and adjusted either by mathematical reasoning of the researcher, by trial and error, and by observing experimental results and making adjustments, with no limitations or restrictions like those given in the SCATS system operation data (such as order of phase sequences, minimum green time, etc).

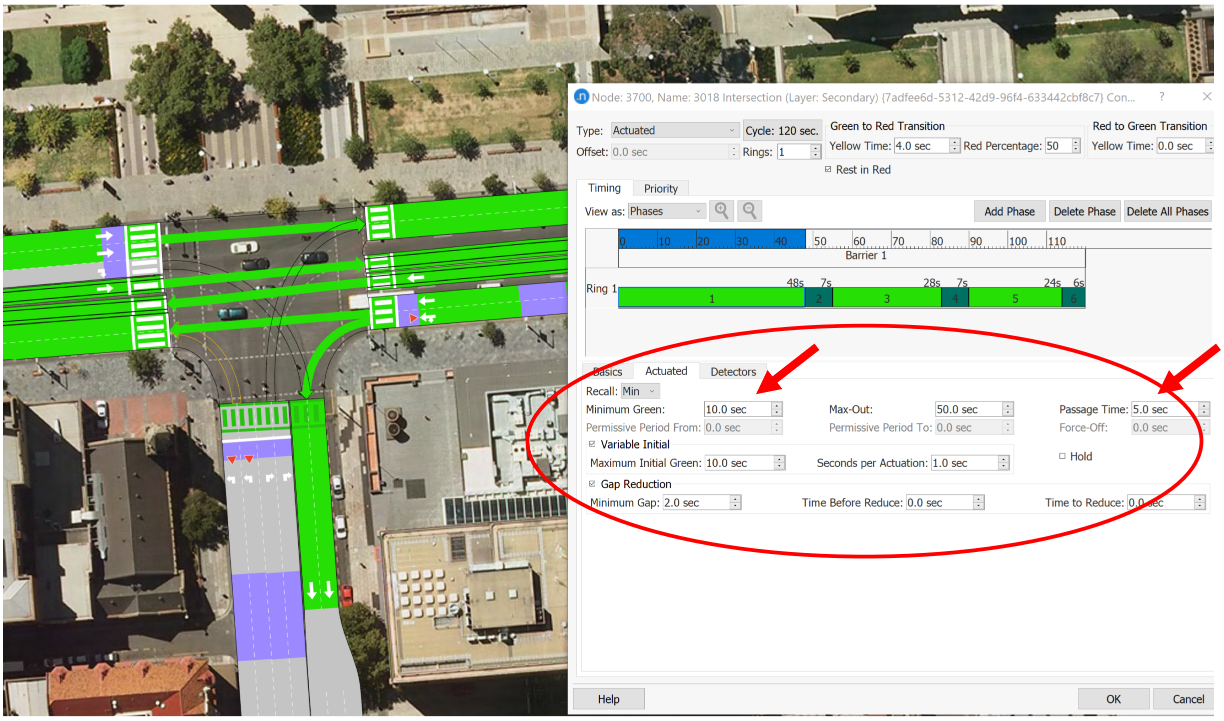


Figure 32: ALGORITHM settings for the DYNAMIC traffic control plan for the DYNAMIC system

Figure 32 shows the control configuration for the algorithm of the DYNAMIC control plan, for intersection 3019, as was shown for the SCATS system. First thing to notice is that the minimum green time was dropped for phase 1 to 10 seconds, while for other phases it was dropped even lower. Unlike the restriction in the SCATS system to have minimum green time, the dynamic system would only have minimum green time if it was completely necessary. The effect of minimum green time is that even when there is a lower demand of vehicles, the phase is still guaranteed to run for the time set for "minimum green time". This means that, if the minimum green time is more than the required amount of time needed for vehicles to pass through intersection at a particular time in a cycle, this would be an overallocation, which is a wastage of time. The SCATS system uses minimum green time because of its inability to see the real-time traffic situation, and so, employs a predictive nature of operation, with minimum green time as a baseline. However, the Dynamic system should aim to eliminate this kind of predictive behaviour and is expected to only allocate green time when demand is "SEEN" and confirmed. In figure 36 above, the minimum green time is reduced as a way of telling the system that any green time allocated above this time should be justified by demand. For other phases, the minimum green time is set down to as low as five seconds on the other intersections, especially for minor phases.

Also, the "Gap Reduction" function is activated for this particular phase on this intersection. In addition, the passage time is increased to 5 seconds. This means a higher maximum vehicle headway is allowed before the system can conclude that demand has reduced. This allows more vehicles to pass through the intersection, but is also monitored by the various detectors strategically placed at the intersection approach as will be discussed below.

It is worth re-emphasizing that in reality, a fully dynamic system would not rely solely on detectors installed at Fixed position on the road, but rather the system would be able to see the actual situation of vehicle demand on the intersection using technology such as camera image processing or infrared scanning. However, by using the available software AIMSUN NEXT, we can model and design this Dynamic system and its behaviour as far as possible by strategically and systematically placing the detectors on each approach.

Figure 33 below shows another example of the ALGORYTHM of the DYNAMIC control system. The first thing worth noting is that for most phases (and ALL minor phases) the "Recall" function was set to "NO". This meant that this particular phase in a cycle was only to run if there is vehicle demand. In the absence of vehicle demand for that movement, the phase would never be granted green time and would be skipped to in order to prevent time wastage. In reality, a fully dynamic system would never allocate green time to a movement whose demand is not sufficient. The available green time is allocated to other phase movements in the cycle with higher demand.

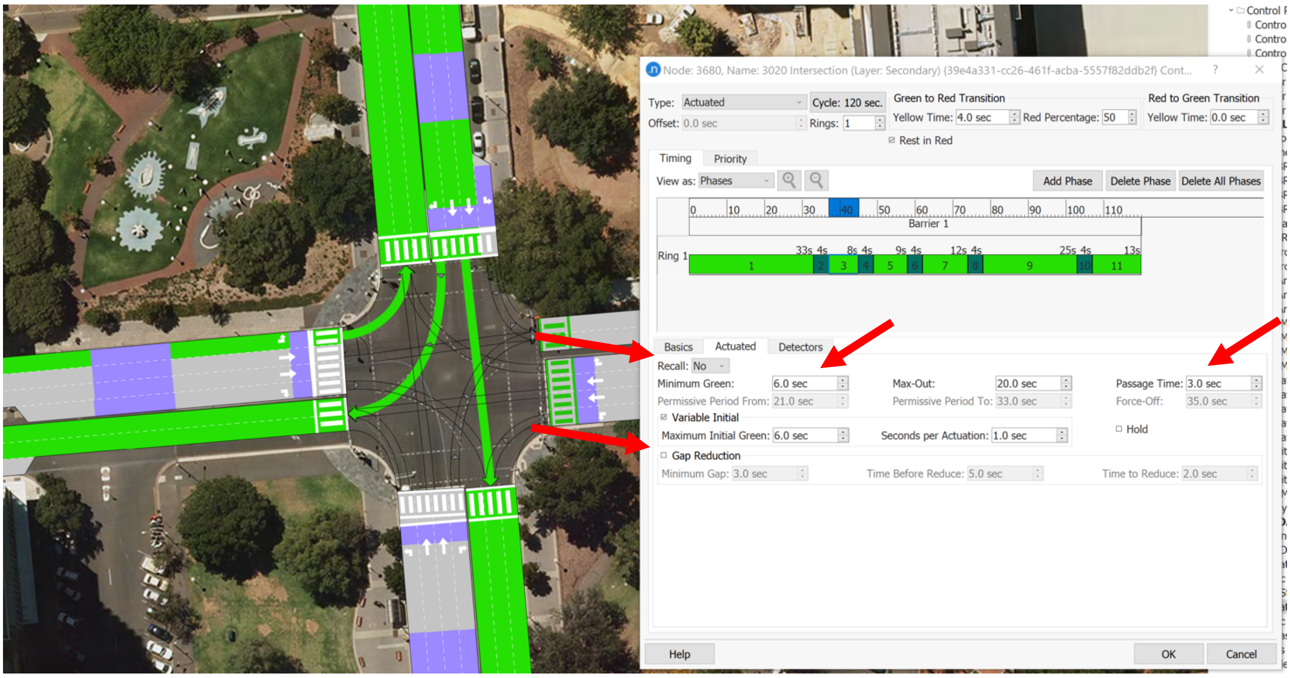


Figure 33: DYNAMIC ALGORITHM strict demand-based rules on recall, minimum green, passage time, no gap reduction.

Additionally, the ‘minimum green time’ as stated previously is reduced to as low as 6 seconds for minor movements to prevent any time wastage. This meant that any additional green time allocated to this phase would have to be justified based on vehicle demand.

Also, the ‘passage time’ is reduced to 3 seconds and the ‘gap reduction’ function is turned off for this particular phase (and for all minor phases). What this combination means is that the maximum allowed vehicle headway it’s three seconds, and if the gap between vehicles exceeds this headway, the phrase is immediately terminated without first going through a ‘gap reduction’ phase. This kind of dynamic thinking works to prevent any overallocation of green time and minimize time wastage. In addition, the “max out” time for minor phases was set to not exceed 20 seconds. This configuration meant that in any cycle, a maximum of 20 seconds should be allocated to Minor movements to prevent competition with major vehicle movements which are more critical during rush hour peak times.

Lastly with the Dynamic control system, was the detector configuration. As previously stated, the configuration of the detectors is a significant part of the dynamic system design, and this is what sets the Dynamic System apart from the other two systems. The main challenge with the dynamic system design was to configure the detectors in such a way as to allow the system to exhibit the behaviour of a fully actuated, active, adaptive and real-time system that can “SEE” and understand accurately the real-time traffic situation in order to manage traffic flow (in real-time) by making real-time calculations. Unlike the SCATS system, figure 38 below shows that a combination of detectors located at the stopline of an approach and detectors located away from the stopline of the approach are used in the dynamic system. The same intersection used in the examples of the other two systems previously discussed is also used in the example below.

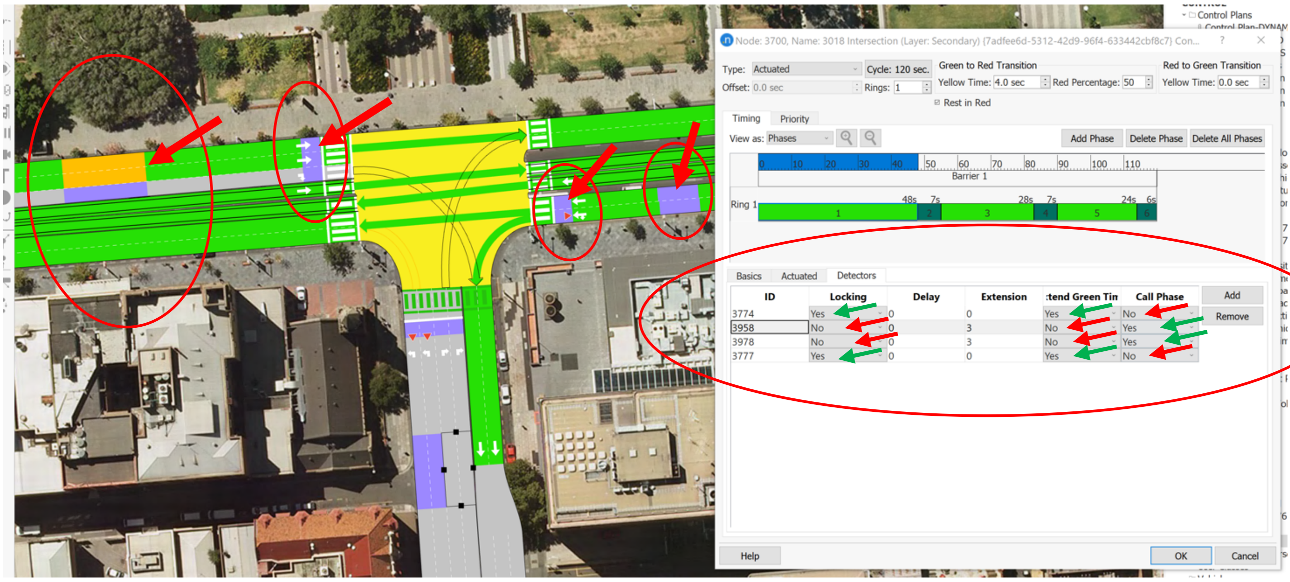


Figure 34: DYNAMIC ALGORITHM Detector configuration.

The configuration of the detectors for the dynamic system was complementary to the set of rules and parameters which were set in the 'actuated' tub previously discussed above. From figure 34 above, it is immediately noticed that more detectors are being used by the dynamic system as compared to the SCATS System previously discussed. In the example above, for phase 1 of the cycle, a total of four (4) detectors were linked to the phase and these were all responsible for the actuation and calculation of that phase demand by the system. For the detectors located at the stopline of their respective approach, their "Locking" function was set to "YES" so as to enable these detectors to record the number of vehicles that passed through the detectors for statistical and analytical purposes. As for the detectors located away from the stopline, the "locking" function was disabled (or set to "NO") because obtaining vehicle count from these detectors was not necessary, and also to prevent duplication of count data.

In addition, the detectors at the stopline were also assigned to "extend green time" by setting the feature to "YES". This meant that these detectors were responsible for monitoring the headway of vehicles as vehicles passed over the stopline and this signal data was used to either request for more green time for that phase from the system or to terminate the phase, according to the calibration in the actuated tab.

Lastly, the detectors at the stopline were NOT given the ability to 'call the phase' regardless of there being a vehicle at a stopline during peak hour. This function was assigned to the detectors located away from the stopline. This was done by setting the "Call Phase" function to "NO" for the stopline detectors, while setting “YES” for the detectors away from the stopline. The reasoning behind this calibration is that the system should only call a phase into action when the back of que (vehicle que) of the traffic builds up to the length crossing the location of the detectors away from the stopline. This event then causes the system to interpret the signal as a significant vehicle traffic demand, hence ensuring that the phase is called into action and allocated green time as soon as possible, with all other demand calls considered.

In order to account for the distance between the offset detectors on the top line, extension time of 3 seconds was allocated to the detectors located away from the stopline, as seen in the figure above. All these unique calibrations were only possible because of the ‘flexibility of design’ allowed for the dynamic system (which is a proposed system) and were not possible with the calibration of the other two systems as this would have tempered with the actual functionality of the systems, making the models inaccurate. The calibrations of the dynamic system and its design were structured in a way that fully models (as close as possible) an active, real-time, adaptive control system that makes calculations and decisions based on actual real-time demand of traffic. In this research, this was achieved by utilizing the available functions for an actuated system in the AIMSUN NEXT software as far as possible.

Once all these calibrations were complete for all the three traffic control systems, the next step was to proceed with setting up the three scenarios, running the experiments and comparing the results

Figure 35: FIXED, SCATS and DYNAMIC Scenarios, Experiments and Replications

of the analysis, based on the performance of the three systems when managing the peak hour traffic demand. These are discussed in the next section.

SCENARIOS, EXPERIMENTS, REPLICATIONS

As shown in figure 35, three "Dynamic Scenarios" were set up using all the information modelled up to this point. The first scenario was the FIXED scenario, the second was the SCATS scenario and the third was the DYNAMIC scenario. All three scenarios worked on the exact same geometric model with the exact same traffic information and peak hour period. The difference between the three traffic scenarios what is the control plan that each scenario was set to use. The FIXED scenario was set to use the 'FIXED MASTER CONTROL PLAN' which was loaded with the Fixed control plan, while the SCATS scenario was set to use 'SCATS MASTER CONTROL PLAN' which was loaded with the SCATS control plan, and lastly the DYNAMIC scenario was set to use the 'DYNAMIC MASTER CONTROL PLAN' which was loaded with the Dynamic control plan. All three scenarios were loaded with the same traffic demand which was loaded with the traffic state modelled earlier, which represented the worst-case traffic situation on the chosen date within the two weeks or sample data.

In each scenario, an experiment was that up, and for each experiment in each scenario, seven different replications were generated in order for the system to run its experiments multiple times for increased accuracy of results. In addition to the seven different experiments set up in each scenario, another replication named "Average" was also created in each experiment, and the purpose of this average was to aggregate the results from all the replications and produce an average result from all the different results from the multiple experiments.

In the data analysis of this research, three main results from each scenario where carefully compared and analysed, starting with the 'Average', followed by the maximum and lastly the minimum result. All these experiments and results were used to compare how the three different traffic management systems performed when managing the peak hour, high demand traffic scenario.

MODEL CALLIBRATION AND VALIDATION

The validation of the Aimsun model results using read data sets is shown in figure 36 and 37 below for the average results. The validation of the remaining main replications is added to Aappendix 5 data. The validation is in accordance with the DPTI Model Validation guidelindes shown in Apendix 6

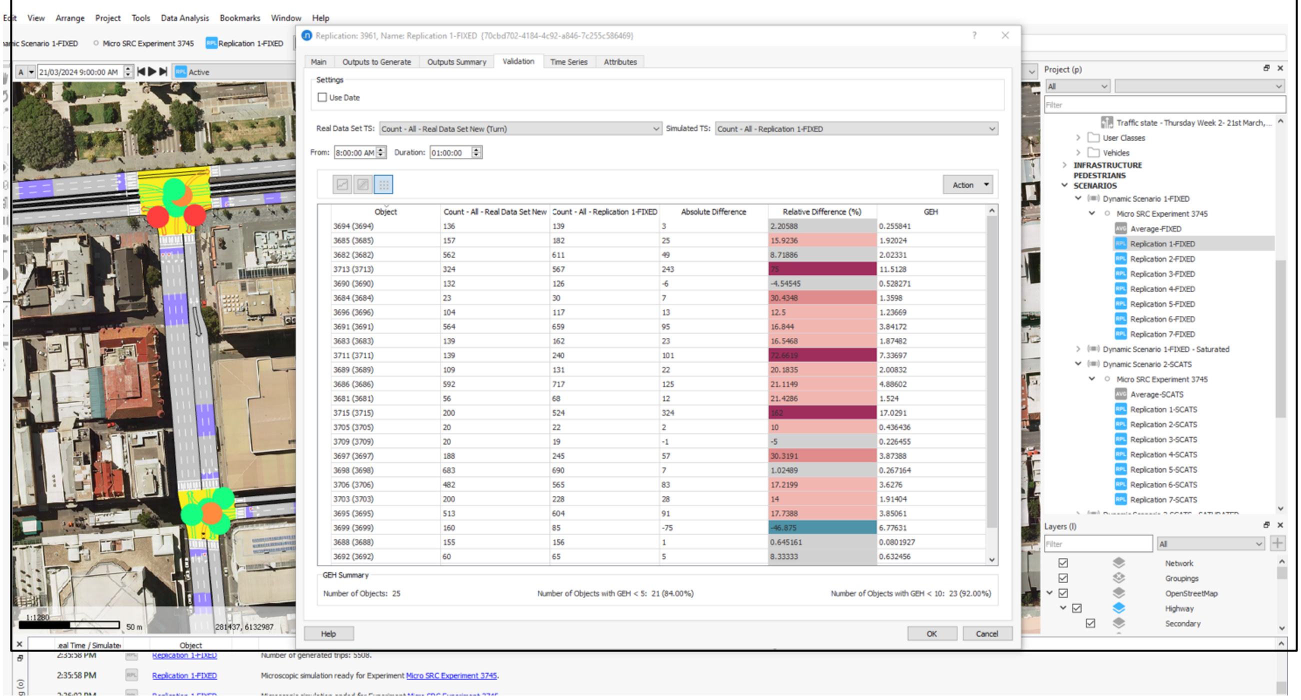


Figure 36: FIXED Model Validation

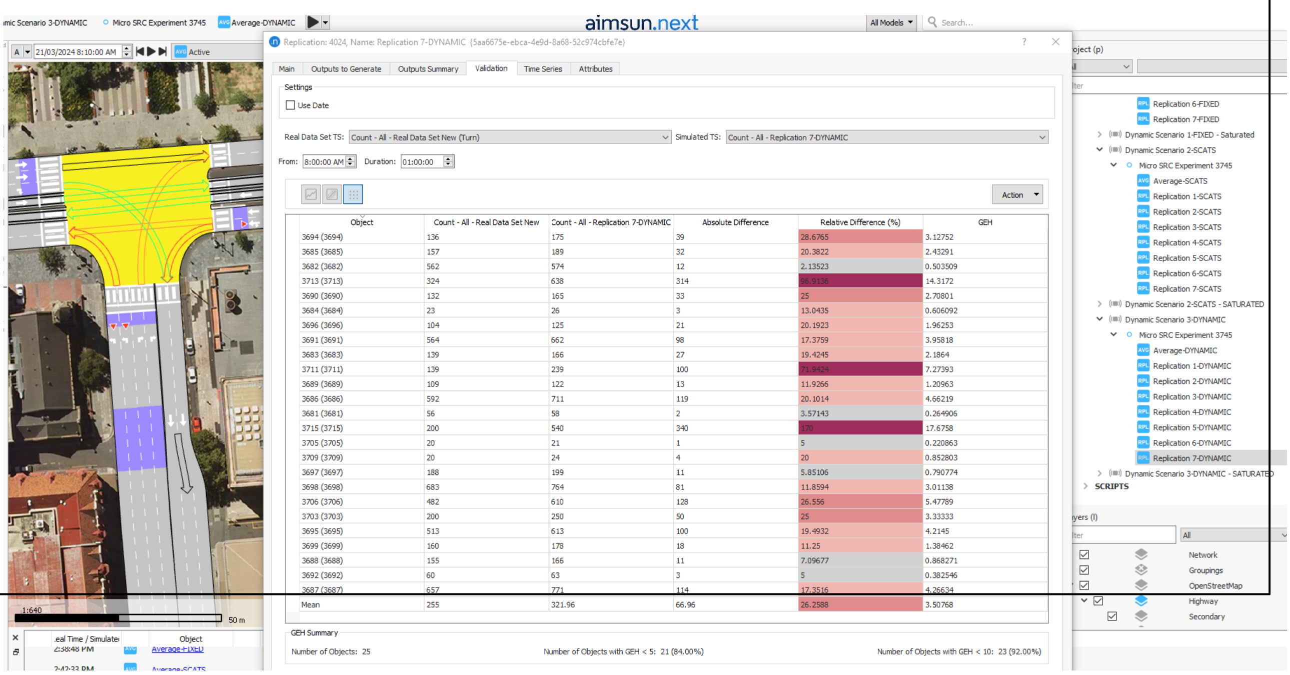


Figure 37: Dynamic Model Validation

RESULTS & DISCUSSION

SIDRA MODEL NETWORK ANALYSIS RESULTS

The first analytical results to be discussed are the results from the Sidra model network analysis which was the first network model to be created and analysed. In the Sidra network analysis, the network was analysed based on the SCATS control plan only, which is the current traffic management system being used in the Adelaide CBD, at the time of this research. The sole purpose of the Sidra network analysis was to analyse and understand the current traffic demand situation in the Adelaide CBD for the selected intersections with the highest peak time traffic flow, and determine the current level of service (LOS) of the network to be studied. This then gives a realistic approach to understanding the need for an improved traffic management system on the intersections of Adelaide (especially the CBD) either now or in the near future.

SIDREA NETWORK ANALYSIS RESULTS

The results of the analysis of the network of intersections produced by Sidra software for the study are shown in figure 38 below.

NETWORK SUMMARY

Network: N101 [Network1 (Network Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.2.202

New Network
Network Category: (None)
Network Cycle Time = 120 seconds (Network Practical Cycle Time)
Critical Site / Common Control Group that determines the Network Cycle Time (for Coordinated Sites): 103 [3020 Grenfell St x Pulteney St]
Design Life Analysis (Network Level of Service Target): Results for 0 years

Network Performance - Hourly Values				
Performance Measure	Vehicles:	All MCs	Pedestrians	Persons
Network Level of Service (LOS)		LOS E[1]		
Speed Efficiency		0.35		
Travel Time Index		2.83		
Congestion Coefficient		2.82		
Travel Speed (Average)	km/h	21.3	3.5 km/h	13.8 km/h
Travel Distance (Total)	veh-km/h	682.2	100.0 ped-km/h	918.7 pers-km/h
Travel Time (Total)	veh-h/h	32.0	28.2 ped-h/h	66.7 pers-h/h
Desired Speed	km/h	60.0		
Demand Flows (Total for all Sites)	veh/h	2418	500 ped/h	3402 pers/h
Arrival Flows (Total for all Sites)	veh/h	2418	500 ped/h	3402 pers/h
Demand Flows (Entry Total)	veh/h	1515		
Midblock Inflows (Total)	veh/h	29		
Midblock Outflows (Total)	veh/h	-112		
Percent Heavy Vehicles (Demand)	%	0.0		
Percent Heavy Vehicles (Arrival)	%	0.0		
Degree of Saturation		0.290		
Control Delay (Total)	veh-h/h	20.53	6.84 ped-h/h	31.48 pers-h/h
Control Delay (Average)	sec	30.6	49.3 sec	39.1 sec
Control Delay (Worst Lane by MC)	sec	73.0		
Control Delay (Worst Movement by MC)	sec	73.0	54.3 sec	73.0 sec
Geometric Delay (Average)	sec	1.9		
Stop-Line Delay (Average)	sec	28.6		
Ave. Que Storage Ratio (Worst Lane)		0.80		
Effective Stops (Total)	veh/h	1474	471 ped/h	2240 pers/h
Effective Stop Rate		0.61	0.94	0.77
Proportion Queued		0.72	0.94	0.76
Performance Index		77.8	30.8	108.6
Cost (Total) *	$/h	1402.53	812.47 $/h	2215.00 $/h
Fuel Consumption (Total)	L/h	109.4		

Figure 38: SIDRA Network output results for Network

As seen from the output results in figure 40, the current level of service (LOS) for the network of intersections during peak hour was level of service “E”.

Level of service “E” is one level away from level of service “F” which is the worst level of service a network can exhibit, characterised by significant delays, long vehicle que’s and high lane saturation to mention a few.

Taking a closer look at the results for each individual intersection, the lane summary analysis of intersection 3018 are shown figure 39 below.

LANE SUMMARY

3018 LANE SUMMARY

Site: 101 [3018 North Tce x Pultney St (Site Folder: General)]

Output produced by SIDRA INTERSECTION Version: 9.1.2.202

Network: N101 [Network1 (Network Folder: General)]

New Site
Site Category: (None)
Signals - EQUISAT (Fixed-Time/SCATS) Coordinated   Cycle Time = 120 seconds (Network Practical Cycle Time)
Design Life Analysis (Network Level of Service Target): Results for 0 years

Lane Use and Performance

	Demand Flows [Total veh/h	HV] %	Arrival Flows [Total veh/h	HV] %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Aver. Delay sec	Level of Service	Aver. Back Of Queue [Veh	Dist] m	Lane Config	Lane Length m	Cap. Adj. %	Prob. Block. %
South: Pulteney Street															
Lane 1	54	0.0	54	0.0	398	0.136	100	31.2	LOS C[11]	1.2	8.3	Full	124	0.0	0.0
Lane 2	54	0.0	54	0.0	398	0.136	100	31.2	LOS C[11]	1.2	8.3	Full	124	0.0	0.0
Lane 3	23	0.0	23	0.0	274	0.084	100	59.6	LOS E[11]	0.8	5.8	Full	124	0.0	0.0
Lane 4	23	0.0	23	0.0	274	0.084	100	57.9	LOS E[11]	0.8	5.6	Full	124	0.0	0.0
Approach	154	0.0	154	0.0		0.136		39.5	LOS D[11]	1.2	8.3				
East: North Terrace (east)															
Lane 1	153	0.0	153	0.0	603	0.254	100	33.9	LOS C[11]	3.8	26.7	Full	173	0.0	0.0
Lane 2	161	0.0	161	0.0	677	0.237	93[5]	26.1	LOS C[11]	3.8	26.8	Full	173	0.0	0.0
Approach	314	0.0	314	0.0		0.254		29.9	LOS C[11]	3.8	26.8				
West: North Terrace (west)															
Lane 1	111	0.0	111	0.0	677	0.164	100	25.2	LOS C[11]	2.6	17.9	Full	117	0.0	0.0
Lane 2	111	0.0	111	0.0	677	0.164	100	25.2	LOS C[11]	2.6	17.9	Full	117	0.0	0.0
Lane 3	67	0.0	67	0.0	398	0.167	100	27.3	LOS C[11]	1.3	8.8	Short	100	0.0	NA
Approach	289	0.0	289	0.0		0.167		25.7	LOS C[11]	2.6	17.9				
All Vehicles	757	0.0	757	0.0		0.254		30.3	LOS C[11]	3.8	26.8				

Site Level of Service (LOS) Method: Delay & Degree of Saturation (SIDRA). Site LOS Method is specified in the Network Data dialog (Override Site Data tab).
Lane LOS values are based on average delay and v/c ratio (degree of saturation) per lane.
Intersection and Approach LOS values are based on average delay for all lanes (v/c not used).
Delay Model: SIDRA Standard (Control Delay: Geometric Delay is included).
Queue Model: SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Green.
Gap-Acceptance Capacity Formula: SIDRA Standard (Akçelik M3D).
HV (%) values are calculated for All Movement Classes of All Heavy Vehicle Model Designation.
Arrival Flows used in performance calculations are adjusted to include any Initial Queued Demand and Upstream Capacity Constraint effects.

5 Lane under-utilisation found by the program
11 Level of Service is worse than the Level of Service Target specified in the Parameter Settings dialog.

Figure 39: SIDRA lane summary results for intersection 3018.

On an intersection level, the level of service (LOS) of each lane can be analysed from the results shown in the figure above. The analysis results show that most lanes on this particular intersection had level of service “C”, while some had level of service as low as “E”. The same pattern of results was observed on the other two intersections and these results are attached in detail in appendix 4. The full results from the network analysis report are attached in Appendix 5. The overall level of service result of “E” for the network is a combination of the effects from each intersection LOS result in the network.

Obtaining a level of service (LOS) result of a “E” for the network empathizes the need to consider employer the use of an improved traffic management system, before the complete failure of the current system that is being used.

AIMSUN NEXT MODEL ANALYSIS RESULTS

Data Comparison

After running all the replications in each of the experiments, in each of the dynamic scenarios, the results of each scenario were ready to be compared.

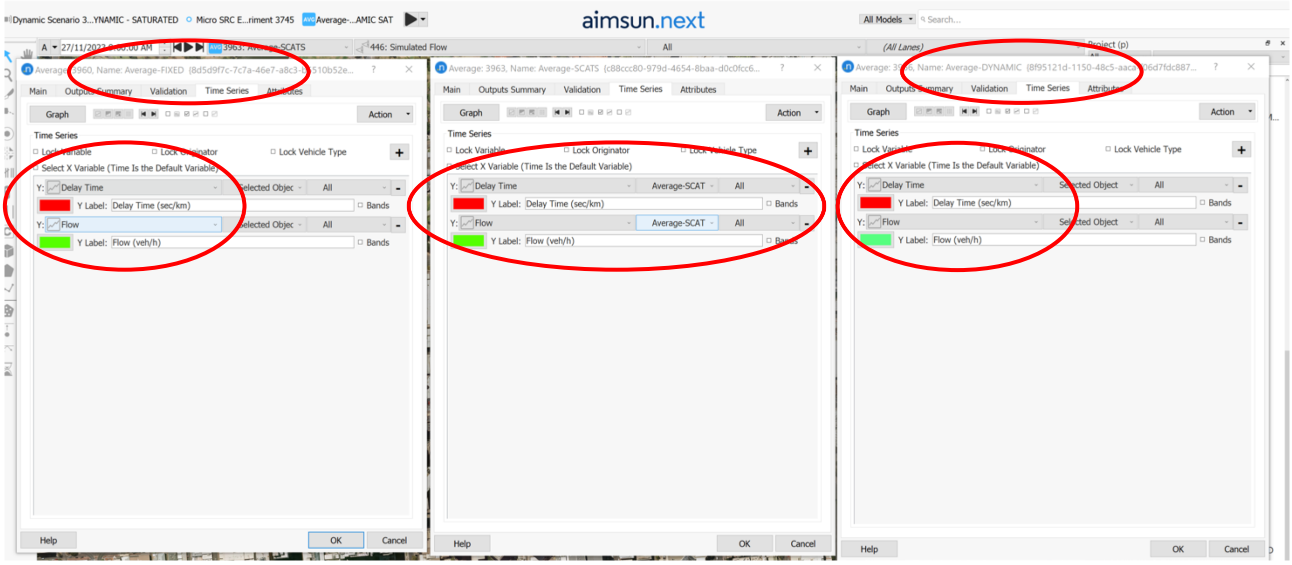


Figure 40: Comparison of results from the three traffic control systems (FIXED, SCATS, DYNAMIC) for the whole network

In order to compare the performance results of the three scenarios the “time series tool” was used. Figure 40 above shows the setup of the side-by-side comparison for the time series results from the three scenarios. The time series results provide a visualization of multiple variables related to the traffic performance of the network, however two main variables were selected and used for comparison, that is: Delay time and Vehicle flow. This is because delay time and vehicle flow are directly related variables. If vehicle flow reduces, then intern vehicle delay increases and vice versa. By analysing the behaviour of the two variables, it was possible to understand the behaviour and performance of the three traffic management systems, on a time scale, during peak hour (60 minutes).

The ‘Time series’ data provides two ways to view data, and these are; Graphs and Tables. Comparison using data Tables will be used to discuss quantitative differences in performance of the three systems because numerical data is easier to translate and compare quantitatively than graphical data. The graphical data will be used to compare the ALGORITHM “mentality”, “thinking pattern” and the performance of the three different management systems.

RESULTS COMPARISON ON USING DATA TABLES

The first results to be compared from the analysis of the performance of the three traffic management systems is the result from the "AVERAGE" time series. Each average from each scenario was compared, and the performance is shown in figure 41 below.

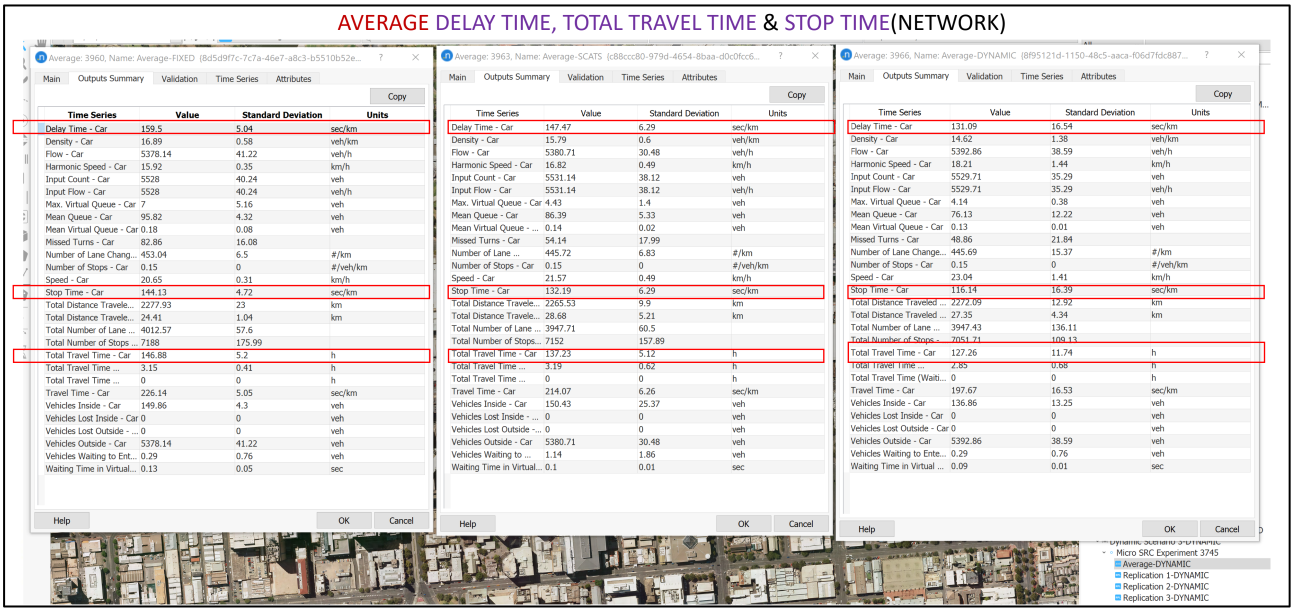


Figure 41: Comparison of the AVERAGE - delay time, total travel time & stop time for the three systems on the whole network

A clear distinction between the three systems is Seen from the results. As predicted, the baseline system, the "FIXED" system, produce the **highest delay** and **worst performance** when managing the traffic scenario with peak hour vehicle volumes. The Average Delay for the FIXED system, in units of seconds per kilometre of the network, was found to be **159.5 sec/km**, while the average delay of the SCATS system was found to be **147.47 sec/km** and the average delay of the dynamic system was found to be **131.09 sec/km**.

In addition, the Average Stop Time per car , which refers to the average que time or idle time of a vehicle, in the same units (seconds per kilometre of the network) can also be compared for the three systems from the data presented above. For the Fixed traffic control system, the average stop time per car was found to be **144.13 sec/km**, while the average stop time for the SCATS system was **132.19 sec/km** and the average stop time for the Dynamic system was found to be **116.14 sec/km.**

Lastly, another key parameter that could be compared from the results was the Total Travel Time per car, in which the same results pattern is observed as with the other two parameters. This parameter describes the Average amount of time it took for a vehicle to travel through the network.

The same analysis and data comparison which was performed on the "Average" results was also performed on the "Maximum" results data, as well as the "Minimum" result data obtained from the Time series of the three scenarios. Both the Maximum and the Minimum tabulated results data comparison is presented in figures 42 and 43 below. It can be noted that the same exact pattern observed with the "Average" results is observed with the "Maximum" as well as the "Minimum" results.

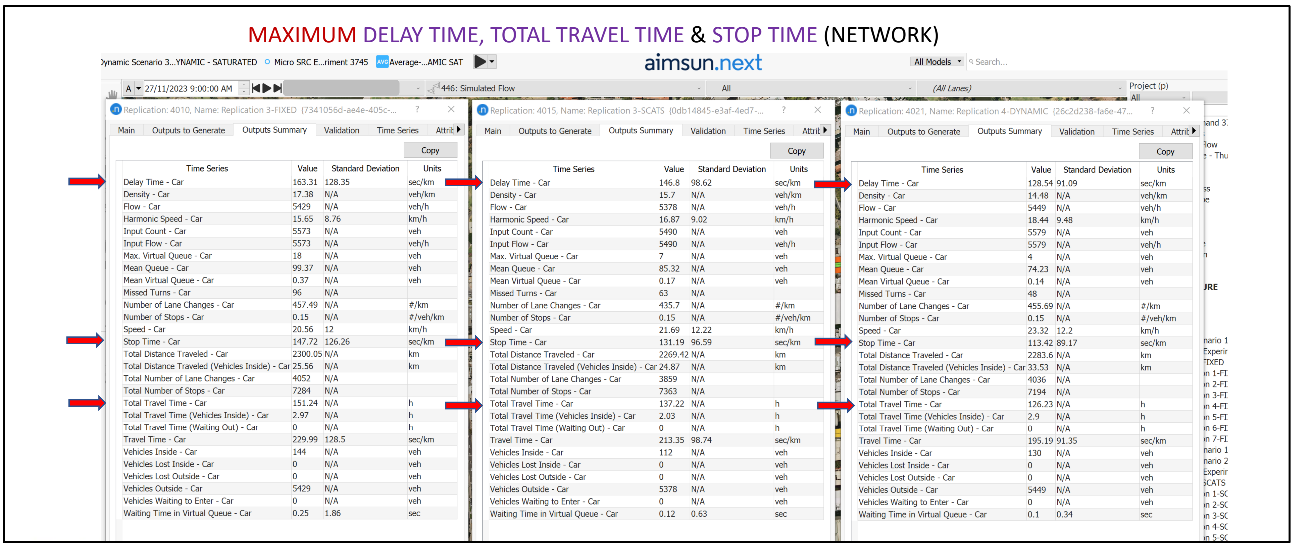


Figure 42: Comparison of the MAXIMUM - delay time, total travel time & stop time for the three systems on the whole network

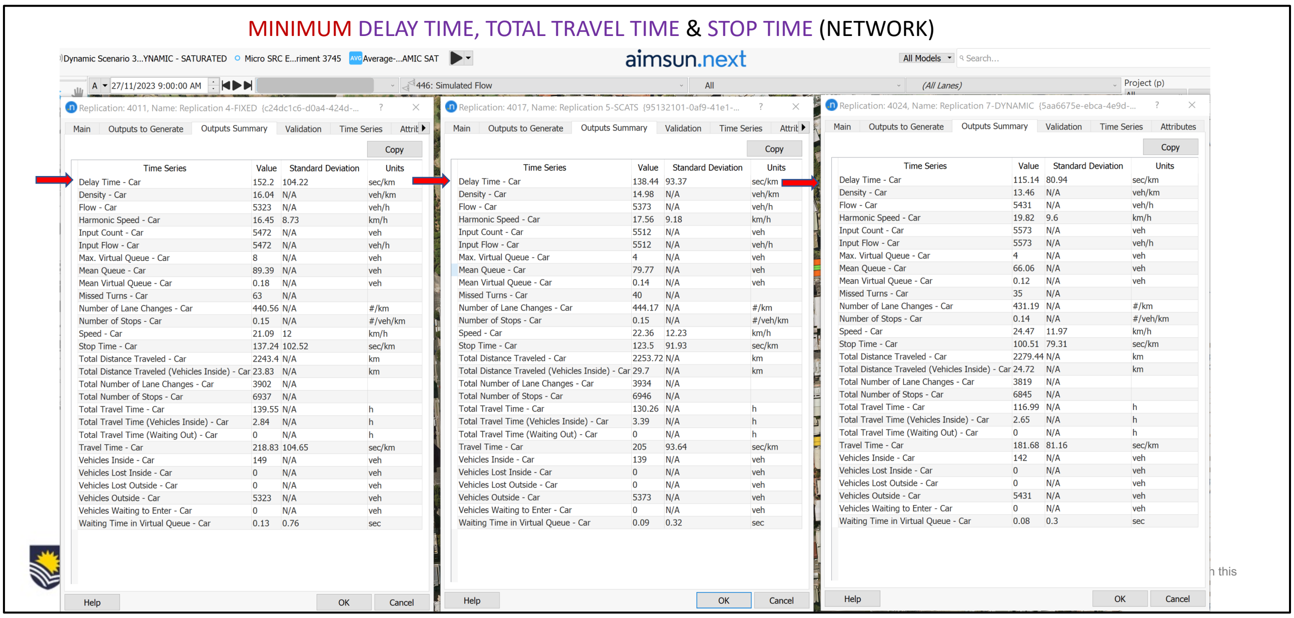


Figure 43: Comparison of the MINIMUM - delay time, total travel time & stop time for the three systems on the whole network

RESULTS COMPARISON ON USING GRAPHICAL DATA (TIME SERIES GRAPHS) (ALGORITHM – "MENTALITY' OF THE SYSTEMS)

in order to closely examine the algorithms or thinking patterns of the three systems and in-turn understand the performance differences between the three traffic management systems, the time series graphs were utilized. As discussed previously, two main variables were selected for these graphs, these being; delay time and vehicle flow. Understanding the variation of these two variables on a time series graph allowed for the interpretation of the Algorithm mentalities for the three systems to be compared as they battled to manage the peak hour traffic volumes in the network.

Figure 44 below shows a graphical comparison of the MINIMUM's time series for the three systems. The Time Series graphs produced for the "Minimum" results for the 3 scenarios are used for data comparison. This is because the minimum graphs show the minimum delays, which means the best possible performance from each traffic control system (in the same way, maximum delay graphs show the worse performance). Using the minimum graphs, we can analyse how the three systems produced their best results, and compare these minimum (best) results.

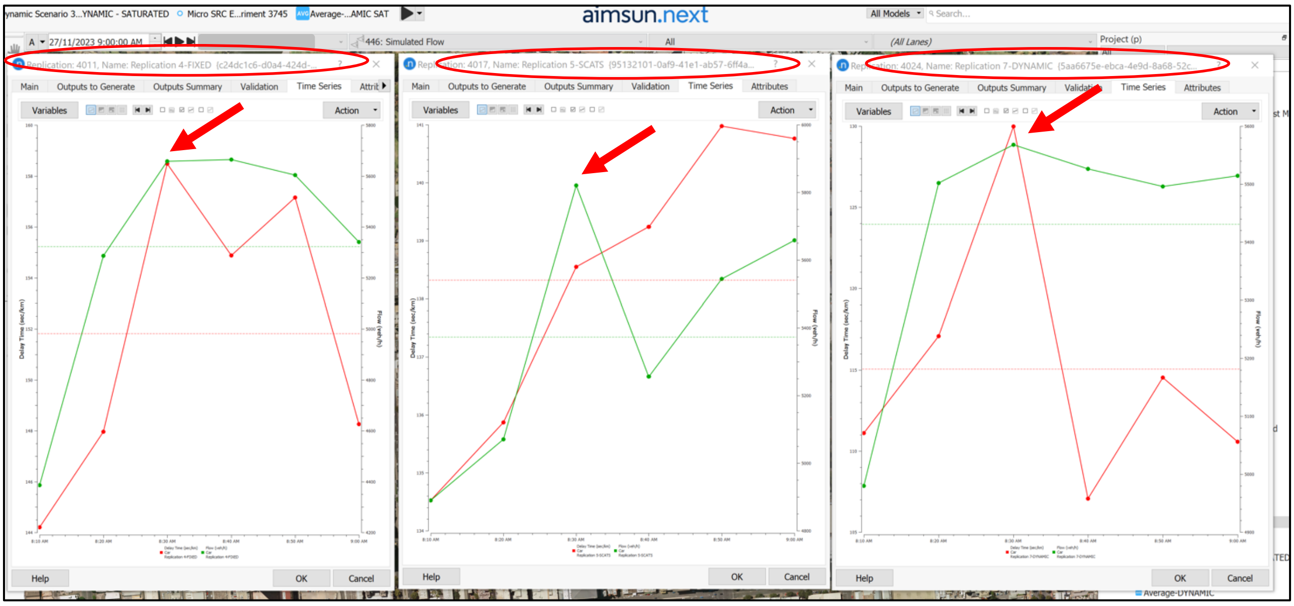


Figure 44: Graphical Comparison of the MINIMUM's time series – Delay Time vs Vehicle Flow – during peak hour.

Studying the graphs of the three systems closely, the first thing to note is that the scale of the graphs is not the same. The Fixed system scale has the largest scale for delays (from 0 to **162**), while the SCATS system delay scale is from 0 to **141** and the Dynamic system delay scale is from 0 to **130**, which agrees with the tabulated results data discussed in the previous section.

Secondly, as the peak hour progressed, clear differences in the mentalities and results of the three systems can be seen from the graphs, between 8 AM to 9 AM. A Key Point is marked by a red arrow on the graphs, and this point represents time 8:30 AM. This timestamp seemed to represent a significant point in the vehicle demand, because there were sudden shifts (gradient changes) in either the vehicle flow or vehicle delay graphs.

Between 8 AM and 8:20 AM, the traffic demand in all three graphs is seen to rise steadily until it reaches a critical maximum point around 8:30AM, at which all three systems exhibit their respective behaviours. After 8:20 AM, the vehicle flow (Green graph) in the FIXED control system stops rising and starts to drop (negative gradient), hence the vehicle Delay (Red graph) increases even more. This is due to traffic demand approaching the peak point, during peak hour. In the first 20 minutes (8:00 AM to 8:20 AM), the fixed control system has a greater between the vehicle delay and vehicle flow compared to the two actuated system. However, because the Fixed system is not an actuated system, it cannot adapt to the change in traffic demand and therefore the vehicle flow gradient takes a dive (negative gradient) for the remainder of the peak hour, while the other two actuated systems work to counteract this increase in traffic demand at peak point. The behaviour of the vehicle flow graph for the Fix system is simple and predictable because the Fixed system does not adjust itself automatically according to the situation.

On the other hand, in graph number two, the SCATS control system works to maximize efficiency by trying to keep the vehicle flow margin close to (and slightly above) the vehicle delays. The system is constantly trying to be fair to all movements in the network (and on each approach) while still trying to predict areas of high demand to prioritize and decongest. I speak point, 8:30 AM, the graph shows that the SCATS system starts to become overwhelmed by the heavy demand in the network and as a result the average vehicle flow starts to reduce between 8:30 AM to 8:40 AM, taking a sharp negative dive, before readjusting itself to combat the heavy vehicle demand. At 8:40 AM, the SCATS system works tirelessly to combat vehicle delays, and the vehicle flow graph starts to increase sharply (positive gradient) with a constant flow increase for the remainder of the peak hour as traffic demand reduces. Looking at the vehicle delay graph on the same diagram, it is noticed that the vehicle delay (Red graph) was on a steady increase from the start of the peak hour to the end of the peak hour. This delay graph however did not smoothly increase to its maximum, but rather experienced several phases of resistance from the SCATS system, as the system constantly worked to buffer the vehicle delays as far as it possibly could. This is noted by the points in the graph where the gradient of the graph was sharply reduced over and over again, signifying resistance. This is only possible because the SCATS system is an actuated system which adjusts as demand increases. The system also showed to be overwhelmed by sudden heavy demand between 8:30AM and 8:40 AM before regaining ground again (increasing vehicle flow) as previously stated. Inspite of this, the performance of the SCATS system is significantly greater than that of the FIXED system, as can be seen by the different scales on the graphs (higher delay scale on Fixed graph, lower delay scale on SCATS graph).

Analyzing the third graph trying to performance of the dynamic system, it is seen that the beginning of the peak hour, the system continue to increase vehicle flow (Green graph) as a vehicle demand/delay increased (Red graph). As the time approaches the critical point, 8:30 AM, when traffic demand was at its highest, very interesting dynamics are observed with the dynamic system at this point. Analyzing the vehicle flow graph, we see that towards the critical point 8:20 AM to 8:30 AM, the gradient of the vehicle flow diagram starts to dive(reduce) as peak point is approached. However, at peak point 8:30 AM, the Dynamic system was able to recognize the heavy traffic demand situation and immediately shifted all its dynamics to account for this heavy changing demand at peak point. The graph shows that at peak point, the Dynamic system shifted to push vehicle flows back up, and this is shown by the resistance in the green graph to dive towards a negative gradient. Unlike the Fixed system and the SCATS system who is vehicle flow graphs took a sharp negative dive at peak point, the dynamic system showed to exhibit a greater tendency and ability to resist this change. As a result of the success of the dynamic system and resisting significant drop in volume flies, it can be seen now from the red graph (delays) that at peak point, the vehicle delays in the network took a sharp negative dive and reduced significantly. From the graph, it can be interpreted that the sharp drop in vehicle delays at the critical peak point must have been as a result of the ability of the Dynamic system to significantly resist vehicle delays by maintaining good traffic flows. After the critical point 8:30 AM, it is seen that as the vehicle flows seemingly **resist** the negative gradient, the vehicle delays clearly exhibit a negative gradient and are pushed down or reduced, which is a result of the system adjustments. In simple terms, from the beginning of the peak hour, the dynamic system was focused on maintaining a high number of vehicle flows and these flows were suddenly affected by the increase in demand which caused a negative drop in the vehicle flows. As soon as the Dynamic system recognised the situation, it worked to maintain these flows by fighting against vehicle delays, and this heavy resistance caused vehicle delays to reduce significantly, despite vehicle flows still taking a negative hit (negative gradient) which the system worked to correct or manage. This is a notably significantly characteristic of the Dynamic control system as it exhibited an outstanding buffering effect to the changes in traffic scenario/demand, and this dynamic nature can be attributed to the significant differences seen in the results when the three systems are compared. It is worth noting at this point that, when the result data tables of the three control systems were compared (Average, Maximum, Minimum), the minimum (lowest) delay times of the FIXED control system and the SCATS control system (**152.2 sec/km** and **138 sec/km**) where still higher than the Maximum delay time (worst result) of the Dynamic control system (**128.54 sec/km**), which was a significant finding when comparing the three control systems.

FURTHER PERFORMANCE ANALYSIS (ROAD SECTION ANALYSIS)

The performance analysis of the three control systems was taken a step further in the research by making use of the volume distribution graphs and the lane saturation visualisation earlier presented.

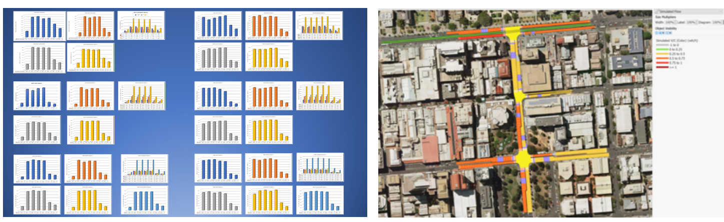


Figure 45: Volume data graphs and volume visualisation

Using the 'volume graphs' and the 'colour-coded volume visualization output' from AIMSUN next software, it was necessary to use this data to check the performance of the road sections which had the highest recorded vehicle flow. It was important to check the impact of the three control systems on these heavily loaded sections in order to establish whether the traffic systems were actually improving the traffic situation in these sections. With the volume data graphs available, it was then easier to pinpoint and identify exactly which road sections in the network had the highest vehicle volumes recorded during peak time, and by selecting these sections, we were able to examine the effect of each control system on the flow of traffic in these heavily loaded sections. In this analysis, two of the most heavily loaded road sections will be examined to compare the performance of the three different traffic management systems.

The first heavily loaded section to be examined was is the EAST approach of intersection 3018. The results of the performance comparison in this road section are shown in the figure below.

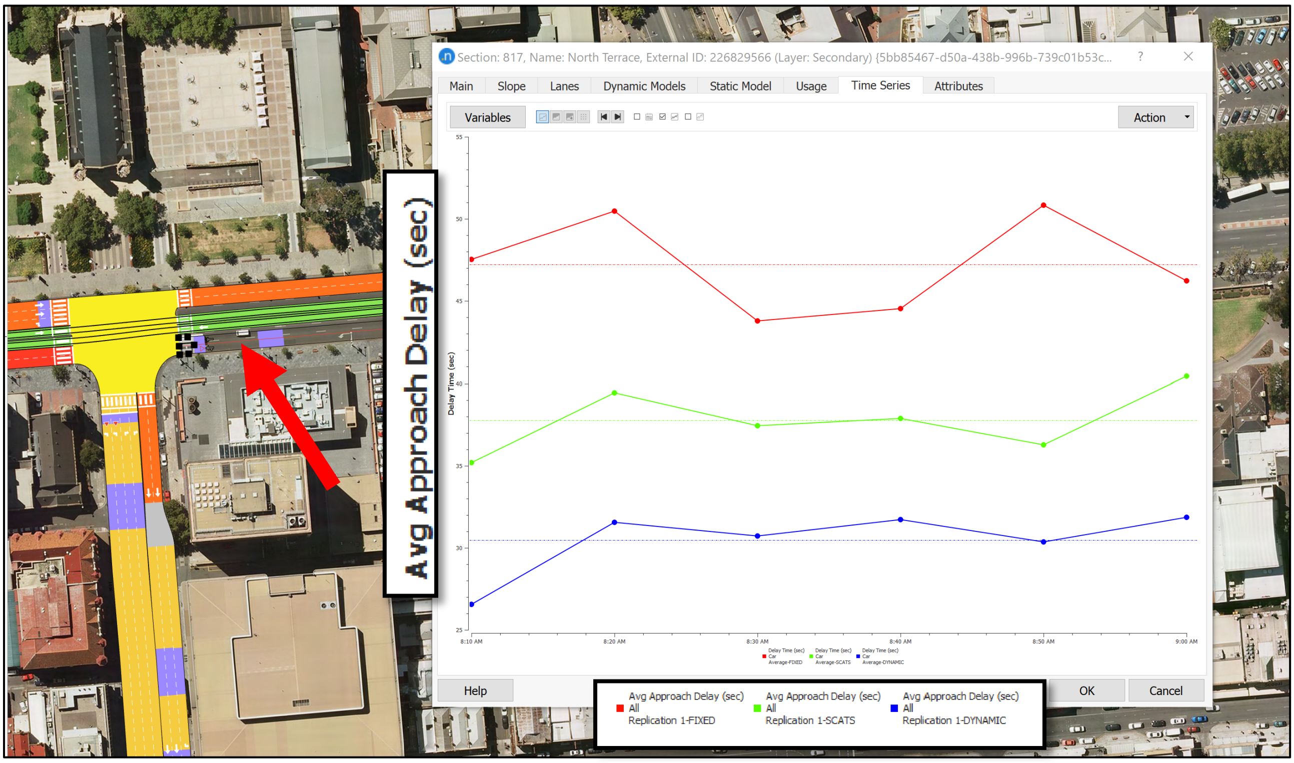


Figure 46: 3018 EAST Approach - Delay performance comparison, FIXED, SCATS, DYNAMIC

The performance comparison was based on the variable "Average Delay" in the section. Using the time series, the average delay in this road section was compared for the three scenarios: Fixed management, SCATS management and Dynamic management. From the graph in figure 46 above, it was clear to see the distinction between the three control systems when managing traffic in this road section. The graph in blue represents delays when the Dynamic control system was used, the graph in green represents delays when this SCATS control system was used, and the graph in red represents delays when the fixed control system was used. From the graph it was clearly seen that, for this road section, significantly higher delays were experienced in the scenario were the fixed control system was used, while the lowest delays were experienced in the scenario were dynamic control system was used. This pattern of results is consistent with the overall pattern of results discussed in the previous sections concerning the three traffic control systems.

Thereafter, a second heavily loaded road section, on a different approach, of a different intersection was analysed; this being the southern approach of intersection 3020. Results of this performance analysis reflected in figure 47 below.

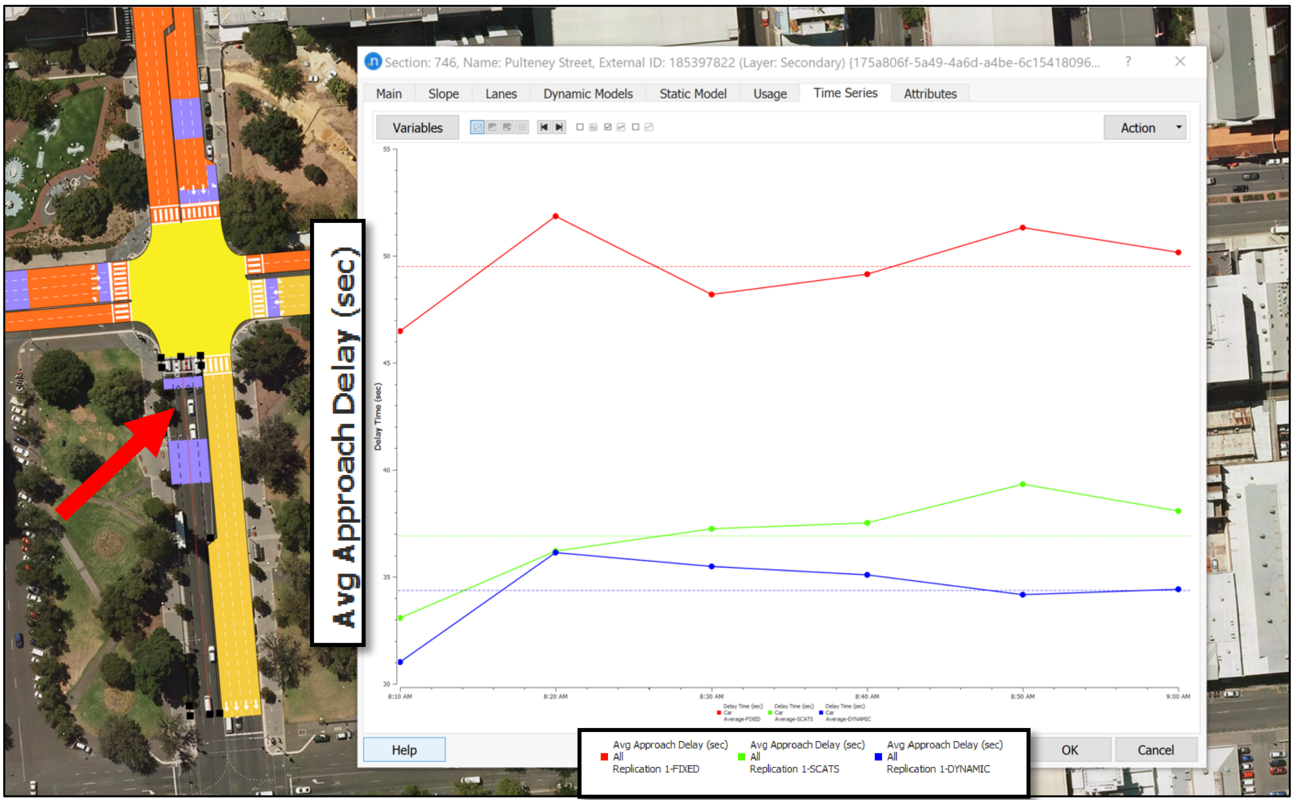


Figure 47: 3020 SOUTH Approach - Delay performance comparison, FIXED, SCATS, DYNAMIC

Again, a similar pattern of results is obtained from the performance analysis of this road section. In this case, however, the SCATS system and the Dynamic system are closer in performance results even though the Dynamic control system still produces significantly lower delays than the SCATS control system. The FIXED control system completely fails this road section, with significantly higher delays. The performance results on this road section are also consistent with the overall performance results discussed previously regarding the three traffic control systems.

FURTHER PERFORMANCE ANALYSIS (INTERSECTION ANALYSIS)

Taking the analysis a step further, the same performance analysis was performed on all of the three intersections in the model to determine the impact of the three different traffic control systems (FIXED, SCATS, DYNAMIC) on the intersections. This analysis was important in order to determine and establish for certain which traffic control system would produce the best intersection performance results; the answer to which is the goal of this research thesis.

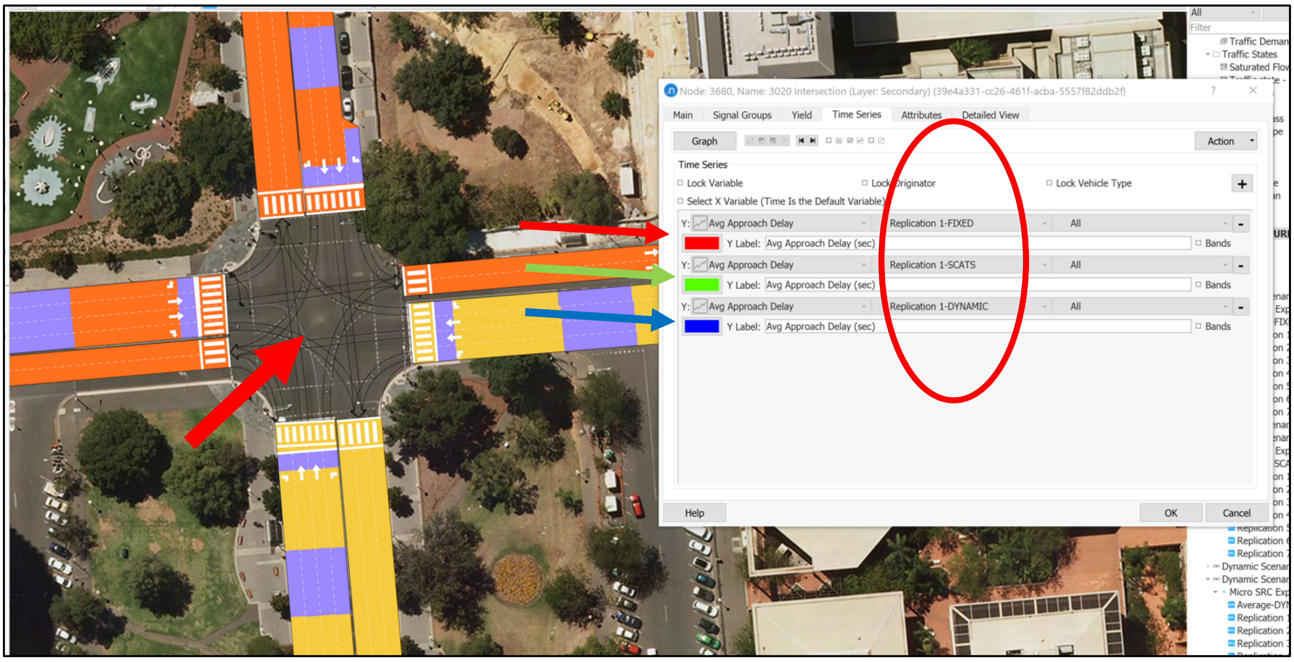


Figure 48: INTERSECTION Performance analysis – comparison of the three systems (FIXED, SCATS, DYNAMIC)

In a similar way, the analysis was carried out by using a Time Series comparison and set up as shown in the figure above. The main variable used for the comparison of the performance was the average Delay. Results of the performance analysis are shown in figure 49, 50 and 51 below.

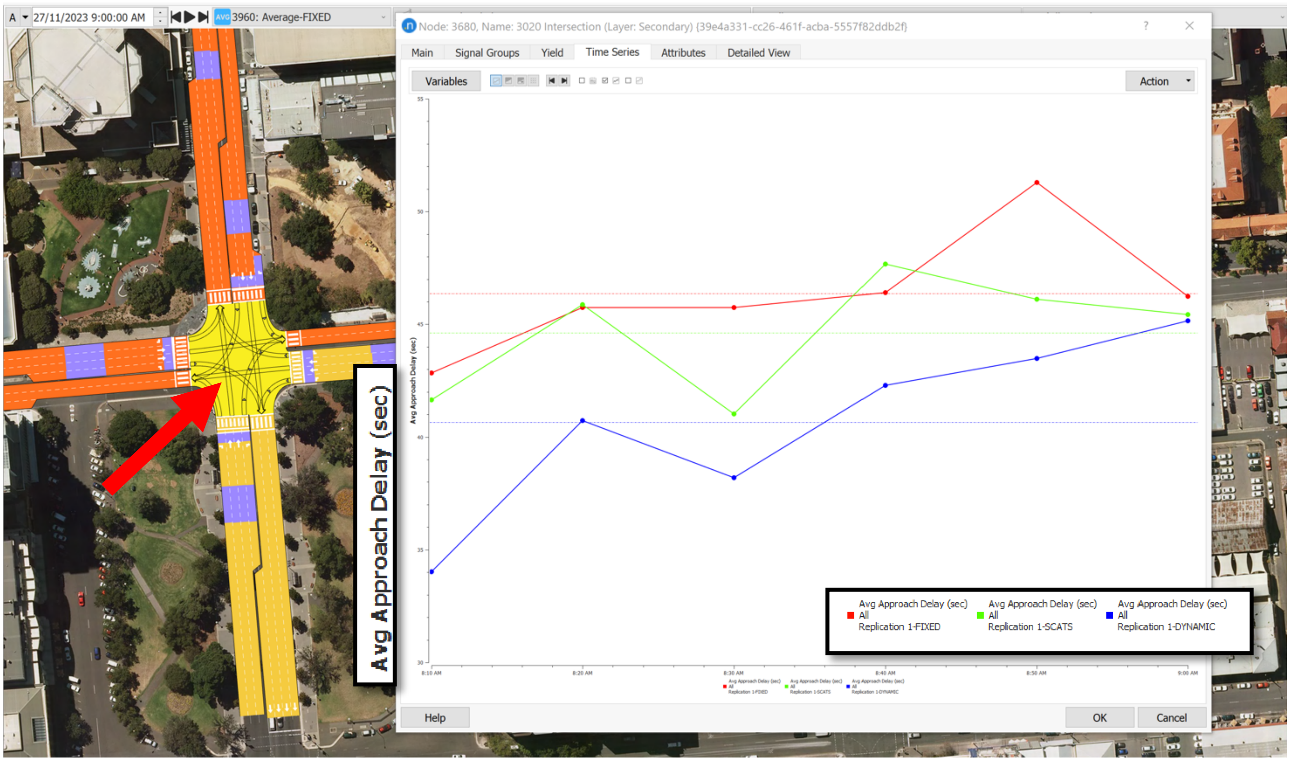


Figure 49: INTERSECTION 3020 control system performance analysis results.

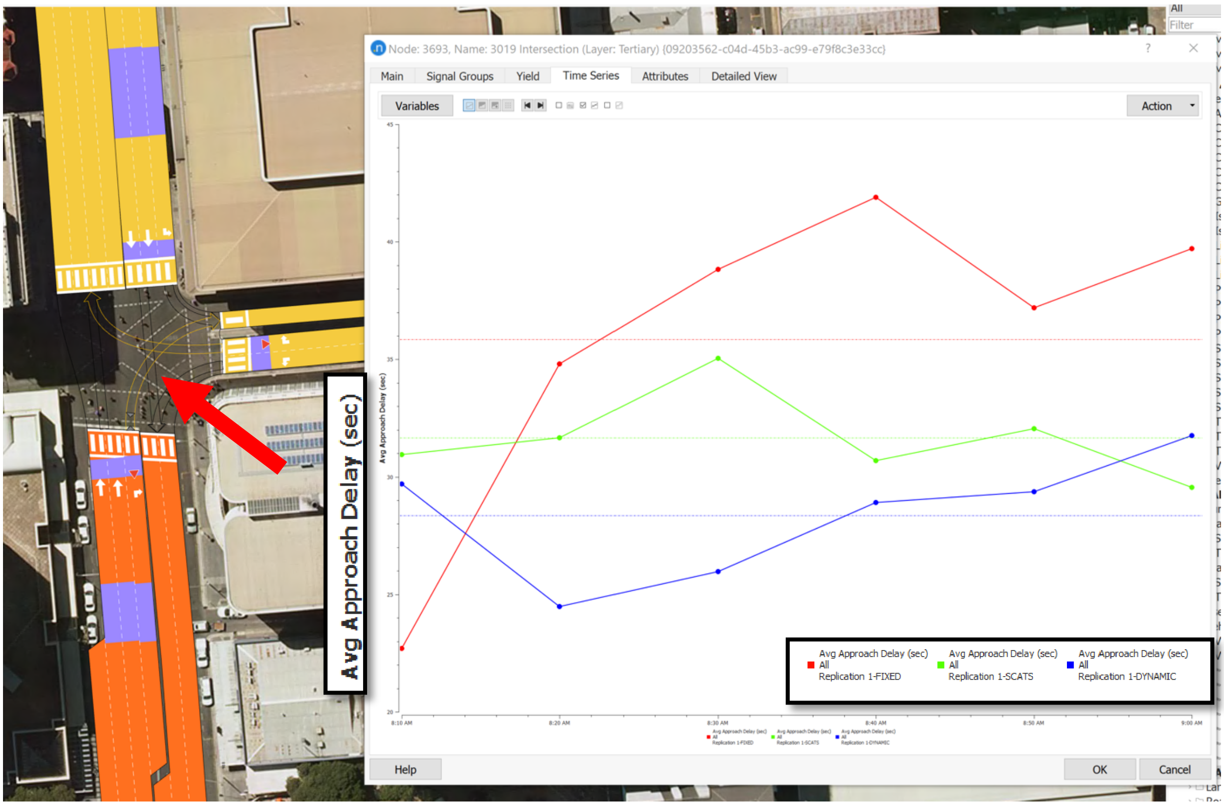


Figure 50: INTERSECTION 3019 control system performance analysis results.

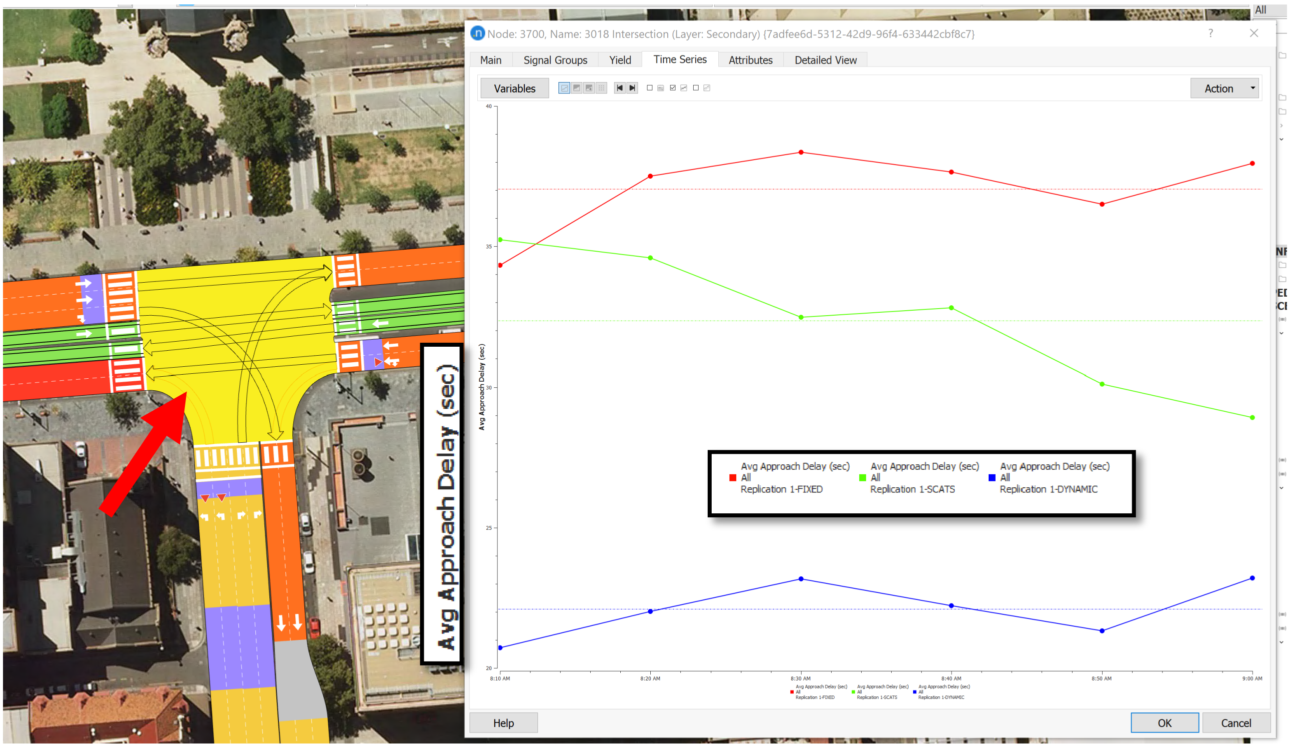


Figure 51: INTERSECTION 3018 control system performance analysis results.

As seen in the results from the three intersections, the same results pattern is again observed when the three scenarios are compared. The Fixed control system produced the worst delays on each intersection while the dynamic system produced the best (least) delays on all three intersections. This pattern of results from all the three intersections is consistent with the overall pattern of results obtained from the overall analysis results obtained from the previous discussions.

HOW IS THIS RESULT BEING ACHIEVED? (FURTHER ANALYSIS)

After concluding the data analysis, the research was taken a step further by asking the question "how is the dynamic system achieving these results"? In order to answer this question, a different tool called the "data comparison" tool was used. This tool is used to compare two systems (or scenarios) and display the comparison on the network, with colour coded and scaled figures. The setup of the comparison is shown in figure 52 below.

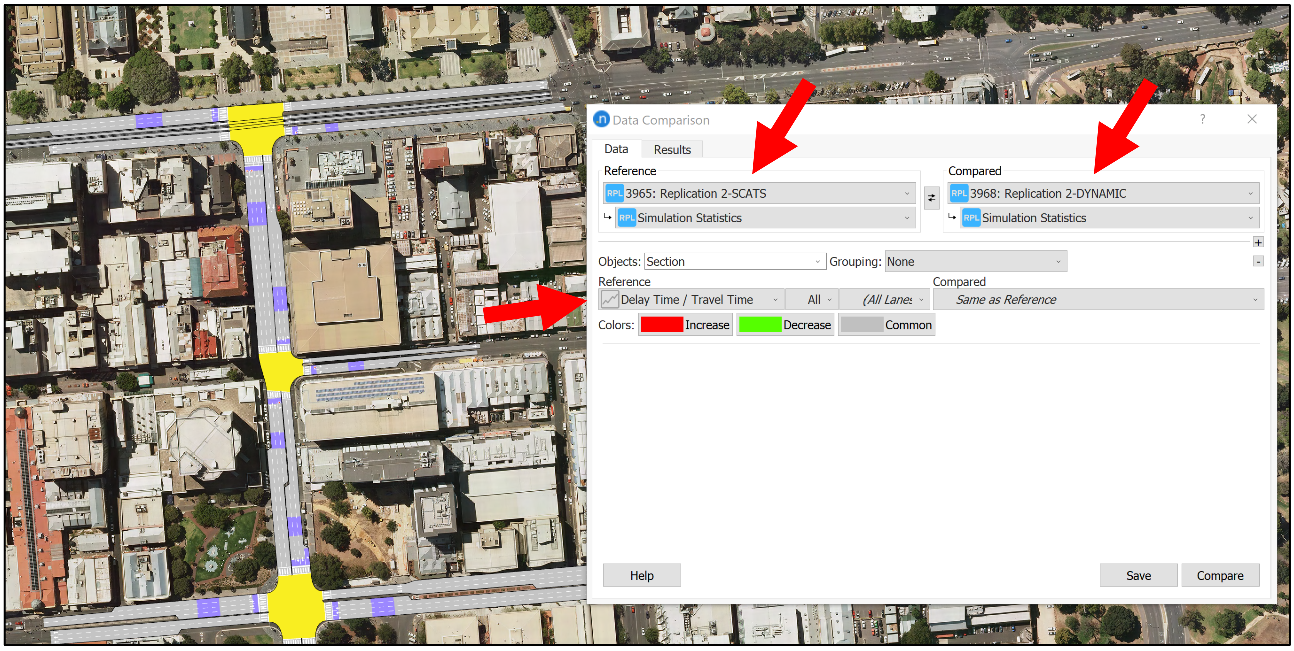


Figure 52: Data comparison tool – SCATS results Vs Dynamic results using delay time parameter

Analysis set up shown above the two systems chosen for the comparison were the SCATS system and the Dynamic system. Reference parameter chosen for this comparison was "Delay Time". This setup entails that SCATS data is compared to Dynamic data with reference to delays. This meant that an increase in Delay between the two comparisons was negative, hence assigned the Red colour code, and a decrease in Delay between the two data sets was positive, hence the Green colour code assigned. The results of this analysis are shown in figure 53 below.

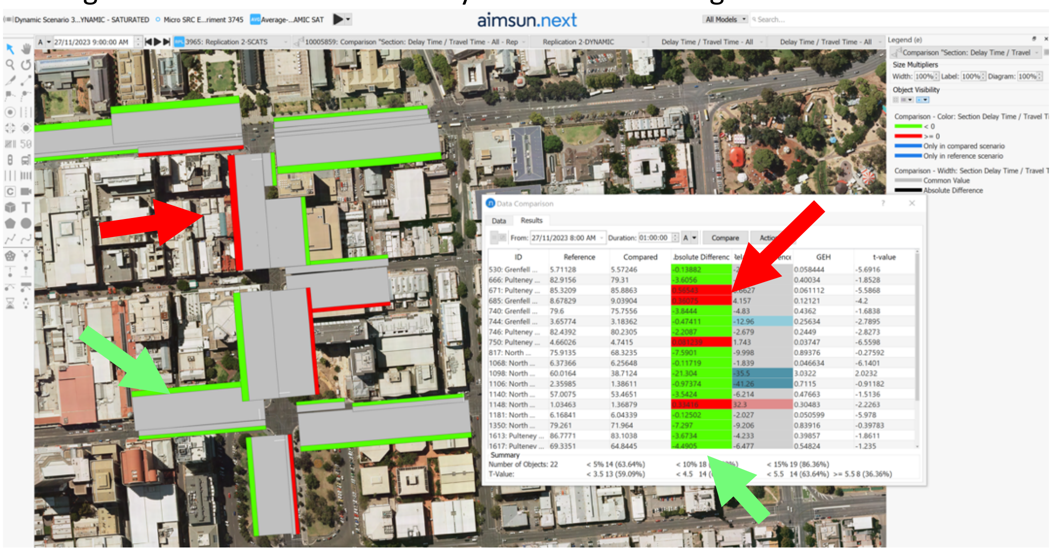


Figure 53: Data comparison Results – Network Delay

As seen in the results shown in figure 53 above, the table shows us the comparison of the delays from the SCATS and Dynamic systems. Some sections are in red signifying the SCATS system produced lower delays in these sections as compared to the Dynamic system, while some sections (most) are in green signifying that the Dynamic control system produced less delays in these sections compared to the SCATS system. This distribution of delay improvements and worsening by both systems brings very important universal scientific laws and principles onto the table to explain the results; specifically, the laws of conservation.

The law of conservation of Mass states that *"Mass cannot be created or destroyed but only converted from one form to another"*

The first law of thermal dynamics states that *"Energy cannot be created or destroyed, but can only be converted from one form to another"*

From these laws of conservation (mass and energy), what could be concluded about "time"? Exactly the same!

In other words, the higher performance of the dynamic system is not because the system is creating extra time for itself, or for the intersections, or for the network. The maximum cycle time for each intersection in the network was limited to 120 seconds. This meant that all three traffic management systems had to manage the 120 seconds for each cycle to the best of their abilities. None of the traffic management systems could "create" their own "extra time" to allocate as Green time for any movement but rather each system had the responsibility to execute proper time management in order to produce the best possible results on the intersections. In other words, *the best manager of time wins the best performance award*. In this research, the best manager of time overall, was the dynamic traffic management system because of its advanced real-time adaptive capabilities. The results of this comparison showed that while other sections were being improved (reduced delays), other sections with less priority demand were being delayed deliberately, as a sacrifice to the higher priority (higher demand) sections of the network. This is why it was observed that when the SCATS and Dynamic systems delays were compared, the Dynamic system produced worse results on minor movements or road sections, and assigned the "STOLEN TIME" to other movements and sections which the system had determined to have higher demand, as per the design of the algorithm discussed in previous sections.

As a quick check of this hypothesis, some minor sections were examined to compare the performance and workings of the three traffic management systems on these minor sections. The performance results of one of these minor sections is presented in the figure below.

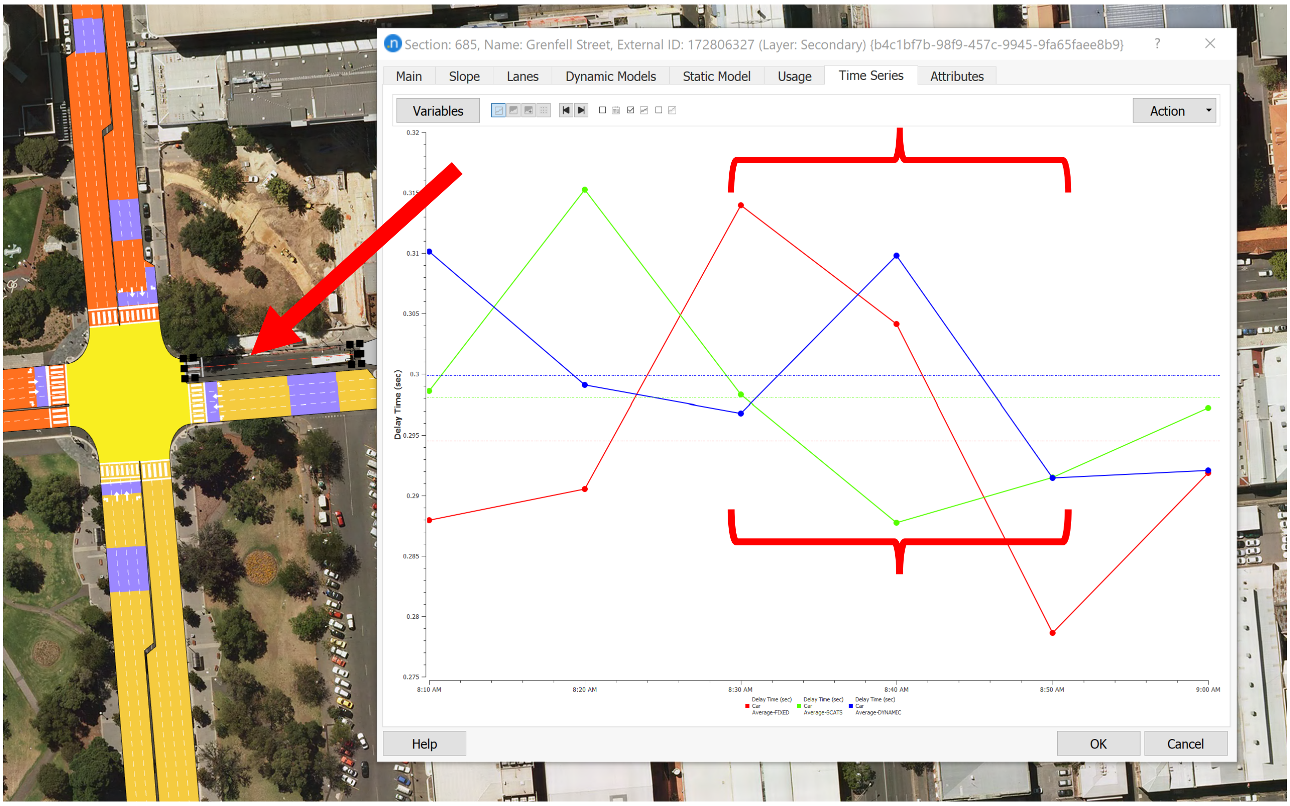


Figure 54: Minor Road section performance analysis at peak point

As clearly seen in figure 54 above between peak point 8:30 AM and 8:40 AM, the dynamic system starts to increase the delay in this minor section, specifically during this peak point period. During this period, the dynamic system deliberately performs poorly with respect to delay compared to the other two systems. It is this very sacrifice of time for minor movements and sections that allows the dynamic system favour (priorities) major movements with higher demand, resulting in higher network performance. This is the Dynamic system's method of "better management", since "extra time" cannot be created according to natures laws of conservation.

WHAT-IF? ANALYSIS (HYPOTHETICAL SCENARIO)

After concluding the results on the real-life scenarios which used real-life data for both the modelling and analysis, the research was taken one step further and a what-if analysis was performed on a hypothetical traffic scenario in order to examine whether or not the three traffic management control systems would maintain the same performance pattern of results when pushed to extreme limits. In order to achieve this, a hypothetical traffic demand scenario was created. This traffic demand scenario involved creating a traffic demand with traffic volumes that were roughly double the realistic volumes that were initially modelled. The goal was to investigate whether the systems would be able to cope with a sudden doubling of the current real-life traffic situation or would they break down and crash altogether. This was a way of investigating their limits. Following the same modelling procedures described in previous sections, a new traffic state was created and named "saturated flow". This new traffic state had roughly double the initial traffic volumes. This is shown in figure 55 below.

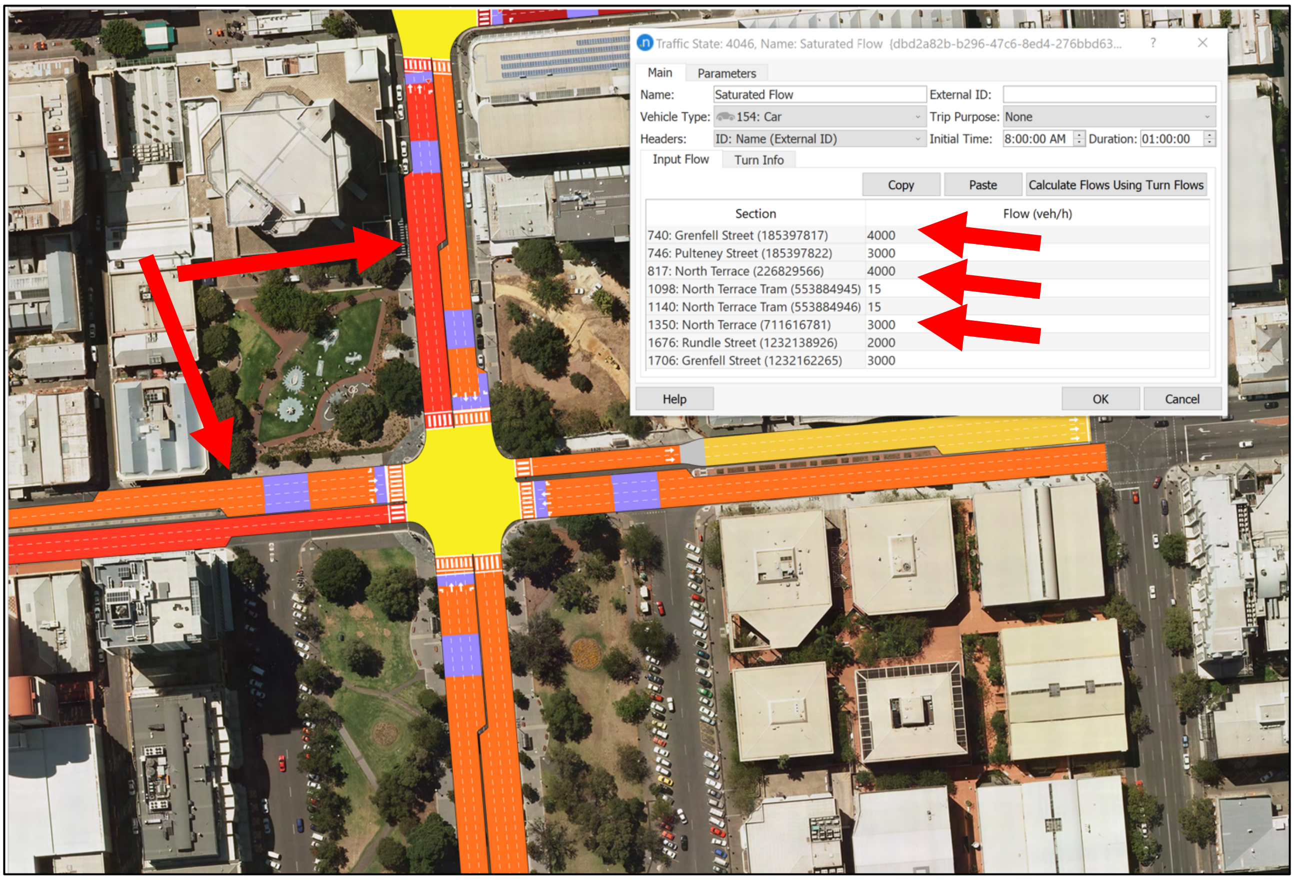


Figure 55: New hypothetical traffic state with heavy saturated flow volumes

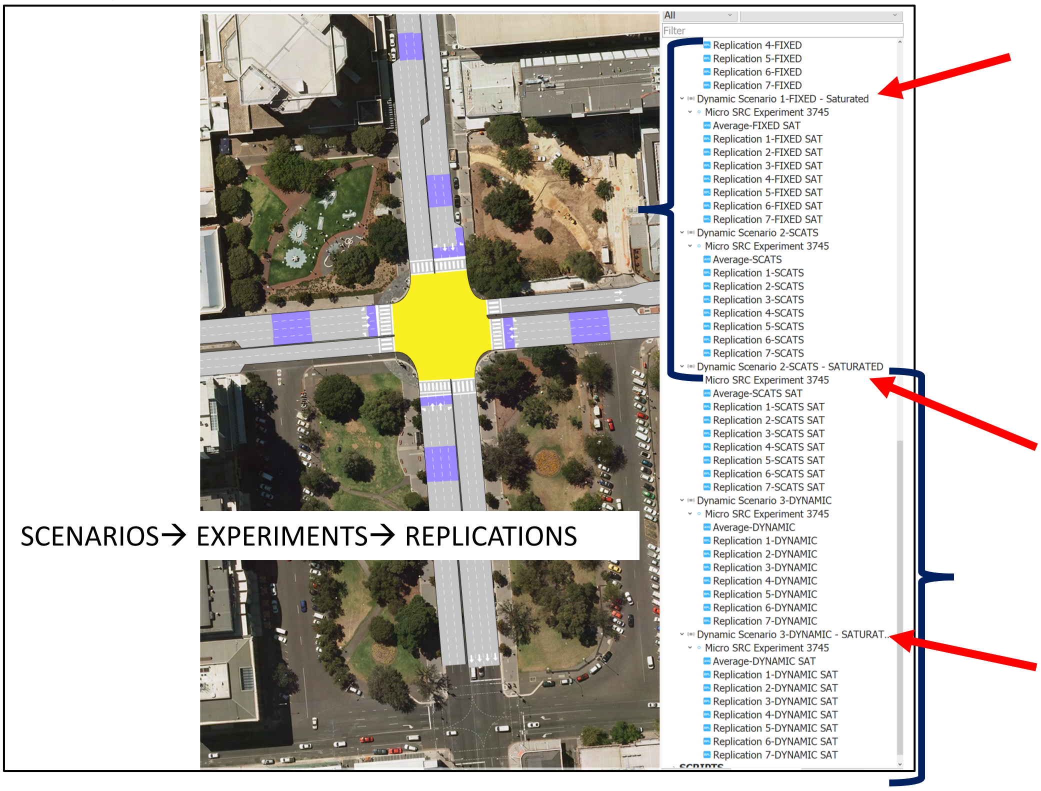
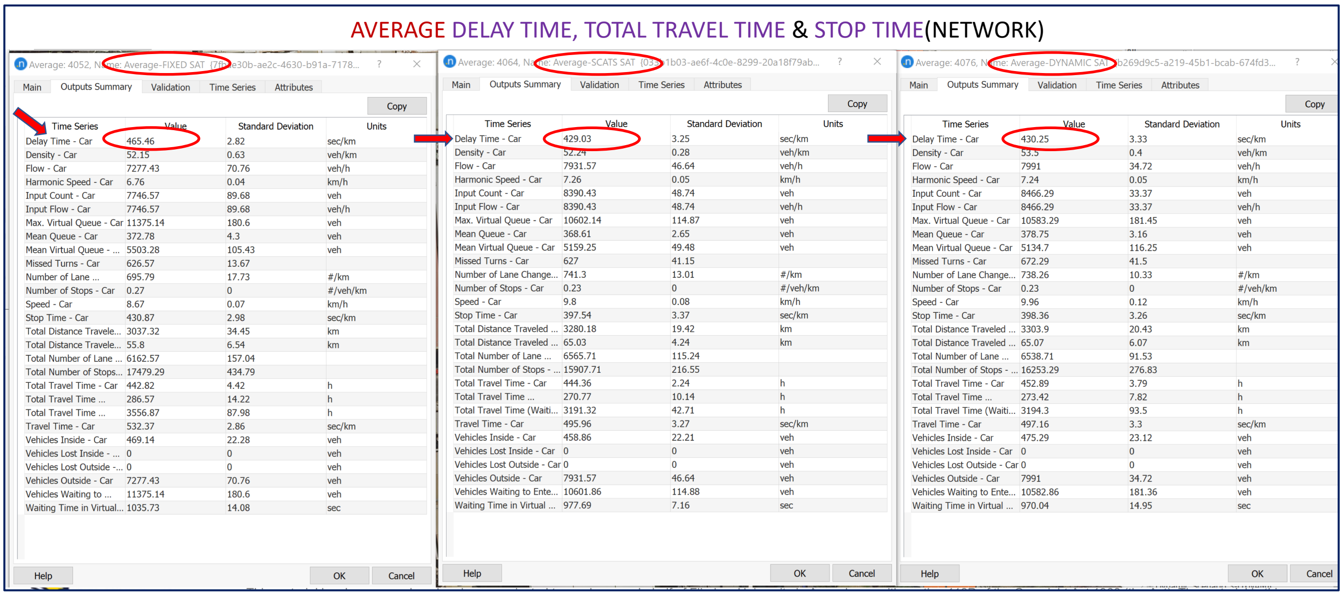


Figure 56: New Scenarios, Experiments and Replications for Saturated flow

The colour code alone in figure 55 above showed the heavy lane saturation in the new traffic state created. Figure 56 above also shows that new scenarios has to be created, each with one of the three control plans. This then doubled the number of Scenarios, Experiments and Replications in the model as shown in the figure above. Each Traffic management system (Fixed, SCATS, Dynamic) was now challenged with the same new traffic demand scenario with saturated flow, and the results of the performance were analysed.

RESULTS OF THE WHAT-IF ANALYSIS

As was done with the real-life scenario model, the tabulated results from the hypothetical scenario for each system were compared side by side, as shown in figure 57.



Time Series	Value	Standard Deviation	Units
Delay Time - Car	465.46	2.82	sec/km
Density - Car	52.15	0.63	veh/km
Flow - Car	7277.43	70.76	veh/h
Harmonic Speed - Car	6.76	0.04	km/h
Input Count - Car	7746.57	89.68	veh
Input Flow - Car	7746.57	89.68	veh/h
Max. Virtual Queue - Car	11375.14	180.6	veh
Mean Queue - Car	372.78	4.3	veh
Mean Virtual Queue - ...	5503.28	105.43	veh
Missed Turns - Car	626.57	13.67	
Number of Lane ...	695.79	17.73	#/km
Number of Stops - Car	0.27	0	#/veh/km
Speed - Car	8.67	0.07	km/h
Stop Time - Car	430.87	2.98	sec/km
Total Distance Travele...	3037.32	34.45	km
Total Distance Travele...	55.8	6.54	km
Total Number of Lane ...	6162.57	157.04	
Total Number of Stops...	17479.29	434.79	
Total Travel Time - Car	442.82	4.42	h
Total Travel Time ...	286.57	14.22	h
Total Travel Time ...	3556.87	87.98	h
Travel Time - Car	532.37	2.86	sec/km
Vehicles Inside - Car	469.14	22.28	veh
Vehicles Lost Inside - ...	0	0	veh
Vehicles Lost Outside -...	0	0	veh
Vehicles Outside - Car	7277.43	70.76	veh
Vehicles Waiting to ...	11375.14	180.6	veh
Waiting Time in Virtual...	1035.73	14.08	sec

Time Series	Value	Standard Deviation	Units
Delay Time - Car	429.03	3.25	sec/km
Density - Car	52.24	0.28	veh/km
Flow - Car	7931.57	46.64	veh/h
Harmonic Speed - Car	7.26	0.05	km/h
Input Count - Car	8390.43	48.74	veh
Input Flow - Car	8390.43	48.74	veh/h
Max. Virtual Queue - Car	10602.14	114.87	veh
Mean Queue - Car	368.61	2.65	veh
Mean Virtual Queue - Car	5159.25	49.48	veh
Missed Turns - Car	627	41.15	
Number of Lane Change...	741.3	13.01	#/km
Number of Stops - Car	0.23	0	#/veh/km
Speed - Car	9.8	0.08	km/h
Stop Time - Car	397.54	3.37	sec/km
Total Distance Traveled ...	3280.18	19.42	km
Total Distance Traveled ...	65.03	4.24	km
Total Number of Lane ...	6565.71	115.24	
Total Number of Stops - ...	15907.71	216.55	
Total Travel Time - Car	444.36	2.24	h
Total Travel Time ...	270.77	10.14	h
Total Travel Time (Waiti...	3191.32	42.71	h
Travel Time - Car	495.96	3.27	sec/km
Vehicles Inside - Car	458.86	22.21	veh
Vehicles Lost Inside - Car	0	0	veh
Vehicles Lost Outside - Car	0	0	veh
Vehicles Outside - Car	7931.57	46.64	veh
Vehicles Waiting to Ente...	10601.86	114.88	veh
Waiting Time in Virtual ...	977.69	7.16	sec

Time Series	Value	Standard Deviation	Units
Delay Time - Car	430.25	3.33	sec/km
Density - Car	53.5	0.4	veh/km
Flow - Car	7991	34.72	veh/h
Harmonic Speed - Car	7.24	0.05	km/h
Input Count - Car	8466.29	33.37	veh
Input Flow - Car	8466.29	33.37	veh/h
Max. Virtual Queue - Car	10583.29	181.45	veh
Mean Queue - Car	378.75	3.16	veh
Mean Virtual Queue - Car	5134.7	116.25	veh
Missed Turns - Car	672.29	41.5	
Number of Lane Change...	738.26	10.33	#/km
Number of Stops - Car	0.23	0	#/veh/km
Speed - Car	9.96	0.12	km/h
Stop Time - Car	398.36	3.26	sec/km
Total Distance Traveled ...	3303.9	20.43	km
Total Distance Traveled ...	65.07	6.07	km
Total Number of Lane ...	6538.71	91.53	
Total Number of Stops - ...	16253.29	276.83	
Total Travel Time - Car	452.89	3.79	h
Total Travel Time ...	273.42	7.82	h
Total Travel Time (Waiti...	3194.3	93.5	h
Travel Time - Car	497.16	3.3	sec/km
Vehicles Inside - Car	475.29	23.12	veh
Vehicles Lost Inside - Car	0	0	veh
Vehicles Lost Outside - Car	0	0	veh
Vehicles Outside - Car	7991	34.72	veh
Vehicles Waiting to Ente...	10582.86	181.36	veh
Waiting Time in Virtual ...	970.04	14.95	sec

Figure 57: What-if Analysis Tabulated Results – FIXED, SCATS, DYNAMIC

From figure 57 above, the tabulated results show an interesting phenomenon in which the SCATS system produced similar delay results to the dynamic system, while the fixed system reduced the highest delay results of the three systems. After observing the previous pattern of results obtained from the previous experiments, it was more likely expected that the fixed system for this scenario would produce the worst performance results of the three systems, while the SCATS system and the dynamic system would produce better performance results, the dynamic system being the over best. Indeed, from the results tabulated above, both the SCATS system and the dynamic system perform better than the Fixed system, however, the results of the two actuated systems are close, and almost identical. For this hypothetical high-demand traffic scenario, the Fixed system produced average vehicle delays of **465.46** sec/km while the SCATS system produced delays of **429.03** and the Dynamic system produced delays of **430.25** sec/km. Interpreting these findings, it can be seen that even though the two actuated systems performed better than the Fixed system, the performance reached and maximum threshold limit of performance in both systems, in other words, “This is the best that the systems can do to improve the delays in the traffic situation.

Further data interpretation could be seen from the time series graphs produced with the results. The time series graphs, as was previously discussed, were able to show the thinking pattern or mentality (Algorithm) of the system as they worked to manage the traffic demand during the peak hour – 60minutes from 8:00am to 9:00am. The time series graphs from the performance of this hypothetical scenario are shown in the figure below, and are compared side-by-side for the three traffic management systems (FIXED, SCATS, DYNAMIC).

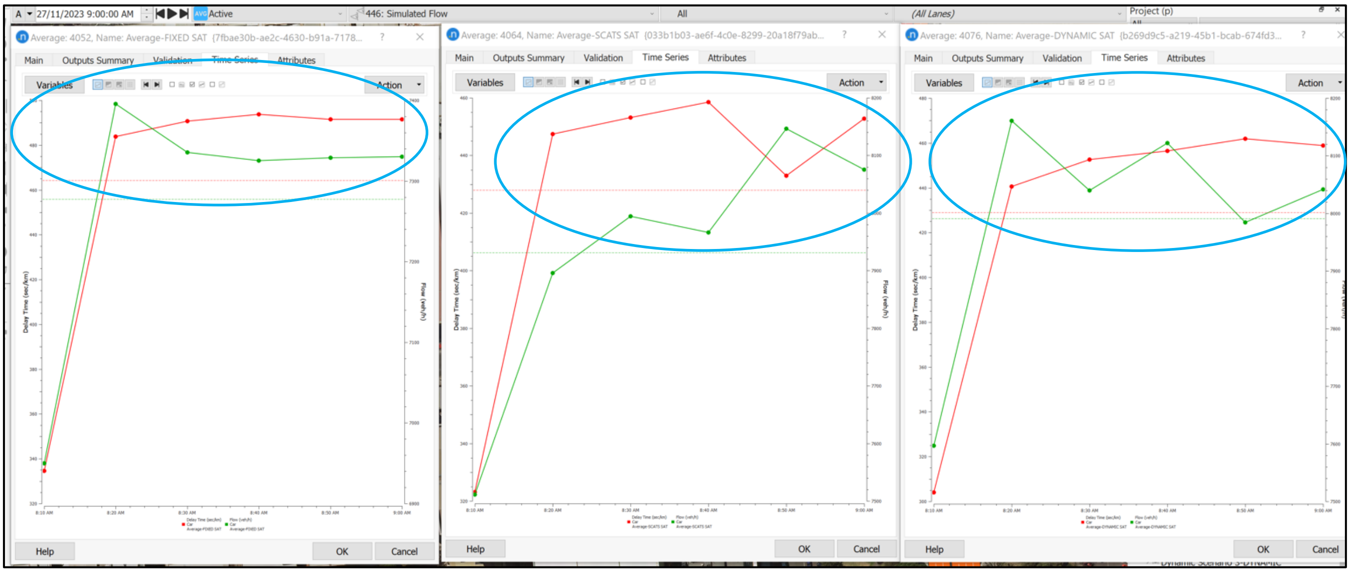


Figure 58: What-if Analysis Graphical Results – FIXED, SCATS, DYNAMIC

At first glance, two key points must be noted when interpreting the three graphs shown in figure 58 above. Firstly, the delay scale of the FIXED system graph is larger than the other two graphs, signifying higher delays. Secondly, from 8:20 AM approaching critical point, the graphs in all three systems exhibit a very similar pattern with vehicle delays and vehicle flows.

From the graph of the fixed system on the left, vehicle flow and vehicle delay increase steadily in the a directly proportional manner. The steady increase continues until 8:20 AM when the demand approaches critical peak point and the network is overly saturated. At this point the vehicle delays hit their maximum value and the delay graph stays around this maximum value all the way through till the end of the peak hour, while the vehicle flows reduce and hit their minimum (which is also their maximum flow) and the vehicle flow graph shows that the flow rate continues constantly at that level until the end of the peak hour. This behaviour can be explained by the fact that the Fixed system is not an actuated system, and hence cannot adjust itself to combat the increased traffic demand. As such, once the peak point is reached at 8:20 AM the system becomes overwhelmed, the network becomes saturated, vehicle delays and vehicle flows reached their maximum values and this situation remains the constant throughout the peak demand hour because the system cannot do any changes. In simple terms, “all the system can do is watch” as the traffic situation relieves itself.

The SCATS system and the Dynamic system exhibited similar behaviour, and despite performing better than the fixed system they also reach a maximum point in their graphs. The only difference between the two graphs is the manner in which the two parameters (delay and flow) reached their maximum values. Similar to the graph of the Fixed system, the two other systems between 8:00 AM to 8:20AM show constant increase in vehicle delay and vehicle flow. However, the major difference between the Fixed system and the two actuated systems is that when the critical point (8:20am to 8:30am) is reached and the delays hit their maximum values, unlike the fixed system which could not adjust and stayed constant, the two actuated systems are seen to actively try to resist these delays from that point onwards. This was a true expression of an actuated system, and clearly showed the difference between an actuated system and a fixed system.

From the graph of the SCATS system, the margin between the vehicle delays and the vehicle flows was larger at peak point signifying a drop in traffic flows and an increase delays. However, it is seen that by 8:40 AM the system worked to reduce this margin by reducing vehicle delays and steadily trying to increase vehicle flows throughout the remainder of the peak hour.

As for the dynamic system, the margin between vehicle flows and vehicle delays was kept to a minimum. This can be noted by the space (margin) between the two horizontal lines in the graph which represent the average of delays and flows respectively. The graph of the dynamic system shows that the rate of increase and decrease of vehicle flow and vehicle delays what is similar throughout the majority part of the peak hour. This shows that the system resisted sudden margin changes significantly be constantly readjusting to the traffic situation in order to maintain a good margin between vehicle flows and vehicle delays as the traffic demand increased. One thing to note from the delayed graph (red) of the dynamic system is the shape of the delay graph. After critical point the delay graph was levelled and caused to exhibit a steady and constant increase, with multiple points along the graph which showed the graph trying to be reduced (forced down). The delay graph in the dynamic system was kept so constant that it resembled the delay graph of the Fixed system. However, the difference is that when you pay attention to the vehicle flow graph, one can then realize what the system is trying to accomplish. The vehicle flow graph constantly fluctuates up and down as the system works to push vehicle flows back up. Each time the vehicle flows were pushed upwards, they were met with a threshold of resistance, signifying a situation where no further improvement was possible. Nevertheless, the dynamic system kept on trying to achieve a better result and as a result of its dynamic nature, the graph of the delays was kept at a constant pace and prevented from fluctuating or creating huge delay margins.

Quantitatively, this threshold limit for improvement which was reached by both actuated systems, seemed to have the same value. Both systems, no matter how good, could not cross this limit, and the performance of the two systems was maximized at that point.

HOW COULD THIS PERFORMACE LIMIT BE EXPLAINED?

Owing to universal consistency of scientific principles, the performance limit experienced by the two actuated systems in the hypothetical scenario can be explained by a scientific principle. This then brings up a principle called "Le_Chatelier's Principle of Dynamic Equilibrium".

Le_Chatelier's Principle of Dynamic Equilibrium states that *"if a system that is in equilibrium is disturbed by changing conditions caused by external factors (such as an increase in vehicles on a network), the system will shift the equilibrium position in an attempt to counteract the effects of this change and re-establish equilibrium, but only as far as possible)"* #Accurately Paraphrased.

This is a universal scientific principle that occurs in nature, and this principle is mostly utilized in chemistry and chemical engineering. In simpler terms, relating to this topic, a dynamic system can fight to restore equilibrium conditions after a disturbance, but this can only be done as far as possible. This means that there is always a threshold limit beyond which the effects of a change cannot be completely undone. Hence, even though results have shown that the Dynamic system performs better than the SCATS system, it is bound to eventually find its limit beyond which it cannot cross. Again, in simple terms, some situations are too dire to correct completely.

This means that, should a traffic situation such as this one occur in future, it would not matter how good the traffic management system would be, there is a limit to the improvement possible on a network.

CONCLUSIONS

From the results of the Sidra network analysis, it was revealed that the current level of service for the network was level of service of "E" , currently experienced on the network during peak hour (8am to 9am) on the busiest days of the week. This result shows the need for better traffic management strategies if the performance of the network is to improve in spite of the growing traffic demand in the city.

From the results produced in the research experiments, it can be concluded that a truly dynamic system significantly manages traffic flow better than the traditional traffic management systems. When the efficiency of a dynamic system was compared to the traditional fixed signal system and the actuated SCATS system, the dynamic system outperformed the two other systems by a significantly large margin, producing lower delays and also showing a more "Active" mentality in its decision making processes when handling traffic flow at peak time. In the models created for this research, the only major differences between the SCATS system model and the Dynamic system model was that the Dynamic system had a significantly higher amount of data input (more detectors) which gave it an edge over the SCATS system when processing the traffic situation and making decisions. The SCATS system has got limited data input to its systems (stopline detectors). This then meant that the SCATS system can be made more dynamic by adopting this method of using more detectors to increase data input, in addition to using more sophisticated algorithms that allow the system to think in real-time and make real-time active traffic management decisions. However, a truly dynamic system has still shown to be the most efficient traffic control system.

Lastly, it was observed that even in traffic engineering, the basic universal scientific laws and principles still stand. The results showed that even the best and most efficient traffic management systems have a limit to which they can improve an impossible traffic situation (maximum saturation). This means that, in as much as we can work to develop more advanced traffic management systems, other efforts should be channeled towards solving the problem at its source. It is much easier to avoid a problem than it is to try and solve its effects. In other words, the increase in vehicle traffic in a growing population is caused by an increase in the number of vehicle uses on the roads. If the demand gets to a point that causes maximum vehicle saturation on the roads, then even the most advanced traffic management system will be powerless and will only manage the vehicle demand as far as possible.

Firstly, as stated above, it is recommended that the rate of vehicle increase on the roads be reduced, and this would require more research into the actual causes of this increase, some of which are obvious and already known. This would also require improvements and investments into the alternative modes of travel, especially in the CBD, in order to discourage the use of individual vehicles on the roads.

Secondly, further extensive research needs to be carried out on the development and impact of a fully dynamic actuated system, as previously discussed. This calls for investments into research and development of technologies, both hardware and software, for use in these advanced traffic management systems. Also, this research was limited by time, budget and available software capabilities to conduct an even more extensive research. There is endless room to look into the prospects of a dynamic system and what kind of technology can be harnessed in order to create these systems. This would require coordination, cooperation and collaboration in the research and scientific realm to tackle these issues and prospects, and this would also involve the need to bring authorities such as governmental bodies on board, to see the need for such developments to take place and in turn support the cause.

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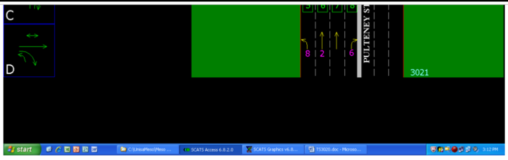
APPENDICIES

APPENDIX 1: SIDRA OPERATIONAL DATA SNIPSHOT



HISTORICAL:
02/11/2010 linking data changed for City east project BF
20/08/2007 P1, P2, P3 set to walk overlap to avoid reintro at start of through phase. RMB
18/07/2007 Right turns activated BF
01/06/2007 ISS enabled - RMB
09/07/2006 New program (Right turn SG's)
02/02/2006 A & B Ped clearance times increased to 26 secs a/c low mobility pedestrians
B walk reduced to 6 secs
Flexi plan 4 removed substituted with plan3 BF

SITE DETAILS:
Standard single diamond phasing.
Site runs ISS
Note: SP2/LP2 = PM, SP4/LP4=AM.
Site runs ADEF all times
Right turns active via XSF 5-7
Site can be dwelled to B or C in emergencies.

COORDINATION:
Controlling LK's at TS3028 SS data changed by action list City east project
Cycle length setting is varied by Link Plan selection. For more details please refer to action list
CL =120 in LP 2 or LP 4,
CL=98 in LP 3

RIGHT TURNS:
Right turns filter by default.
SG5 or 6 can be fully controlled (if RT permitted) and XSF9 or 10 is applied.
To cancel default right turns and give NGA for all RT's apply XSF8.
To permit SG5 - apply ZNEG (B) or XSF5 (F1), will override XSF8 above.
To permit SG6 - apply ZPOS (C) or XSF6 (F2), will override XSF8 above.
To permit SG7 at all times - apply XSF7 (D), will override XSF8 above.
XSF13, 14 are green time restrictions for SG5, 6 in G.

PEDESTRIANS:
P1 can late intro until XSF1 (disabled in VP's TD/JJB ...25/05/07)
P2 can late intro until XSF2 (disabled in VP's TD/JJB ...25/05/07)
Y- (in Masterlink) or XSF4 will demand all pedestrians.
Peds auto intro via Y- 08:00 - 18:00 mon to fri at request of ACC.

TS 3020 – Pulteney St, Grenfell St – City Central

Phasing operation:

- Single diamond operation
- Running phase sequence: ADEF all times

Turning movement operation:

- Right turns filter at all times.

Pedestrians:

- Pedestrian's auto intro Mon to Fri 08:00 - 18:00.

Phase percentage during peak periods:

- A phase (Pulteney St) is the stretch phase
- Average phase percentage from 16 May to 20 May 2011

Period	Time	A	D	E	F
AM	700 - 900	41	12	35	13
BUS	1200 - 1500	40	13	35	12
PM	1600 - 1800	39	15	32	14

Linking:

- TS3020 is linked to TS3021 (Pulteney Street/Pirie St)
- TS3019 (Pulteney St /Rundle Mall/ Rundle Street) is linked to TS3020.

Intergreen Time

- Phase A & F have 7 secs of intergreen time (Yellow = 4.0, Red = 2.0)
- D & E has 6.5 secs of intergreen time (Yellow = 4.0, Red = 2.5)

Cycle Time

- Maximum cycle time for TS3020 is 120 seconds
- During Business peak maximum cycle time is 98secs
- Average CL in business hours = 90 seconds
- Average CL in AM peak = 120 seconds
- Average CL in PM peak = 120 seconds

APPENDIX 2: VOLUME TURNING COUNT DATA SNAPSHOT

2 WEEKS COUNT DATA – 14 DAYS (MON-SUN).

N23

	A	B	C	D	E	F	G	H	I
1	Counter	Total Count	Min Count	Average Count	Max Count	counts	Fault Count	Record Coun	Interval Time
2	(1) (3018 - 1) SCATS Site 3018 - Detector 1	7	7	7	7	[7]	0	1	11/3/24 07:00
3	(1) (3018 - 1) SCATS Site 3018 - Detector 1	9	9	9	9	[9]	0	1	11/3/24 07:05
4	(1) (3018 - 1) SCATS Site 3018 - Detector 1	15	15	15	15	[15]	0	1	11/3/24 07:10
5	(1) (3018 - 1) SCATS Site 3018 - Detector 1	8	8	8	8	[8]	0	1	11/3/24 07:15
6	(1) (3018 - 1) SCATS Site 3018 - Detector 1	11	11	11	11	[11]	0	1	11/3/24 07:20
7	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 07:25
8	(1) (3018 - 1) SCATS Site 3018 - Detector 1	6	6	6	6	[6]	0	1	11/3/24 07:30
9	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 07:35
10	(1) (3018 - 1) SCATS Site 3018 - Detector 1	20	20	20	20	[20]	0	1	11/3/24 07:40
11	(1) (3018 - 1) SCATS Site 3018 - Detector 1	16	16	16	16	[16]	0	1	11/3/24 07:45
12	(1) (3018 - 1) SCATS Site 3018 - Detector 1	13	13	13	13	[13]	0	1	11/3/24 07:50
13	(1) (3018 - 1) SCATS Site 3018 - Detector 1	7	7	7	7	[7]	0	1	11/3/24 07:55
14	(1) (3018 - 1) SCATS Site 3018 - Detector 1	10	10	10	10	[10]	0	1	11/3/24 08:00
15	(1) (3018 - 1) SCATS Site 3018 - Detector 1	7	7	7	7	[7]	0	1	11/3/24 08:05
16	(1) (3018 - 1) SCATS Site 3018 - Detector 1	9	9	9	9	[9]	0	1	11/3/24 08:10
17	(1) (3018 - 1) SCATS Site 3018 - Detector 1	7	7	7	7	[7]	0	1	11/3/24 08:15
18	(1) (3018 - 1) SCATS Site 3018 - Detector 1	7	7	7	7	[7]	0	1	11/3/24 08:20
19	(1) (3018 - 1) SCATS Site 3018 - Detector 1	15	15	15	15	[15]	0	1	11/3/24 08:25
20	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 08:30
21	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 08:35
22	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 08:40
23	(1) (3018 - 1) SCATS Site 3018 - Detector 1	13	13	13	13	[13]	0	1	11/3/24 08:45
24	(1) (3018 - 1) SCATS Site 3018 - Detector 1	12	12	12	12	[12]	0	1	11/3/24 08:50
25	(1) (3018 - 1) SCATS Site 3018 - Detector 1	15	15	15	15	[15]	0	1	11/3/24 08:55
26	(1) (3018 - 1) SCATS Site 3018 - Detector 1	22	22	22	22	[22]	0	1	12/3/24 07:00
27	(1) (3018 - 1) SCATS Site 3018 - Detector 1	25	25	25	25	[25]	0	1	12/3/24 07:05
28	(1) (3018 - 1) SCATS Site 3018 - Detector 1	32	32	32	32	[32]	0	1	12/3/24 07:10
29	(1) (3018 - 1) SCATS Site 3018 - Detector 1	26	26	26	26	[26]	0	1	12/3/24 07:15
30	(1) (3018 - 1) SCATS Site 3018 - Detector 1	31	31	31	31	[31]	0	1	12/3/24 07:20
31	(1) (3018 - 1) SCATS Site 3018 - Detector 1	33	33	33	33	[33]	0	1	12/3/24 07:25
32	(1) (3018 - 1) SCATS Site 3018 - Detector 1	44	44	44	44	[44]	0	1	12/3/24 07:30
33	(1) (3018 - 1) SCATS Site 3018 - Detector 1	38	38	38	38	[38]	0	1	12/3/24 07:35
34	(1) (3018 - 1) SCATS Site 3018 - Detector 1	42	42	42	42	[42]	0	1	12/3/24 07:40
35	(1) (3018 - 1) SCATS Site 3018 - Detector 1	46	46	46	46	[46]	0	1	12/3/24 07:45
36	(1) (3018 - 1) SCATS Site 3018 - Detector 1	48	48	48	48	[48]	0	1	12/3/24 07:50
37	(1) (3018 - 1) SCATS Site 3018 - Detector 1	41	41	41	41	[41]	0	1	12/3/24 07:55
38	(1) (3018 - 1) SCATS Site 3018 - Detector 1	40	40	40	40	[40]	0	1	12/3/24 08:00
39	(1) (3018 - 1) SCATS Site 3018 - Detector 1	40	40	40	40	[40]	0	1	12/3/24 08:05
40	(1) (3018 - 1) SCATS Site 3018 - Detector 1	48	48	48	48	[48]	0	1	12/3/24 08:10
41	(1) (3018 - 1) SCATS Site 3018 - Detector 1	38	38	38	38	[38]	0	1	12/3/24 08:15
42	(1) (3018 - 1) SCATS Site 3018 - Detector 1	35	35	35	35	[35]	0	1	12/3/24 08:20
43	(1) (3018 - 1) SCATS Site 3018 - Detector 1	37	37	37	37	[37]	0	1	12/3/24 08:25
44	(1) (3018 - 1) SCATS Site 3018 - Detector 1	34	34	34	34	[34]	0	1	12/3/24 08:30
45	(1) (3018 - 1) SCATS Site 3018 - Detector 1	33	33	33	33	[33]	0	1	12/3/24 08:35
46	(1) (3018 - 1) SCATS Site 3018 - Detector 1	47	47	47	47	[47]	0	1	12/3/24 08:40
47	(1) (3018 - 1) SCATS Site 3018 - Detector 1	27	27	27	27	[27]	0	1	12/3/24 08:45
48	(1) (3018 - 1) SCATS Site 3018 - Detector 1	43	43	43	43	[43]	0	1	12/3/24 08:50
49	(1) (3018 - 1) SCATS Site 3018 - Detector 1	34	34	34	34	[34]	0	1	12/3/24 08:55
50	(1) (3018 - 1) SCATS Site 3018 - Detector 1	29	29	29	29	[29]	0	1	13/3/24 07:00

SCATS_Aggregated 5 mins

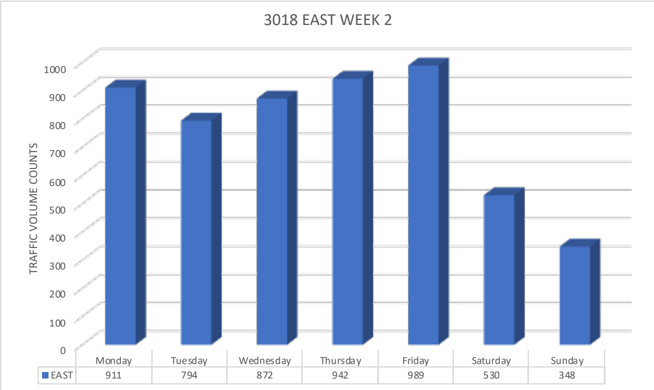
MARCH WEEK 2 & 3 (Middle Weeks)

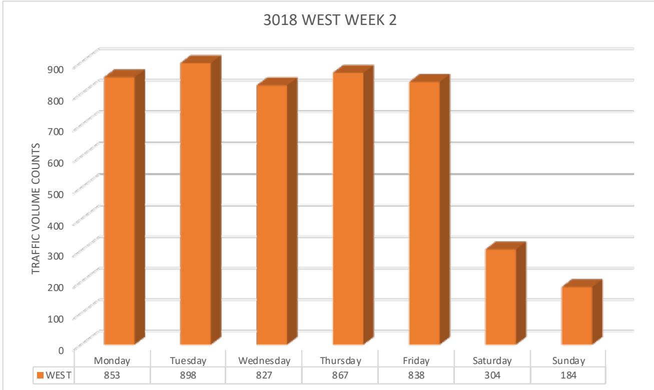
O15147

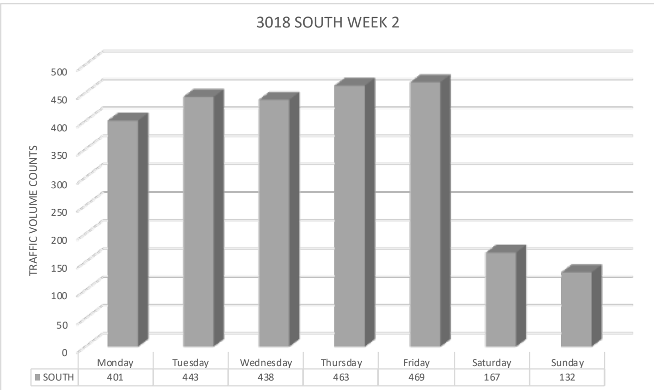
	A	B	C	D	E	F	G	H	I	J	K
1	Counter	Total Count	Min Count	Average Count	Max Count	counts	Fault Count	Record Coun	Interval Time	Query Name	
15122	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:00	Counter Stats by Counter (0)	
15123	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:05	Counter Stats by Counter (0)	
15124	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:10	Counter Stats by Counter (0)	
15125	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:15	Counter Stats by Counter (0)	
15126	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:20	Counter Stats by Counter (0)	
15127	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:25	Counter Stats by Counter (0)	
15128	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:30	Counter Stats by Counter (0)	
15129	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:35	Counter Stats by Counter (0)	
15130	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:40	Counter Stats by Counter (0)	
15131	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:45	Counter Stats by Counter (0)	
15132	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:50	Counter Stats by Counter (0)	
15133	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 07:55	Counter Stats by Counter (0)	
15134	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:00	Counter Stats by Counter (0)	
15135	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:05	Counter Stats by Counter (0)	
15136	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:10	Counter Stats by Counter (0)	
15137	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:15	Counter Stats by Counter (0)	
15138	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:20	Counter Stats by Counter (0)	
15139	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:25	Counter Stats by Counter (0)	
15140	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:30	Counter Stats by Counter (0)	
15141	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:35	Counter Stats by Counter (0)	
15142	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:40	Counter Stats by Counter (0)	
15143	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:45	Counter Stats by Counter (0)	
15144	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:50	Counter Stats by Counter (0)	
15145	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	14/3/24 08:55	Counter Stats by Counter (0)	
15146	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:00	Counter Stats by Counter (0)	
15147	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:05	Counter Stats by Counter (0)	
15148	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:10	Counter Stats by Counter (0)	
15149	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:15	Counter Stats by Counter (0)	
15150	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:20	Counter Stats by Counter (0)	
15151	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:25	Counter Stats by Counter (0)	
15152	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:30	Counter Stats by Counter (0)	
15153	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:35	Counter Stats by Counter (0)	
15154	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:40	Counter Stats by Counter (0)	
15155	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:45	Counter Stats by Counter (0)	
15156	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:50	Counter Stats by Counter (0)	
15157	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 07:55	Counter Stats by Counter (0)	
15158	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:00	Counter Stats by Counter (0)	
15159	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:05	Counter Stats by Counter (0)	
15160	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:10	Counter Stats by Counter (0)	
15161	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:15	Counter Stats by Counter (0)	
15162	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:20	Counter Stats by Counter (0)	
15163	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:25	Counter Stats by Counter (0)	
15164	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:30	Counter Stats by Counter (0)	
15165	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:35	Counter Stats by Counter (0)	
15166	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:40	Counter Stats by Counter (0)	
15167	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:45	Counter Stats by Counter (0)	
15168	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:50	Counter Stats by Counter (0)	
15169	(24) (3018 - 24) SCATS Site 3018 - Detector 24	0	0	0	0	[0]	0	1	20/3/24 08:55	Counter Stats by Counter (0)	
15170											

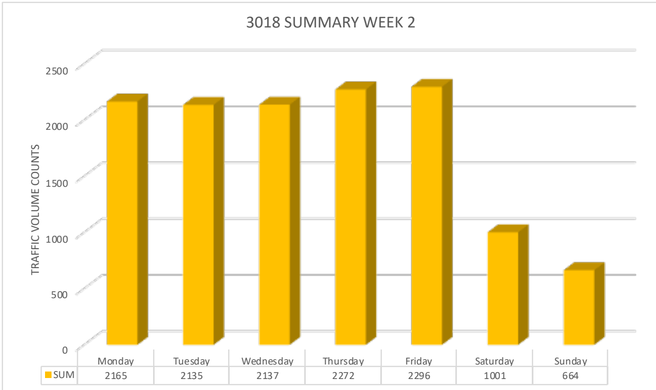
SCATS_Aggregated 5 mins

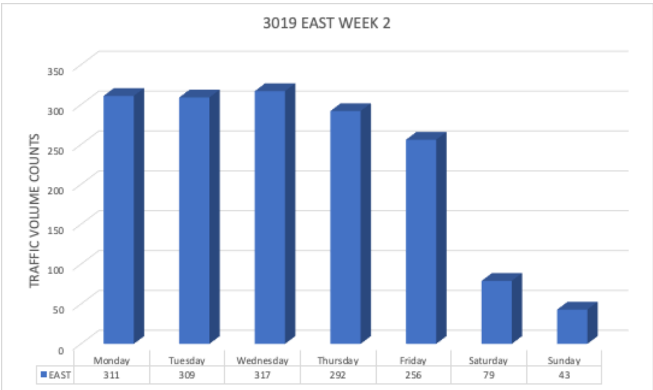
APPENDIX 3: VOLUME GRAPHS FROM TABULATED VEHICLE VOLUME DATA

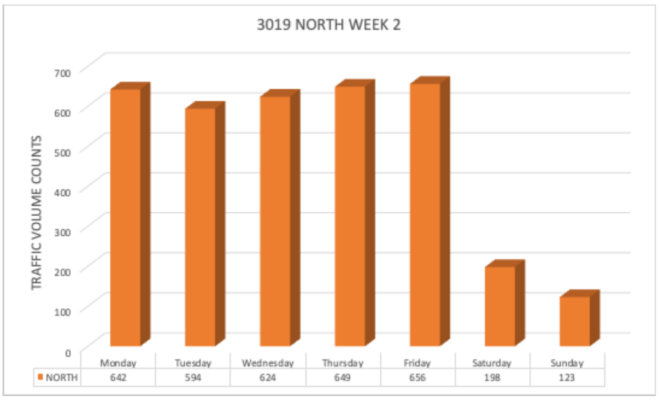


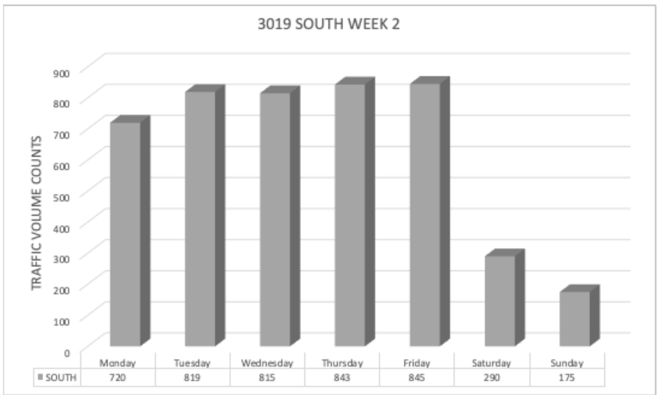


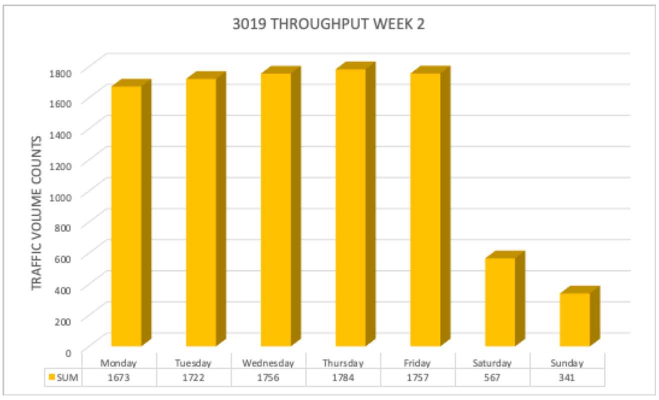


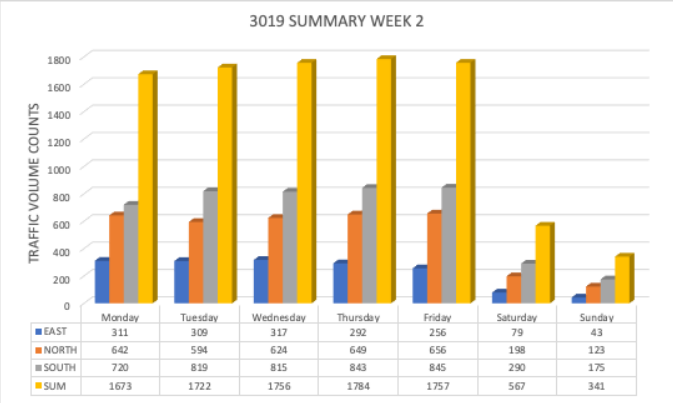


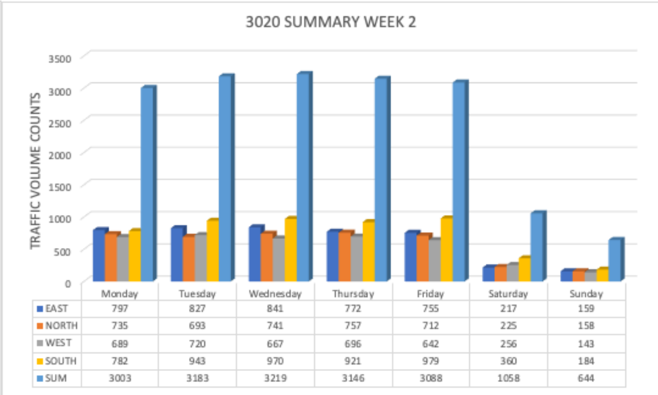


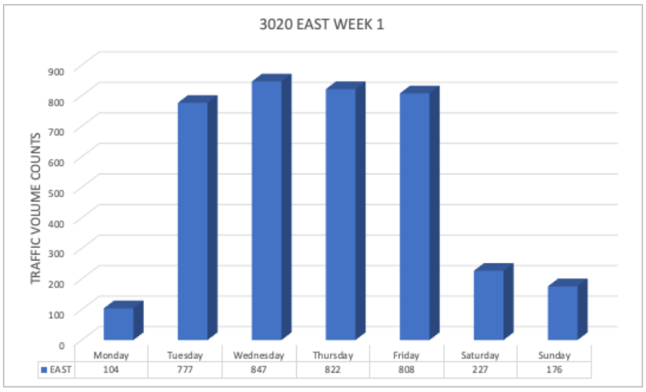


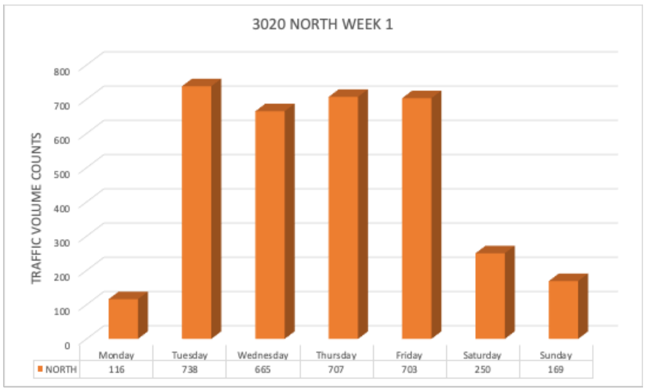


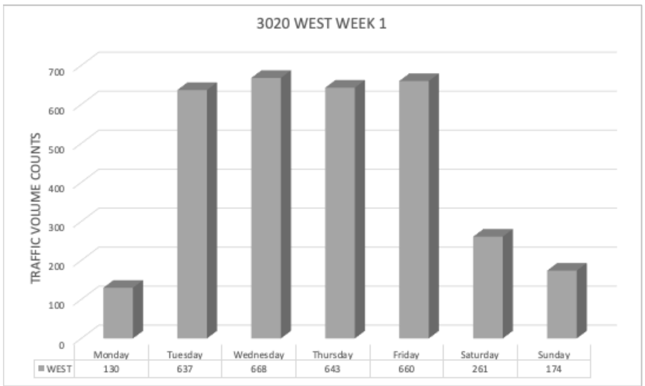


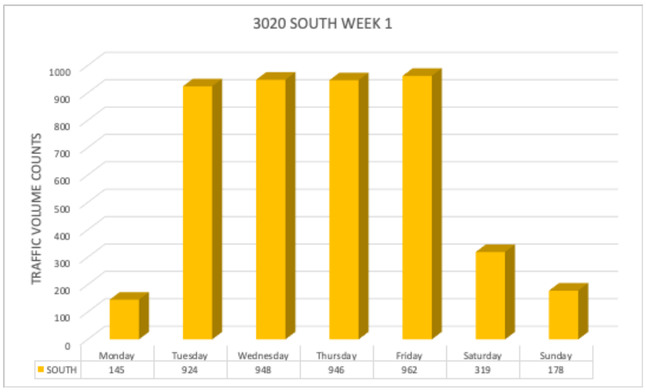

3019 SUMMARY WEEK 2
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
EAST 311 309 317 292 256 79 43
NORTH 642 594 624 649 656 198 123
SOUTH 720 819 815 843 845 290 175
SUM 1673 1722 1756 1784 1757 567 341

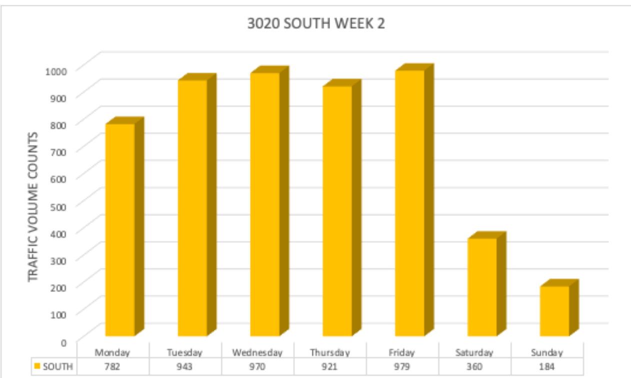

3020 SUMMARY WEEK 2
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
EAST 797 827 841 772 755 217 159
NORTH 735 693 741 757 712 225 158
WEST 689 720 667 696 642 256 143
SOUTH 782 943 970 921 979 360 184
SUM 3003 3183 3219 3146 3088 1058 644

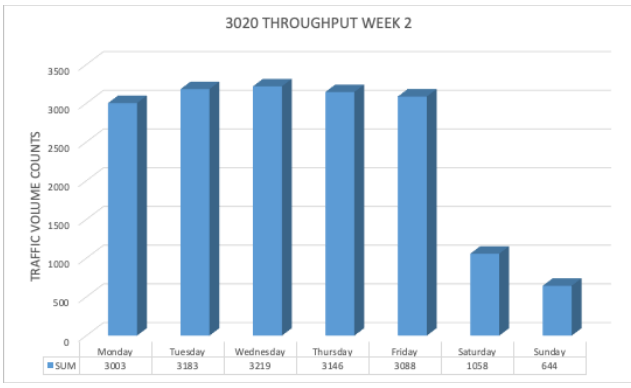

3020 EAST WEEK 1
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
EAST 104 777 847 822 808 227 176


3020 NORTH WEEK 1
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
NORTH 116 738 665 707 703 250 169

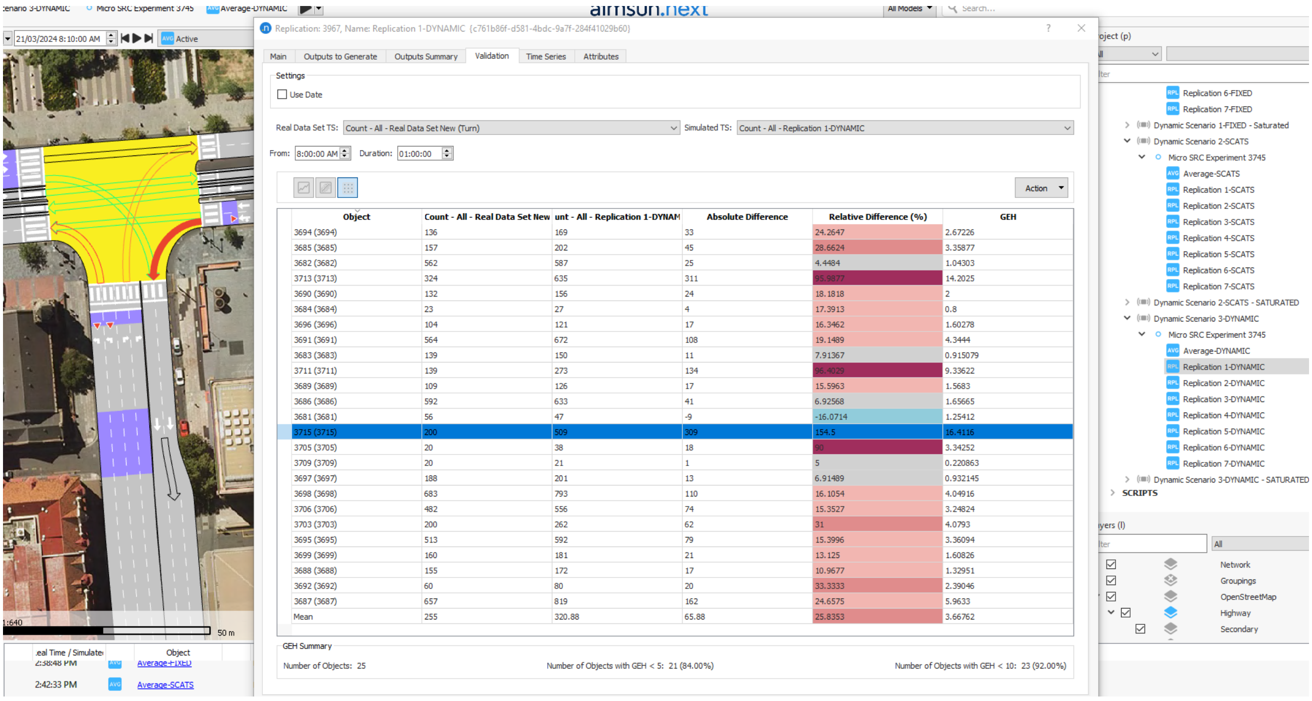

3020 WEST WEEK 1
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
WEST 130 637 668 643 660 261 174


3020 SOUTH WEEK 1
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
SOUTH 145 924 948 946 962 319 178


3020 SOUTH WEEK 2
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
SOUTH 782 943 970 921 979 360 184


3020 THROUGHPUT WEEK 2
TRAFFIC VOLUME COUNTS
Monday Tuesday Wednesday Thursday Friday Saturday Sunday
SUM 3003 3183 3219 3146 3088 1058 644

APPENDIX 4 – VALIDATION OF AIMSUN MODEL DATA



Replication: 3967, Name: Replication 1-DYNAMIC {c761b86f-d581-4bdc-9a7f-284f41029b60}

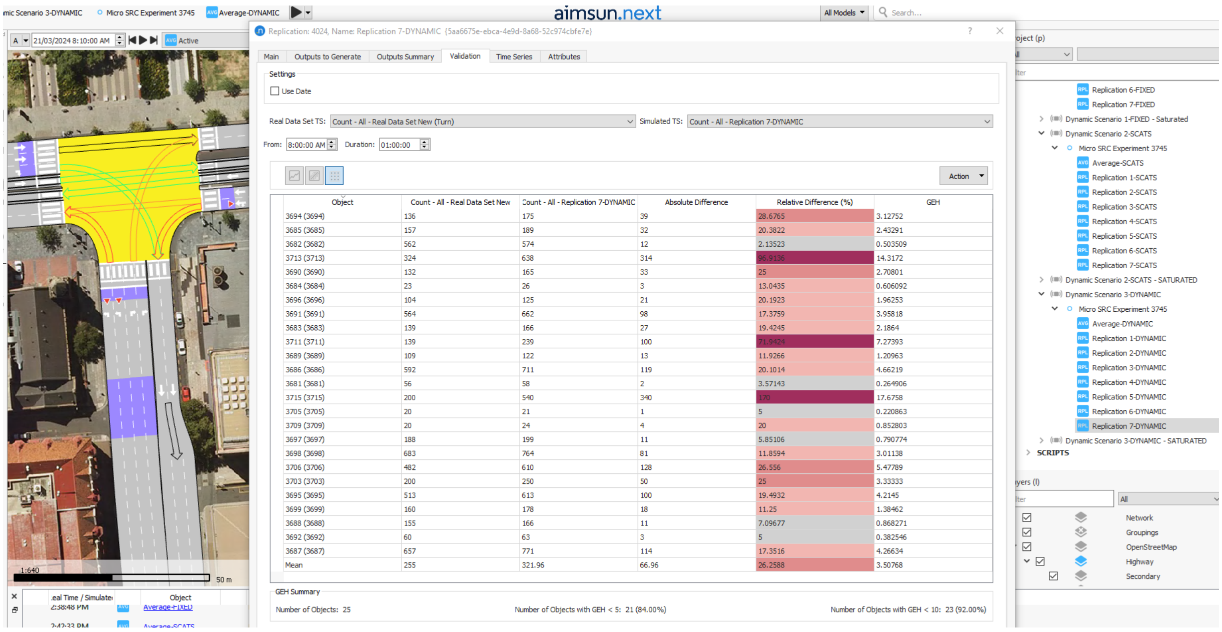
Real Data Set TS: Count - All - Real Data Set New (Turn) Simulated TS: Count - All - Replication 1-DYNAMIC

From: 8:00:00 AM Duration: 01:00:00

Object	Count - All - Real Data Set New	unt - All - Replication 1-DYNAM	Absolute Difference	Relative Difference (%)	GEH
3694 (3694)	136	169	33	24.2647	2.67226
3685 (3685)	157	202	45	28.6624	3.35877
3682 (3682)	562	587	25	4.4484	1.04303
3713 (3713)	324	635	311	95.9877	14.2025
3690 (3690)	132	156	24	18.1818	2
3684 (3684)	23	27	4	17.3913	0.8
3696 (3696)	104	121	17	16.3462	1.60278
3691 (3691)	564	672	108	19.1489	4.3444
3683 (3683)	139	150	11	7.91367	0.915079
3711 (3711)	139	273	134	96.4029	9.33622
3689 (3689)	109	126	17	15.5963	1.5683
3686 (3686)	592	633	41	6.92568	1.65665
3681 (3681)	56	47	-9	-16.0714	1.25412
3715 (3715)	200	509	309	154.5	16.4116
3705 (3705)	20	38	18	90	3.34252
3709 (3709)	20	21	1	5	0.220863
3697 (3697)	188	201	13	6.91489	0.932145
3698 (3698)	683	793	110	16.1054	4.04916
3706 (3706)	482	556	74	15.3527	3.24824
3703 (3703)	200	262	62	31	4.0793
3695 (3695)	513	592	79	15.3996	3.36094
3699 (3699)	160	181	21	13.125	1.60826
3688 (3688)	155	172	17	10.9677	1.32951
3692 (3692)	60	80	20	33.3333	2.39046
3687 (3687)	657	819	162	24.6575	5.9633
Mean	255	320.88	65.88	25.8353	3.66762

GEH Summary

Number of Objects: 25 Number of Objects with GEH < 5: 21 (84.00%) Number of Objects with GEH < 10: 23 (92.00%)



Replication: 4024, Name: Replication 7-DYNAMIC {5aa6675e-ebca-4e9d-8a68-52c974cbfe7e}

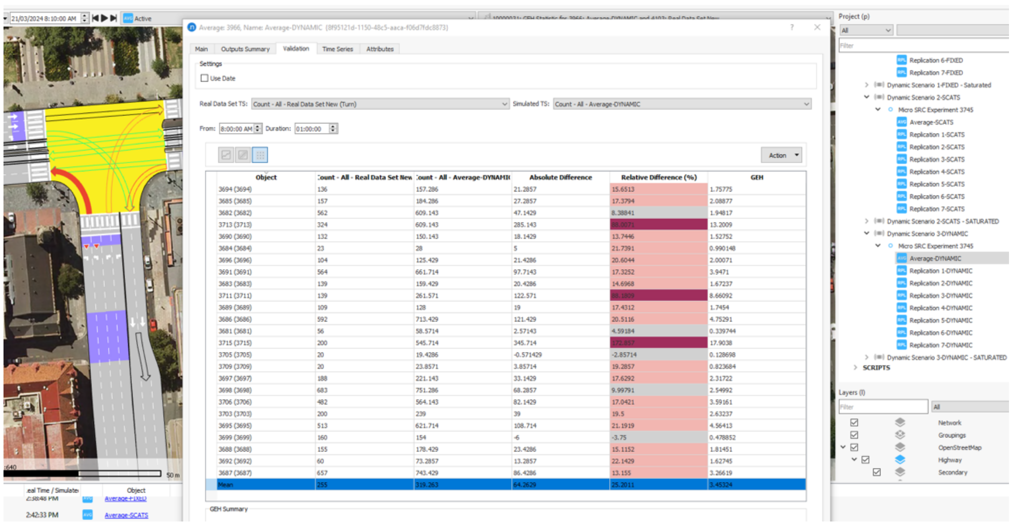
Real Data Set TS: Count - All - Real Data Set New (Turn) Simulated TS: Count - All - Replication 7-DYNAMIC

From: 8:00:00 AM Duration: 01:00:00

Object	Count - All - Real Data Set New	Count - All - Replication 7-DYNAMIC	Absolute Difference	Relative Difference (%)	GEH
3694 (3694)	136	175	39	28.6765	3.12752
3685 (3685)	157	189	32	20.3822	2.43291
3682 (3682)	562	574	12	2.13523	0.503509
3713 (3713)	324	638	314	96.9136	14.3172
3690 (3690)	132	165	33	25	2.70801
3684 (3684)	23	26	3	13.0435	0.606092
3696 (3696)	104	125	21	20.1923	1.96253
3691 (3691)	564	662	98	17.3759	3.95818
3683 (3683)	139	166	27	19.4245	2.1864
3711 (3711)	139	239	100	71.9424	7.27393
3689 (3689)	109	122	13	11.9266	1.20963
3686 (3686)	592	711	119	20.1014	4.66219
3681 (3681)	56	58	2	3.57143	0.264906
3715 (3715)	200	540	340	170	17.6758
3705 (3705)	20	21	1	5	0.220863
3709 (3709)	20	24	4	20	0.852803
3697 (3697)	188	199	11	5.85106	0.790774
3698 (3698)	683	764	81	11.8594	3.01138
3706 (3706)	482	610	128	26.556	5.47789
3703 (3703)	200	250	50	25	3.33333
3695 (3695)	513	613	100	19.4932	4.2145
3699 (3699)	160	178	18	11.25	1.38462
3688 (3688)	155	166	11	7.09677	0.868271
3692 (3692)	60	63	3	5	0.382546
3687 (3687)	657	771	114	17.3516	4.26634
Mean	255	321.96	66.96	26.2588	3.50768

GEH Summary

Number of Objects: 25 Number of Objects with GEH < 5: 21 (84.00%) Number of Objects with GEH < 10: 23 (92.00%)



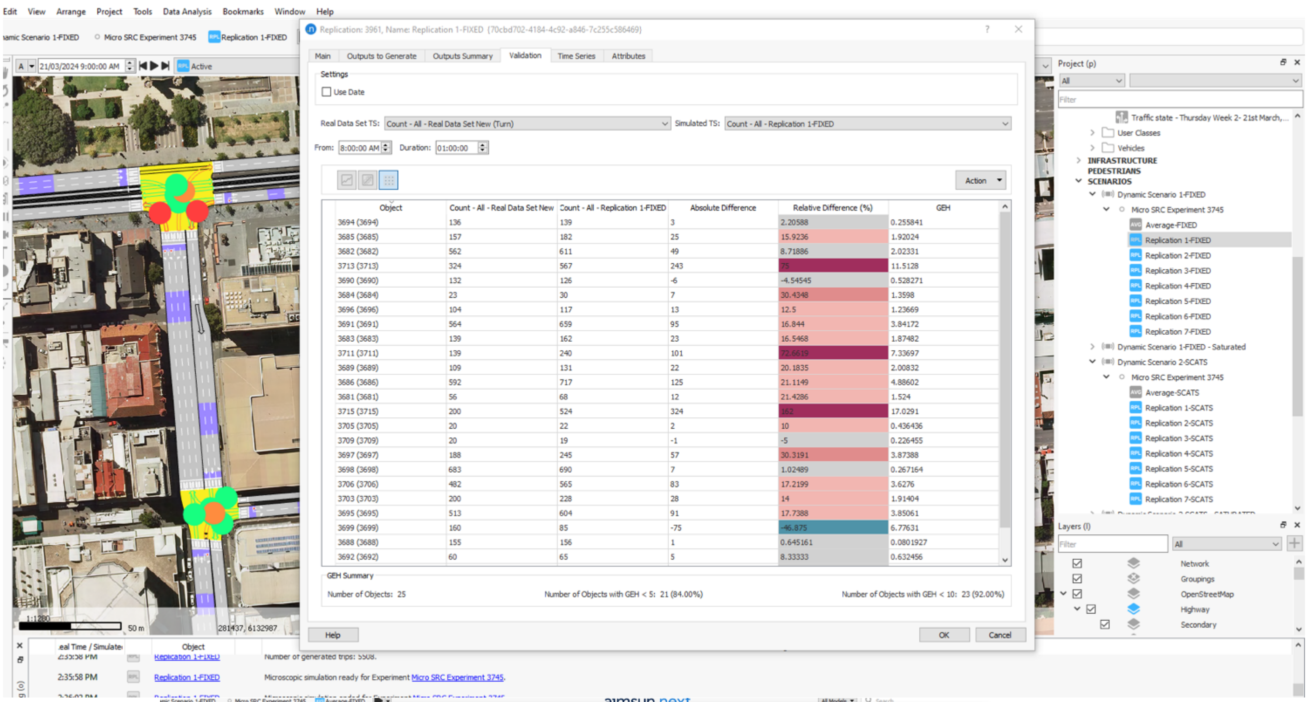
Average: 3966, Name: Average-DYNAMIC {8f95121d-1150-48c5-aaca-f06d7fdc8873}

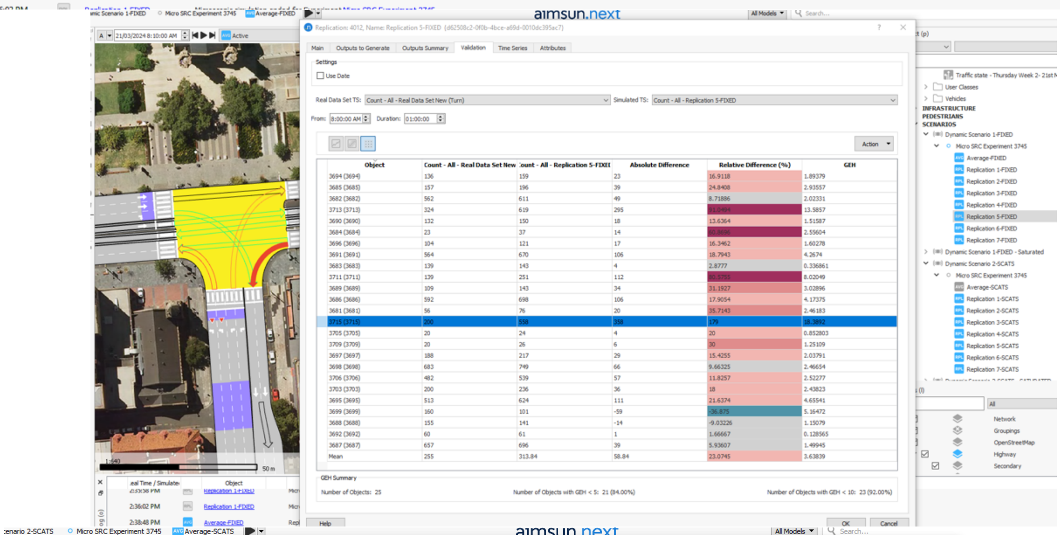
Real Data Set TS: Count - All - Real Data Set New (Turn) Simulated TS: Count - All - Average-DYNAMIC

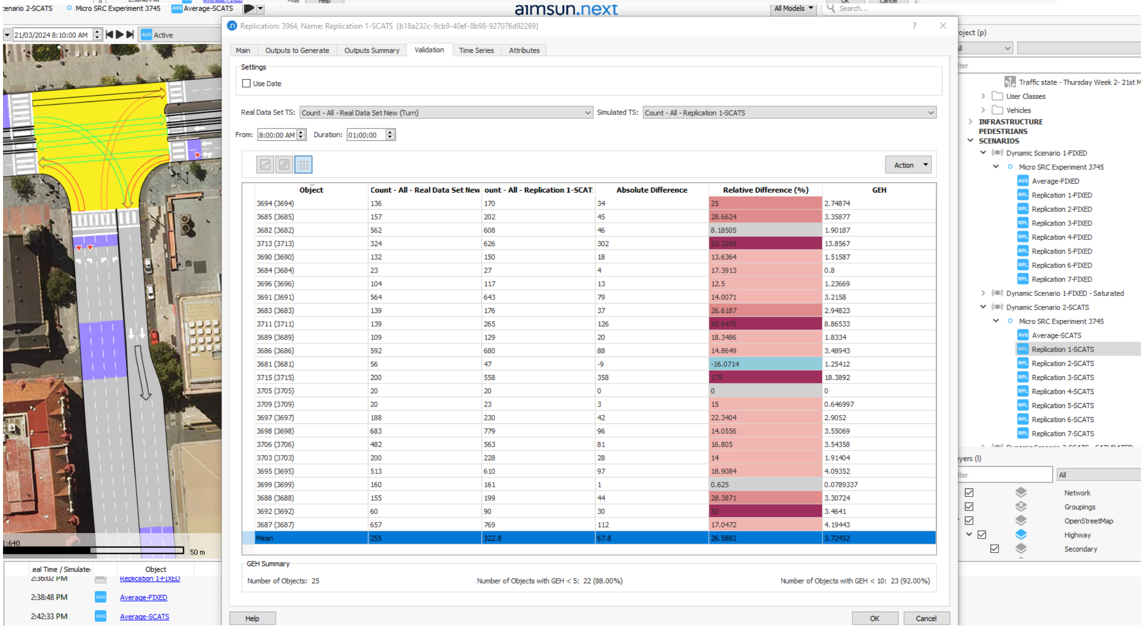
From: 8:00:00 AM Duration: 01:00:00

Object	Count - All - Real Data Set New	Count - All - Average-DYNAMIC	Absolute Difference	Relative Difference (%)	GEH
3694 (3694)	136	157.286	21.2857	15.6513	1.75775
3685 (3685)	157	184.286	27.2857	17.3794	2.08877
3682 (3682)	562	609.143	47.1429	8.38841	1.94817
3713 (3713)	324	609.143	285.143	[illegible]	13.2009
3690 (3690)	132	150.143	18.1429	13.7446	1.52752
3684 (3684)	23	28	5	21.7391	0.990148
3696 (3696)	104	125.429	21.4286	20.6044	2.00071
3691 (3691)	564	661.714	97.7143	17.3252	3.9471
3683 (3683)	139	159.429	20.4286	14.6968	1.67237
3711 (3711)	139	261.571	122.571	[illegible]	8.66092
3689 (3689)	109	128	19	17.4312	1.7454
3686 (3686)	592	713.429	121.429	20.5116	4.75291
3681 (3681)	56	58.5714	2.57143	4.59184	0.339744
3715 (3715)	200	545.714	345.714	[illegible]	17.9038
3705 (3705)	20	19.4286	-0.571429	-2.85714	0.128698
3709 (3709)	20	23.8571	3.8571	19.2857	0.823684
3697 (3697)	188	221.143	33.1429	17.6292	2.31722
3698 (3698)	683	751.286	68.2857	9.99791	2.54992
3706 (3706)	482	564.143	82.1429	17.0421	3.59161
3703 (3703)	200	239	39	19.5	2.63237
3695 (3695)	513	621.714	108.714	21.1919	4.56413
3699 (3699)	160	154	-6	-3.75	0.478852
3688 (3688)	155	178.429	23.4286	15.1152	1.81451
3692 (3692)	60	73.2857	13.2857	22.1429	1.62745
3687 (3687)	657	743.429	86.4286	13.155	3.26619
Mean	255	318.263	64.2629	25.2011	2.45324

GEH Summary


Replication: 3961, Name: Replication 1-FIXED
Real Data Set TS: Count - All - Real Data Set New (Turn)
Simulated TS: Count - All - Replication 1-FIXED
GEH Summary
Number of Objects: 25
Number of Objects with GEH < 5: 21 (84.00%)
Number of Objects with GEH < 10: 23 (92.00%)


aimsun.next
Replication: 4012, Name: Replication 5-FIXED
Real Data Set TS: Count - All - Real Data Set New (Turn)
Simulated TS: Count - All - Replication 5-FIXED
GEH Summary
Number of Objects: 25
Number of Objects with GEH < 5: 21 (84.00%)
Number of Objects with GEH < 10: 23 (92.00%)


aimsun.next
Replication: 3964, Name: Replication 1-SCATS
Real Data Set TS: Count - All - Real Data Set New (Turn)
Simulated TS: Count - All - Replication 1-SCATS
GEH Summary
Number of Objects: 25
Number of Objects with GEH < 5: 22 (88.00%)
Number of Objects with GEH < 10: 23 (92.00%)

APPENDIX 5 – DPTI MODEL VALIDATION GUIDENINES

3.2.5.3.8 Calibration and Validation Criteria

Table 3.2.5-2 details the criteria for model calibration and validation.

Table 3.2.5-2 Calibration and Validation Requirement for a Microsimulation Subarea Model from TAM

Check	Criteria and Measures – Full Model Period, Warm-Up Period and Peak Hour(s) to be reported	Acceptability Level
Calibration Check	**Turning Movements**	
	GEH Statistic for individual flows / movements	
	Defined non-critical flows / movements	All <5.0
	(Any values >5.0 to be documented)	
	All other flows / movements	All <3.0
	(Any values >3.0 to be documented)	
	Average GEH Statistic for all flows / movements	<1.5
	Plot of observed vs modelled individual flows / movements	
	Line of Best Fit	
	Slope	1.00±0 01
	R^2	>0.99
	(Slope equation to be included, intercept = 0)	
	Queue Lengths Comparison required	Maximum modelled queue lengths to match the maximum observed queue lengths
Validation Check	**Travel Times** Plot for the full model period minimum and maximum observed vs average modelled travel times required. Note: If using Addinsight, minimum and maximum travel time must be determined by ±15% of the median travel time for at least 80% of routes/times. For remaining routes/times, the minimum and maximum travel time can be determined by ±25% of the median trave time.	Average modelled travel time to fit within the observed minimum-maximum travel time band.

Note: For model calibration, all movements associated with datapoints, determined for creating traffic flow Real Data Set (RDS) for a subarea, are ***critical*** movements unless otherwise agreed with DIT Transport Analytics and Network Management Services and documented in the TMSD.