A Study of Road Network Performance During Incident

by

Mohitkumar Gajera

Academic Supervisors: Mr. Branko Stazic
Academic Co-Supervisor: Dr. Nicholas Holyoak
ENGR9700 – 18 units

Thesis
Submitted to Flinders University
For the master's degree of engineering (ME Civil)

Master of Engineering (Civil)

Flinders university, South Australia
May 2023

ABSTRACT

This proposal describes an investigation of road network performance during the incident on the road. As a result of the continued growth of the population in South Australia, transportation demand is also increasing. With the demand for transportation, forecasting the traffic on the road is very hard. Transport designers are using different types of simulation (micro-simulation, meso-simulation, and macro-simulation) software for the design of unpredictable situations. Transport designers are facing many difficulties due to unpredictable impacts on traffic, in which traffic incidents are a critical impact during transport design. In this paper, I will analyze road network performance during the incident on the North-East (arterial) Road and its impact on travelers, pedestrians, the economy, and the environment at the midblock as well as at the signalized intersections and pedestrian crossings. I will analyze different locations of incidents, different durations of incidents, future years of operation, and traffic diversion needs and how. I will show the features of the road during the incident with the current road network design. Furthermore, I will analyze the impact of the road incident, how it depends on the location and duration of the incident.

Keywords: Incident study, Traffic incident impacts, Incident management, micro-simulation, Meso-simulation, macro-simulation, SIDRA, AIMSUN

Academic integrity declaration

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university.
2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and
3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

Mohitkumar Gajera
(Student)

I certify that I have read this thesis. In my opinion it is/is not (please circle) fully adequate, in scope and in quality, as a project proposal for the master's degree in civil engineering. Furthermore, I confirm that I have provided feedback on this project proposal and the student has implemented it minimally/partially/fully (please circle).

Mr. Branko Stazic
(Supervisor)

Dr. Nicholas Holyoak
(Co-Supervisor)

Acknowledgement

I would like to express my sincere gratitude to all those who have supported me in completing this thesis on "A Study of Road Network Performance During Incidents".

Expressing my gratitude is something I find difficult to do justice to in words, as I feel incredibly humbled by the support and valuable guidance, I received from **Research Associate Mr. Branko Stazic** and **Dr. Nicholas Holyoak**, my supervisor and co-supervisor, respectively, during my thesis and my two years at Flinders University. I owe a deep debt of gratitude to **Mr. Branko Stazic** and **Dr. Nicholas Holyoak**, whose unwavering enthusiasm and willingness to help every student played a major role in the completion of my thesis. From teaching me software to assisting with results generation, theme efforts and kindness have been a constant source of inspiration that I will cherish for the rest of my life. **Dr. Nicholas Holyoak** always assists me to find research books on both academic topics and thesis and motivated me to learn something new and creative.

I also wish to extend my thanks to **Prof Karl Sammut**, who was my companion throughout my studies at the university, for her valuable guidance and suggestions during the thesis. Additionally, I am grateful to **Dr. Hongyu Qin, Dr. Thomas Vincent, Dr. Rocco Zito,** and **Dr. Cristina Solorzano Rivas** for their constant encouragement to work harder.

Furthermore, I cannot express enough gratitude to my family brother, **Mr. Rutvik Gajera**, for his unwavering love and support during tough times. Without him, I would not have been able to complete this degree.

Lastly, I would like to thank my friends **Mr. Akshay Ahlawat**, **Mrs. Chathushika,** and **Mr. Jaineel Patel** at Flinders University, for their consistent support and help each other throughout my entire university study.

In conclusion, the support, insight, and belief from my supervisors, friends, and family have culminated in this report. I thank all of you once again for your continuous support and motivation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

TS029 – North-East Rd, Nottage Tce: Walkerville

TS168 – North-East Rd, Smith St: Collinswood

TTR - Travel Time Reliability

VSL - Value of a Statistical Life

DIT: Department of Infrastructure and Transport.

DPTI: Department of Transport Planning and Infrastructure. ITS: Intelligent Transport System

LOS: Level of Service

O-D (matrix): Origin-Destination Matrix

TIM: Traffic Incident Management

CO2: Carbon Dioxide

1. INTRODUCTION

The North-East Road is a major arterial road in Adelaide, South Australia, running from the city center to the northeastern suburbs, passing through densely populated residential areas and commercial districts. The road stretches for approximately 30 km, with a speed limit ranging from 60 km/h, depending on the section. The North-East Road serves as a vital transport corridor for both commuters and freight transportation, connecting the inner city with several northeastern suburbs, including Tea Tree Gully, Modbury, and Golden Grove. It is also an important link to the Northern Expressway, connecting to Gawler and the Barossa Valley wine region.

In recent years, traffic congestion and safety issues on the North-East Road have become a significant concern for local authorities and residents. According to the Department of Planning, Transport, and Infrastructure (DPTI), the North-East Road is one of the busiest and most heavily congested roads in Adelaide, with an average daily traffic volume of over 62,000 vehicles. The traffic flow on the North-East Road is further exacerbated during peak hours, with traffic jams and delays commonly reported during morning and afternoon rush hours. This congestion not only causes frustration for commuters but also has significant economic implications, resulting in lost productivity, increased fuel consumption, and increased vehicle emissions. Moreover, the North-East Road has a high accident rate, with a significant number of crashes occurring each year. According to the South Australian Police, between 2015 and 2020, there were a total of 2,467 crashes reported on the North-East Road, resulting in 550 injuries and 7 fatalities (Crash statistics 2021).

To address these issues, the South Australian government has initiated several projects and measures to improve the traffic performance and safety of the North-East Road. In 2019, the government announced a $177 million upgrade project for the North-East Road, aimed at improving safety and reducing congestion (Gov of SA, 2019). The project includes the construction of new lanes, roundabouts, and intersections, as well as upgrades to existing infrastructure, such as traffic signals and pedestrian crossings. The project is expected to be completed by 2023 and is expected to reduce travel times and improve traffic flow on the North-East Road.

In addition to these infrastructure improvements, the government has also implemented several traffic management measures to alleviate congestion and improve safety on the North-East Road.

These measures include the installation of CCTV cameras, variable speed limits, and improved signage and road markings (Gov of SA, 2021).

Overall, the North-East Road remains a vital transport corridor for Adelaide, connecting the inner city with several northeastern suburbs and the Northern Expressway. The road'sr, the road's traffic performance and safety have been a significant concern for local authorities and residents, with congestion and accidents being major issues. With the government's ongoing upgrade and traffic management projects, it is hoped that the traffic performance and safety of the North-East Road will continue to improve.

1.1 Study Area Information

The North-East Road (Figure 1) is a major route for transportation between the CBD and Adelaide's north-eastern suburbs. According to the current situation, it is a very busy road. Approximately a thousand vehicles use this road daily, and it is creating traffic jams during both the morning and evening peak times. We are presently experiencing substantial delays throughout both the morning and evening peak hours.

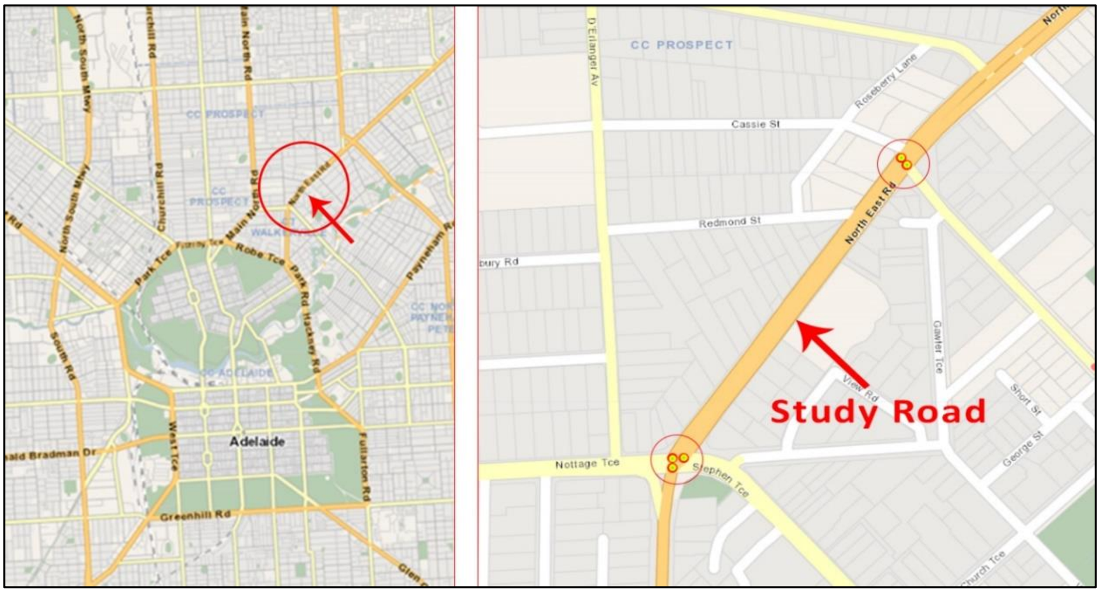


FIGURE 1 LOCATION OF STUDY AREA (NORTH-EAST ROAD)

According to the Government of South Australia Location SA Map Viewer 2019, 45300-45500 vehicles traffic volume is estimated per day. As per the Department of Infrastructure and Transport (DIT), in the last five years, there were 50 reported crashes at the Nottage Terrace and North-East Road Intersection. Of those crashes, one had a very serious injury, 11 minor injury crashes, and 38 property damage crashes (DIT 2022). Overall, North-East Road (Figure 1) was selected as a case study to analyze the performance of the road network during the incident on the North-East (arterial) Road and its impact on travelers, pedestrians, the economy, and the environment at the midblock as well as at the signalized intersections and pedestrian crossings. I will also analyze different locations of the incident, different times (AM or PM), duration of the incident, future years of operation, traffic diversion needed or not to operate, and how much traffic diversion is needed. Furthermore, analyze delays, travel time, emissions, and congestion during incidents using SIDRA and AIMSUN software. This analysis of the road network performance during the incident identifies the best possible solution, which will help to minimize the impact of the incidents, minimize travel time and emissions, as well as improve safety for travelers.

1.2. Structure of the Report

This research paper is organized into six chapters, each of which is subdivided into sections and subsections. Chapter 1 offers a general overview of the project, followed by Chapter 2, which provides a detailed review of relevant literature discussing the significance and importance of the research.

Chapter 3 then presents the adapted methodology and specifications used for modeling the Freeway using AIMSUN microsimulation software. This chapter includes information on data collection, modeling, calibration, and validation of the model, as well as justifications for using the AIMSUN microsimulation package along with the SIDRA Intersection software. Additionally, the limitations of the existing model are discussed.

Chapter 4 focuses on presenting the results generated from the AIMSUN model for several traffic incidents occurring at different locations, durations, and peak hours on the Darlington Freeway. The chapter includes an assessment of the freeway's performance using traffic performance indicators such as travel time, delay time, congestion, and emissions. Furthermore, the chapter discusses the results from using SIDRA Intersection to evaluate the effects of vehicle diversion from the freeway to arterial roads during incidents. Finally, the chapter presents suggestions for mitigating the consequences generated by sudden incidents on the freeway using Intelligent Transport Systems.

Chapter 5 provides a brief description of the generated results, as well as implications of integrating Intelligent Transport Systems into the Freeway section. This chapter describes how the introduction of ITS affects the movement of people and the use of the Freeway.

In conclusion, Chapter 6 offers a summary of the research findings, recommendations, and future research scope using Intelligent Transport Systems for evaluating incidents on the Freeway. Overall, this research paper offers a comprehensive analysis of the modeling and evaluation of the Darlington Freeway's performance during traffic incidents and provides useful insights for improving traffic management systems.

2. LITERATURE REVIEW

In this literature review will describe the importance of this thesis and justify it by providing vision of existing research about incident modelling in arterial road. The research to be undertaken in this article will be based on an evaluation of several of the methods that are available to measure the effects of accidents.

2.1 Impacts of Incidents on Arterial Roads

Day by day the number of vehicles on the road has gradually increased due to the need for personal mobility, which has led to an increase in traffic on the road and a corresponding decline in the capacity of the road. Due to the ever-growing global population, there is currently a serious problem with the overcrowding of motorways, which has negative effects on the environment, travel times, and expenditures (Ferrara et al. 2013). Also, due to increase in traffic volume, road death also increasing every year, which is showing in below figure. When the transportation system's capacity is temporarily and unexpectedly reduced because of incidents, traffic congestion is classified as either recurring or non-recurring. Recurring congestion happens when the transportation system's capacity is consistently insufficient to satisfy traffic demand (for example, Crashes, vehicle breakdowns during peak period of the day (Koorey, et al., 2015). Currently, the annual death rate per 100,000 population is 4.6, representing a 2.6% increase from the rate recorded for the 12-month period ending February 2022. About 50% of Australia's largest cities' traffic congestion is caused by road incidents (Taylor, 2008).

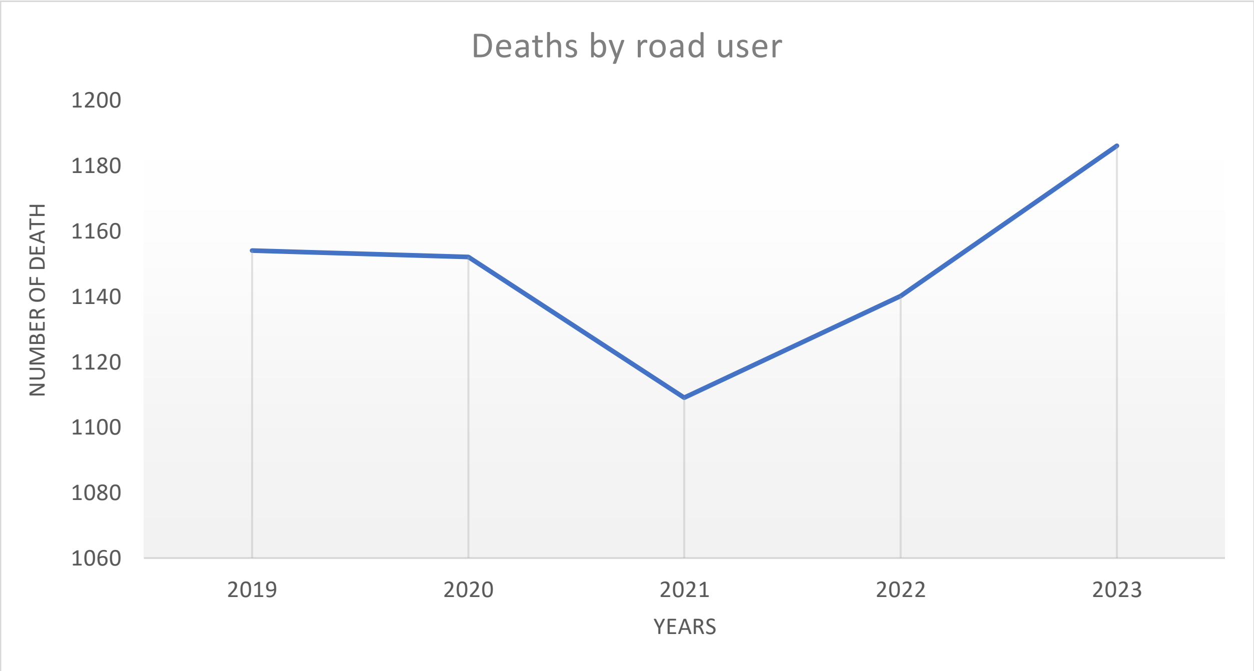


Figure 2 Deaths by road user between 2019 to 2023

2.1.1 Impacts of Incidents on Congestion and Delay

Within densely populated cities, traffic congestion can have serious negative economic, social, and environmental effects. One of the main causes of traffic congestion is traffic accidents. To indicate overall changes in congestion along all routes in a city, BITRE has estimated composite indices (BITRE, 2021). As per the graph below, congestion is growing every year as per the recent three years data. Sydney, Melbourne, Brisbane, and Perth, have significant change in congestion during COVID-19 period, but in Adelaide it's continuously growing up. Freeway congestion has a significant impact on transport conditions, including longer travel times, more consumption, and environmental effects. (Ferrara et al., 2013). Most major roads in Adelaide city are operating at/or above capacity during peak hours resulting in an increasing potential for traffic incidents and significant delay to the travelers (Mfinanga, 2013). There is a need to address the incident problem to avoid the resulting delays, which also may result in one or more of the following travel time, consumption, cost, and environmental impacts (David, et aL, 2013). Between 1980 and 1992, total vehicle miles travelled (VMT) grew by 78.5 percent, and between 1992 and 2004 by 23.3 percent (Wang, Y. and Cheevarunothai, P., 2008). In addition, a few lanes blocking incidents make it impossible to operate and control traffic (Sheu, 2013). In situations where there is an unexpected reduction in the capacity of the transportation system, traffic congestion can be categorized as either recurring or non-recurring. Recurring congestion occurs when the system's capacity is constantly inadequate to meet the demands of traffic, such as during peak periods of the day, due to incidents such as crashes or vehicle breakdowns (as per Koorey et al., 2015). In recent years, several control strategies, including ramp metering, variable speed restrictions, route diversion, and vehicle infrastructure integrated systems, have been suggested and applied for traffic management to lessen congestion in highway networks (Ferrara, et al., 2013).

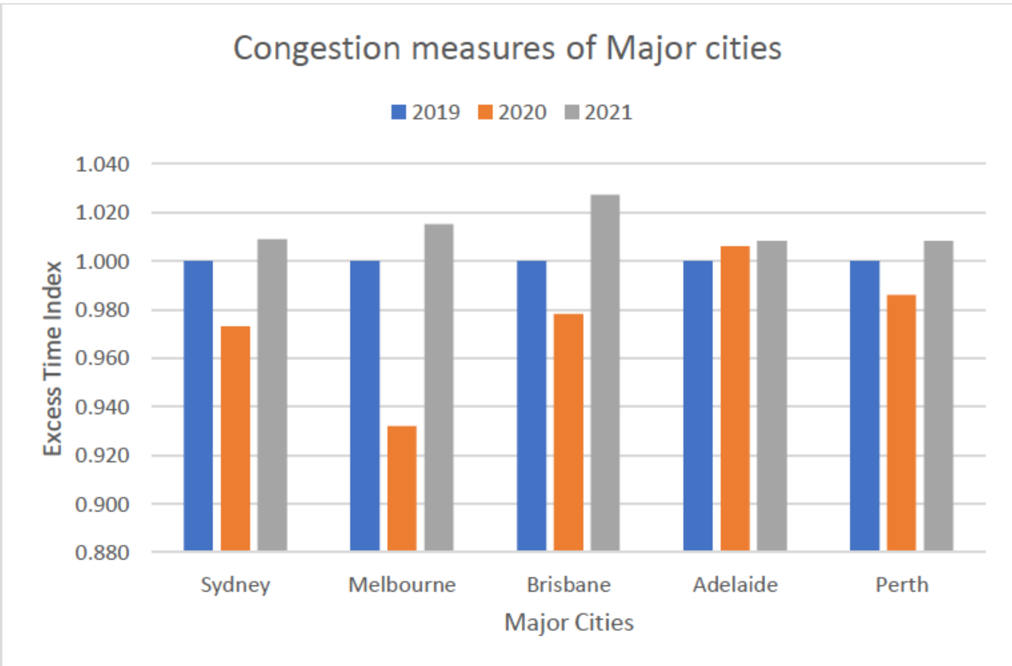


Figure 3 CONGESTION MEASURES OF MAJOR CITIES

2.1.2 Impacts of Incidents on Travel time

Several studies have attempted to estimate and forecast travel times by incorporating reliability measures to evaluate and compare Travel Time Reliability (TTR) measures (Emam and Al-Deek 2006: and Taylor 2013). However, only a few studies have concentrated on modelling TTR. Elefteriadou and Cui (2007) developed linear regression models for travel time estimation using traffic data from a 15 km freeway in Philadelphia. The models were based on four primary factors, which were congestion, weather, work zones, and incidents, and were implemented in 24 different scenarios. Expected travel times were calculated for each scenario, and the travel time distribution was established by evaluating the frequency of each scenario. The buffer time index was applied as a reliability measure to determine the percentage of reliable trips based on various on-time performance approaches. The models utilized dummy variables for weather, work zones, and incidents. However, the primary drawback of the models is that they did not account for all the unexpected events' effects, particularly incidents. Travelers spend 47 extra hours per year on travel compared to 40 hours in 1993. The proportion of freeway mileage experiencing congestion has increased from 51% to 60%.

2.1.3 Impacts of Incidents on Economy

Li et al. (2006) describes several ways to measure traffic performance, including road delays. This delay measurement can then be used to calculate the economic impact of incidents and emissions. Kabit et al. (2014) provide a definition of delay cost that considers the time spent by passengers, vehicle operating expenses, and external costs such as air pollution. According to Dia (2011), incidents like vehicle breakdowns, queues, and environmental emissions have a significant impact on society. Kim (2019) reports that the estimated annual cost of congestion due to queuing time for all US commuters is $29 billion, which is supported by BTRE's (2020) estimation that the social cost of congestion in Australia's major metropolitan areas was $20.36 billion in 2020, a 20% increase from 2015. The social cost of road crashes in 2006 was $17.85 billion, which was 1.7% of the GDP. This represents a 7.5% decrease from the 1996 estimates, as reported by the Bureau of Transport Economics (BTRE 2009). The cost of a fatality refers to the economic value of a human life lost because of an accident or other catastrophic event. As per below pie graph, highest cost of fatality is about $6.19 million in Australia.

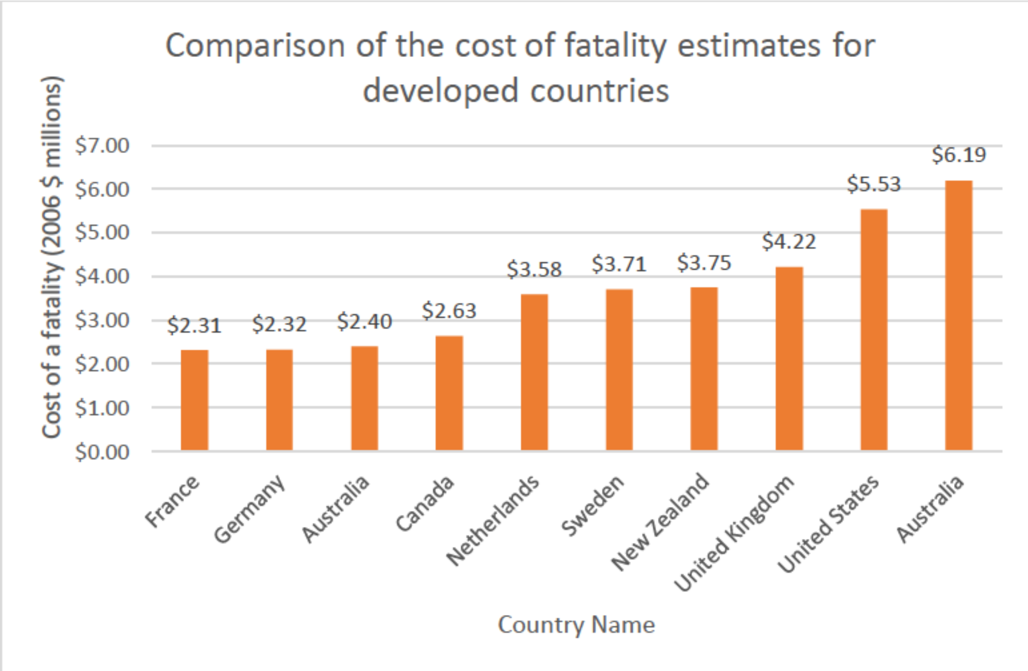


Figure 4 Comparison of the cost of fatality estimates for developed countries.

2.1.4 Impacts of Incidents on Environment

The Bureau of Infrastructure Transport and Regional Economics (2009) states that when there is heavy traffic, vehicle engines operate less efficiently, leading to an increase in the emission of air pollutants. In Australia, the transport sector is responsible for 14% of the nation's gross emissions, with road transport contributing about 90% of it. A case study conducted on vehicles traveling on the Monash Freeway in Melbourne revealed that 95% of these emissions were carbon dioxide (CO_2) (Luk, Kazantzidis & Han, 2009). In 2012, the transport sector in Australia released 91Mt of CO_2 equivalents (CO_2e), with 84% of it coming from road transport (Commonwealth of Australia, 2013). CO_2e is a unit of measurement that expresses the impact of different greenhouse gases on climate change as the equivalent amount of carbon dioxide. According to the National Greenhouse Gas Inventory, emissions in the year leading up to September 2022 were significantly lower compared to the year leading up to June 2005, specifically 21.0% lower. However, on a quarterly basis, emissions for the September quarter of 2022 increased slightly by 0.3% or 0.3 Mt CO_2-e compared to the previous quarter. The increase in emissions was observed in various sectors, including transport, fugitive emissions, agriculture, and stationary energy (excluding electricity). In contrast, there were decreases in emissions from electricity, industrial processes, and Land Use, Land Use Change, and Forestry (LULUCF) sectors. Australia's 2030 target under the Paris Agreement is based on the emissions from the year 2005. Preliminary estimates show that national emissions for the year leading up to December 2022 are 490 Mt CO_2-e, a decrease of 0.3% from the previous year. On a quarterly basis, national emissions for the same period are preliminarily estimated to be 123 Mt CO_2-e, a decrease of 0.1% compared to the previous quarter.

Quarterly Emissions

Figure removed due to copyright restriction.

Figure 5 Transport Emissions, actual and trend, 2005 – 2022

2.2 Simulation modeling of Incident based on computer software.

Road incidents can have profound consequences, including property damage, personal injury, and loss of life. To mitigate the risks associated with road incidents, researchers and practitioners have developed various simulation techniques to understand the underlying causes and explore potential solutions. This literature review provides an overview of four simulation techniques used in road incident analysis: microscopic, mesoscopic, macroscopic, and nanoscopic simulation. Simulation techniques have been used to predict and analyze traffic behavior and road incidents under different conditions. Microscopic simulation models individual vehicles' movements and their interactions with the road environment (Gomes et al., 2019). Mesoscopic simulation, on the other hand, models traffic flow between road network cells (Liao et al., 2021). Meanwhile, macroscopic simulation considers aggregate traffic flow parameters such as density, speed, and flow rate (Liao et al., 2021). Nanoscopic simulation models pedestrian and bicycle behavior in the presence of surrounding infrastructure (Jin & Chen, 2020; Knoop et al., 2019). Each simulation technique offers a different level of detail and abstraction, depending on the research question, and can provide insights for road incident analysis and traffic management. Numerous studies have utilized computer-based traffic simulation methods to estimate the impacts of incidents on transportation networks (As per Holyoak & Stazic, 2009; and many other). These simulations provide many advantages by allowing incidents to be replicated during peak and non-peak hours and evaluating their effects on network performance in a cost-effective and safe manner, eliminating the need for on-site or laboratory-based evaluations. Traffic analysis using computer models can be performed at various levels of detail, including microscopic, mesoscopic, macroscopic, and nanoscopic, each offering increasingly more intricate outputs. Computer simulation is also valuable for testing policy strategies, operational performance, and network changes for all modes of transportation. Public and private entities use this application of computer simulation to justify or identify necessary changes within a particular road network.

2.2 1 Microscopic simulation of Incidents

Microscopic simulation is a simulation technique that models individual vehicles and their behavior in detail. The technique considers the characteristics of each vehicle, such as its size, weight, and acceleration, as well as driver behavior, such as speed, lane changing, and turning. Microscopic simulation is often used to model complex road networks, including intersections and roundabouts, and can be used to evaluate the impact of changes to the road network or traffic flow, congestion, and safety issues.

Microscopic simulation has been widely used to model and analyze various types of road incidents. Holyoak and Stazic (2009) suggested that linking macro-demand forecasting models with microscopic simulation models could provide significant benefits in incident analysis. The authors emphasized the importance of integrating both the demand and supply aspects of transportation systems to develop an accurate and comprehensive simulation model. They demonstrated the usefulness of their proposed approach in predicting the impacts of incidents on traffic flow and travel time. Similarly, Lu et al. (2018) used microscopic simulation to investigate the impacts of different incident scenarios on traffic flow and safety. The authors simulated three types of incidents, including a rear-end collision, a lane change accident, and a vehicle breakdown, using VISSIM software. They found that incidents could significantly reduce traffic speed and increase the probability of secondary accidents and suggested that appropriate incident management strategies could mitigate the impacts. One more study by Punzo et al. (2019) used microscopic simulation to investigate the impacts of speed limit reductions on traffic flow and safety. The study found that speed limit reductions can improve traffic flow and reduce the risk of accidents, particularly in areas with high pedestrian activity. Another study by Mohammadian et al. (2018) used microscopic simulation to investigate the impacts of different traffic control strategies on traffic flow and congestion. The study found that intelligent traffic control systems can significantly improve traffic flow and reduce congestion, particularly during peak hours. Microscopic simulation has also been used to investigate the impacts of road design on traffic flow and safety. A study by Li et al. (2019) used microscopic simulation to investigate the impacts of roundabout design on traffic flow and safety. The study found that roundabouts can improve traffic flow and reduce the risk of accidents, particularly in areas with high traffic volumes. Another study by Anderson et al. (2017) used microscopic simulation to investigate the impacts of different road designs on traffic flow and safety. The study found that road designs that prioritize pedestrian and cyclist safety can significantly improve traffic flow and reduce the risk of accidents. Numerous studies conducted by

Barceló et al. (2005), Dia (2011), Holyoak and Stazic (2009), Archer (2000), Hadi et al. (2007), and Helbing et al. (2002) illustrate the importance of using micro-simulation techniques in traffic incident modeling on freeways. Micro-simulation modeling requires a greater amount of empirical data, including relevant driver and vehicular characteristics and behavior, compared to macro-simulation modeling. Dia (2011) emphasizes that microscopic traffic simulation is a cost-effective approach for incident modeling, which can be used in both peak and non-peak conditions. Unlike macro-simulation modeling, micro-simulation models consider vehicle acceleration and deceleration rates, leading to improved vehicle emissions calculations (Holyoak & Stazic, 2009). Additionally, micro-simulation models are suitable for evaluating intelligent transportation systems (ITS) due to their detailed modeling of vehicle and driver behavior, as noted by Burghout et al. (2005) and Holyoak and Stazic (2009). These models can incorporate driver interaction attributes, such as vehicle awareness and network familiarity, into the evaluation of ITS technologies.

Overall, microscopic simulation is a powerful tool for road traffic studies in Australia. This simulation method allows researchers to investigate the impacts of different traffic control strategies, road designs, and speed limit reductions on traffic flow, congestion, and safety issues. These findings have important implications for policymakers who are considering different strategies for improving road safety and reducing congestion on Australian roads. By modeling individual vehicle movements and interactions, microscopic simulation provides a detailed understanding of the impacts of incidents on traffic flow and safety. Moreover, the ability to evaluate different incident management strategies and their effectiveness is significant in mitigating the impacts of incidents and improving traffic flow and safety.

2.2.2 Nanoscopic simulation of Incidents

Nanoscale simulation is a simulation technique that models the behavior of individual atoms and molecules in materials. This technique can be used to model the properties of materials used in road construction, such as asphalt and concrete, and to understand the fundamental mechanisms that control their behavior. Nanoscale simulation can also be used to investigate the properties of materials used in vehicle manufacturing, such as tires and brake pads. Nanoscopic simulation stands out as a highly sophisticated traffic simulation model that accounts for individual parameters of each vehicle, including perception, cognition, errors, and decision-making (Ni, 2003; Ratrout & Rahman, 2009). Ni (2006) notes that this simulation model focuses on replicating individual behavior, including waiting times and interactions. While nanoscopic simulation and micro-simulation share network descriptions, the former considers person-based travel, while the latter focuses on vehicle-based travel. The NSW Government (2013) reports that due to the similarities between these two modeling approaches, various microsimulation software, such as AIMSUN, now employ nanoscopic agent-based simulation in their models.

Overall, nanoscale simulations are a promising technique for studying road traffic in Australia. This method allows researchers to investigate the physical and chemical processes that govern the behavior of road surfaces and vehicles, providing insights into the factors that impact vehicle safety, efficiency, and air pollution. These findings have important implications for policymakers who are considering strategies for improving road safety and reducing air pollution on Australian roads. However, it should be noted that nanoscale simulations are still a relatively new and developing field, and further research is needed to fully understand their potential applications in road traffic studies.

2.2.3 Mesoscopic simulation of Incidents

Mesoscopic simulation is a simulation technique that models' groups of vehicles, rather than individual vehicles. This technique is less detailed than microscopic simulation but can still capture important features of traffic flow, such as the formation of queues and the propagation of shocks through the traffic stream. Mesoscopic simulation is often used to model larger road networks, such as urban or highway networks, and can be used to evaluate the impact of changes to traffic management strategies. One study by Rakha et al. (2019) used mesoscopic simulation to investigate the impacts of autonomous vehicles on traffic flow and safety. The study found that autonomous vehicles can significantly improve traffic flow and reduce the risk of accidents, particularly in areas with high traffic volumes. Another study by Chen et al. (2018) used mesoscopic simulation to investigate the impacts of different lane configurations on traffic flow and safety. The study found that lane configurations that prioritize safety and efficient traffic flow can significantly improve traffic flow and reduce the risk of accidents. According to a study by Burghout (2005), mesoscopic models are well-suited for predictive applications, where they simulate route choices with limited detail of driver behavior. Mesoscopic simulation has also been used to investigate the impacts of different traffic management strategies on traffic flow and congestion.

Overall, mesoscopic simulation is a valuable technique for road traffic studies in Australia. This simulation method allows researchers to investigate the impacts of different traffic management strategies, lane configurations, and autonomous vehicle deployment on traffic flow, congestion, and safety issues. These findings have important implications for policymakers who are considering different strategies for improving road safety and reducing congestion on Australian roads.

2.2.4 Macroscopic simulation of Incidents

Macroscopic simulation is a simulation technique that models traffic flow at a high level, without modeling individual vehicles or their behavior. This technique is based on aggregate variables, such as traffic density and flow rate, and can be used to model large-scale traffic patterns over time. Macroscopic simulation is often used to evaluate the impact of changes to transportation infrastructure, such as the addition of new roads or the implementation of new transportation policies. Macroscopic simulation has been extensively used in Australian research is in transportation modeling. According to Holyoak and Stazic (2009), macroscopic simulation models are used to estimate travel patterns for an entire region with many road networks. These models are commonly utilized for wide-scale strategic policy testing in travel demand, considering factors such as land-use strategies, socio-demographic influences, mode, route, and destination choices. However, these models do not account for traveler interactions and often produce simpler travel pattern outputs, compromising driver attribute details. Additionally, vehicle emission estimates from macroscopic models are limited as the models only apply constant speed to the entire road. To improve accuracy, researchers have proposed linking macro-simulation and micro-simulation models, as seen in the study by Helbing et al. (2002), to achieve simultaneous modeling parameters. A study conducted by Wong et al. (2018) used macroscopic simulation to model the impacts of connected and automated vehicles (CAVs) on traffic flow. The study found that CAVs can improve traffic flow and reduce congestion, leading to a more efficient and sustainable transportation system. Study by Piterou and Pagonis (2019) used macroscopic simulation to model the impacts of road pricing schemes on traffic flow in Sydney. The study found that road pricing schemes can reduce congestion and improve air quality, leading to a more sustainable transportation system. These findings have important implications for policymakers who are considering the implementation of road pricing schemes as a means of reducing congestion and improving environmental outcomes.

In summary, macroscopic simulation is a powerful tool that has been extensively used in Australian research to model complex systems and predict their behavior under different conditions. This technique has numerous applications in fields such as transportation, population dynamics, and economics, and is likely to become even more important as the world becomes increasingly complex and interconnected.

2.3 Traffic management during Incident

Traffic management during incidents is a critical issue in modern transportation systems. To ensure the safety of commuters and to minimize the impact of incidents on traffic flow, Intelligent Transportation System (ITS) technologies have been widely adopted in many countries, including Australia. One of the most used ITS technologies in Australia for incident management is ramp metering. This literature review aims to examine the current state of research on the use of ITS technology and ramp metering in traffic management during incidents in Australia. …

2.3.1 Traffic management during Incident using ITS Technology

ITS technologies are used in traffic management to improve safety, reduce congestion, and enhance the efficiency of the transportation system. The use of ITS technologies in Australia for traffic management during incidents has been studied extensively. Rijavec et al. (2018) investigated the effectiveness of ITS technologies such as traffic cameras and variable message signs in reducing traffic congestion during incidents. They found that these technologies can significantly reduce traffic congestion and improve traffic flow during incidents. In another study, Sarvi et al. (2019) examined the use of ITS technologies for traffic management during major incidents such as earthquakes, terrorist attacks, and pandemics. They concluded that ITS technologies, such as traffic control centers and intelligent traffic systems, can effectively manage traffic during major incidents and help to minimize their impact on traffic flow.

Variable message signs (VMS) and variable speed limits (VSL) offer multiple benefits for improving road efficiency and reducing the impact of incidents. When incidents occur, VMS can divert traffic and clear lanes, resulting in reduced incident duration and improved travel times. Dia (2011) conducted a study that demonstrated the effectiveness of VMS in minimizing delays and travel times during incidents on the freeway. Additionally, the study evaluated the viability of VSL for reducing delay and travel times during incidents. Below Table summarizes the benefits of introducing VMS during incidents in a freeway section. Case 2 represents the incident occurrence with no response, while case 4 shows the introduction of VMS as a response to traffic incident management.

In-depth research by Kabit et al. (2014) and Hojati et al. (2011) shows that analyzing the impact of incidents and estimating costs provides reliable data for evaluating traffic incident management programs. Kabit et al. (2014) specifically examined the use of VMS for route diversion and associated cost estimation in terms of incident-induced delay, fuel consumption, and CO2 emissions. A below table presents a summary of the incident's impact reduction in financial savings. Research indicates that assigning a VMS to reduce a two-hour incident to a 90-minute incident clearance duration saves 23% of the financial cost during one lane clearance and 37% of the cost savings when all lanes are cleared in the same duration.

Table 1 Comparison with and without VMS route Diversion on Delay, speed, and Travel time

Scenario	Route	Delay (Sec)	Speed (kph)	No. of stops (Per Veh)	Travel time (Sec per Veh)
Case 2: Incident occurs on normal route, but no response is initiated (no diversions or dynamic signal plans)	Exit 66	159	44	9	451
Case 4: Incident occurs in a normal route, 30% traffic is diverted to alternating routes, where traffic signal timing is increased to 160s cycle	Exit 67	145	46	7	436
Benefits(%) (Case 4 over case 2)		8.8%	4.5%	22.2%	3.3%

Table 2 Incident impact reduction in terms of financial savings using ITS

Parameters	Clear one lane after 90 minutes	Percentage savings (%)	Clear all lanes after 30 minutes	Percentage savings (%)
Average travel time (sec)	10626	6	10351	9
Total delay (hr.)	3518.8	21	3063.4	31
Avg. speed (kph)	47.6	-10	50.1	-16
Delay cost (AU$)	109885	21	95667	31
Fuel cost (AU$)	59490	27	43984	46
CO2 cost (AU$)	60870	27	4515	46
Total cost (AU$)	175463		144167	
Saving (AU$)	52150	23	83446	37

2.3.2 Traffic management during Incident using Ramp metering.

Ramp metering is an ITS technology that involves the use of traffic signals on entrance ramps to regulate the flow of traffic onto highways. Ramp metering has been widely adopted in Australia and has been found to be effective in reducing congestion during peak traffic hours. In the context of traffic management during incidents, ramp metering has also been studied extensively.

For example, Khattak et al. (2014) investigated the impact of ramp metering on traffic flow during incidents in Melbourne, Australia. They found that ramp metering can significantly reduce congestion and improve traffic flow during incidents. Similarly, Wang et al. (2017) studied the impact of ramp metering on incident management on a major freeway in Sydney, Australia. They found that ramp metering can help to reduce the impact of incidents on traffic flow and improve the overall efficiency of incident management.

Moreover, ramp metering can also be combined with other ITS technologies to further improve incident management. For example, a study conducted by Ma et al. (2020) proposed a ramp metering strategy that uses a predictive model to anticipate traffic demand during incidents and adjust ramp metering rates accordingly. The study found that this strategy can improve traffic flow and reduce delays during incidents. Ramp metering is an Incident Management Technique (TIM) used less frequently on freeways, and the literature assessing its capabilities is limited (Dia 2011; Dia, Gondwe & Panwei 2006; Ozbay & Bartin 2004). It is a type of traffic control that regulates the number of vehicles allowed to enter the freeway at each time based on current traffic conditions (Dia 2011). Ozbay and Bartin (2004) demonstrate the benefits of implementing coordinated arterial signals with ramp metering, which can be effective. However, this same literature suggests that local roads may experience unexpected congestion due to traffic spill-over from the freeway access ramp. Nevertheless, a study conducted by Dia (2011) suggests that ramp metering can be beneficial during incident conditions when traffic demand increases. Results from this study reveal that travel times were reduced by 2.8%, the number of stops by 23%, and the average delay by 10.5% because of implementing ramp metering during congested periods, as summarized in below table.

2.4 Optimal Traffic Analysis Software

Microscopic traffic simulators are widely recognized as powerful and versatile traffic analysis tools that can provide accurate results for complex traffic engineering phenomena (Barceló, et al., 2005). Based on a literature review comparing various modelling approaches, microsimulation has been identified as the most efficient approach for incident modelling and evaluating the impacts of incidents on traffic flow in terms of travel times, delay, speed, emissions, and the use of Intelligent Transportation Systems (ITS) for warning drivers and traffic diversion.

AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) is a leading and versatile microsimulation software that generates vehicle movement data and driver data for traffic modelling (AIMSUN, 2021). This software was used to develop a detailed model for simulating traffic incidents on a freeway during morning peak hour traffic flow in our research, using MASTEM (Metropolitan Adelaide Strategic Transport Evaluation Model).

Moreover, SIDRA Intersection is a powerful software tool for analyzing intersections in terms of intersection delay, queue length, and level of service (SIDRA SOLUTIONS, 2021). In this research, we compared the performance of intersections before and after traffic incidents to assess the impact of vehicle diversion from the arterial road to sub-arterial roads during incidents.

AIMSUN microsimulation software was chosen for the detailed modelling and simulation of traffic incidents due to its widespread acceptance for strategic transport modelling by the Department of Infrastructure and Transport (DIT). It can quantify the impact of incidents in terms of travel times, emissions, delay times, and congestion. Additionally, AIMSUN can incorporate Variable Message Signs as traffic demand and incident management strategies.

While AIMSUN can simulate an entire traffic network at a detailed level of individual vehicles, SIDRA is limited to the analysis of intersections and roundabouts. However, SIDRA can optimize intersection signal timing for future models, a limitation of AIMSUN. Hence, each software was used together in this research to address each research objective.

2.4.1 SIDRA INTERSECTION

SIDRA INTERSECTION is a widely used software tool for analyzing the performance of signalized intersections and roundabouts. It provides a comprehensive set of features and capabilities for analyzing different types of intersections, including signalized, unsignalized, and roundabouts. The software is developed by Akcelik & Associates Pty Ltd and is used by transportation engineers, planners, and researchers around the world.

SIDRA is designed to help transportation professionals evaluate the performance of intersections and roundabouts in terms of several performance measures, such as delay, queue length, level of service, and safety. The software provides a range of analysis tools that allow users to test different scenarios and evaluate the impacts of various traffic control strategies on intersection performance. For example, SIDRA can be used to evaluate the impacts of traffic signal phasing and timing, lane configuration, and geometric design features on intersection performance.

Key Advantages of SIDRA INTERSECTION software.

1. SIDRA software can analyze the performance of signalized and unsignalized intersections, as well as roundabouts.
2. It provides accurate and reliable estimation of intersection delays, level of service, and queue length.
3. SIDRA can be used to evaluate the impact of various design options on intersection performance and safety.
4. The software can also be used for optimization of signal timings and geometric design.
5. SIDRA is widely accepted and used in the transportation engineering field.

Despite its strengths, SIDRA does have limitations. Some of the main limitations of SIDRA include:

1. Limited scope: SIDRA is mainly designed for intersection analysis and optimization and is not suitable for modeling larger networks or simulating traffic flow in real-time.
2. Data requirements: The accuracy and usefulness of SIDRA results depend on the availability and quality of input data, including traffic volumes, vehicle types, and signal timings.
3. Lack of dynamic traffic modeling: SIDRA does not include dynamic traffic modeling, meaning it cannot capture the impact of real-time traffic conditions, incidents, or unexpected events.
4. Complexity: The software can be complex and difficult to use, requiring significant training and experience to produce accurate results.
5. Expensive: The cost of purchasing and maintaining the software can be high, making it less accessible to smaller transportation agencies or consulting firms.

2.4.2 AIMSUN

AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) is a traffic microsimulation software that is widely used for transportation planning and traffic engineering purposes. It is a powerful tool that allows users to model and analyze complex traffic systems, including highways, arterials, roundabouts, and intersections. The software is developed and marketed by the Barcelona-based company, Transport Simulation Systems (TSS).

AIMSUN uses microscopic modeling, which simulates individual vehicles, drivers, and their interactions with the road network. This approach provides a detailed and realistic representation of traffic dynamics, making it ideal for analyzing complex scenarios such as incident management, signal timing optimization, and intelligent transportation systems (ITS) implementation.

The software's user-friendly interface allows users to model and analyze a variety of transportation scenarios, including vehicular and non-motorized traffic, public transportation, and pedestrians. AIMSUN can be used for both short-term and long-term planning, as well as for evaluating the impact of new infrastructure projects on traffic flow.

The AIMSUN microsimulation software is widely recognized and utilized in the field of traffic analysis globally, and it is also widely accepted by the Department of Infrastructure and Transport in South Australia. The AIMSUN user's guide (2021) identifies several capabilities of the software that are relevant to the scope of this research mentioned below.

- Ability of incident impact analysis of highway infrastructure (Arterial Road)
- Ability of environmental impact analysis in terms of fuel consumptions and emissions
- Ability to evaluate the travel demand management strategies.
- Ability to integrate Intelligent Transport Systems (ITS)
- Ability of freeway capacity analysis and safety analysis
- Microscopic traffic flow modeling and simulation
- Dynamic route assignment and traffic assignment modeling
- Capability to model complex traffic management scenarios and strategies.
- Optimization of signal timings for isolated and coordinated signalized intersections.
- Advanced data analysis and visualization capabilities
- Compatibility with various types of data inputs, including real-time data.

Despite its many strengths, AIMSUN has some limitations that should be taken into consideration when using the software.

1. The accuracy of the simulation depends on the quality and quantity of the input data. Therefore, it is important to ensure that the data used for modeling is accurate and up to date.

2. AIMSUN is computationally intensive software that requires high-end hardware to run efficiently. Large-scale simulations can be time-consuming, and users may need to invest in powerful computing equipment to obtain reliable results.
3. AIMSUN's microsimulation approach makes it challenging to simulate large-scale networks, particularly in urban areas with dense traffic flow. This limitation can be mitigated by using network aggregation techniques or by dividing the network into smaller sub-areas.
4. AIMSUN's ability to optimize signal timings is limited to the current period, and it does not consider future scenarios or changes in traffic demand. To address this limitation, some researchers have proposed the use of hybrid models that combine AIMSUN with other software tools, such as TRANSYT-7F or PARAMICS, to improve signal timing optimization for future scenarios (Ma and Li, 2016).
5. The accuracy of AIMSUN's simulation results may be affected by the modeler's assumptions and calibration procedures. It is important to carefully calibrate the model based on real-world data and to validate the simulation results using field data or other independent sources (Wang et al., 2018).

In conclusion, AIMSUN is a powerful and versatile traffic simulation software that can be used for a wide range of transportation planning and traffic engineering applications. Its strengths include its realistic microscopic modeling approach, real-time traffic simulation capabilities, and user-friendly interface. However, it is important to consider its limitations, such as its computational requirements and limitations on signal timing optimization.

Table 3 Benefits of implementing ramp metering during incident conditions (Dia 2011)

Performance Measures	Route	Without ramp metering	With ramp metering	% Difference
Speed (kmph)	On ramp	57.6	52	-9.7
	Mainline	83.2	83.8	0.6
Number of stops	On ramp	0.0	0.2	200
	Mainline	1.4	1.1	-23
Travel time (seconds/vehicle)	On ramp	36.3	40.6	11.8
	Mainline	192.1	186.8	-2.8
Delay (seconds/vehicle)	On ramp	2.7	7.1	156.5
	Mainline	50.5	45.2	-10.5

In conclusion, the use of ITS technologies and ramp metering in traffic management during incidents has been extensively studied in Australia. The research has shown that these technologies can significantly reduce traffic congestion, improve traffic flow, and minimize the impact of incidents on traffic. As such, they are crucial for the effective management of incidents and the efficient operation of transportation systems. Further research can focus on the optimization of ITS technologies and ramp metering to enhance their effectiveness in traffic management during incidents.

2.5 Aims and Objectives:

This study examines the effects of various incident characteristics, such as different locations, durations, and time of day (AM or PM peak), on the performance of the North-East Road Section. The study analyzes key parameters including delay, congestion, vehicular travel time, and emissions, utilizing analytical and simulation methods such as AIMSUN and SIDRA software. Recommendations are provided to mitigate the impact of incidents, reduce traffic congestion, and enhance safety. Through extensive research and literature review, a research gap has been identified, highlighting the need for further investigation. As a result, specific objectives have been formulated to achieve more robust research outcomes.

AIMs:

1. To analyze the impact of incidents on road network performance with and without incidents and compare it by creating various scenarios of incidents using SIDRA and AIMSUN.
2. To identify the factors that contribute to the delay in traffic flow during incidents.
3. To evaluate the effectiveness of the existing incident management strategies in reducing traffic delays and congestion during incidents.
4. To propose new incident management strategies based on the findings of the study.

Objectives:

1. To collect traffic data and incident data from various sources for analysis.
2. To develop a methodology for analyzing the impact of incidents on road network performance.
3. To identify the factors that contribute to delays in traffic flow during incidents using statistical and data mining techniques.
4. To evaluate the effectiveness of existing incident management strategies by comparing their outcomes with the analyzed data.
5. To propose new incident management strategies based on the analysis of the data and best practices from other regions.
6. To validate the proposed strategies using simulation models and compare their performance with existing strategies.
7. To provide recommendations for implementing the proposed incident management strategies to relevant stakeholders such as transportation agencies, emergency services, and the public.

3. METHODOLOGY

The methodology for this research involved a detailed process of incident modeling using two different software applications, AIMSUN and SIDRA. The selection of these software applications was based on their capabilities and strengths in handling various aspects of traffic management strategies. AIMSUN was chosen for its ability to simulate and model complex traffic networks, including the implementation of traffic management strategies such as vehicle diversion. On the other hand, SIDRA INTERSECTION was selected for its specialized focus on traffic signal analysis and intersection design.

The process of incident modeling involved several steps, beginning with the validation of the base model. Once this was complete, the AIMSUN model was calibrated and validated using a range of metrics, including queue lengths, and travel times. This process ensured that the model accurately reflected the real-world traffic conditions and could be used as a reliable basis for incident modeling.

In the incident modeling process, various traffic management strategies were analyzed and modeled using AIMSUN. This included vehicle diversion, which involved rerouting traffic away from the incident site to minimize congestion and delays. The modeling process for vehicle diversion involved careful consideration of various factors, including the location of the incident, the capacity of the surrounding road network, and the expected traffic volume.

Inputs for the SIDRA INTERSECTION software was also carefully selected and analyzed as part of the methodology. This involved detailed consideration of various factors, such as traffic volumes, signal timings, and the geometric layout of the intersection. By incorporating these inputs into the SIDRA model, the impact of the incident on intersection performance could be accurately analyzed and evaluated.

Flow Chart of the Report:

Overall, the methodology for this research involved a detailed and comprehensive approach to incident modeling, incorporating the strengths of two different software applications to provide a thorough analysis of traffic management strategies and their impact on intersection performance.

3.1 Data Collection

In the master thesis work, data collection was performed from two primary sources, namely the Department of Infrastructure and Transport (DIT) and the Sydney Coordinated Adaptive Traffic System (SCATS). The data collection process involved obtaining several types of data, including intersection drawings, manual turning counts from DIT, and SCATS counts for one week (7 March 2022 – 13 March 2022).

Intersection drawings were obtained from the DIT to provide information about the geometry and layout of the intersection. These drawings helped to ensure the accuracy of the simulation model developed using the SIDRA software. Manual turning counts were conducted by DIT at the intersection, and the data was collected manually by observing the turning movements of vehicles at the intersection over a specified period. This data provided information about the volume of traffic at the intersection, which was later used to calibrate the simulation model.

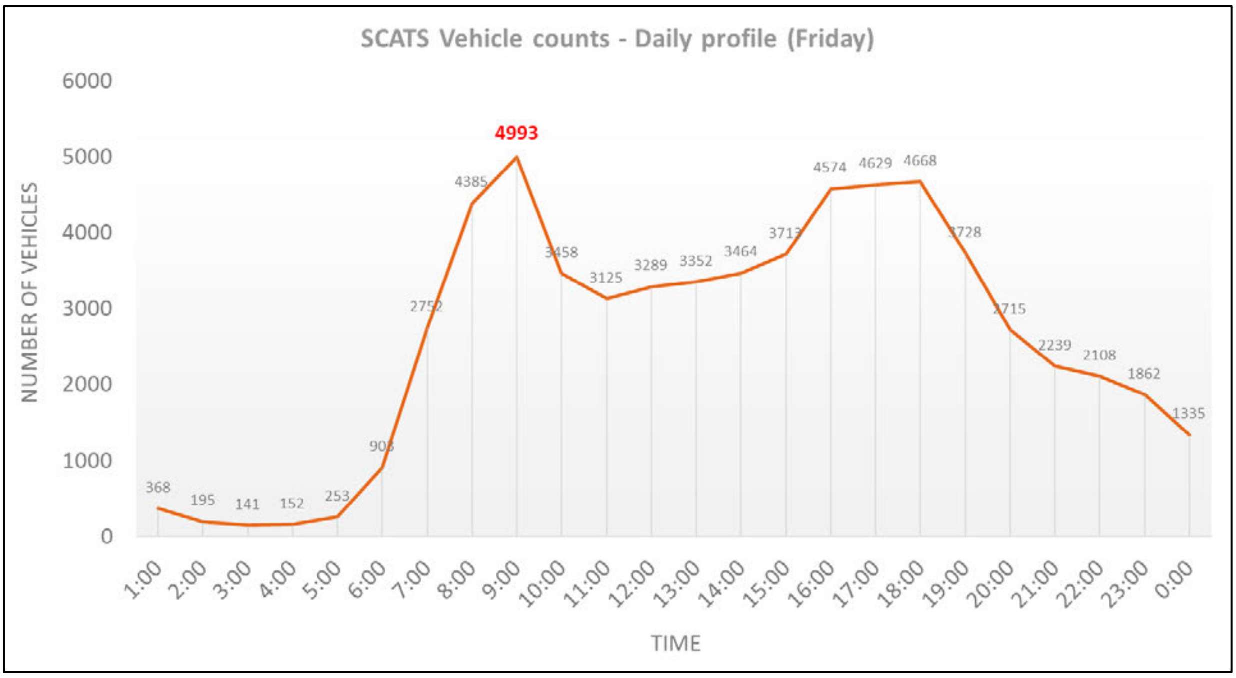


FIGURE 6 SCATS VEHICLES COUNT - DAILY PROFILE

SCATS counts were collected over one week (7 March 2022 – 13 March 2022) using the Sydney Coordinated Adaptive Traffic System as shown in figure 6. This data provided detailed information about traffic volume, speed, and other relevant parameters for each lane at the intersection. As show in figure 6, SCATS data was used to plan site visit (11 November, 8:00-9:00 AM) with Akshay Ahlawat and collect latest data, and that used to validate the simulation model's performance by comparing the model's output to the observed traffic data from site visit.

Prior to conducting a site visit, two locations were chosen for the mobile camera recording of traffic flow, as indicated in figure 8. The team arrived on-site at 7:30 AM to conduct a review of the intersection and to position themselves for recording, which was completed by 7:50 AM. The first camera, C1, was positioned on a street between two roads, providing a wide-angle view of incoming and outgoing vehicles from TS168 to TS029 on the North-East Road section. The second camera, C2, was positioned to cover a long view of the back of the queue on the North-East Road.

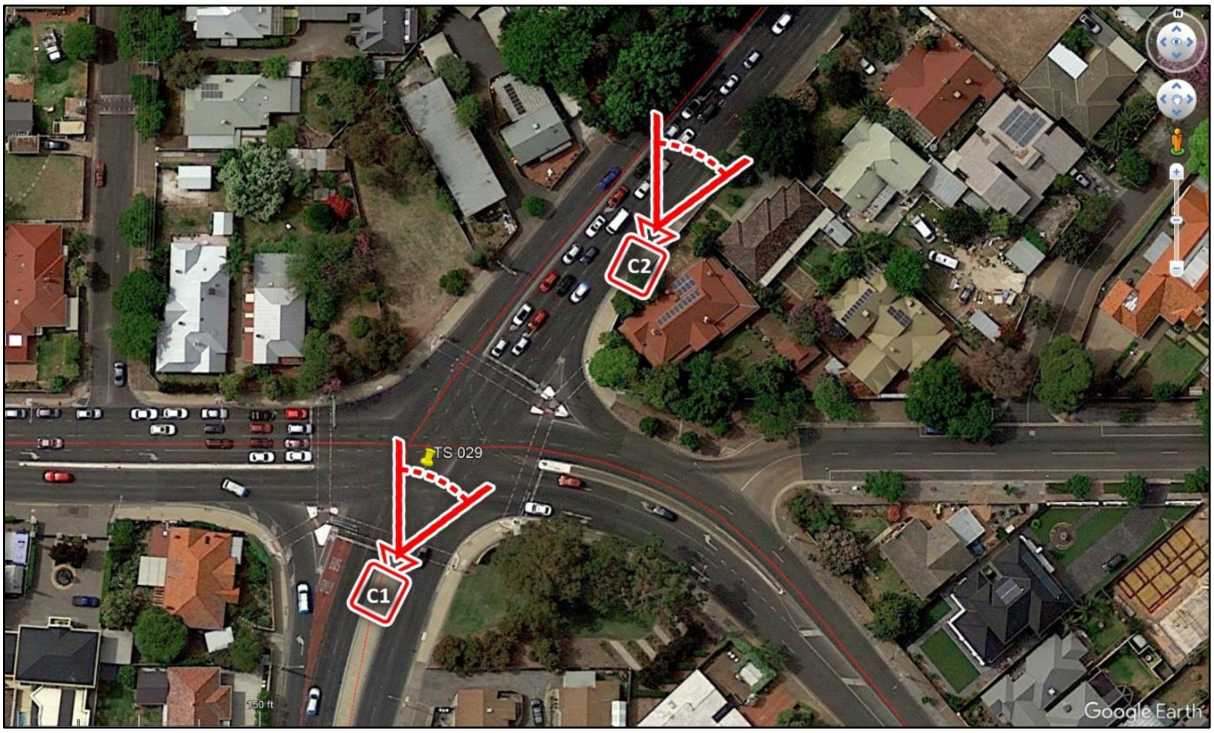


FIGURE 7 CAMERA POSITIONS DURING SITE VISIT AND VIDEO RECORDING

The team commenced video recording from 8:00 AM to 8:15 AM. The resulting footage was reviewed, and vehicle counts for cars, trucks, buses, and bikes were manually extracted. The proportion method was used with existing SCATS vehicle count data to extrapolate one hour of data from the 15-minute collection period, which was then used to calculate all manual turning counts for one hour, as presented in table 4.

TABLE 4 MANUAL TURNING COUNT DURING SITE VISIT

North-East Road	TS029 to TS168			TS168 to TS029		
8:00 – 9:00	Left	Through	Right	Right	Through	Left
Cars	452	636	40	1660	2184	228
Trucks	28	8	0	16	4	0
Bus	4	12	0	0	12	0
Bike	0	8	0	4	16	0
Total	484	664	40	1680	2216	228

Overall, the data collection process from DIT and SCATS, and Site visit was a crucial component of the master thesis work, providing necessary information about the intersection's geometry, traffic volume, and other relevant parameters to develop an accurate and reliable simulation model using the SIDRA software.

3.2 SIDRA Intersection Modelling

SIDRA Intersection Modelling involved creating a simulation model of an intersection using the SIDRA Intersection software. Geometric and traffic data was inputted to generate a preliminary layout, which was then adjusted as necessary. The simulation model was then analyzed using various parameters to evaluate the intersection's performance. The results of the analysis were used to identify potential improvements to the intersection and make informed decisions regarding its design and operation. The general steps to create a model in SIDRA with Professor Branko Stazic were as follows:

1. Selected the “New Project” option from the File menu in the SIDRA Intersection software.
2. Selected the intersection type, which could be a signalized intersection.
3. Entered the basic geometric data for the intersection, including the number of lanes, the width of the lanes, the radius of the curves, and other relevant details.
4. Entered the traffic volume data for the intersection, including the number of vehicles and their turning movements.
5. Adjusted the preliminary layout of the intersection as necessary.
6. Finalized the layout, which automatically generated a simulation model for the intersection.
7. Analyzed the simulation model using various parameters, including level of service, capacity, delay, and safety.
8. Saved and exported the data for AIMSUN modelling and Calibration, such as Avg Back of Queue (distance in meter).

3.2.1 SIDRA Intersection Geometry.

Developing Intersection TS029 and TS168 Geometry using DIT drawings and SCATS data into SIDRA software involved a series of steps to ensure accurate and reliable results. Firstly, I selected type of Intersection as per the DIT drawings into the software to create a digital representation of the intersection and specify all the Information as per real-data set. Then, I used Movements Classes (Light vehicles, Heavy vehicles, and Buses) and OD Movements for each approach. Then, I adjusted the geometry of the intersection, including Lane Configuration and Lane Disciplines, to create a base model geometry of Intersection TS029 and TS168 which represent real-word situation. Also, I removed cycle lanes and pedestrian movement. Final network of the study area in SIDRA intersection showing in below figure 8.

Figure removed due to copyright restriction.

FIGURE 8 SIDRA INTERSECTION NETWORK MODELLING

In the past, I used the "Flow Proportions" tab of the Lane Movements dialog to specify individual lane movements, from an approach lane to an exit lane. I was able to specify different proportions for different movement classes. It was important to specify the Lane Movements so that vehicles were not allowed to change lanes through an intersection. By default, SIDRA allocated 100% proportion from an entry lane to the closest exit lane, subject to some constraints. However, I had the option to customize these proportions. I made use of this option and customized the proportions to suit the intersection design. When customizing the proportions, I ensured that the sum of proportions for each OD movement and movement class was 100%. I created OD Matrix as well about cars and trucks, which I used to create AIMSUN model for further investigations.

3.2.2 Volumes – OD Matrix

I specified vehicle volumes as an Origin-destination (OD) matrix for each movement class from Nort-East Road to another roads at Intersection TS029. I had three options available when specifying light (LV) and heavy (HV) vehicles. I selected the third option was labelled "Total & Veh," which allowed me to separately specify HV and total vehicle volume. The "Volumes" item in the data input was solely used for vehicle volume specifications.

TABLE 5 TRAFFIC VOLUME COUNT OF INTERSECTION TS029

Figure removed due to copyright restriction.

3.2.3 Phasing and timing

One of the important aspects of traffic analysis was the optimization of signal phasing and timing. To set the phasing and timing in the SIDRA software, Input on various parameters such as cycle length, phase & sequence data, and green times for each phase of the signal mentioned below in figure 9 about Intersection TS029. Input three phases with different phase splits 24%, 50%, and 26% respectively for phase A, phase B, and phase C. Output Phase Sequence is also mentioned below in figure 9, where reference phase is A, and remain phase B and C is variable phase. Additionally, the software provided visualizations of the signal phasing and timing, allowing me to better understand how the traffic flow was affected by different settings.

Figure removed due to copyright restriction.

FIGURE 9 PHASING SUMMARY FROM SIDRA MODEL

3.2.4 SIDRA Base Model Calibration

During my thesis work in traffic analysis, I recognized the importance of calibration in ensuring that the simulation accurately reflected real-world traffic conditions. To calibrate traffic simulations, I utilized the Avg Back of Queue (dis) method in SIDRA software. I collected data on the 165m length of the queue of vehicles waiting at the end of a signalized intersection during peak traffic conditions, and then input this data into the simulation. I then adjusted the signal timings until the simulated avg queue length (171m) matched the observed queue length as mentioned in figure 10 below. By using the Avg Back of Queue method in SIDRA software to calibrate traffic simulations, I was able to improve the accuracy of my models and make more informed decisions about traffic management and road network design.

Figure removed due to copyright restriction.

FIGURE 10 SIDRA OUTPUT - AVG BACK OF QUEUE (DISTANCE)

3.3 AIMSUN Modelling

AIMSUN was a powerful traffic simulation software that allowed you to create detailed models of traffic networks, test different scenarios, and analyze the results. This section outlines the detailed process of incident generation and traffic management strategies implemented through the AIMSUN model. Additionally, we describe the calibration and validation of the model, which confirms its accuracy in representing real-world traffic scenarios. The general steps to create a model in AIMSUN with Professor Branko Stazic were as follows:

1. Launch the AIMSUN software and create a new project.
2. Define the study area and its boundaries by drawing the network using the built-in network editor tools. Also add intersections, roads, lanes, and other elements to accurately represent the real-world scenario I want to model.
3. Define the traffic demand by specifying origin-destination (OD) matrices, trip tables, or other input data from SIDRA Model and collected data sets.
4. Define the simulation parameters, such as simulation time, simulation steps, and other settings.
5. Configure the model's behavior by specifying the traffic rules, signal timing, and other parameters that affect the way vehicles move through the network.
6. Validate the model by running simulations and comparing the results with real-world data or other reference models. Use SIDRA output and the real-world value of the average back of the queue (distance).

7. Calibrate the model by adjusting the parameters until the model's performance matches the observed data.
8. Save the model and use it to conduct further analysis or experiments.
9. Create different scenarios with different locations, times, and incident starting times, and conduct analysis and obtain results.

3.3.1 AIMSUN Intersection Network Modelling.

The study area's AIMSUN intersection modeling considers the major intersection TS029 in the North-East Road network. Both intersection TS029 and TS168 were created in AIMSUN as mentioned in figure 11 and figure 12 below. However, the research scope focuses on a particular section of North-East Road from TS168 to TS029. Parking is not available during peak and off-peak periods based on intersection drawings. Streets were ignored in the network modeling because SCATS data analysis shows that most vehicles use the North-East Road. Additionally, it is easier to create two signalized intersections. The network model consists of six centroids that determine the proportion of vehicles released to each road section and serve as the source of traffic generation.

Micro-level details, including individual lanes and vehicular characteristics, make network modeling the most time-consuming and complicated part of this research. Therefore, the base model was created, calibrated, validated, and used for detailed North-East Road modeling that includes geometric configuration features.

Below figure portrays the microsimulation model of whole network showing road links and centroids. Every individual vehicular characteristic and behavior is modelled in this research.

Figure removed due to copyright restriction.

Figure 11 AIMSUN Intersection Network Modelling

Figure removed due to copyright restriction.

Figure 12 AIMSUN Detailed Modelling of Intersection TS029

3.3.2 Travel Demand

AIMSUN, a microscopic traffic simulation software, is one of the commonly used tools for travel demand modeling (AIMSUN 2021). It considers various socio-economic factors such as population, employment, and land use, as well as transportation infrastructure, to estimate the future travel demand and simulate the network performance under different scenarios. A traffic simulation model was developed using an Origin-Destination (O-D) matrix that divided the demand data into light vehicles, such as cars, and heavy vehicles, such as buses/trucks, in table 6 and table 7 below. The O-D demand indicated the travel demand between various centroids. As the traffic data was obtained from the Department of Transport, a more accurate O-D count was produced. Below table 6 and table 7 shows several vehicles travel from/to each centroid. The precision of the model's output was assessed by comparing it to real-world observations, allowing for the evaluation of its reliability.

TABLE 6 O-D MATRIX FOR LIGHT VEHICLES (CARS)

Centroid Number	1789	1790	1791	1792	1793	1794	Total
1789		9	228	2190	1568		3995
1790	46			20		1	67
1791	43			7	665	1	716
1792	624	9			220		853
1793	505		926	135			1566
1794							
Total	1218	18	1154	2352	2453	2	7197

TABLE 7 O-D MATRIX FOR HEAVY VEHICLES (BUSES/TRUCKS)

Centroid Number	1789	1790	1791	1792	1793	1794	Total
1789				6	4		10
1790							
1791				1			1
1792	3						3
1793	2			2			4
1794							
Total	5			9	4		18

3.3.3 AIMSUN Base Model Calibration and Validation

Model calibration aims to evaluate the accuracy of the model and refine it to produce more precise and reliable outcomes. The microsimulation base model replicates the traffic conditions of 2022 and was calibrated based on queue length, section flows, and traffic volume to enhance the consistency between observed and modeled traffic movements by utilizing Avg back of Queue Length data. Travel time measure enhances the precision of trips estimation. Consequently, the calibrated model enables the assessment and comparison of multiple traffic scenarios for 2031, producing more dependable outcomes.

TABLE 8 TRAVEL TIME COMPARISON BETWEEN BASE MODEL AND REAL-LIFE DATA

Figure removed due to copyright restriction.

To ensure that a traffic incident simulation produces realistic results, it is necessary to validate the model outputs with real-world data. The validation of the microsimulation model involved comparing observed travel times with the model outputs. The comparison of travel times between the base model in 2022 and the real-life observed data was presented in Table 8. The results showed that the modelled and observed traffic movements were in reasonable agreement, indicating an acceptable level of confidence in the model. As shown in table 8, maximum GEH value is 4.578 which is also less than 5. As a result, the model was deemed to be well-calibrated and suitable for use in testing construction staging scenarios.

3.3.4 Incident Modelling

Once the AIMSUN model for AM peak was calibrated and validated, the maximum traffic flow volume during 08:00 AM - 09:00 AM was identified from the total traffic count. The data was analyzed, and the total travel time for the network was determined for a 1-hour period of maximum flow volume to identify the busiest time and duration of traffic flow in the North-East Road during normal operation. The results were then used to generate a representative graph for the average travel time, as depicted in below Figure 13

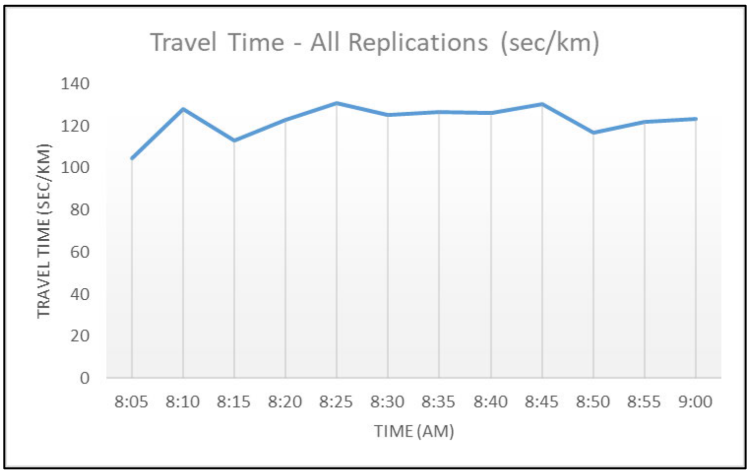


FIGURE 13 TRAVEL TIME BETWEEN 8-9 AM

The time around 8:10 AM seemed to be busiest time based on travel time. Hence, the incident starting time selected 8:10 AM, and 8:20 AM for each location for 5 min, 10 min, and 15 min incident duration. Selected a short period for the thesis work, because they are simple incidents of short duration. For the Impact of Incident during AM peak period, a total of 2 locations were selected, which is near by CBD area, and which is a busiest point on the North-East Road. Location 1st at the middle portion of the network, and 2nd location nearby Intersection TS029 as show in below figure 14.

It is out of scope of this report to investigate incidents outside of peak period. The reason for this is that the road capacity is the same during, and outside peak time scene no parking allowed. This means; worst case situation will happen during the peak time due to having highest traffic flows but the same road capacity, as in the off-peak period.

All the incidents investigated involved only one lane blockages, scene the road investigated has only two traffic lanes. Simulating an incident with two lane blocks is ineffective, as it quickly disrupts the entire network.

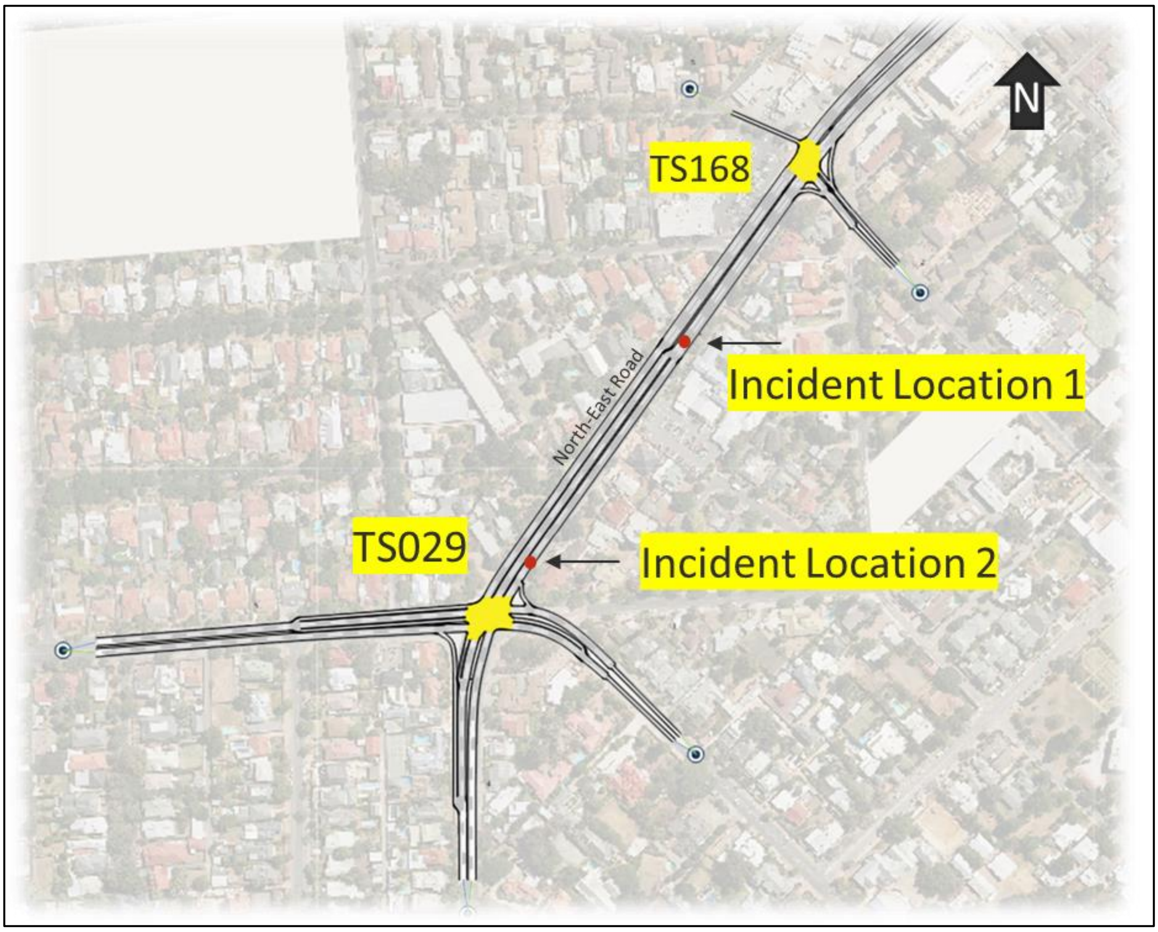


FIGURE 14 INCIDENT LOCATIONS

The study used Table 9 to summarize the time of day, incident location, and duration.

TABLE 9 DIFFERENT SCENARIOS

Case	Incident Location	Incident Starting Time	Incident Duration	No. of Lane Blockage
1	1	8:10 AM	5 min, 10 min, 15 min	1
2	1	8:20 AM	5 min, 10 min, 15 min	1
3	2	8:10 AM	5 min, 10 min, 15 min	1
4	2	8:20 AM	5 min, 10 min, 15 min	1
5	1	8:10 AM	5 min	2
6	1	8:20 AM	5 min	2
7	2	8:10 AM	5 min	2
8	2	8:20 AM	5 min	2

3.4 AIMSUN Incident Specifications

AIMSUN Incident specifications section will demonstrate the process of incident scenario specifications, starting time of the incident, incident duration according to different locations. The incident modelling is divided into two different incident locations; each location divided into two incident severity types of lane blockages which is dependent on incident duration. All the scenarios mentioned below table 10.

TABLE 10 INCIDENT SCENARIOS IN AIMSUN

Scenario	Incident Description
1	Base Model - No Incident
2A	Incident starting at 8:10 AM which will run for 5 min, 10 min, 15 min at the Location 1 with one lane blocked
2B	Incident starting at 8:20 AM which will run for 5 min, 10 min, 15 min at the Location 1 with one lane blocked
2C	Incident starting at 8:10 AM which will run for 5 min, 10 min, 15 min at the Location 2 with one lane blocked
2D	Incident starting at 8:20 AM which will run for 5 min, 10 min, 15 min at the Location 2 with one lane blocked
3A	Incident starting at 8:10 AM which will run for 5 min only at the Location 1 with two lanes blocked
3B	Incident starting at 8:20 AM which will run for 5 min only at the Location 1 with two lanes blocked

3C	Incident starting at 8:10 AM which will run for 5 min only at the Location 2 with two lanes blocked
3D	Incident starting at 8:20 AM which will run for 5 min only at the Location 2 with two lanes blocked

In addition, the AIMSUN model includes a depiction of lane blockage severity for one lane, which Incident start at 8:10 AM and run for 5 min at the Location 1 in Figure 15, while Appendix B contains analogous diagrams for other scenarios involving one-lane and two-lanes blockages with different durations and starting time. Figure 15 specified the number of lane closures for each lane blockage severity during the incident. In addition, the vehicle speed was reduced to 50.0 km/h for all scenarios. Also, as per base model outputs, normal average speed was around 36.2 km/h during peak time between 8:00 – 9:00 AM.

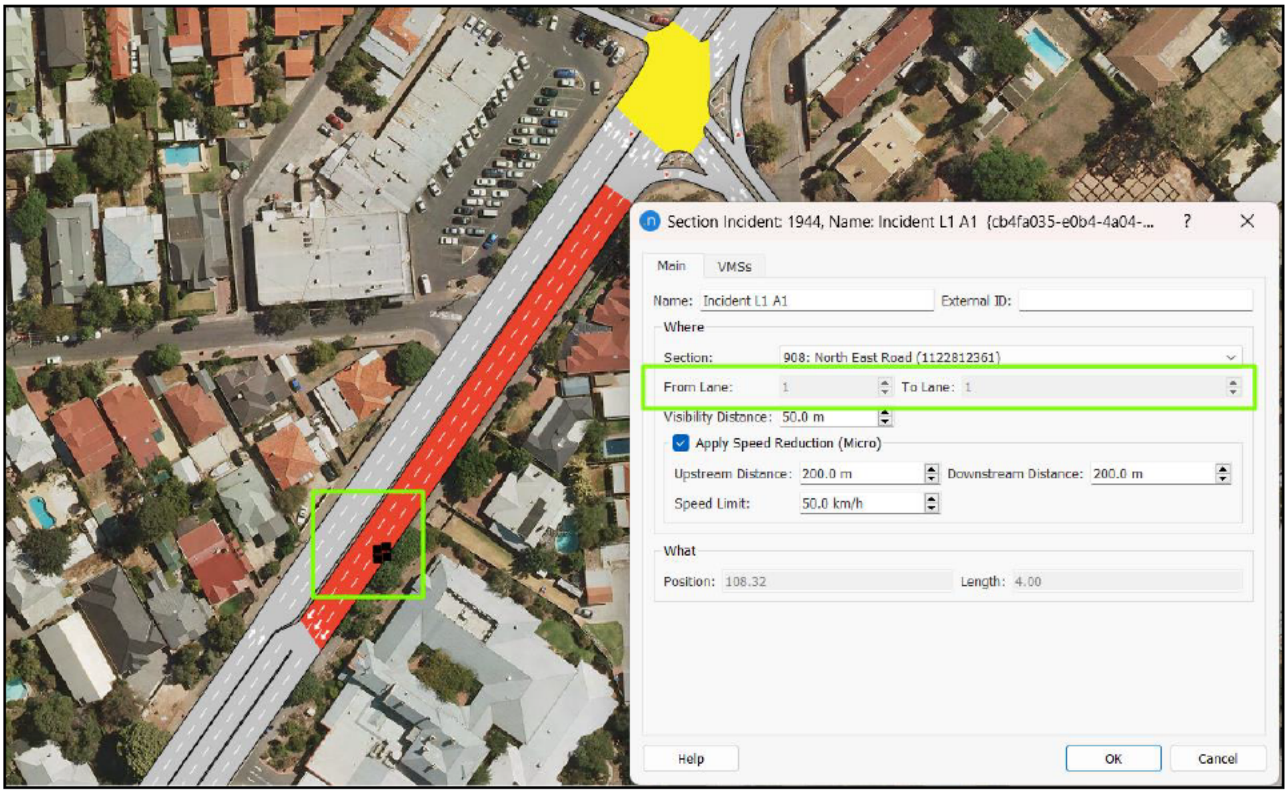


FIGURE 15 INCIDENT MODELLING SCENARIO 2A (1 LANE BLOCK AT LOCATION 1)

Once the network was set up, I defined the incident in AIMSUN. I selected the road segment (908: North-East Road) where the incident was supposed to occur and then chose the incident type from the incident menu. In AIMSUN, under traffic management option assigned an incident in traffic condition mentioned in below figure 16.

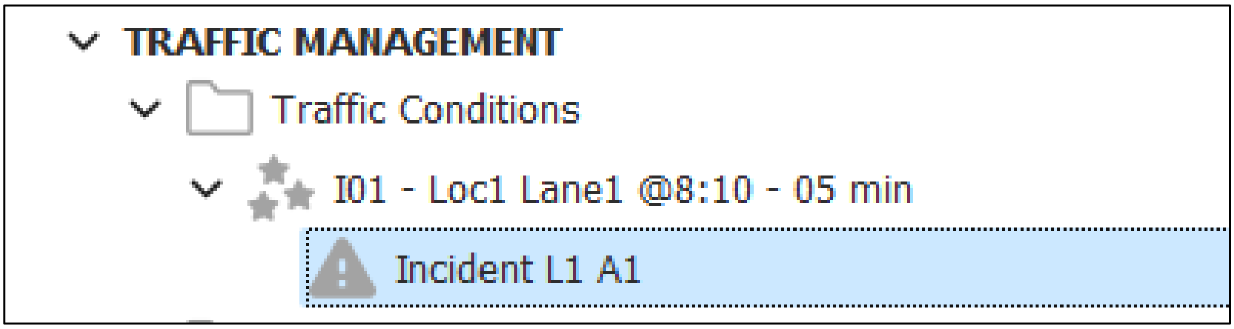


FIGURE 16 TRAFFIC MANAGEMENT – INCIDENT L1 A1

Figure 17 illustrates the traffic condition in AIMSUN modeling with activation condition is time, which duration of an incident that began at 08:10 AM and lasted for 5 minutes. The incident starts at 8:10 AM and finishes at 8:15 AM. In addition, for the purposes of the study, two other incidents were also assigned with different time durations of 10 minutes and 15 minutes at same location, also same incidents assigned at different locations and times of the day attached screenshots in Appendix B.

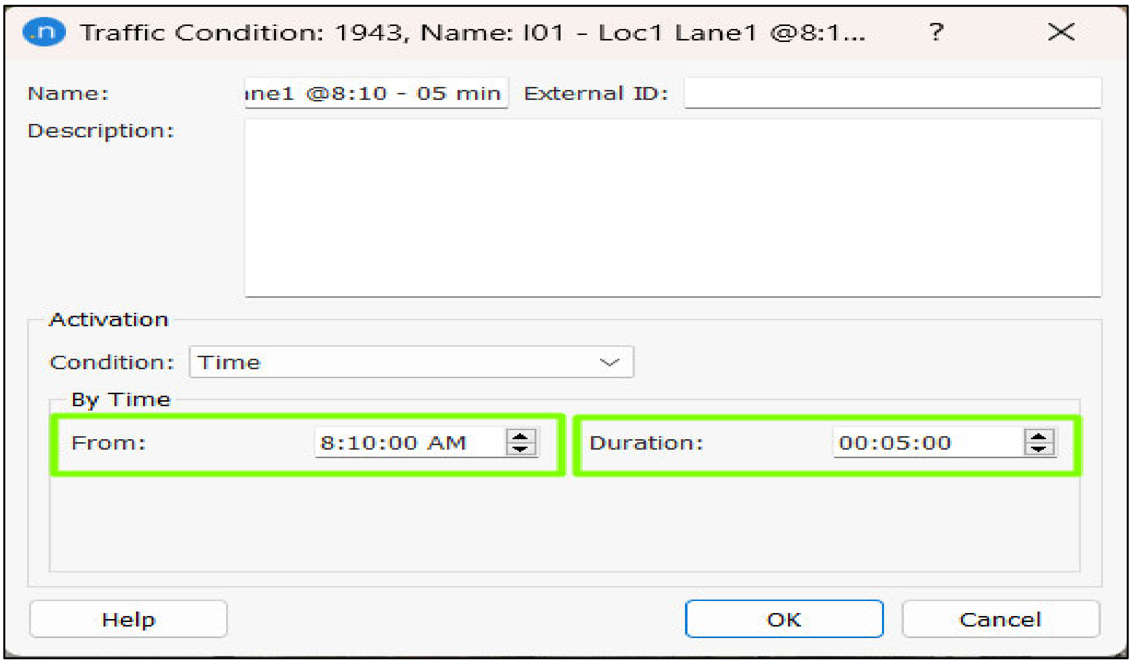


FIGURE 17 INCIDENT DURATION AND STARTING TIME

As the incident occurs on the North-East Road, traffic demand increases. To overcome traffic congestion problems in future due to incidents, more traffic management strategies are required to cope with the extra demand. Thus, the management strategies to divert the flow from one origin centroid to destination centroid through a different route need to be assigned in the model. AIMSUN base model and scenario 2A outputs mentioned in result section. As per AIMSUN output, 5 minutes duration is not a major issue, while 10- and 15-minutes incident duration create a significant change.

4. RESULTS

In this chapter, we will present the results obtained from two different approaches, namely microsimulation AIMSUN model and SIDRA Intersection assessment, to evaluate the impact of incidents on the North-East Road traffic. The results obtained from these two methods will be used to quantify the impact of incidents in terms of various metrics, such as travel times, queue length, emissions, and delay. The analysis will consider factors such as incident location, duration, time of day, and lane blockage severity levels. The results will be presented and discussed to provide a comprehensive understanding of the impact of incidents on the North-East Road traffic, and to identify effective strategies to minimize their impact and improve network performance.

4.1 SIDRA Intersection

The performance of signalized intersections can be evaluated using various performance measures provided by the SIDRA software. These measures are crucial for assessing both the efficiency and safety of intersections. The performance measures offered by SIDRA include capacity, delay, level of service, queue length, and speed. This section of the report will focus specifically on the Avg Back of the Queue (distance) and Level of Service outputs from SIDRA, which are key indicators of intersection performance.

4.1.1 Avg Back of the Queue

In the context of SIDRA Intersection, delay refers to the amount of time that a vehicle is delayed at an intersection due to traffic congestion. It is a measure of the Level of Service (LOS) that an intersection provides to vehicles. Delay is typically expressed in seconds per vehicle, and it represents the time that a vehicle spends waiting in queues or at signalized intersections. From the results of the SIDRA base model, insignificant increase in delay time is observed in the network as a result of AM peak period, which suggests that increases the congetion without any incident. SIDRA queue estimation methods are used for Back of Queue and Queue at Start of Green. The Avg Queue Distance of the Entire network show in figure 18 below. Average Back of Queue Distance for any lane on the approach in metres. Average back of the Queue is 268 m on the North-East Road during morning peak period, and that’s why intersection TS168 also facing very high number of Average Back of the Queue which ia about 530 m.

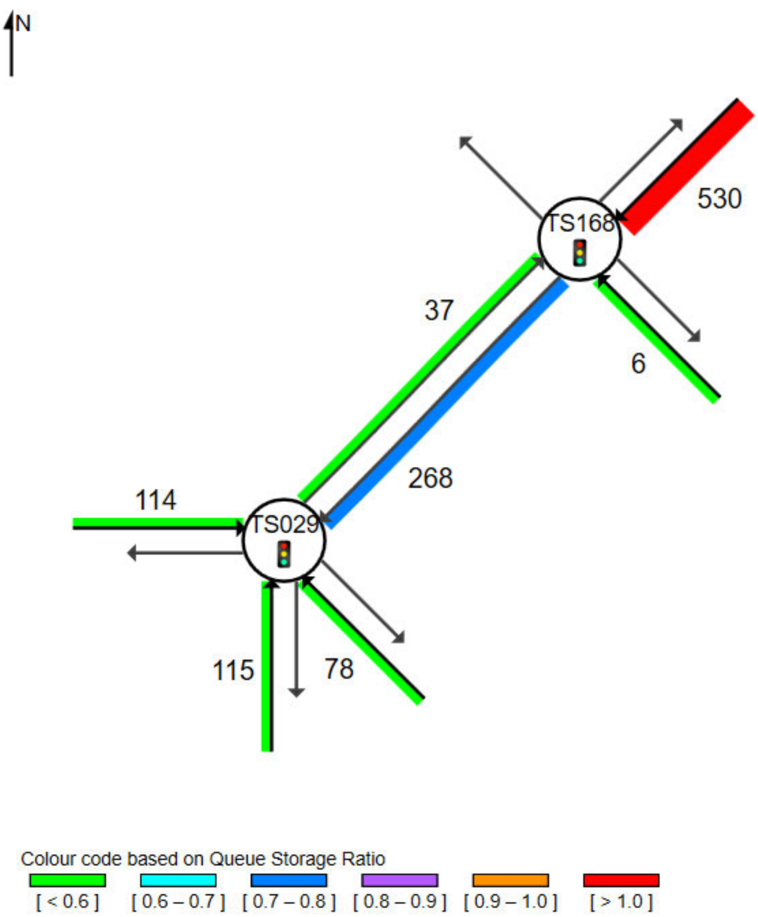


FIGURE 18 AVG BACK OF QUEUE DISTANCE OF THE EXISTING NETWORK

4.1.2 Level of Service

Table 12 contains the criteria for measuring the Level of Service (LOS) for signalized intersections using the SIDRA intersection model developed by Akçelik & Associates in 2011. The table outlines the maximum acceptable control delay per vehicle, which is 80 seconds. If the control delay per vehicle is less than or equal to 80 seconds, the intersection is deemed to be operating at an acceptable Level of Service E. However, if the control delay per vehicle exceeds 80 seconds, the intersection is operating at a poor Level of Service F. This indicates a reduction in network capacity and increased delays, travel time, and queue length.

TABLE 11 LOS CRITERIA FOR SIGNALIZED INTERSECTIONS

LOS	*Control delay (s/vehicle)*
A	0–10
B	> 10–20
C	> 20–35
D	> 35–55
E	> 55–80
F	> 80

Results generated from SIDRA intersection, tabulated in figure 18, indicate that the network would operate with Almost poor LOS (i.e., LOS=E) during the busiest morning peak currently. As per SIDRA output, Intersection TS029 of North-East Road is currently running with over capacity as I mentioned in the Introduction of the report. The North-East Road from TS168 to TS029 is facing a very high amount of traffic as compared to the road in opposite directions. The SIDRA summary reports for the future design 10-year reports are presented in Appendix A which LOS F.

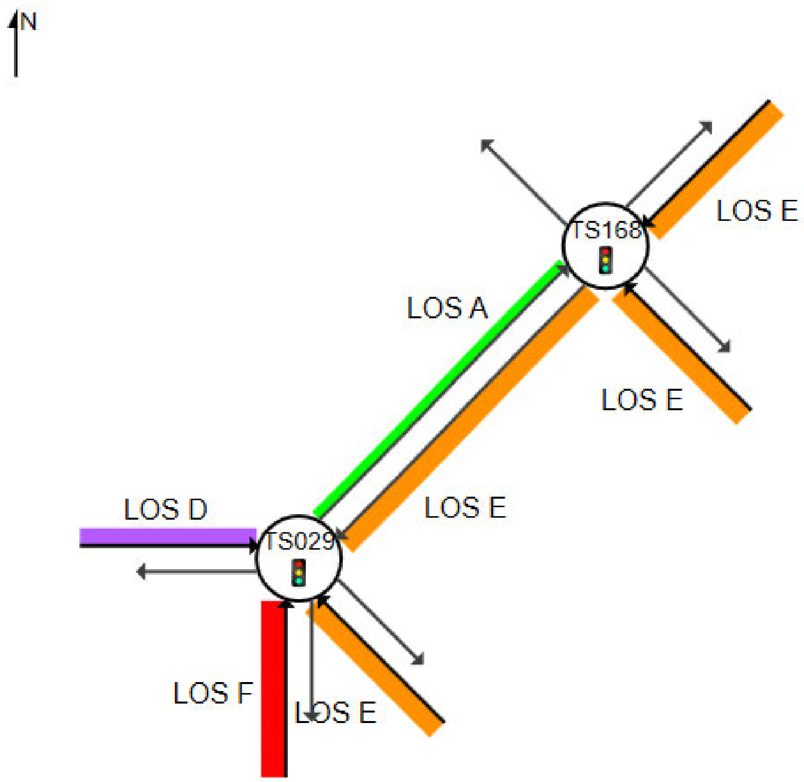


FIGURE 19 LEVEL OF SERVICE OF THE EXISTING NETWORK

4.2 AIMSUN

The performance of signalized intersections can be evaluated using various performance measures provided by the AIMSUN software. The performance measures offered by AIMSUN include travel time, delay, congestion, queue length, and speed. This section of the report will focus specifically on the Delay, Mean Queue (distance), and Speed outputs from SIDRA, which are key indicators of intersection performance.

4.2.1 Delay Time

Delay Time comparison of different incident duration with one Lane blocked at location 1.

During the simulation study on the North-East Road at location 1, it was observed that when a one lane is blocked due to incidents, the remaining one lane has sufficient capacity to handle the traffic. If the incident starts at 8:10 AM, the delay times, as depicted in Figure 20, show a slight increase during the 5-minute duration of the incident. However, the incident is cleared within the next 10 minutes, and traffic flow returns to normal. Conversely, for incidents lasting 10 and 15 minutes, there is a significant increase in delay time. During the 15-minute incident, the delay time experienced a 1.48-fold increase compared to normal conditions. Additionally, it took more than 15 minutes to clear the queue and restore normal traffic flow.

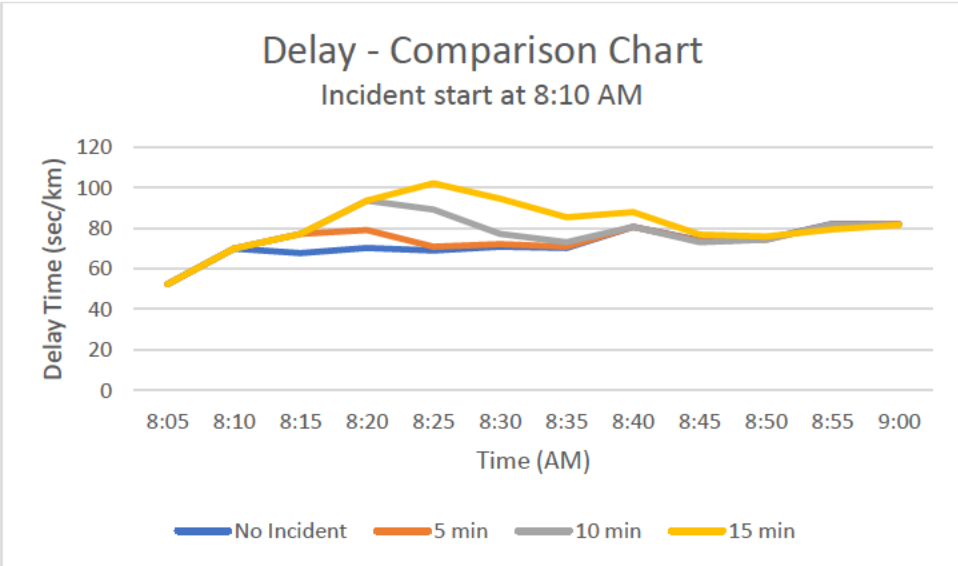


FIGURE 20 SCENARIO 2A - DELAY TIME COMPARISON AT LOCATION 1

If the incident starts at 8:20 AM, as shown in Figure 21, the delay times exhibit a slight increase during the 5-minute incident duration. Again, the incident is cleared within the following 10 minutes, and traffic flow returns to normal. However, for incidents lasting 10 and 15 minutes, there is a significant increase in delay time. During the 15-minute incident, there was a 1.52-fold increase in the delay time, indicating a significant impact on traffic performance compared to normal conditions. Furthermore, the incident required more than 15 minutes to clear the queue, leading to a prolonged period of disrupted traffic flow before returning to its regular state.

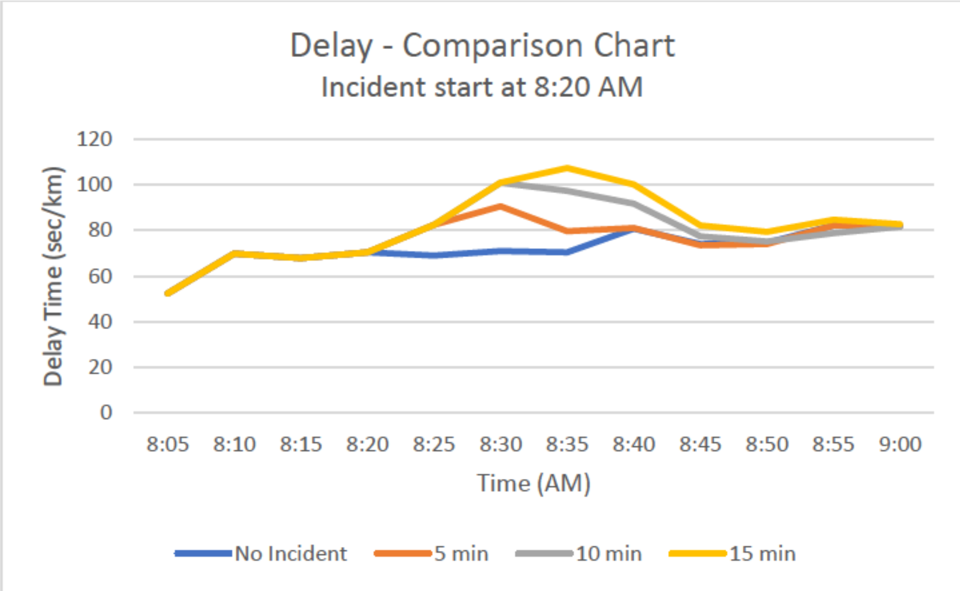


FIGURE 21 SCENARIO 2B - DELAY TIME COMPARISON AT LOCATION 1

Delay Time comparison of different incident duration with one Lane blocked at location 2.

When a lane is stopped by an accident on the North-East Road at site 2, it was discovered during the simulation research that the remaining lane has enough capacity to handle the traffic. The delay times for the incident's 5-minute duration show a modest increase if it begins at 8:10 AM, as shown in Figure 22. However, the situation is resolved within the following 10 minutes, and the flow of traffic resumes as usual. On the other hand, there is a large rise in delay time for incidents lasting between 10 and 15 minutes, and it takes more than 15 minutes to clear the queue.

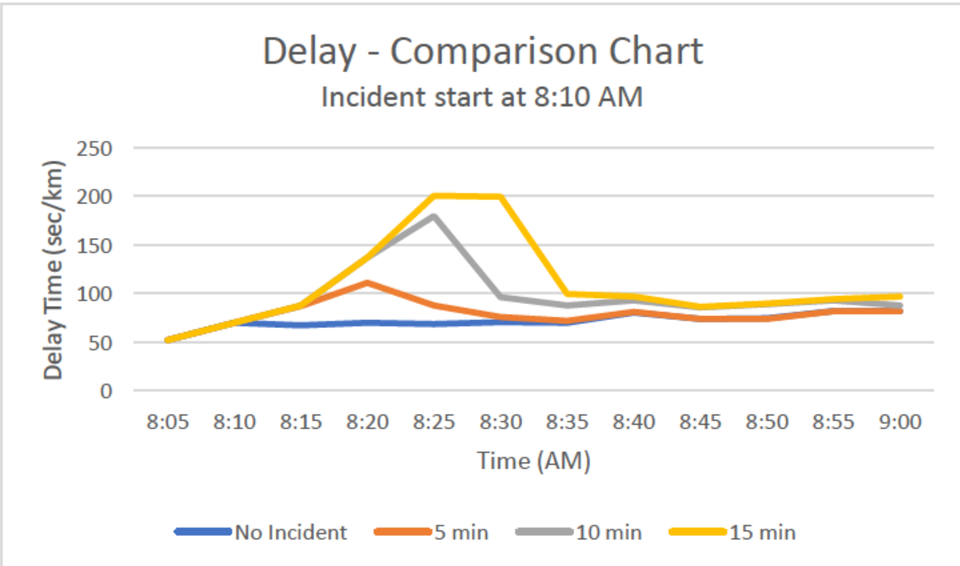


FIGURE 22 SCENARIO 2C - DELAY TIME COMPARISON AT LOCATION 2

If the incident occurs at 8:20 AM, as depicted in Figure 23, there is a slight rise in delay times during the 5-minute duration of the incident. Once again, the incident is resolved within the subsequent 15 minutes, and traffic flow returns to its usual state. However, for incidents lasting 10 and 15 minutes, there is a noteworthy increase in delay time. In the case of the 15-minute incident, the delay time experiences a three-fold increase, indicating a significant impact on traffic performance compared to normal conditions. Moreover, it takes more than 20 minutes to clear the queue of vehicles during the incident, resulting in an extended period of disrupted traffic flow before returning to its regular state.

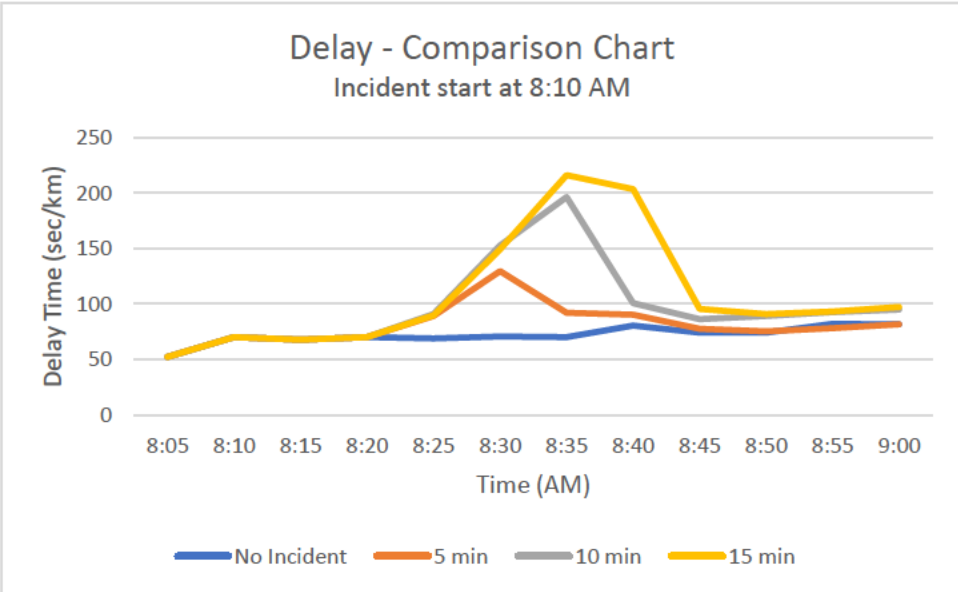


Figure 23 Scenario 2D - Delay Time Comparison at Location 2

Delay Time comparison of different Location with two Lane blocked which incident start and 8:10 AM.

During the simulation study conducted at locations 1 and 2 on the North-East Road, it was observed that when both lanes are blocked due to incidents, the capacity is insufficient to handle the traffic. If the incident begins at 8:10 AM, the delay times, as shown in Figure 24, exhibit a slight increase during the 5-minute duration of the incident at location 1, reaching almost twice the standard delay time. However, the incident is resolved within 10 minutes, and traffic flow returns to its normal state.

In contrast, for incidents lasting 5 minutes at location 2, there is a significant increase in delay time. Specifically, during the 5-minute incident at location 2, the delay time experiences a 3.18-fold increase compared to normal conditions. Moreover, it takes more than 10 minutes to clear the queue of vehicles and restore normal traffic flow.

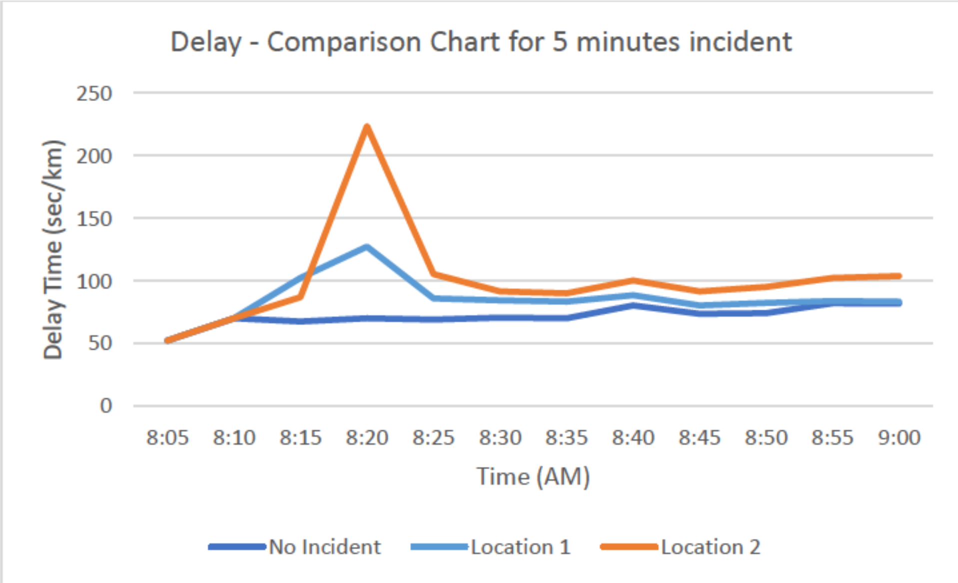


FIGURE 24 SCENARIO 3A & 3B - DELAY TIME COMPARISON AT LOCATION 1 AND 2

Delay Time comparison of different Location with two Lane blocked which incident start and 8:20 AM.

During the simulation study conducted on the North-East Road at locations 1 and 2, it was observed that when both lanes are blocked due to incidents, the capacity is insufficient to handle the traffic. If the incident occurs at 8:20 AM, as depicted in Figure 25, there is a slight increase in delay times during the 5-minute duration of the incident at location 1, almost doubling the standard delay time. However, the incident is resolved within 10 minutes, and traffic flow returns to normal.

On the other hand, for incidents lasting 5 minutes at location 2, there is a significant increase in delay time. Specifically, during the 5-minute incident at location 2, the delay time undergoes a 3.18-fold increase compared to normal conditions. Additionally, it takes more than 10 minutes to clear the queue of vehicles and restore normal traffic flow.

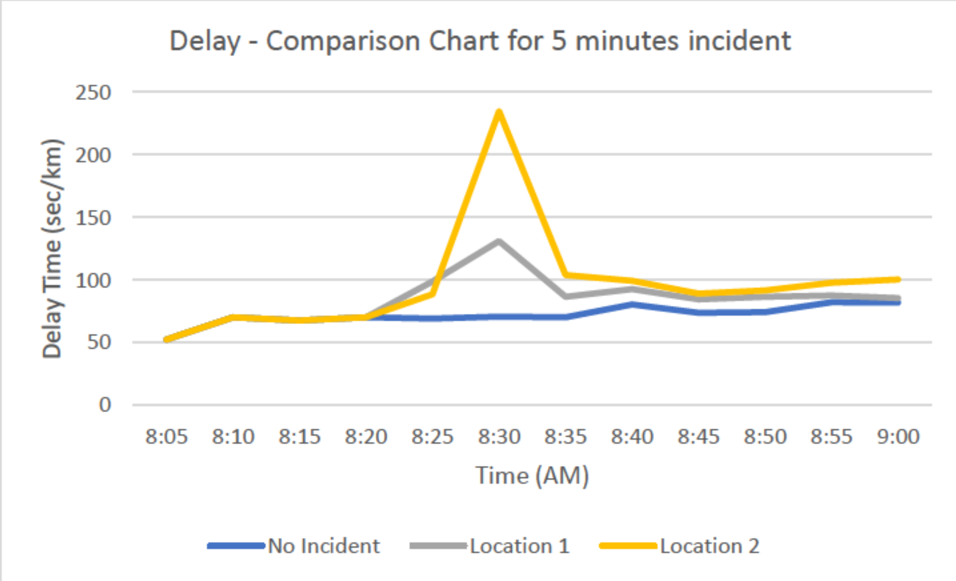


FIGURE 25 SCENARIO 3C & 3D - DELAY TIME COMPARISON AT LOCATION 1 AND 2

4.2.2 Mean Queue

The queue generated in the entire network from the different severity scenarios of lane blockage from figure 26 shows that the queue length increases by 92.97 vehicles at the worst case of incident occurrence and two lanes blockage for 5 minutes at location 1. Also, All the incidents investigated involved only one lane blockages, scene the road investigated has only two traffic lanes. Simulating incident, the blocks both lanes it is pointless, and whole network block in just few minutes.

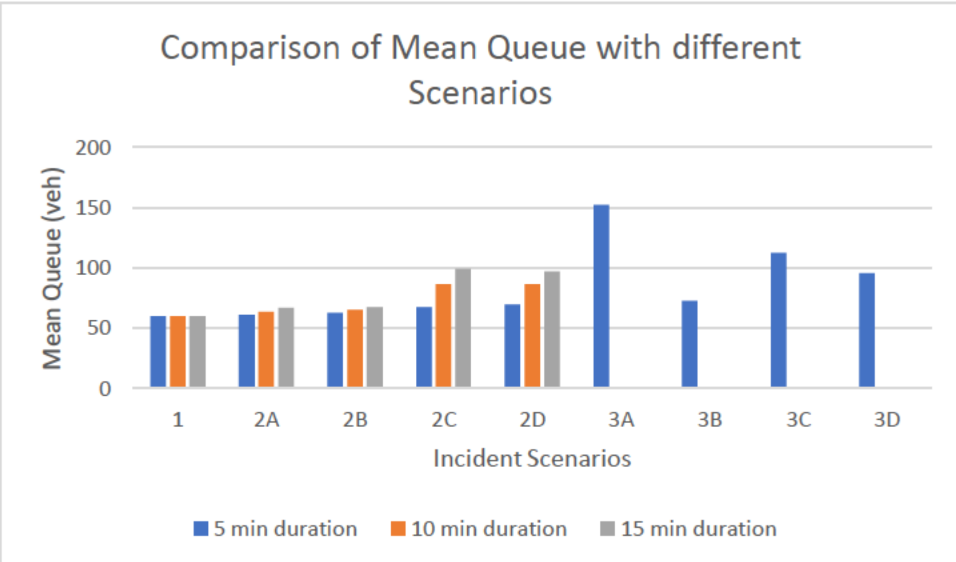


FIGURE 26 COMPARISON OF QUEUE LENGTHS WITH DIFFERENT SCENARIOS

Figure 26 demonstrates the mean queue (congestion) in the entire network before and during incidents with different locations, different incident duration, different incident starting time and different number of lane blockage. Figure 26 shows that the Mean Queue increased by 2.58 times more as worst-case scenario. Scenario 3A is worst case scenario in study report, which Incident starting at 8:10 AM which will run for 5 min only at the Location 1 with two lanes blocked. while Appendix B contains analogous diagrams for other each scenarios involving one-lane and two-lanes blockages with different durations and starting time.

4.2.3 Speed

The outcome from AIMSUN related to speed analysis can provide several valuable insights. Firstly, it helps in understanding the impact of existing or proposed infrastructure designs on vehicle speeds. By simulating North-East Road configurations with one lane blockage and two lanes blockage at different locations shows in figure 27, it shows Average Speed 18.53% decreased for 15 minutes incident in scenario 2C, indicating a significant impact on traffic performance compared to normal conditions. If we block 2 lanes at location 1, it will create worse scenarios. But 2 lanes blockage at location 2 is pointless, because it will crash the whole road network. Appendix B provides comparable illustrations of speed for each scenario that involves blockages with one lane or two lanes, differing durations, and varying starting times.

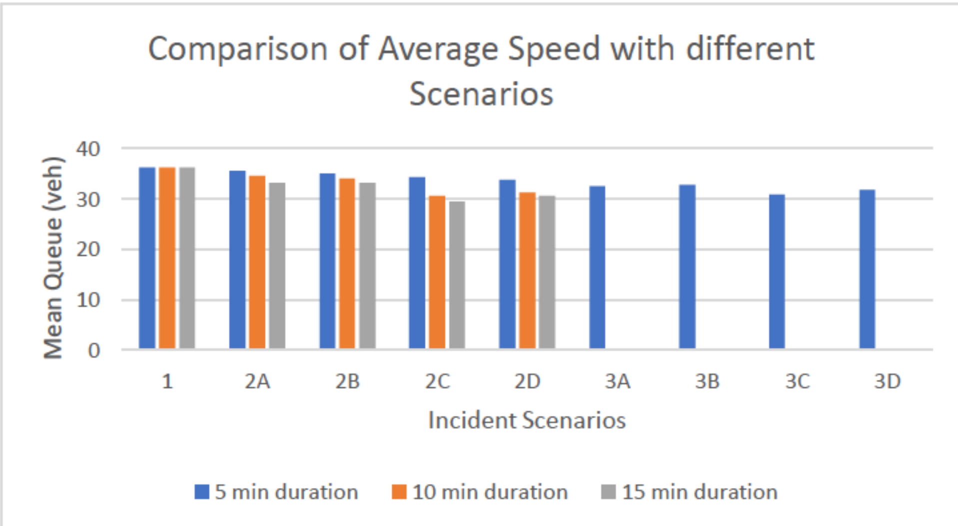


FIGURE 27 COMPARISON OF AVERAGE SPEED WITH DIFFERENT SCENARIOS

4.2.4 Emission

Congestion and delays in road networks lead to various environmental problems. The occurrence of nonrecurrent traffic incidents on freeways results in increased fuel consumption and the emission of harmful pollutants, which has detrimental effects on mobility and safety (Chou et al., 2010). These incidents contribute to environmental pollution by generating carbon dioxide and many more emissions, which have negative impacts on health. Therefore, it is crucial to quantify these emissions in order to assess the effectiveness of traffic management strategies aimed at reducing their impact. AIMSUN outcomes show in figure 28, the amount of CO_2 emissions for all each scenario considered in the study.

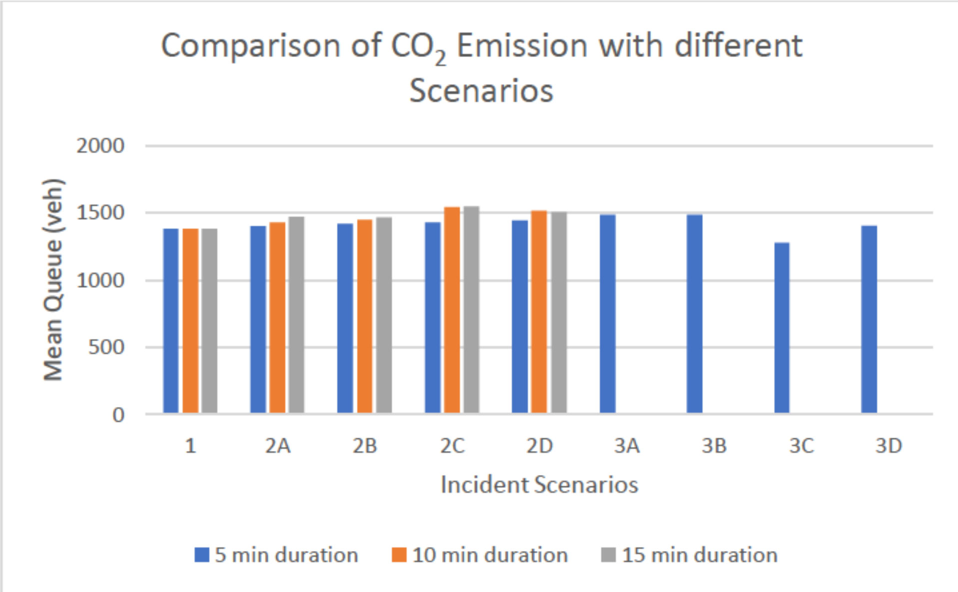


FIGURE 28 COMPARISON OF CO_2 EMISSION WITH DIFFERENT SCENARIOS

The results have demonstrated in figure 28, that the CO_2 emissions increased by 11.87% during one lane blockages in location 2 and 6.30% during the worst case of one lane closure in location 1 than the normal traffic flow. The CO_2 emissions increased by 7.46% during two lane blockages for 5-minute incident in location 1, which incident start at 8:10 AM. Appendix B provides comparable illustrations of CO_2 Emission for each scenario that involves blockages with one lane or two lanes, differing durations, and varying starting times.

It is out of scop of this report to investigate incidents outside of peak period. The reason for this is that the road capacity is the same during, and outside peak time scene no parking allowed. This means; worst case situation will happen during the peak time due to having highest traffic flows but the same road capacity, as in the off-peak period.

All the incidents investigated involved only one lane blockages, scene the road investigated has only two traffic lanes. Simulating incident, the blocks both lanes it is pointless, and whole network block in just few mints. So, in this study, only 5 minutes incident investigated with 2 lanes blockage.

5. DISCUSSIONS

The findings of this study provide valuable insights into the study of road network performance during incidents on arterial roads. The discussion will focus on three key aspects: congestion, travel time delays, and environmental implications.

Firstly, incidents on arterial roads were found to have a significant impact on congestion levels. The occurrence of nonrecurrent traffic incidents disrupts the normal flow of vehicles, leading to bottlenecks and increased congestion. This congestion not only affects the incident location but also propagates upstream and downstream, affecting the overall performance of the arterial road network. The study revealed that incidents resulted in a substantial increase in traffic volume and reduced traffic flow rates, exacerbating congestion and impeding the movement of vehicles along the arterial road corridors.

Secondly, incidents were found to cause substantial travel time delays for motorists. The disruption caused by incidents leads to slower travel speeds and increased queuing, resulting in extended travel times for commuters. The study observed that incidents on arterial roads resulted in significant travel time increases, with delays ranging from a few minutes to several hours depending on the severity and duration of the incident. Such delays not only impact the efficiency of the transportation system but also have environmental implications, as productivity is hampered, and operating pollutions increase.

From the incident modelling, the results revealed that the incident duration of 15 minutes during morning peak 8:00-9:00 AM at location 2 on the North-East Road will cause significant increase in travel time and delay time for all incident severity types and lane blockages. Delay time was increased by 49.77%, and mean queue was increased by 66.55% for 15 minutes duration with 1 lane blockage at location 2. The analysis of the data revealed that a reduction in speed of 18.54%, which was an average of 36.2 km/hr., resulted in significant increases in delay time and mean queues. For incident response because of increased delay time, certain number of vehicles needs to be detoured from their original route to the adjacent sub-arterial roads to maintain a reasonable freeway operation.

Moreover, incidents on arterial roads have noteworthy environmental implications. The study demonstrated that incidents contribute to increased fuel consumption and emissions of pollutants, such as carbon dioxide and nitrogen oxide. These emissions have detrimental effects on air quality, public health, and the environment. For a specific scenario involving a 15-minute duration with a one-lane blockage at location 2, the analysis demonstrated a 49.77% increase in delay time and a 66.55% increase in the mean queue. Furthermore, the examination of data indicated that there was a notable rise in CO_2 emissions, specifically an increase of 164 kg per hour. This increase in emissions corresponded to significant elevations in both delay time and mean queue. The findings highlight the need for effective incident management strategies that not only focus on minimizing travel time delays but also aim to mitigate the environmental impacts by reducing fuel consumption and emissions.

Implications of the Research Findings

In conclusion, incidents on arterial roads have a significant impact on congestion, travel time delays, and the environment. The findings underscore the importance of implementing effective incident management strategies to mitigate these impacts. Future research focusing on incident detection, prompt response, and coordinated traffic control measures, transportation agencies can minimize congestion, reduce travel time delays, and mitigate the environmental implications associated with incidents on arterial roads. moreover, explore advanced incident management techniques and evaluate their effectiveness in further improving the resilience and performance of arterial road networks in the face of incidents.

6. CONCLUSION

In conclusion, this master thesis has provided a comprehensive analysis of road network performance during incidents on arterial roads (North-East Road). The study examined various aspects such as congestion, travel time delays, and environmental implications, shedding light on the significant negative impacts that incidents have on the performance of arterial road networks. North-East Road connects the north-east suburbs and city area, which road used by many public transports, private vehicles, and commercial vehicles too which may create biggest impact during road incident. Thus, traffic incident management is of extreme importance to maintain the serviceability of infrastructure and safety and comfort of the road users.

The findings of this research highlight the adverse effects of incidents on arterial roads. It was observed that incidents lead to increased congestion levels, delays in the flow of traffic and causing bottlenecks along the road network. This congestion not only affects the incident location but also propagates upstream and downstream, leading to reduced traffic flow rates, speeds, and impeded mobility for commuters.

In addition, it was discovered that incidents led to significant disruptions in travel time for drivers. The effects of incident location, duration, and timing on selected sections of the North-East Road were measured in terms of travel times, level of service (LOS), queue length (congestion), and emissions during the morning peak. Based on the modeled incident scenarios, recommendations for solutions are provided.

Results demonstrated that if a 5-10 minutes' incident occurred blocking one lane in the North-East Road, there will be enough capacity for the network to operate properly even during the busiest time of the day and no vehicle diversion is required for the scenario. On the contrary, if two lanes were blocked as a result of incident, a significant number of vehicles requires to be diverted towards the adjacent sub-arterial roads.

Results also showed that the incident duration of 15 minutes in incident location 2, in 8:00 AM – 9:00 AM will have significant increase in the travel time, delay time, and emission as well for all incident severity types. The busiest time at location 2, travel time increased by 28.23% which was 127.41 sec/km in normal condition.

Furthermore, incidents on arterial roads contribute to environmental pollution. The study revealed that incidents lead to increased fuel consumption and emissions of harmful pollutants such as carbon dioxide and nitrogen oxide. The busiest time at the location 2,CO_2 emission increased by 11.87% which was 1381 kg in normal condition. These emissions have detrimental effects on air quality, public health, and the environment, highlighting the need for effective incident management strategies that aim to mitigate both travel time delays and environmental impacts.

To address these challenges, proactive incident management strategies are essential. Early incident detection, efficient response and clearance procedures, and effective traffic control measures play a vital role in minimizing the impact of incidents on arterial road performance.

Future Research

Future research should continue to explore advanced incident management techniques and evaluate their effectiveness in further improving the resilience and performance of arterial road networks during incidents. Additionally, the integration of intelligent transportation systems (ITS) technologies and real-time data analysis can enhance incident detection, response, and traffic management capabilities, leading to more efficient and sustainable arterial road operations.

Overall, this master thesis contributes to the understanding of road network performance during incidents on arterial roads and provides a foundation for developing strategies to enhance the resilience and efficiency of transportation systems in the face of incidents. By addressing the challenges associated with incidents, we can create safer, more reliable, and environmentally friendly arterial road networks that meet the needs of communities and support sustainable development.

REFERENCES

1. Avetisyan, HG; Miller-Hooks, E; Melanta, S; Qi, B 2014; Effects of vehicle technologies, traffic volume changes, incidents, and work zones on greenhouse gas emissions production. Transportation research part D: transport and environment, 26, 10-19.
2. Archer, J., 2000, October. Developing the potential of micro-simulation modelling for traffic safety assessment. In Proceedings of the 13th ICTCT Workshop (Vol. 44). Citeseer.
3. Aimsun (2021). Aimsun Next 8.4 User's Manual, Aimsun Next Version 8.4.4, Barcelona, Spain. Accessedon:Jan.3,2022.[In software]
4. Anderson, J. M., Lu, L., & Gkritza, K. (2017). Using microscopic traffic simulation to evaluate the impacts of alternative intersection designs on traffic flow and safety. Journal of Traffic and Transportation Engineering (English Edition), 4(5), 347-356.
5. Ahmad, S., Saeed, S., & Islam, T. (2019). Mesoscopic simulation of variable speed limits to investigate their impacts on traffic flow and congestion. Journal of Advanced Transportation, 2019, 1-13.
6. Akçelik, R. (1990). SIDRA: Signalised intersection delay and capacity model. In Proceedings of the Australian Road Research Board Conference (Vol. 19, pp. 47-68).
7. Akçelik, R., & Rouphail, N. M. (2017). SIDRA INTERSECTION: A powerful tool for analyzing signalized intersections and roundabouts. ITE Journal, 87(10), 33-39.
8. Barceló, J., Codina, E., Casas, J., Ferrer, J.L. and García, D., 2005. Microscopic traffic simulation: A tool for the design, analysis, and evaluation of intelligent transport systems. Journal of intelligent and robotic systems, 41(2), pp.173-203.
9. Barceló, J., 2010. Fundamentals of traffic simulation (Vol. 145, p. 439). New York: Springer.
10. Burghout, W., Koutsopoulos, H.N. and Andreasson, I., 2005. Hybrid mesoscopic– microscopic traffic simulation. Transportation Research Record, 1934(1), pp.218-225.
11. Burghout, W., Van Zuylen, H. J., & Immers, L. H. (2005). Evaluating intelligent transport systems with microscopic traffic simulation. Transportation Research Part C: Emerging Technologies, 13(3), 185-210.
12. Burghout, W., 2005. Mesoscopic simulation models for short-term prediction. PREDIKT project report CTR2005, 3.
13. Bourrel, E. and Lesort, J.B., 2003. Mixing microscopic and macroscopic representations of traffic flow: Hybrid model based on Lighthill–Whitham–Richard's theory. Transportation Research Record, 1852(1), pp.193-200.
14. BITRE 2022, Freight vehicle congestion in Australia's five major cities – 2021, BITRE, Canberra. https://www.bitre.gov.au/publications/2022/freight-vehicle-congestion-australias-five-major-cities-2021
15. BITRE 2023, Road Deaths Australia—Monthly Bulletins, BITRE, Canberra. https://www.bitre.gov.au/publications/ongoing/road_deaths_australia_monthly_bulletins

16. Bliemer, M. C. J., & Raadsen, M. P. J. (2004). A review of travel demand forecasting models used in practice. Transport Reviews, 24(2), 175-200.
17. Cambridge Systematics, 2015. Inc. with Texas Transportation Institute, Traffic Congestion and Reliability; Trends and Advanced Strategies for Congestion Mitigation.
18. Cost of road crashes in Australia 2006, Bureau of Infrastructure, Transport and Regional Economics.
19. Chen, Y., Zhang, Y., Xu, Y., Ma, W., & Wang, X. (2018). A mesoscopic simulation study of the impacts of different lane configurations on traffic flow and safety. Transportation Research Part C: Emerging Technologies, 88, 214-229.
20. Dia, H., and Director, I.T.S., 2011, March. Evaluation of the Impacts of ITS Using Traffic Simulation. In Institution of Professional Engineers New Zealand (IPENZ) Transportation Conference, 2011, Auckland, New Zealand.
21. Dia, H. and Gondwe, W., 2008, August. Evaluation of incident impacts on integrated motorway and arterial networks using traffic simulation. In Submitted to the 29th Australasian Transport Research Forum, to be held on the Gold Coast.
22. Department of Planning, Transport, and Infrastructure (DPTI). (n.d.). North-East Road. Retrieved from https://www.dpti.sa.gov.au/infrastructure/northeast_road
23. David A. Mfinanga and Emmanuel Fungo, 2013. Impact of Incidents on Traffic Congestion in Dar es Salaam City, International Journal of Transportation Science and Technology · vol. 2, no. 2, pages 95 – 107
24. Elefteriadou, L., Cui, X., 2007. A framework for defining and estimating travel time reliability. In: Proceedings of the TRB 86th Annual Meeting Compendium of papers, Washington, D.C.
25. Ferrara, A., Oleari, A.N., Sacone, S. and Siri, S., 2013, July. Case-study based performance assessment of an event-triggered MPC scheme for freeway systems. In 2013 European Control Conference (ECC) (pp. 4027-4032). IEEE.
26. Fontes, T., Lemos, A., Fernandes, P., Pereira, S.R., Bandeira, J.M. and Coelho, M.C., 2014. Emissions impact of road traffic incidents using Advanced Traveller Information Systems on a regional scale. Transportation research procedia, 3, pp.41-50.
27. Government of South Australia. (2019, July 1). $177 million for safety and congestion improvements on North-East Road. Retrieved from https://www.premier.sa.gov.au/news/media-releases/news/$177-million-for-safety-and-congestion-improvements-on-northeast-road
28. Government of South Australia. (2021, February 23). CCTV cameras boost safety on North-East Road. Retrieved from https://www.premier.sa.gov.au/news/media-releases/news/cctv-cameras-boost-safety-on-northeast-road
29. Gattis, J. L., & Porter, R. J. (2009). NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets. Transportation Research Board.
30. Gomes, G. M., De Vlieger, I., & De Moor, B. (2019). Microscopic simulation of urban road networks: A review of applications, models, and data requirements. Transport Reviews, 39(2), 189-212.

31. Houfu Dai , Shaobo Li, Genyu Chen., 2018, Comparison of subsurface damages on mono-crystalline silicon between traditional nanoscale machining and laser-assisted nanoscale machining via molecular dynamics simulation. Nuclear Inst. and Methods in Physics Research B 414 (2018) 61-67.
32. Helbing, D., Hennecke, A., Shvetsov, V. and Treiber, M., 2002. Micro-and macrosimulation of freeway traffic. Mathematical and computer modelling, 35(5-6), pp.517- 547.
33. Holyoak, N. and Stazic, B., 2009. Benefits of linking macro-demand forecasting models and microsimulation models. Institute of Transportation Engineers. ITE Journal, 79(10), p.30.
34. Hojati, A.T., Ferreira, L., Charles, P., and bin Kabit, M.R., 2012. Analysing freeway traffic-incident duration using an Australian data set. Road & Transport Research: A Journal of Australian and New Zealand Research and Practice, 21(2), p.19.
35. Hidas, P., 2002. Modelling lane changing and merging in microscopic traffic simulation. Transportation Research Part C: Emerging Technologies, 10(5-6), pp.351- 371.
36. Hall, R., & Hutton, M. (2004). Two applications of AIMSUN, a microsimulation transport modelling package. Transportation Research Part C: Emerging Technologies, 12(5), 317-334.
37. International Road Assessment Program (2004); Hensher, Rose, de Ortúzar and Rizzi (2009); Szabat and Knapp (2009); BITRE estimates.
38. Jin, W., & Chen, Y. (2020). Microscopic simulation modeling and analysis of bicycle and pedestrian activity: a review. Journal of Advanced Transportation, 2020.
39. Kabit, M.R.B, Charles, P., Ferreira, L. and Hojati, A.T., 2011. Examination of traffic incident records and development of a rapid incident response plan. Universiti Malaysia Sarawak.
40. Kabit, M.R.B., Charles, P., Ferreira, L. and Kim, I., 2014. Modelling major traffic incident impacts and estimation of their associated costs. Transportation planning and technology, 37(4), pp.373-390.
41. Koorey, G., McMillan, S. and Nicholson, A., 2015. Incident management and network performance. Transportation research procedia, 6, pp.3-16.
42. Knoop, V. L., De Winter, J. C., & Janssen, W. H. (2019). Overview of pedestrian behavior models in microscopic simulation tools. Transportation Research Record, 2673(10), 41-51.
43. Li, J., Lan, C.J. and Gu, X., 2006. Estimation of incident delay and its uncertainty on freeway networks. Transportation research record, 1959(1), pp.37-45.
44. Li, Z., Yu, H., Wang, W., Wang, J., & Liu, Y. (2019). Investigation of the impacts of roundabout design on traffic flow and safety using microscopic simulation. Journal of Traffic and Transportation Engineering (English Edition), 6(2), 142-154.
45. Lu, C., Xie, X., Guo, F., & Chen, H. (2018). Impacts of different incidents on traffic flow and safety: a microscopic simulation study. Journal of Traffic and Transportation Engineering (English Edition), 5(3), 207-215.
46. Liao, X., Chen, S., & Ma, Y. (2021). A review of traffic flow modeling and simulation: from macroscopic to microscopic scale. Journal of Advanced Transportation, 2021.
47. Leclercq, L., Parzani, C., Knoop, V. L., Amourette, J. & Hoogendoorn, S. P. 2015. Macroscopic traffic dynamics with heterogeneous route patterns. Transportation Research Procedia, 7, 631-650.

48. Mohammadian, A., Tavana, M., & Zanjani, M. K. (2018). Microscopic simulation investigation of the impacts of different traffic control strategies on traffic flow and congestion. Journal of Advanced Transportation, 2018, 1-13.
49. Ma, X., & Li, H. (2016). Development of a hybrid optimization approach for real-time traffic signal control. Transportation Research Part C: Emerging Technologies, 70, 46-60.
50. Ozbay, K. and Bartin, B., 2004. Estimation of economic impact of VMS route guidance using microsimulation. Research in transportation economics, 8, pp.215-241.
51. Punzo, V., Simonelli, F., & Vitale, A. (2019). Impacts of speed limit reductions on traffic flow and safety: A microscopic simulation approach. Transportation Research Part C: Emerging Technologies, 107, 96-114.
52. Rakha, H., Ramadan, O., Guo, Y., Ahn, K., & Zhang, Y. (2019). Modeling and analysis of the impacts of autonomous vehicles on traffic flow and safety using a mesoscopic simulation approach. IEEE Transactions on Intelligent Transportation Systems, 20(1), 330-339.
53. Schreckenberg, M., Neubert, L. & Wahle, J. 2001. Simulation of traffic in large road networks. Future Generation Computer Systems, 17, 649-657.
54. Song, X., Xie, Z., Xu, Y., Tan, G., Tang, W., Bi, J. and Li, X., 2017. Supporting real-world network-oriented mesoscopic traffic simulation on GPU. Simulation Modelling Practice and Theory, 74, pp.46-63.
55. South Australian Police. (2021). Crash statistics. Retrieved from https://www.police.sa.gov.au/services-and-events/crash-statistics
56. Transportation Research Board. (2000). Highway Capacity Manual (4th ed.). Washington, DC: National Research Council.
57. Transport Accident Commission. (2017). The economic cost of road crashes in South Australia. Retrieved from https://www.tac.vic.gov.au/__data/assets/pdf_file/0005/338600/Economic-Cost-Road-Crashes-South-Australia.pdf
58. Transport Department of South Australia. (2020). North-East Road Upgrade. Retrieved from https://www.dpti.sa.gov.au/infrastructure/northeast_road_upgrade
59. Travel Time Reliability Working Group. (2012). Travel time reliability. Retrieved from https://ops.fhwa.dot.gov/publications/fhwahop12038/fhwahop12038.pdf
60. Transport Simulation Systems (n.d.). AIMSUN. Retrieved from https://www.aimsun.com/
61. Taylor, M.A., 2008. Critical transport infrastructure in Urban areas: impacts of traffic incidents assessed using accessibility-based network vulnerability analysis. Growth and Change, 39(4), pp.593-616.
62. Wang, L., Li, J., Li, Y., & Feng, J. (2018). Evaluation of microscopic simulation model calibration using data-driven methods. Transportation
63. Wang, Y., Li, J., & Li, M. (2016). Analysis of un-signalized intersection safety using SIDRA. Journal of Safety Science and Technology, 12(6), 89-94.
64. Wang, Y. and Cheevarunothai, P., Quantifying Incident-Induced Travel Delays on Freeways Using Traffic Sensor Data. Final research report for Washington State Department of Transportation, US Department of Transportation, No. WA-RD 700.1-TNW2008-07, 2008.

65. Younshik Chung, Hanseon Cho, Keechoo Choi, 2013. Impacts of freeway accidents on CO2 emissions: A case study for Orange County, California, US. Transportation research part D: transport and environment, 24, 120-126.
66. Zhu, J., & Abdel-Aty, M. (2014). Investigating the impact of intersection design on safety performance using microscopic simulation. Accident Analysis & Prevention, 72, 288-299.
67. Zhang, Z., Sun, D., Xu, Y., & Zhang, H. (2019). Macroscopic simulation of bus priority strategies on urban road networks. Transportation Research Part A: Policy and Practice, 129, 110-130.

Appendix A

SIDRA

Figure removed due to copyright restriction.

FIGURE 29 SITE LAYOUT TS029

Figure removed due to copyright restriction.

FIGURE 30 VOLUME DATA TS029

Figure removed due to copyright restriction.

FIGURE 31 PRIORITIES TS029

Figure removed due to copyright restriction.

FIGURE 32 VEHICLE MOVEMENT DATA TS029

Figure removed due to copyright restriction.

FIGURE 33 PHASING SUMMARY TS029

Figure removed due to copyright restriction.

FIGURE 34 DEGREE OF SATURATION TS029

Figure removed due to copyright restriction.

FIGURE 35 LEVEL OF SERVICE TS029

s

Figure removed due to copyright restriction.

FIGURE 36 AVG QUEUE DISTANCE TS029

Figure removed due to copyright restriction.

FIGURE 37 SPEED EFFICIENCY TS029

Figure removed due to copyright restriction.

FIGURE 38 SITE LAYOUT TS168

Figure removed due to copyright restriction.

FIGURE 39 VOLUME DATA TS168

Figure removed due to copyright restriction.

FIGURE 40 PRIORITIES TS168

Figure removed due to copyright restriction.

FIGURE 41 VEHICLE MOVEMENT DATA TS168

Figure removed due to copyright restriction.

FIGURE 42 PHASING SUMMARY TS168

Figure removed due to copyright restriction.

FIGURE 43 DEGREE OF SATURATION TS168

Figure removed due to copyright restriction.

FIGURE 44 LEVEL OF SERVICE TS168

Figure removed due to copyright restriction.

FIGURE 45 AVG QUEUE DISTANCE TS168

Figure removed due to copyright restriction.

FIGURE 46 SPEED EFFICIENCY TS168

Figure removed due to copyright restriction.

FIGURE 47 NETWORK LAYOUT

Figure removed due to copyright restriction.

FIGURE 48 NETWORKING TIMING

Figure removed due to copyright restriction.

FIGURE 49 NETWORK SIGNAL PHASE TIMINGS

Figure removed due to copyright restriction.

FIGURE 50 LEVEL OF SERVICE EXISTING NETWORK

Figure removed due to copyright restriction.

FIGURE 51 LEVEL OF SERVICE AFTER 10 YEARS

Figure removed due to copyright restriction.

FIGURE 52 DEGREE OF SATURATION

Figure removed due to copyright restriction.

FIGURE 53 LEVEL OF SERVICE EXISTING NETWORK

Figure removed due to copyright restriction.

FIGURE 54 LEVEL OF SERVICE AFTER 10 YEARS

Figure removed due to copyright restriction.

FIGURE 55 AVG QUEUE DISTANCE

Figure removed due to copyright restriction.

FIGURE 56 SPEED EFFICIENCY

Figure removed due to copyright restriction.

FIGURE 57 NETWORK PERFORMANCE - HOURLY VALUES

Figure removed due to copyright restriction.

FIGURE 58 NETWORK PERFORMANCE - ANNUAL VALUES

Appendix B

AIMSUN

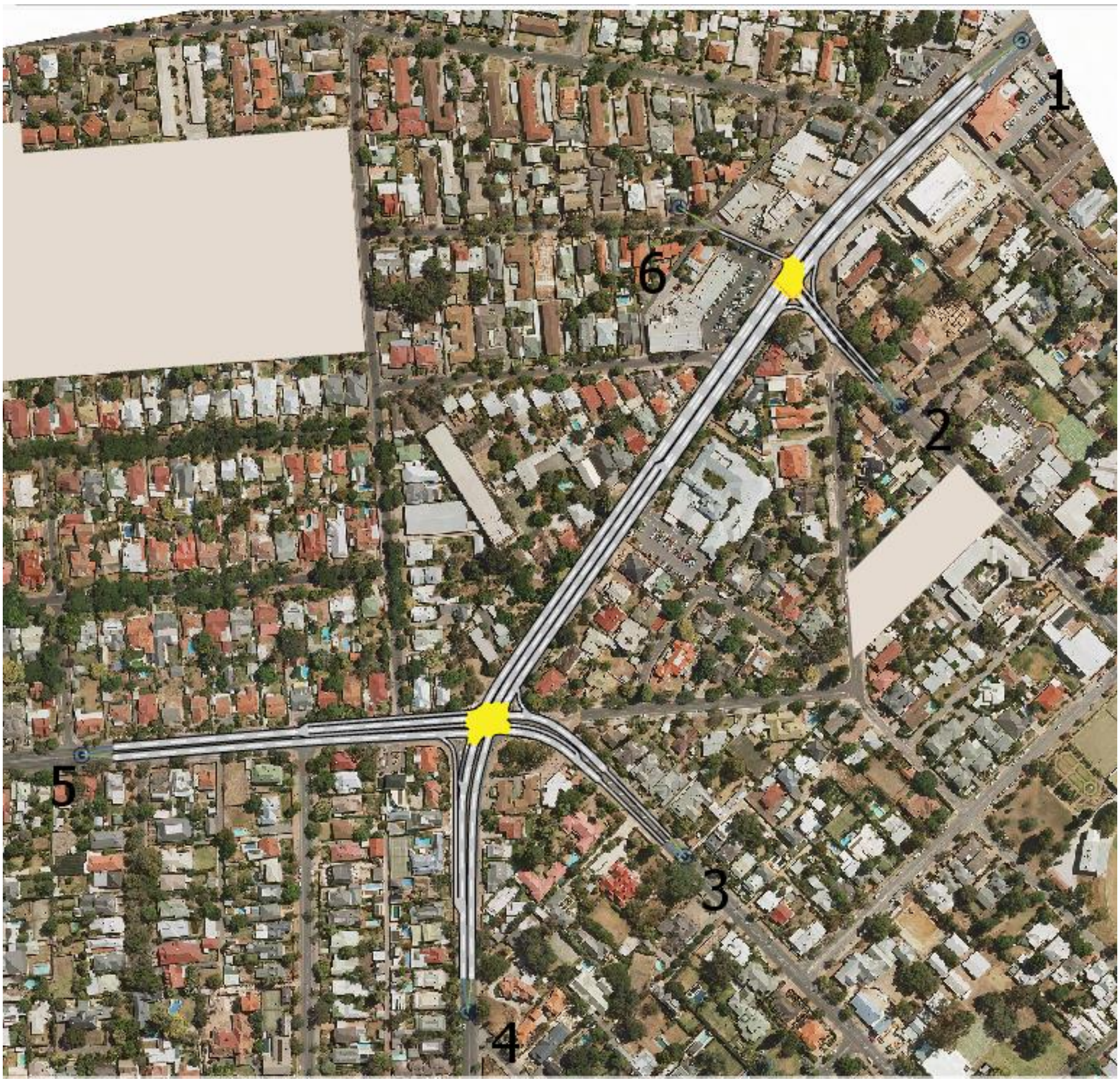


FIGURE 59 WHOLE NETWORK LAYOUT IN AIMSUN

Figure removed due to copyright restriction.

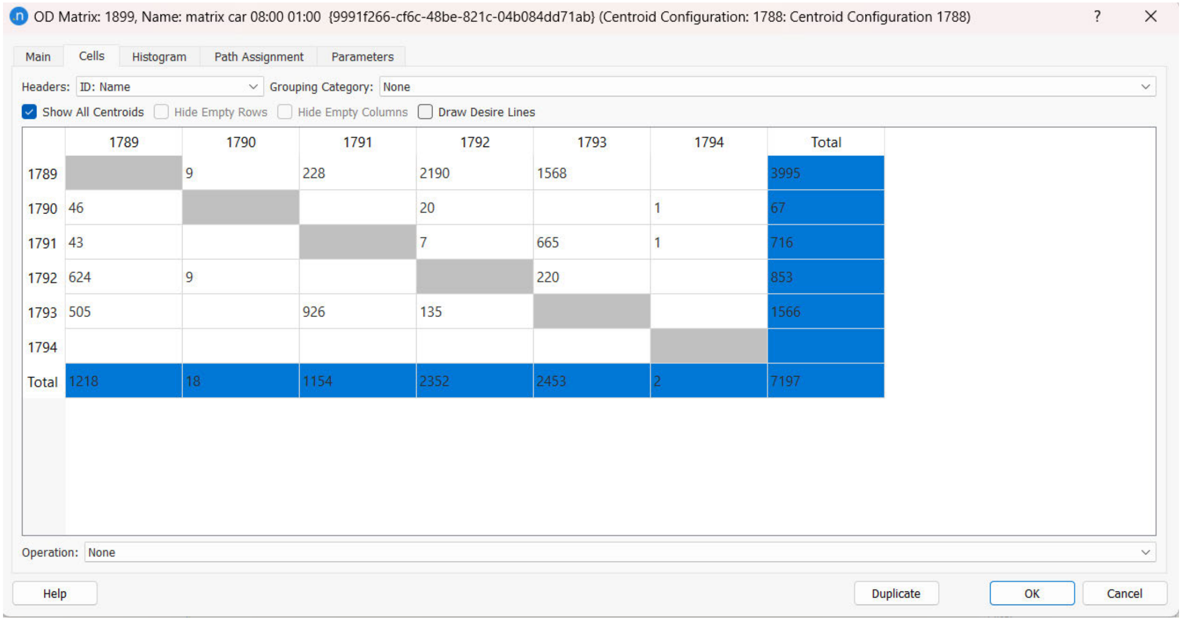
FIGURE 60 INTERSECTION LAYOUT TS029

Figure removed due to copyright restriction.

FIGURE 61 INTERSECTION LAYOUT TS168

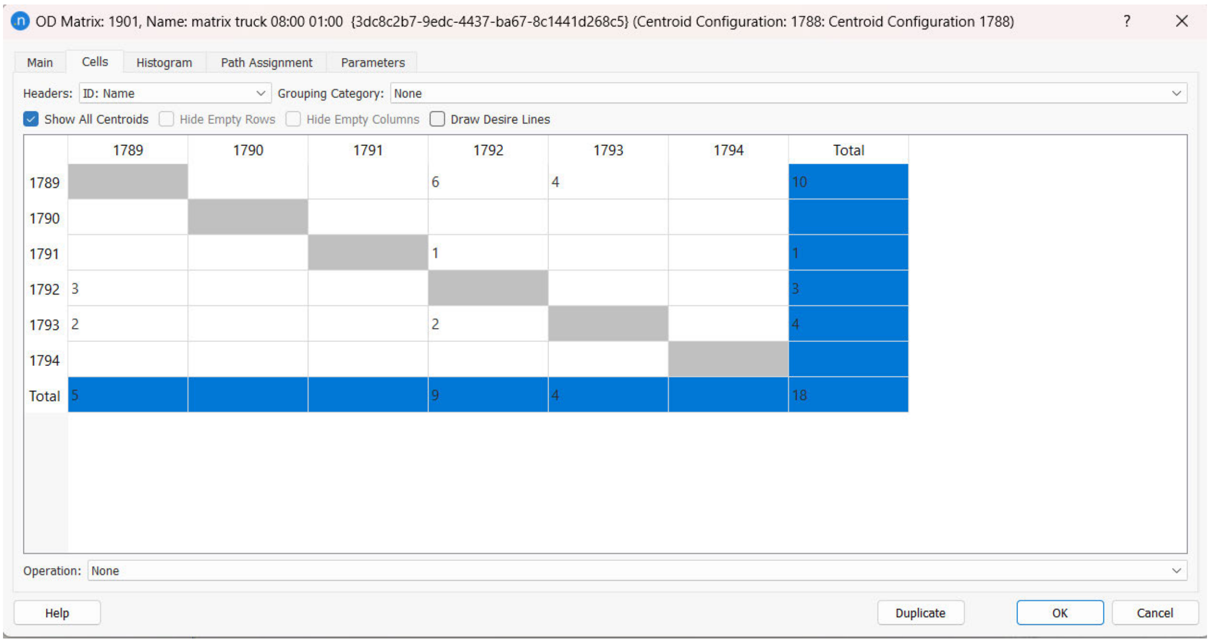
Figure removed due to copyright restriction.

FIGURE 62 NETWORK LAYOUT



	1789	1790	1791	1792	1793	1794	Total
1789		9	228	2190	1568		3995
1790	46			20		1	67
1791	43			7	665	1	716
1792	624	9			220		853
1793	505		926	135			1566
1794							
Total	1218	18	1154	2352	2453	2	7197

FIGURE 63 O-D MATRIX FOR CAR



	1789	1790	1791	1792	1793	1794	Total
1789				6	4		10
1790							
1791				1			1
1792	3						3
1793	2			2			4
1794							
Total	5			9	4		18

FIGURE 64 O-D MATRIX FOR TRUCK

Figure removed due to copyright restriction.

FIGURE 65 GEH VALUE FOR THE MODEL CALIBRATION

Figure removed due to copyright restriction.

FIGURE 66 INCIDENT LOCATION 1

Figure removed due to copyright restriction.

FIGURE 67 INCIDENT LOCATION 2

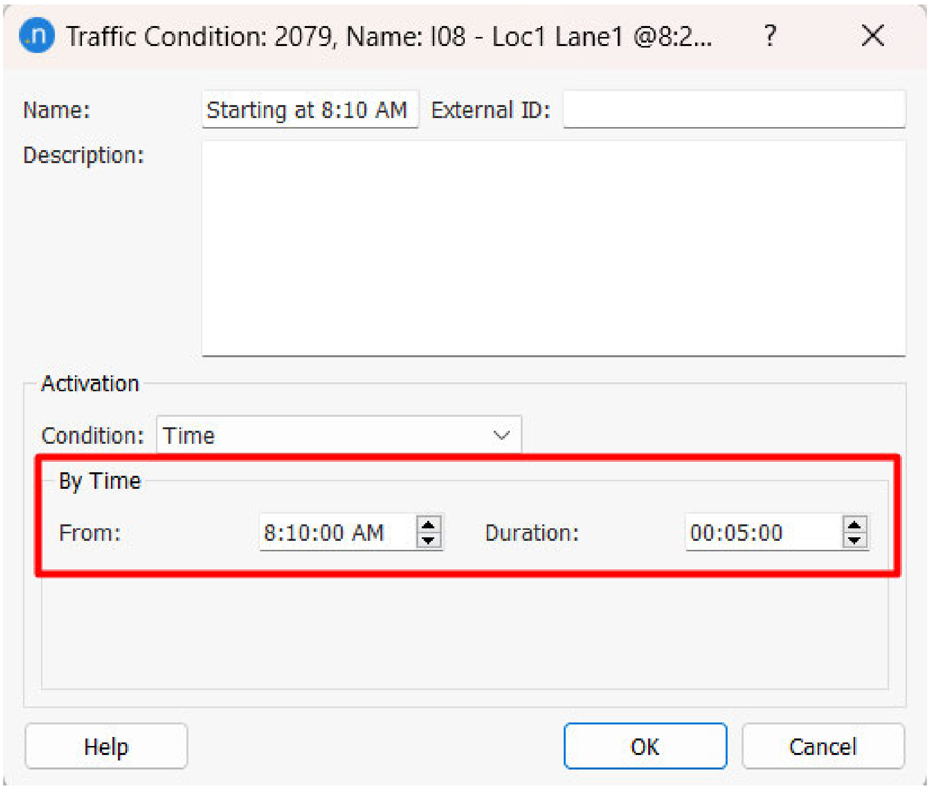


FIGURE 68 INCIDENT STARTING AT 8:10 AM FOR 5 MINUTES DURATION

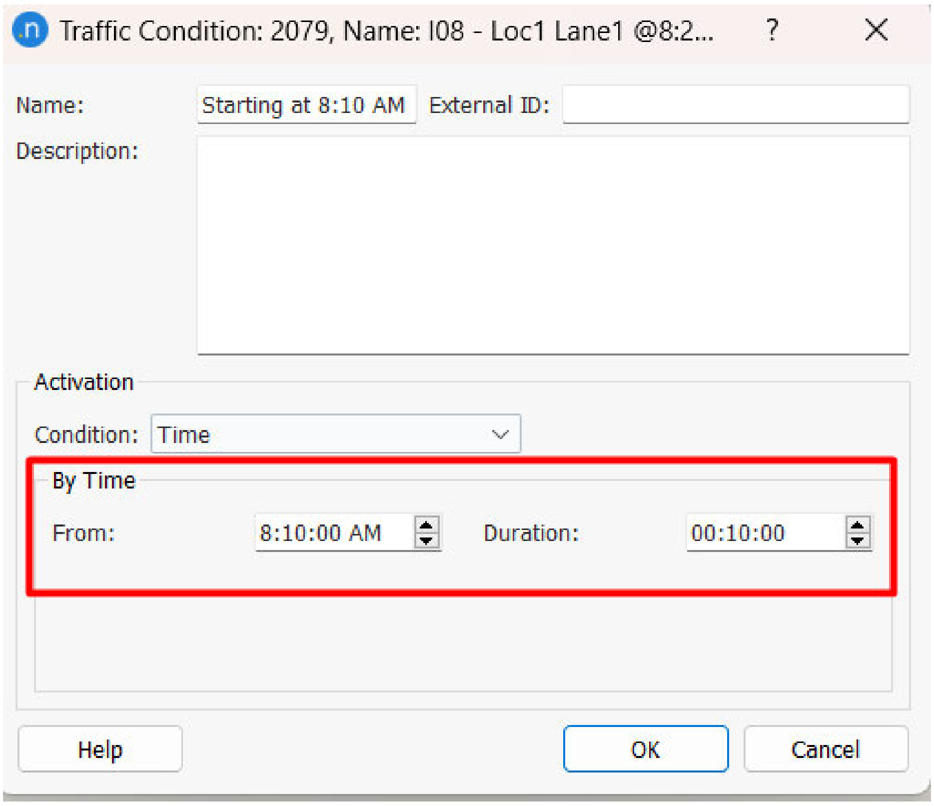


FIGURE 69 INCIDENT STARTING AT 8:10 AM FOR 10 MINUTES DURATION

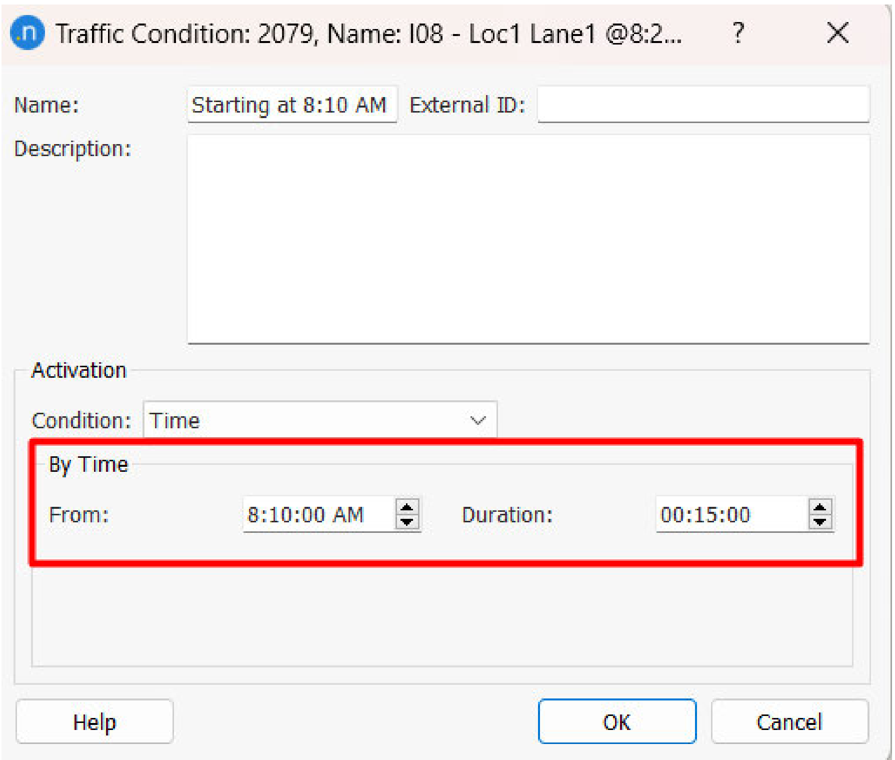


FIGURE 70 INCIDENT STARTING AT 8:10 AM FOR 15 MINUTES DURATION

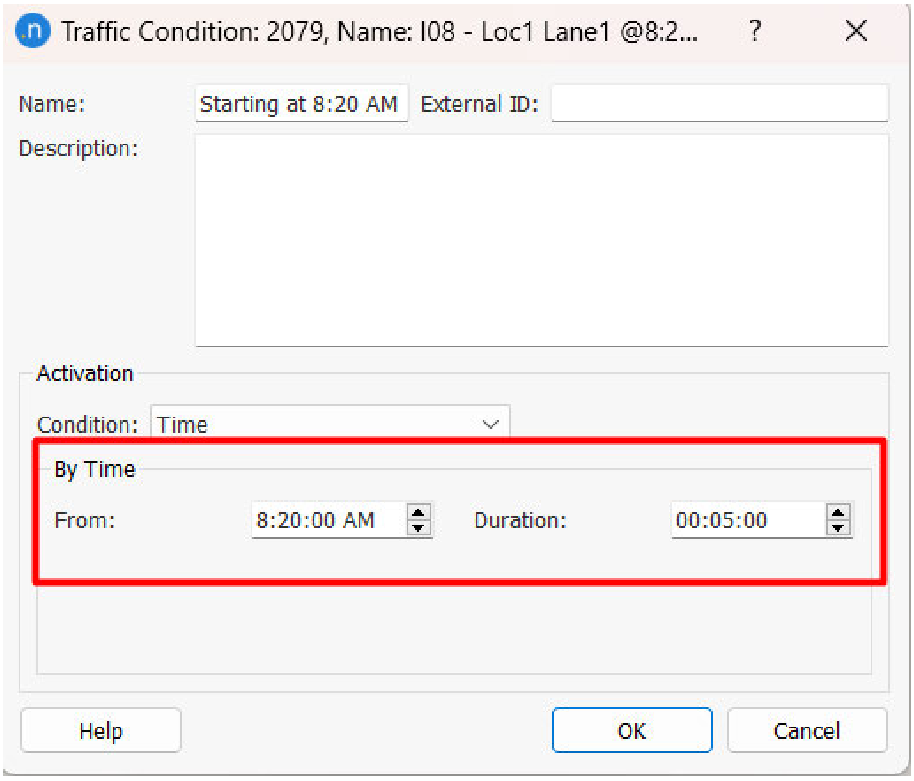


FIGURE 71 INCIDENT STARTING AT 8:20 AM FOR 5 MINUTES DURATION

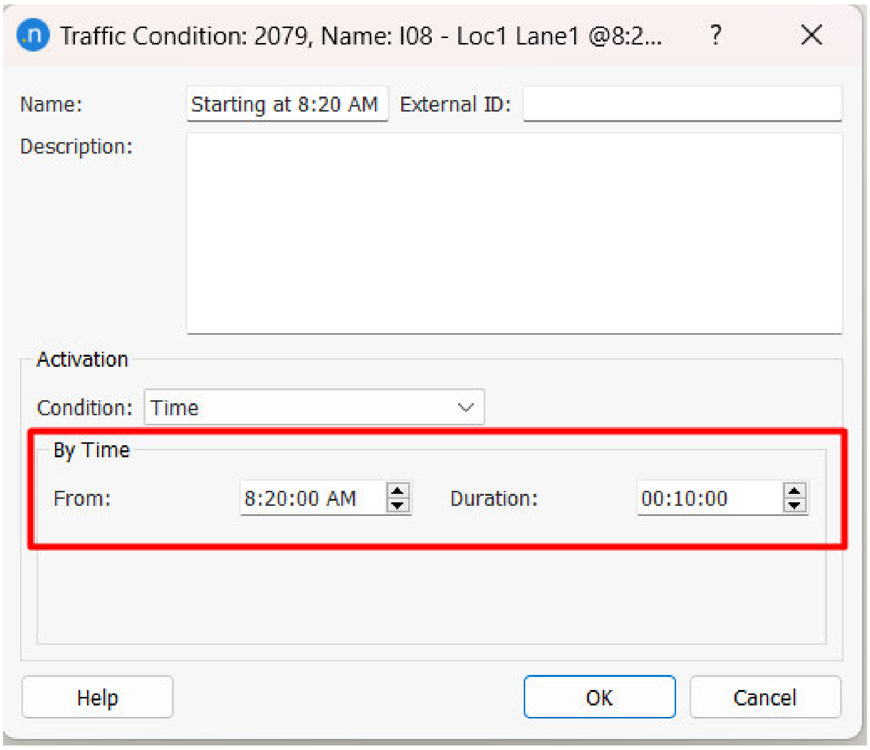


FIGURE 72 INCIDENT STARTING AT 8:20 AM FOR 10 MINUTES DURATION

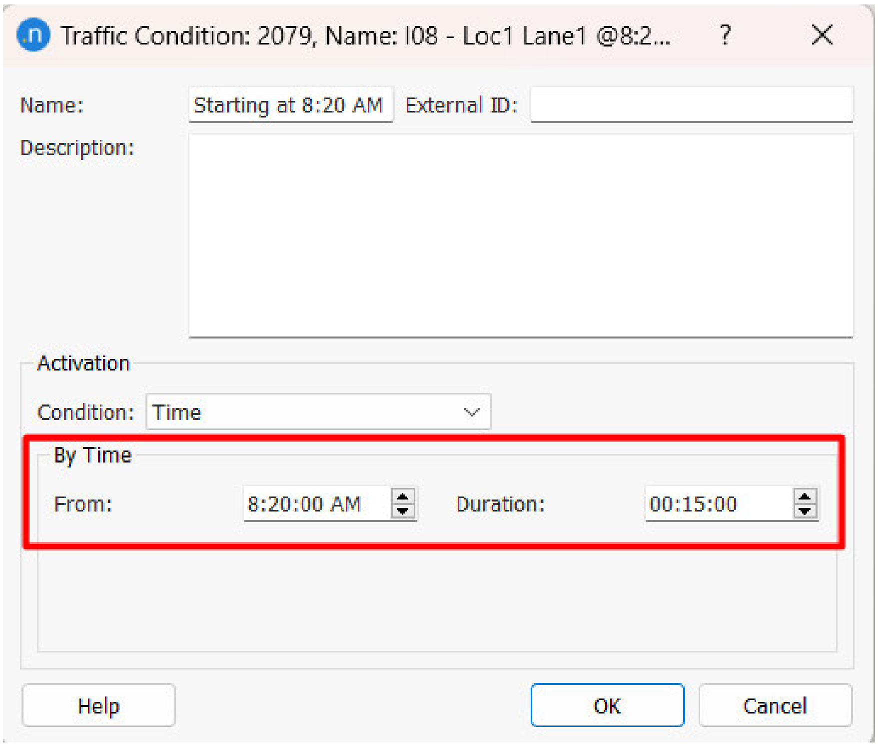


FIGURE 73 INCIDENT STARTING AT 8:20 AM FOR 15 MINUTES DURATION

Click here to check All outputs from AIMSUN - [Master Thesis - AIMSUN Outputs.xlsx]

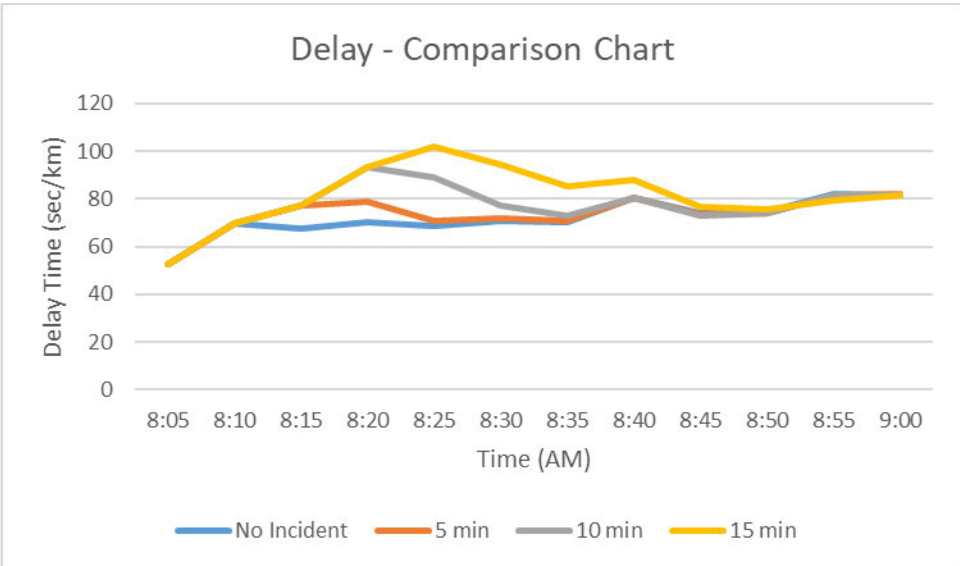


FIGURE 74 SCENARIO 2A - DELAY COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

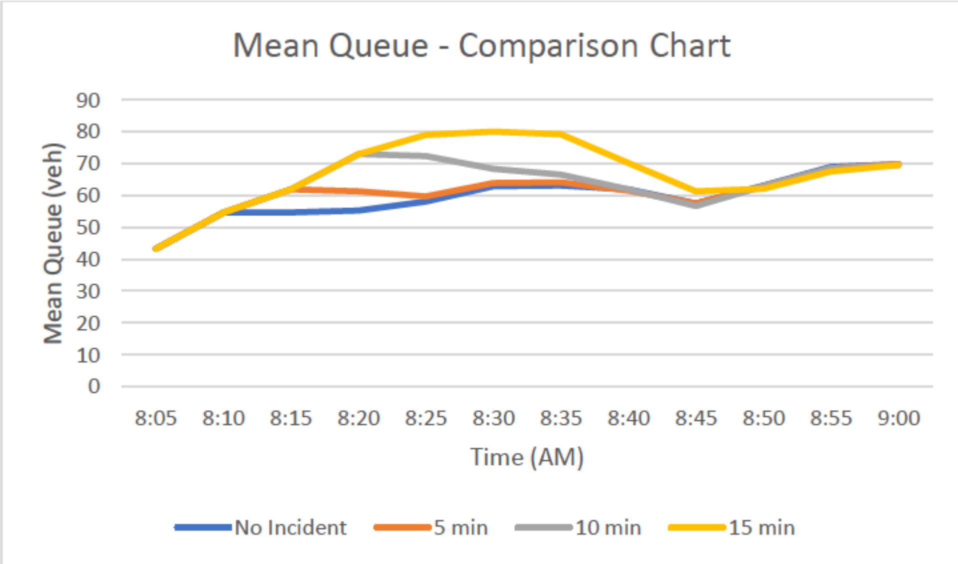


Figure 75 Scenario 2A - Mean Queue comparison between 5, 10, and 15 minutes duration incident outputs

Figure 76 Scenario 2A - speed comparison between 5, 10, and 15 minutes duration incident outputs

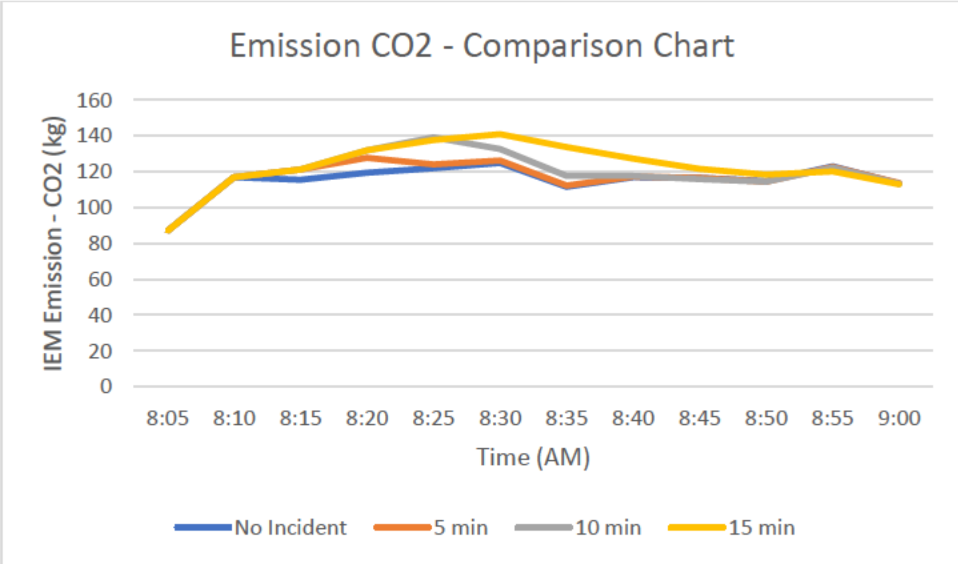


FIGURE 77 SCENARIO 2A - EMISSION CO2 COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

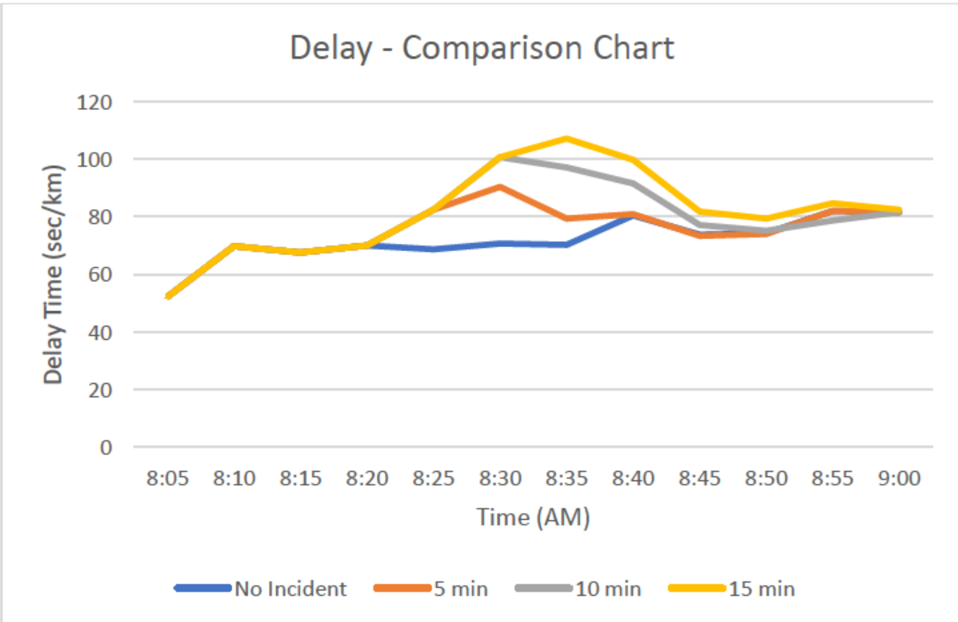


FIGURE 78 SCENARIO 2B - DELAY COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

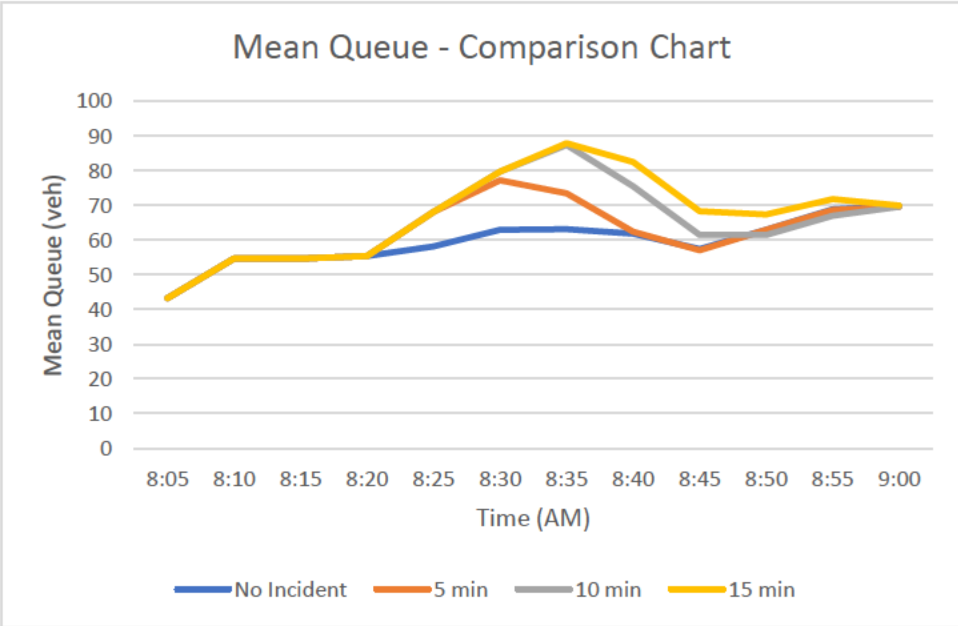


Figure 79 Scenario 2B - Mean Queue comparison between 5, 10, and 15 minutes duration incident outputs

Figure 80 Scenario 2B - Speed comparison between 5, 10, and 15 minutes duration incident outputs

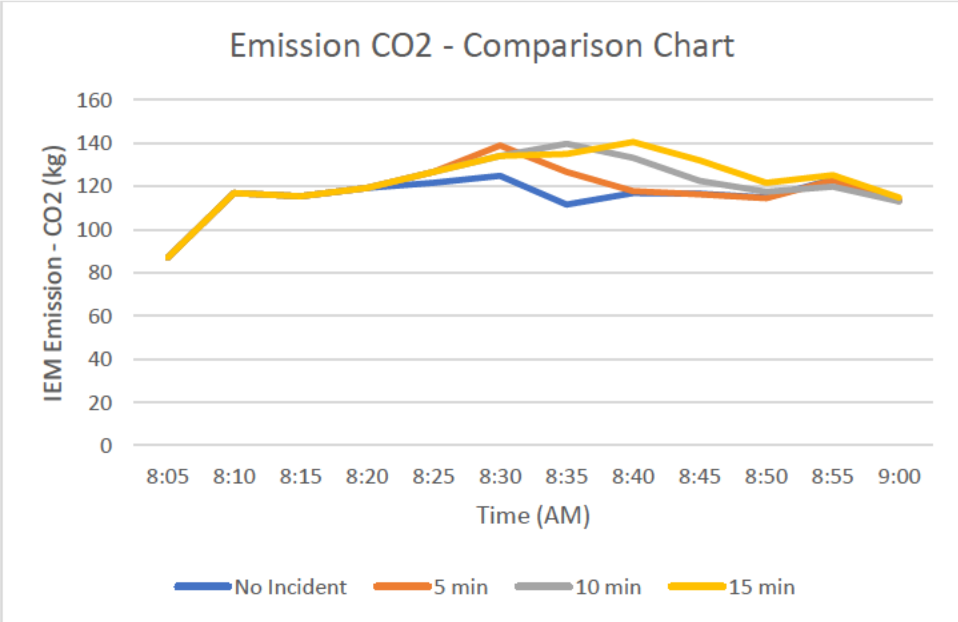


FIGURE 81 SCENARIO 2B - EMISSION CO2 COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

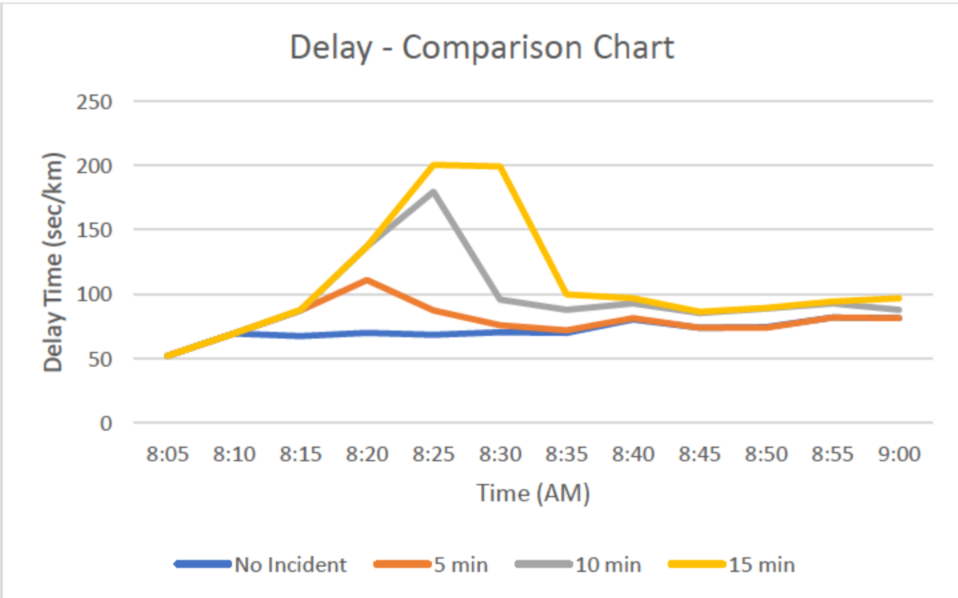


FIGURE 82 SCENARIO 2C - DELAY COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

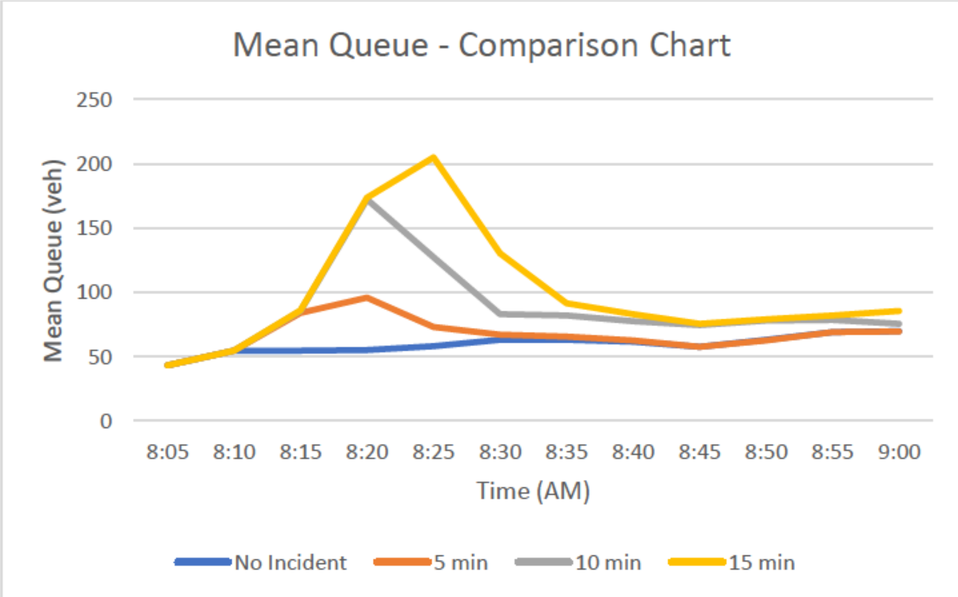


Figure 83 Scenario 2C - Mean Queue comparison between 5, 10, and 15 minutes duration incident outputs

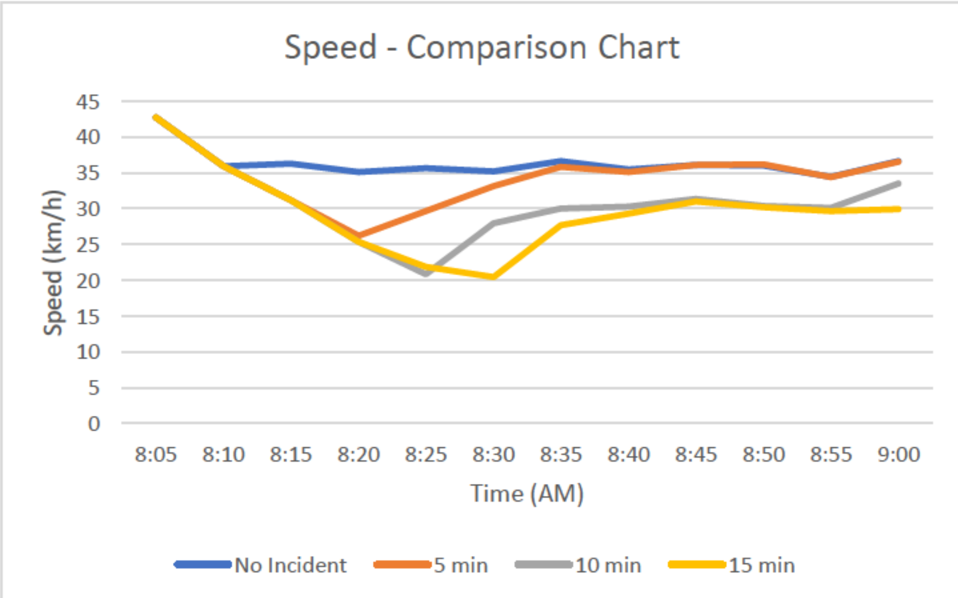


Figure 84 Scenario 2C - Speed comparison between 5, 10, and 15 minutes duration incident outputs

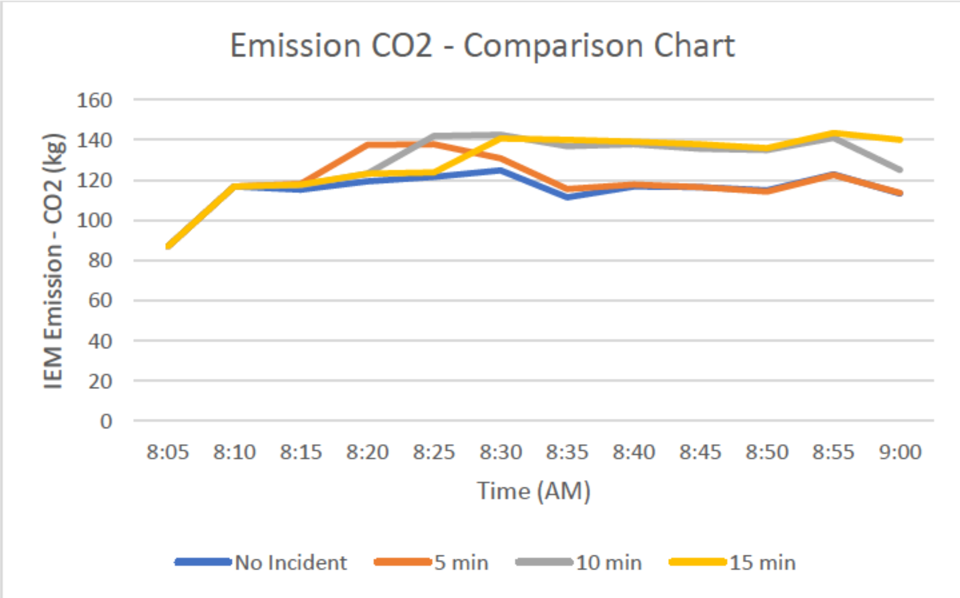


FIGURE 85 SCENARIO 2C - EMISSION CO2 COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

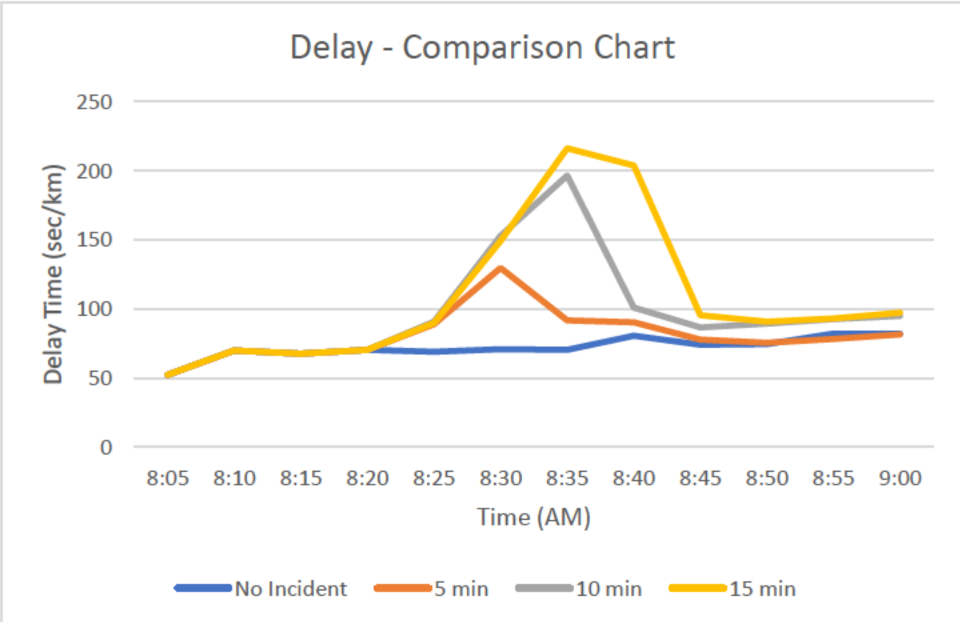


FIGURE 86 SCENARIO 2D - DELAY COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

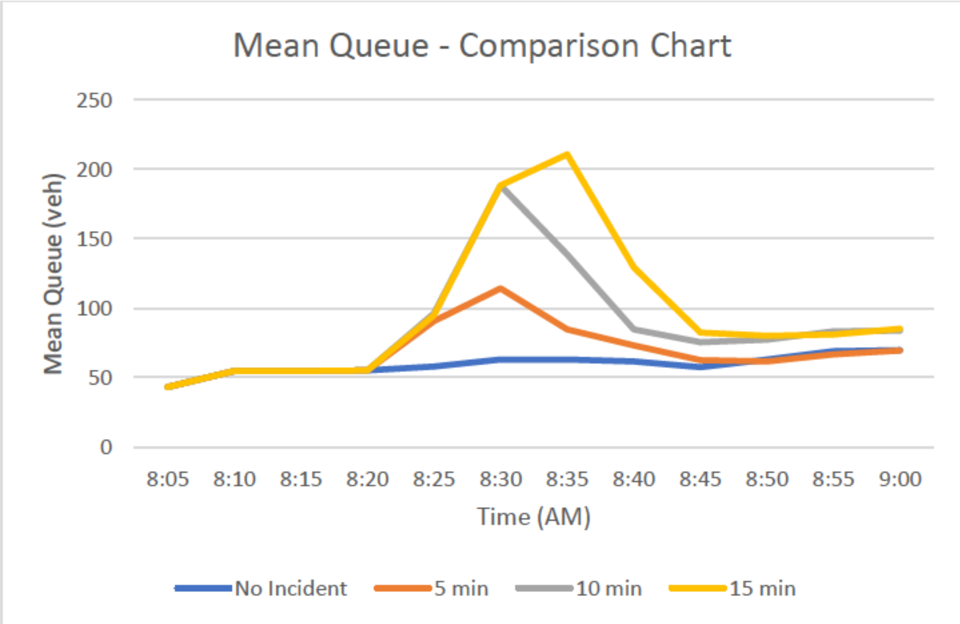


FIGURE 87 SCENARIO 2D - MEAN QUEUE COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

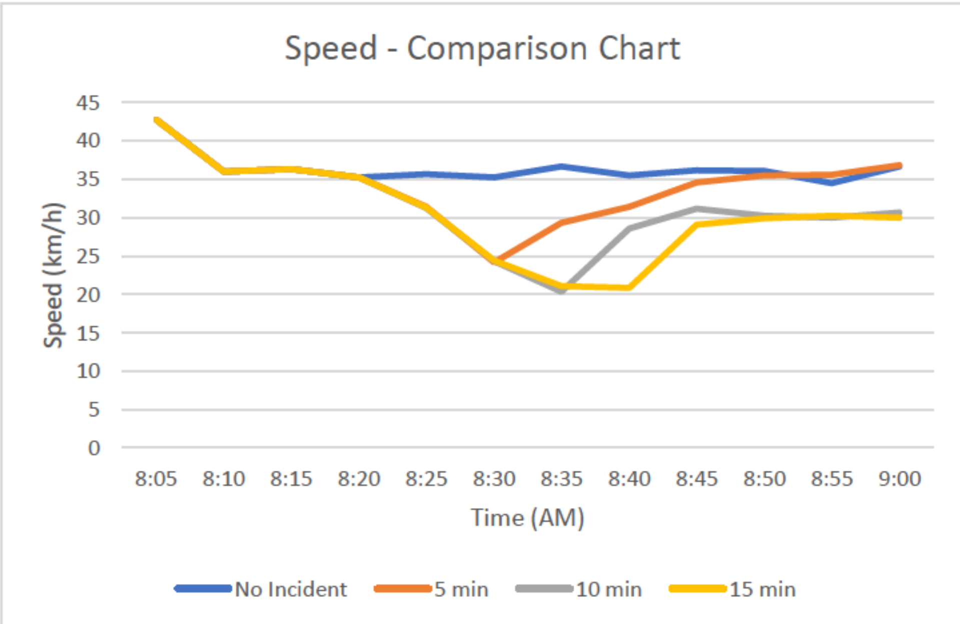


FIGURE 88 SCENARIO 2D - SPEED COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

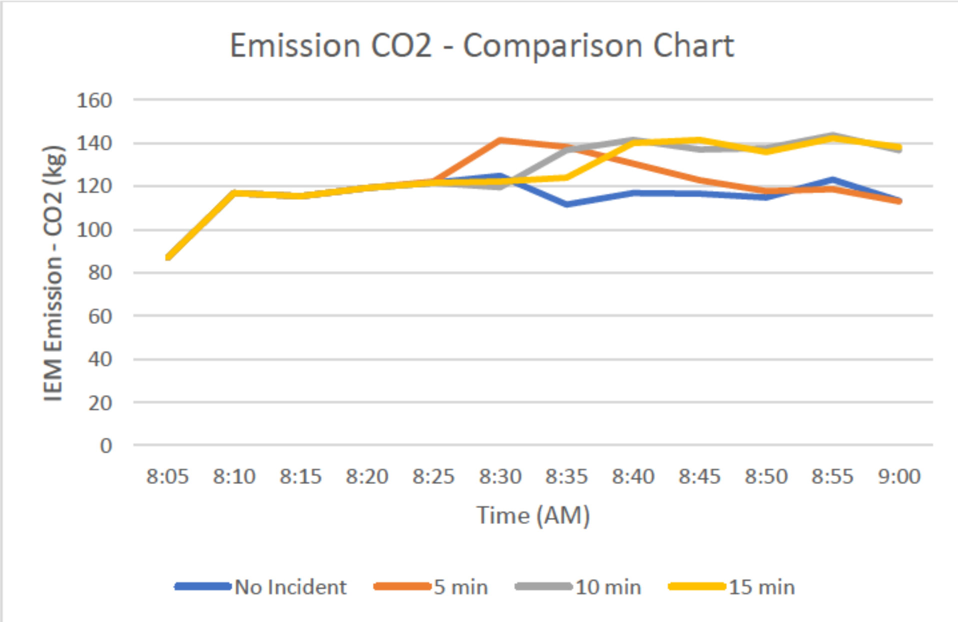


FIGURE 89 SCENARIO 2D - EEMISSION CO2 COMPARISON BETWEEN 5, 10, AND 15 MINUTES DURATION INCIDENT OUTPUTS

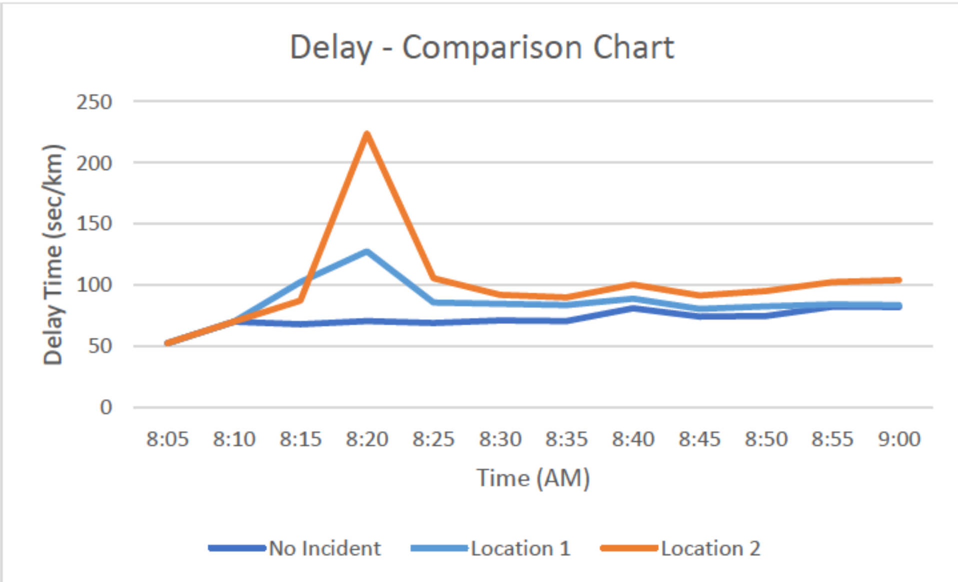


FIGURE 90 SCENARIOS 3 - DELAY COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:10 AM OUTPUTS

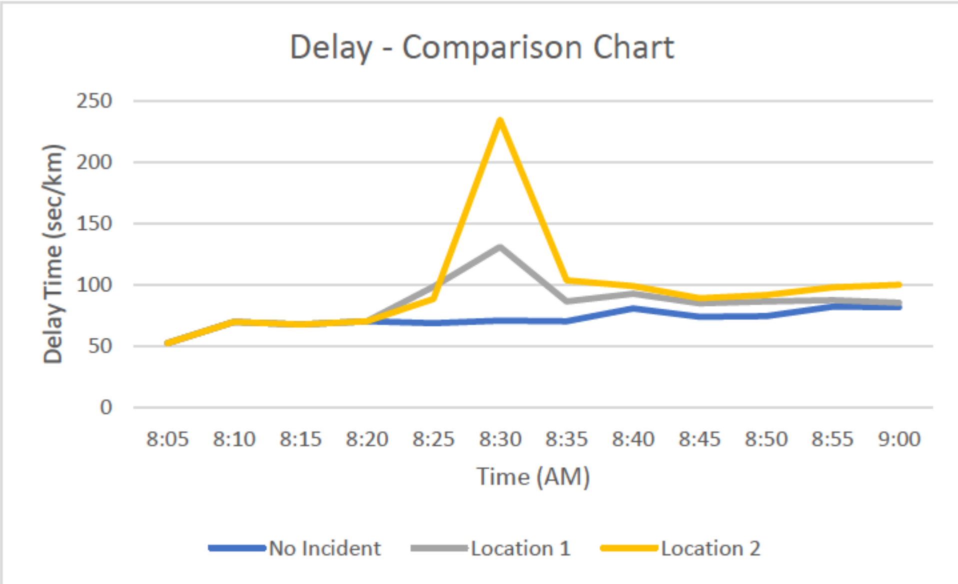


FIGURE 91 SCENARIOS 3 - DELAY COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:20 AM OUTPUTS

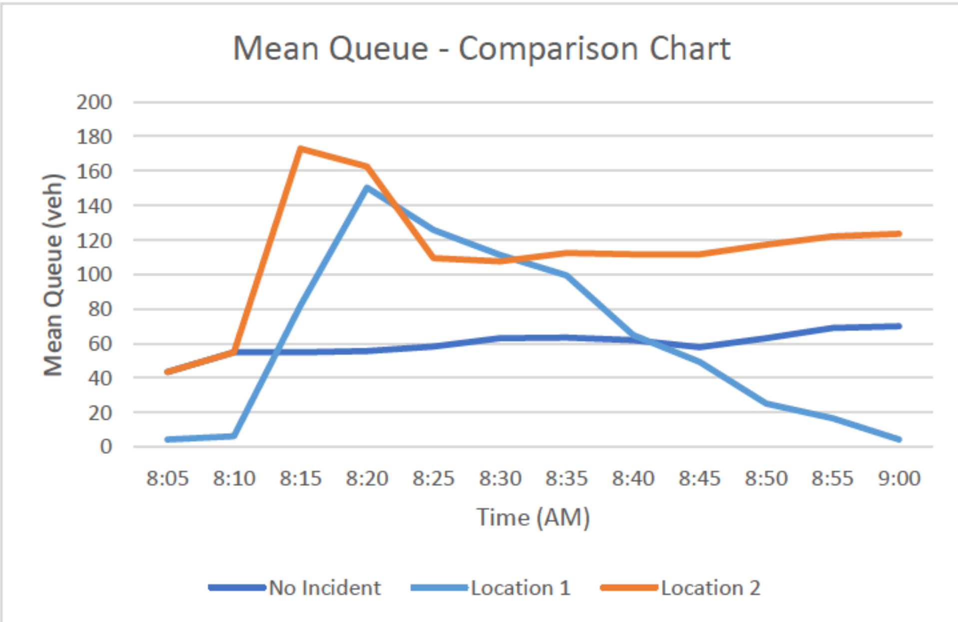


FIGURE 92 SCENARIOS 3 – MEAN QUEUE COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:10 AM OUTPUTS

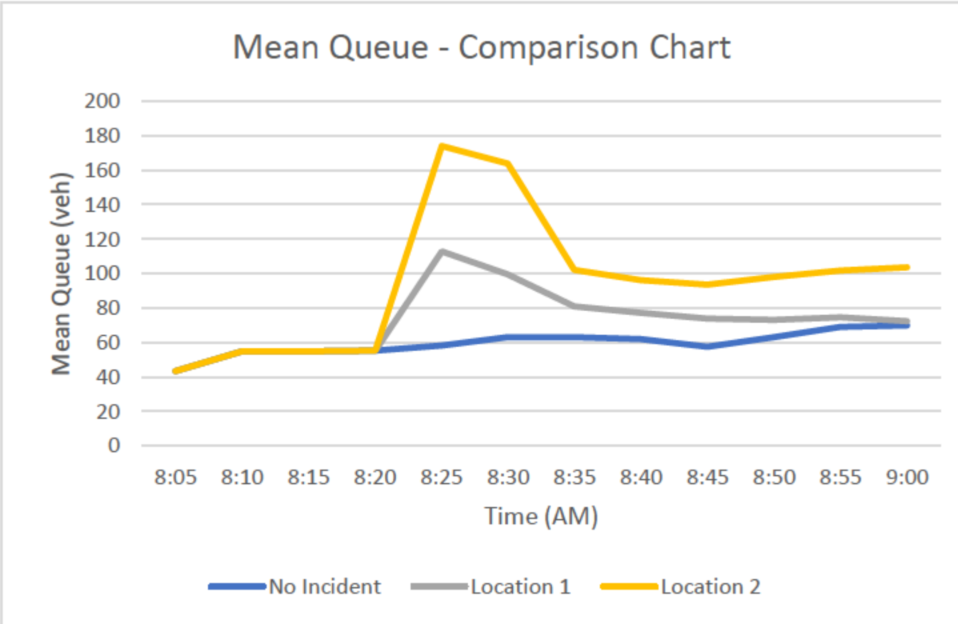


FIGURE 93 SCENARIOS 3 – MEAN QUEUE COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:20 AM OUTPUTS

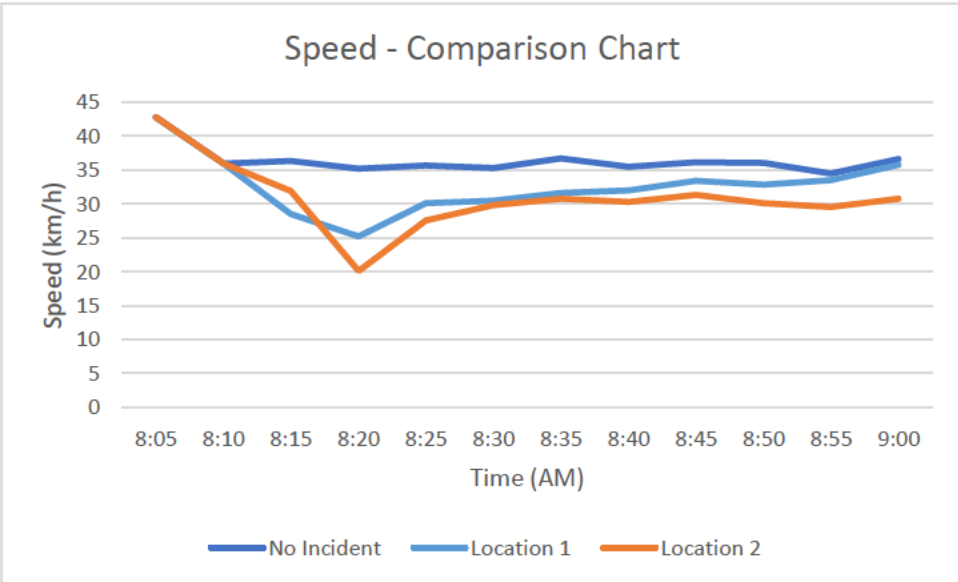


FIGURE 94 SCENARIOS 3 – SPEED COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:10 AM OUTPUTS

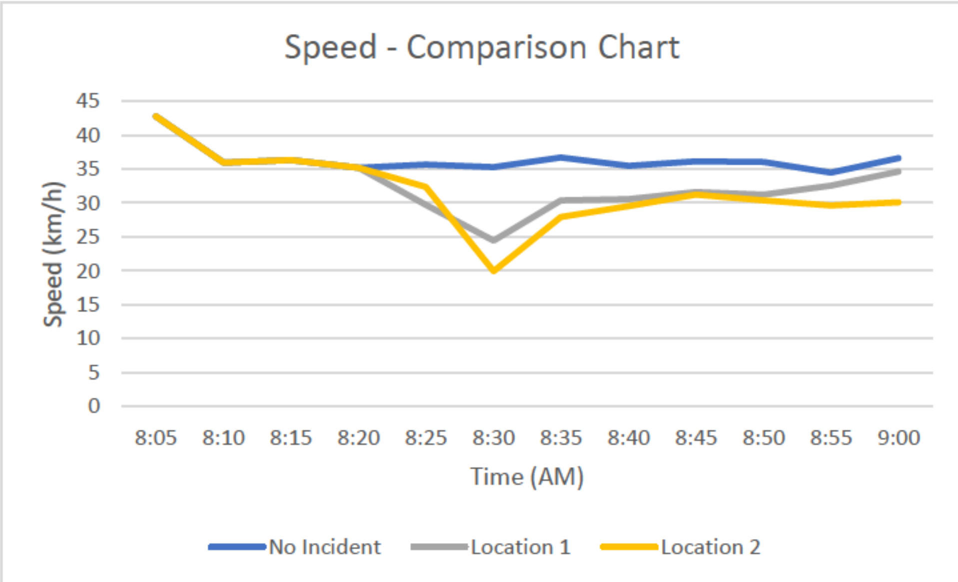


Figure 95 Scenarios 3 – Speed comparison between location 1 and location 2, which Incident starting at 8:20 AM outputs

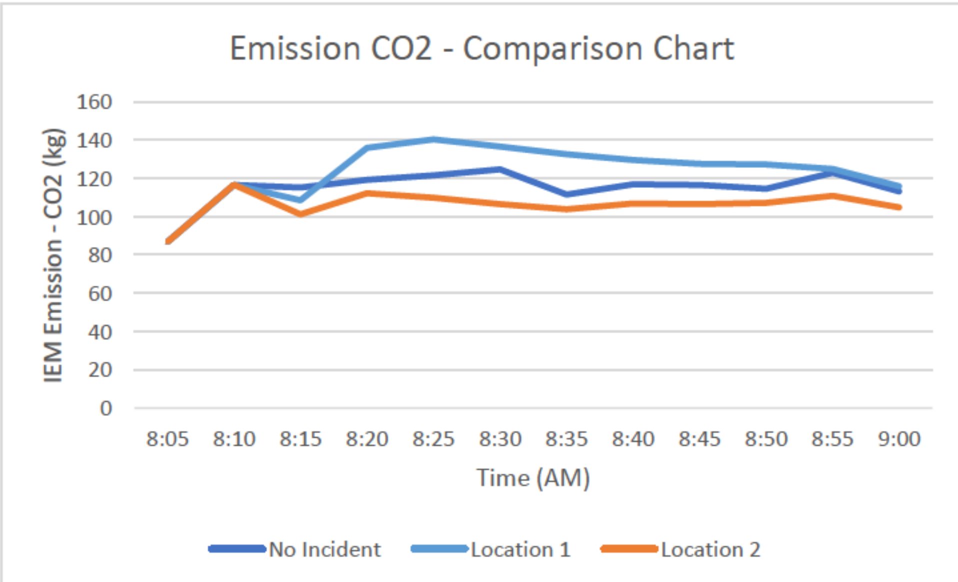


Figure 96 Scenarios 3 – Emission CO2 comparison between location 1 and location 2, which Incident starting at 8:10 AM outputs

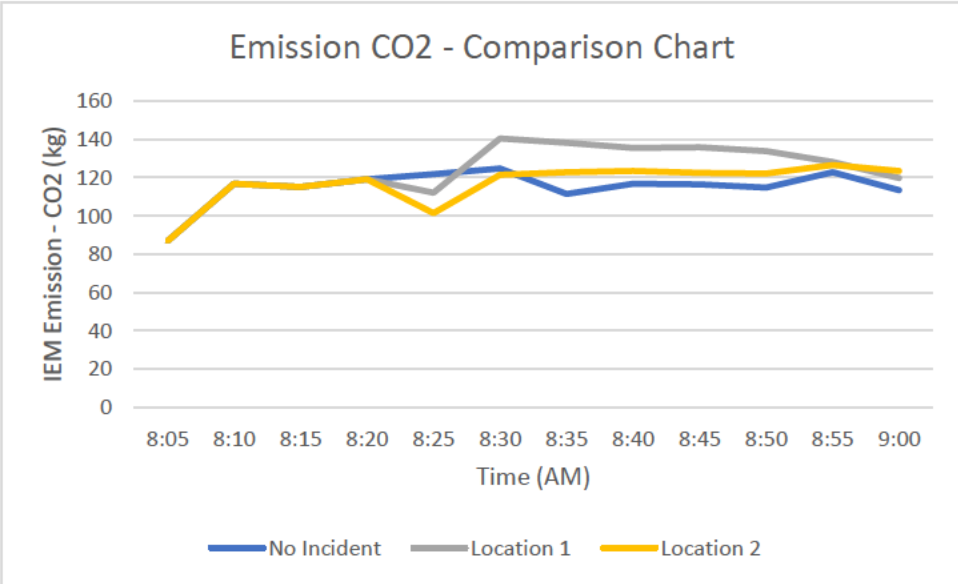


FIGURE 97 SCENARIOS 3 – EMISSION CO2 COMPARISON BETWEEN LOCATION 1 AND LOCATION 2, WHICH INCIDENT STARTING AT 8:20 AM OUTPUTS

Click here to check more outputs from AIMSUN - [Master Thesis - AIMSUN Outputs.xlsx]