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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Automatic accident detection and notification system using IoT-based vehicular environment

Mohmad Iqbal Mir

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

SUPERVISOR :

Prof. dr. ir. Ansar-Ul-Haque YASAR

MENTOR :

De heer Dimitrios ZAVANTIS

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PREFACE

During the course of Master of Transportation sciences at Hasselt University, I gained enormous knowledge in various aspects of transportation sciences that helped me to discover my work even more. I have been working at Sharjah Roads and Transport Authority (SRTA) in UAE since 2012 and have good experience in traffic management issues. SRTA is a government entity, which deals with roads and transport sectors within Sharjah Emirate of United Arab Emirates. The core business of SRTA is to provide access free road infrastructure, and public transport and taxi services within the Emirate. During my academic years at Hasselt, I have been taught about different modes of transport, human behavior, transport planning etc. I did not only gain a lot of knowledge but more importantly, I also had a great chance to sharpen my skills in a professional working environment. This was crucial in developing my professional career, which helped me to become more efficient in my work. The university studies helped me a lot to strengthen my problem-solving skills that made me think more scientifically.

During all these years, I have been hearing frequently about the Intelligent transport system (ITS). These definitions were not that familiar to me. How difficult is it to monitor and implement such types of systems? What are the main challenges associated with such types of systems? How difficult is to implement a centralized system and other ITS features for mobility? Is it possible to apply these ITS features in the UAE? These were important concerns and challenging questions for me while selecting the specific topic to my research.

With these thoughts, I have started reading about these systems and I was impressed with what the possibilities could be for these systems. Moreover, I was keen to search all possible potential issues or problems that were associated with these systems. People working with traffic engineering aspects are well aware about the importance of traffic safety in day-to-day life. Our job is to protect the people that are using the transportation system and keep the traffic moving smoothly throughout the traffic diversion or any traffic calamity such as traffic accidents. In order to succeed, we use cutting-edge equipment and plenty of systems. However, how difficult is it to keep the traffic moving smoothly in case of a dense traffic, since we know that the human factor is one of the most important factors that cause traffic accidents and is challenging to solve as well.

Finally, I would like to thank my parents and family for their endless support in all these years. I would like to appreciate Dr. Prof. Ansar Yasar, my promotor at Hasselt. Dr. Yasar gave me free hand to practice all the skills and assigned me a wonderful supervisor Mr. Dimitrios. Not only that the tips, which Dr. Ansar provided me during the induction meeting of this project, were quite amazing. I also would like to express my gratitude to Mr. Dimitrios Zavantis who has provided me a lot under his supervision, and more importantly for his enthusiastic encouragement and precious instructions during my research period. He gave me in-time feedback on my research and helped to organize an interesting thesis draft in which I could present my ideas and achievements to other professors and researchers of the faculty. In conclusion, I would like to thank Hasselt University for introducing me to this great opportunity in which I have developed myself both academically and professionally.

SUMMARY

This report is a detailed overview of my master thesis that elaborates on automatic accident detection and notification system using IoT-based vehicular environment such as Advanced Monitoring, Management and Enforcement of Road Traffic Infrastructures using ITS more specifically on the enforcement of traffic signal at the intersection in order to overcome traffic congestions such as bottlenecking. I have tried my level best to make it meaningful by reflecting on my works, however, there are many challenges that I faced.

In this research paper, I have examined hot spots where we have more traffic issues such as more traffic accidents, careless driving issues and various others. Hence, to control such violations and consequently improve road safety. One of the strategies I have deployed is to enforce Road Traffic Infrastructures by using Intelligent Transport Systems (ITS) such as installation of traffic signals at the intersections to reduce traffic accidents and congestion on the roads. Therefore, I have chosen "T-intersection" within the Sharjah emirate of UAE in which I have performed VISSIM analysis. While performing VISSIM analysis, initially I deployed "Stop Signs" as a control mode and fetched "Queue and Travel time result". Then, I deployed "Traffic Signals" as a control mode and fetched "Queue and Travel time results". After completing the analysis, I have compared the results and represented all the results in terms of line graph. The line graph shows that "Queue lengths and travel times" are less in stop sign control mode than traffic signal control mode. As it is not possible to analyze safety parameters such as accidents, aberrant behaviors at this level while using VISSIM analysis, therefore, the results, which I measured, are for the ideal condition where the commuters do not face any accidents or there will be no reckless driving or some other careless behaviors. Hence, my results not only rely on VISSIM outcome but also the data (i.e. police reports, unpublished statements and so on) received from local authorities such as police, SRTA and various others. Moreover, survey analysis helped me as well in interpreting the impact of traffic signals at the intersections as the condition, which I am using while performing VISSIM analysis, is ideal and does not consider any accident or other reckless behaviors.

The primary objective of my master thesis is to evaluate the impact of traffic signals, to control driver behaviors by installation of traffic signals and consequently to improve road safety. In addition to this, how automatic accident detection and notification systems are effective in mobility services. Hence to achieve the objective of my research, the tasks which I performed as below:

- Collected detailed data and analyzed the existing traffic issues.
- Reviewed the literature in order to analyze various alarming situations of vehicle mobility such as speeding, careless driving, tailgating and disregarding traffic regulations as well as solutions to these issues.
- Examined the role of traffic signals in speed reduction and other driver behaviors.
- Performed "Before" and "After" study methodology by using different control modes.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Road accidents are expected to become the fifth greatest cause of mortality in the future, according to the Association for Safe International Road Travel (ASIRT) (Nikhlesh Pathik et.al, 2022). According to ASIRT, approximately 1.3 million people die each year from road accidents and 20 to 50 million are injured on the roads. Nearly 2% of each country's annual GDP (Gross Domestic Product) is dedicated to road accidents. Road accidents are the ninth leading cause of death in the world and almost 2.2% of the world's deaths are due to road accidents, and other organizations, such as the World Health Organization, have reported similar statistics, too (Mahziar Mohammadrezaei et.al, 2020).

In addition to this, traffic congestion in urban areas has been increased intensively and the people's life in such areas are affected tremendously in terms of pollution, high travel cost, delay, etc. One of the main reasons for the traffic congestion is the excessive delays at the intersections because the capacity of an intersection is usually lower than the other parts of the street, therefore, bottlenecks are frequently experienced at the intersections. If the intersection cannot discharge demanding traffic in an efficient way, there are more chances of traffic congestion. This inefficiency of road intersections develops various negative impacts on mobility and the environment such as delay, increase in travel time, increase in air pollutant emissions, increase in noise pollution due to slow movement of vehicles, idling, and acceleration, increase in energy consumption and increase in rate of accidents. Hence, the capacity of the road network will be reduced (P.T.Adeke, A.A.Atoo & A.E.Zava, 2018). It is seen that globally traffic congestion causes enormous losses to the economies with the loss of valuable time on the roads. (N. Jayasooriya & S. Bandara, 2019).

Therefore, it becomes necessary to find hot spots and analyze various scenarios in order to have optimum solutions for the aberrant driving behavior and other harmful concerns. Hence, to control such behavior and consequently improve road safety, several strategies shall be implemented across the affected area. One of the strategies is to enforce Road Traffic Infrastructures by using Intelligent Transport Systems (ITS) such as camera enforcement, installation of traffic signals to reduce traffic accidents and congestion on the roads. By implementing proper traffic management initiatives, capacity of the roads at the intersections can be improved significantly. This can be achieved by using proper traffic signal design with optimum phasing arrangement at the intersections and will certainly reduce the existing traffic congestion that will save time and cost for road users. In this paper, I have chosen "T-intersection" within the Sharjah emirate of UAE in which I have performed VISSIM analysis. While performing VISSIM analysis, initially I deployed "Stop Signs" as a control mode and fetched "Queue and Travel time result". Then, I deployed "Traffic Signals" as a control mode and fetched "Queue and Travel time results". After completing the analysis, I have compared the results and represented all the results in terms of line graph. The line graph shows that "Queue lengths and travel times" are less in stop sign control mode than traffic signal control mode. As it is not possible to analyze safety parameters such as accidents, aberrant behaviors at this level while using VISSIM analysis, therefore, the results, which I measured, are for the ideal condition where the commuters do not face any accidents or there will be no reckless driving or some other careless behaviors. However, I have done a survey analysis where the majority of respondents feel safer while using traffic signals at the intersections and believe that driver behavior is controlled at the signalized intersections than non-signalized intersections. In terms of traffic accidents, the majority of participants believe that there are more traffic accidents at the non-signalized intersections than signalized intersections. In terms of traffic congestion and efficiency, the majority of participants believe that traffic accidents build more traffic congestion at the intersections and believe that capacity of the road network is improving by implementing proper traffic management initiatives. Furthermore, the majority of participants believe that traffic signal controls vehicle movements without conflicts and traffic accidents and in terms of capital investment, majority of the participants believe that traffic signal is a low capital investment than other forms. Further to this, the majority of participants believe that road safety, quality and efficiency of the road network are improved by using IoT with the traffic signals. The last part of the survey deals with performance measures by using a centralization optimization system with the signals in which the majority of the participants believe that performance measures are improved by using a centralization optimization system with the signals.

In addition to this, the director of the traffic engineering department at Sharjah Roads and Transport Authority believes that traffic signals should be operated in an optimal way if not then there will be delay and congestion. He also mentioned that implementation of traffic signals at the intersections reduce traffic accidents drastically than stop sign control modes by controlling driver behavior. With the result, it improves traffic flow of the roads adjacent to this intersection as well. He also said that traffic signals are much better option if there is budget constraint during the project proposal phases and importantly we need to take care of the optimization system. By deploying such systems at the traffic signals, we improve performance measures exponentially (Balwan, 2023).

1. PROBLEM DEFINITION, OBJECTIVES, RESEARCH QUESTIONS, METHODOLOGY

1.1. Problem Statement

Road traffic is one of the biggest problems that has a negative impact on the daily lives of people around the world and puts pressure on people in different ways. One of the biggest causes of heavy traffic is road accidents (Mahziar Mohammadrezaei et.al, 2020).

The demand for vehicles is increasing exponentially as the population increases. The percentage of road accidents has grown tremendously in the last few years, which is an alarming situation for everyone (Nikhlesh Pathik et.al, 2022). As the number of vehicles increases, road accidents are on the rise every day. According to the World Health Organization (WHO) survey, 1.4 million people have died, and 50 million people have been injured worldwide every year (Nikhlesh Pathik et.al, 2022).

According to ASIRT (Association for Safe International Road Travel), approximately 1.3 million people die each year from road accidents and 20 to 50 million are injured on the roads. Nearly 2% of each country's annual GDP (Gross Domestic Product) is dedicated to road accidents. Road accidents are the ninth leading cause of death in the world and almost 2.2% of the world's deaths are due to road accidents, and other organizations, such as the World Health Organization, have reported similar statistics, too (Mahziar Mohammadrezaei et.al, 2020). Road accidents are expected to become the fifth greatest cause of mortality in the future, according to the ASIRT (Nikhlesh Pathik et.al, 2022).

Nowadays, people's lives are compromised on the roads due to their careless conduct and flouting of traffic laws on their whims and fancies. There are multiple causes of an accident such as high speed, careless driving, overtaking, using a mobile phone, weather conditions, traffic loading etc.

According to a recent study, over speeding is the main cause of accidents and in the rescue operation, the location of the accident spot is important (Nikhlesh Pathik et.al, 2022). Not only vehicle accidents may cost life and damages to the vehicle and the affected people, but it may also result in damages to the road infrastructure. When vehicles collide in an accident, the resulting impact may cause damage to the road surface and nearby facilities such as guardrails and kerbs.

Traffic loading is the main external factor affecting the performance of a pavement. Road pavements are designed to withstand pressure provided by the wheel or axle load, tyre pressure, the configuration of vehicle axles, and the number of axles loads to be carried during the design life. Furthermore, the horizontal force resulting from vehicle braking and turning may cause slippage cracking on the pavement. In practice, traffic loading needs to be controlled and monitored to avoid traffic accidents. The authority needs to ensure that the traffic passing through a particular road network does not exceed the intended load-bearing capacity (Ezri Hayat et.al, 2015).

In conclusion, it becomes necessary to find hot spots and analyze various scenarios in order to have optimum solutions for the aberrant driving behavior and other harmful concerns. Hence, to control such behavior and consequently improve road safety, several strategies shall be implemented across the affected area. One of the strategies is to enforce Road Traffic Infrastructures by using Intelligent Transport Systems (ITS) such as camera enforcement, installation of traffic signals to reduce traffic accidents and congestion on the roads. Therefore, Automatic accident detection and notification systems using IoT-based vehicular environments play a vital role in effective mobility services. Henceforth, I would be very interested to work on this strategy by collecting the data, applying a set of steps such as analyzing the data, installation of traffic signals, simulation results using software tools such as VISSIM/Sumo or so forth, and then to compare the outcomes with the existing situation. Finally, see how the recommended strategy reduces the problem.

1.2. The objective

The primary objective of my master thesis is to evaluate the impact of traffic signals, to control driver behaviors by installation of traffic signals and consequently to improve road safety. In addition to this, how automatic accident detection and notification systems are effective in mobility services. This research will try to evaluate the effectiveness of traffic signals by using "Before" and "After" study methodology. Hence to achieve the objective of my research, the tasks to be performed as below:

- To collect detailed data and try to analyze the existing traffic issues.
- Literature review on the role of illegal speed and other driver behaviors in road traffic crashes.
- Examine the role of traffic signals in speed reduction and other driver behaviors.
- "Before" and "After" study methodology.

1.3. The Key Research Question and Sub Questions

As the number of vehicles increases exponentially, the percentage of road accidents increases tremendously, which is an alarming situation for everyone. Therefore, it is imperative to find the factors that create such a situation and consequently to control the careless behaviors of drivers. Some of the peculiar driving behaviors such as speeding, careless driving, tailgating and disregarding traffic regulations are the prime factors for road crashes. This thesis will try to figure out some of the following questions and try to provide realistic answers:

Which system needs to be deployed at the intersections in order to mitigate the problems such as speeding, careless driving, tailgating that monitor and enforces the ITS features?

To provide answer to this question, the sub-questions are formulated in a way that will facilitate this main question:

- How can we evaluate the existing situation based on the available data? Are there chances for improvement?
- Does an intervention have a positive impact on drivers and surroundings under the enforcement of traffic signals at the intersections?
- Is it possible to evaluate the effectiveness of traffic signals in terms of reduction in crash frequency and the net economic benefit?
- How to make automatic accident detection and notification systems more effective?
- Is it possible to integrate traffic signals with the traffic management control center?

1.4. Scope of the Study

With the increase in vehicles, road safety issues become more prominent, and people are more vulnerable to crashes. Therefore, drivers and commuters must feel safer while driving vehicles on the roads and hence roads must be regulated to avoid aberrant driving behavior. The first part of the study consists of a literature review about traffic signals in which various aspects such as effectiveness, crash reduction at the intersections, impact on driver behavior and various other parameters are to be analyzed.

The second part of the study is to perform surveys and the main goal of the survey is to gain knowledge about people's perception while facing the traffic signals. What do people think about traffic signals? Do they have enough knowledge about traffic signals? What do they think in terms of traffic safety about traffic signals? Is this setup organizing the traffic while crossing the yellow areas of the junction?

The third part of the study is to analyze the hotspot data; Why do we have more accidents at the non-signalized intersections? Is it something related to human behavior or the confusing nature while crossing junctions? Does the deployment of traffic signals at the intersections overcome the confusing nature? Finally, I will compare the situation before and after implementation of traffic signals at the intersection. Hence, a particular answer will be provided once all the three parts of the study are performed, and the available data will be analyzed.

While using different methods, there can be challenges as well such as peoples' participation can be limited in my survey. Required data for analysis can be limited in order to cover all the aspects of my research such as contacting various authorities for the automatic and notification system, there can be mixed reactions.

1.5. Methodology

To answer the main question: "Which system needs to be deployed at the intersection in order to mitigate the problems such as speeding, careless driving, tailgating that monitor and enforce the ITS features?" Some sub-questions are formulated and finding answers to these questions provide answers to the main research question.

The first sub-question, "How can we evaluate the existing situation based on the available data? Are there chances for improvement?" investigates the volume of the problem and possibilities for the mitigation of such aberrant behaviors and other harmful concerns. To obtain all the necessary information, a software analysis in either VISSIM or sumo to be performed to figure out the magnitude of the problem.

For the second question, "Does an intervention have a positive impact on drivers and surroundings under the enforcement of traffic signals at the intersections?" A literature review needs to be performed to see the impacts on the daily lives of the people. This will certainly improve the driver behaviors and encourage following traffic regulations. In addition to this, surveys need to be conducted to see how the drivers behave, therefore, to include the participants of different ages, ranging from young novice to old-experienced drivers.

In the third sub question "Is it possible to evaluate the effectiveness of traffic signals in terms of reduction in crash frequency and the net economic benefit?" It is somehow important to estimate the number of crashes and to measure cost benefits that determine the success of the project. Therefore, to perform "before" and "after" study methodology, then to compare the mitigated situation with the old situation both in number of crashes and in net economic benefit. In addition to this, the effectiveness of traffic signals in terms of cost benefits can be done by the literature review to see the results where it has been already deployed.

In the fourth sub-question, “How to make automatic accident detection and notification systems more effective?” This can be done by connecting different hardware, especially sensors of the enforcement system with the Internet of Things (IoT) and making this information available to the relevant authorities such as the police and medical emergencies. This depends on the consent of concerned authorities and for this, we need to meet relevant authorities and discuss the solution. In addition to this, I will try to perform survey analysis as well to have a better understanding about this. Finally, the fifth question, “Is it possible to integrate traffic signals with the traffic control center?” which is related to the integration of the enforcement system with the traffic management control center (TMC). The TMC is to collect and analyze road traffic condition related data and provide real-time feedback to users, such as on traffic congestion, detour suggestions due to severe weather and road maintenance works or traffic incidents. The data will strengthen their ability to manage the development and maintenance of the network and allow more effective long-term planning.

Data from traffic monitoring has three primary functions in network operations:

- Capacity modeling of road links and junctions.
- Incident detection.
- Congestion monitoring.

Real-time information about traffic conditions and travel times contributes strongly to the improvement of traffic efficiency. It enables road operators to understand how well the road network is operating and enables the timely detection of incidents. For example, the TMC may wish to measure the performance of its road network to provide tangible evidence that the methods to reduce congestion and improve the consistency of journey times are having a positive effect. Therefore, we have to see whether this is possible at the implementation area or not, such as the availability of TMC and availability of data communication in that region. Further to this, I will also perform survey analysis to see the impacts of centralized adaptive systems. Once all the answers and sub-questions have been provided, the answer to the main research question will be answered.

2. LITERATURE REVIEW

Literature review is an important criterion to be performed to have empirical evidence that will support and provide a sensible answer to the research question. There is enormous data related with the scientific literature, which analyzes various alarming situations of vehicle mobility such as speeding, careless driving, tailgating and disregarding traffic regulations as well as solutions to these issues. There are several problems such as traffic congestion as the number of vehicles increased due to swift global urbanization (Siham G. Farrag et.al, 2021). In urban areas, the human population increases swiftly which increases the volume of vehicular traffic as the rate of automobile ownership increases proportionally. Therefore, the traffic congestion in urban areas has been increased intensively and the people's life in such areas are affected tremendously in terms of pollution, high travel cost, delay, etc. One of the main reasons for the traffic congestion is the excessive delays at the intersections because the capacity of an intersection is usually lower than the other parts of the street, therefore, bottlenecks are frequently experienced at the intersections. If the intersection cannot discharge demanding traffic in an efficient way, there are more chances of traffic congestion. This inefficiency of road intersections develops various negative impacts on mobility and the environment such as delay, increase in travel time, increase in air pollutant emissions, increase in noise pollution due to slow movement of vehicles, idling, and acceleration, increase in energy consumption and increase in rate of accidents. Hence, the capacity of the road network will be reduced (P.T.Adeke, A.A.Atoo & A.E.Zava, 2018). It is seen that globally traffic congestion causes enormous losses to the economies with the loss of valuable time on the roads. By implementing proper traffic management initiatives, capacity of the roads at the intersections can be improved significantly. This can be achieved by using proper traffic signal design with optimum phasing arrangement at the intersections and will certainly reduce the existing traffic congestion that will save time and cost for road users (N. Jayasooriya & S. Bandara, 2019). In India, most of the people use separate vehicles for commuting which results in an increase in the traffic congestion particularly at the intersections. This will not only increase the traffic congestion but also increase traffic accidents, queues at the intersections. Therefore, it is recommended to signalize all the intersections in these areas, as the traffic cannot be controlled manually such as by the traffic police in most of the intersections and henceforth it is much needed to have an optimized traffic signal system. Traffic signals are a better option for effective transportation and is the best possible way to control the vehicle movements at the intersections without any accidents and conflicts. Traffic signals are one of the most effective and flexible active controls of traffic and are widely used all over the world (P.K.Pal & K.N.Tripathi, 2022).

In addition to this, there are various reasons for the traffic congestion such as poor infrastructure, low speed, violation in traffic rules and various others (Amardeep Das et. al, 2018). Traffic congestion deteriorates the economy and the environment, and in the US, it is estimated that nearly $166billion has been wasted due to delays and fuel expenses caused by traffic congestion. In the European Union, it has been observed that urban transportation is responsible for 40% of CO_2 emissions due to traffic congestion that worsens the environment. Traffic congestion can be recurrent or non-recurrent such as due to rush hours or by traffic incidents respectively. Unlike recurrent ones, non-recurrent congestions are unpredictable in nature and cannot be regulated or mitigated by predefined measures (Siham G. Farrag et.al, 2021). Non-recurrent traffic accidents are random and cause unpredictable blockage of lanes, therefore, reduces the roadway capacity. Such accidents cause almost 60% of the congestion within urban areas and on highways. These are not only responsible for the traffic congestion but also increase the chances of another crash called a secondary crash by six times. In order to avoid non-recurrent congestion, the solution for this is to extend and improve the road infrastructure, which involves high costs and long delays of implementation. Therefore, transportation planners need to focus on smart solutions that utilize the existing infrastructure in an efficient way. Hence, ITS plays a vital role in non-recurrent congestion and various countries have deployed modernized and customized Traffic Incident Management Systems (TIM), which improves the safety of road users, mobility services and the efficiency of transportation systems. A study conducted by the US department of transport in Southern California noticed a reduction in 65% incident duration, up to 50% secondary crashes and 1.2% fuel consumption per annum by using an efficient TIM (Siham G. Farrag et.al, 2021). Road traffic accidents in terms of personal injuries, fatalities and infrastructure damage have shown a severe concern by the World Health Organization. Therefore, ITS based on advanced telecommunication and information technology provides great support in improving road safety for all the users. It is a collective name for several technology-based approaches that are designed to improve the quality, safety, and efficiency of transport networks. These approaches can be categorized into the traffic management and control, tolling, road pricing, road safety and law enforcement, public transport travel information and ticketing, driver information and guidance, freight and fleet management, and vehicle safety applications (Gholamreza Khorasani et.al., 2013). One of the imperative features of ITS i.e. the traffic management system is a fundamental component of the Intelligent Transportation System (ITS) domain and the basic function of this system is to integrate various technologies such as traffic signals in order to improve traffic flow and road safety. This can be achieved by mitigating the road safety and traffic flow in terms of utilizing the capacity more efficiently. Some of the important goals of the ITS domain are as below:

- Increase transportation system efficiency.
- Mobility enhancement.
- Safety Improvement.
- Reduce fuel consumption and environmental cost.
- Increase economic productivity.
- Create an environment for ITS market (Amardeep Das et. al, 2018).

ITS offers two kinds of advantages: one is to solve traffic problems that include traffic congestion, air pollution and traffic accidents; another is to improve services for users and increase efficiency of the transportation system and its operators. ITS assists in enhancing the mobility of people and freight in every mode of transportation by providing traveler information, traffic management such as by optimizing timing for traffic signals, demand management and commercial vehicle management. ITS assists in reducing the congestion by providing an optimal traveler plan to the commuters i.e. by suggesting alternate routes and travel times, by keeping travelers well informed, by leveling traffic loads on roadways, and by responding to incidents swiftly. ITS reduces the environmental impacts of road traffic by optimizing travel trips, reducing congestion and crashes, improving vehicle and driver performance, and helping to manage the transportation system well. ITS also provides better and more current information about the state of the transportation system for both drivers and users of public transport. Therefore, it helps travelers to plan their trips in an organized way, makes better connections and reduces the uncertainty of travel. Nowadays, the number one safety related ITS concept is intelligent speed adaptation (ISA). Speed choice of the drivers in different situations has a tremendous effect on traffic safety by influencing the probability of avoiding an accident to occur in a critical situation and by having influence on the impact of collision and on the outcome of an accident.

ITS systems have a direct or indirect impact on safety and its safety implications are commonly classified into three areas: one is system safety that covers safety problems in terms of hardware and software design especially on reliability, the propensity for malfunction and the potential to go into a dangerous and/or unanticipated system mode. Second is human machine interaction that is an interaction between the user and the system, and the key issues are the design of buttons and controls and finally is a traffic safety that is the overall effect of system use on the safety of the traffic system as a whole. It covers the outcome of system safety and human machine interaction. It also covers the overall ways in which a particular system might affect the road user behavior to alter the interaction between the driver, the vehicle, the road infrastructure, and other road users including pedestrians, cyclists and motorcyclists (Gholamreza Khorasani et.al., 2013).

2.1. Safety Impacts of Traffic Signal System

In order to determine the safety effect of traffic signals, 117 intersections that were controlled by stop control signs have been examined in rural and suburban areas in North Carolina and it was clear that by adding traffic signals to these intersections' total crashes, injury and fatal crashes were reduced. In another study i.e. NCHRP Project 17-25 evaluated the effect of converting rural stop-controlled intersections to signalized intersections. The authors conducted an empirical before-after study methodology in California and Minnesota on 45 converted intersections and used a reference group of approximately 3,500 intersections. They concluded that signalization caused a decrease in total crashes of 44% (crash modification factor, i.e., CMF 0.56), right-angle crashes by 77% (CMF 0.23), and left turn crashes by 60% (CMF 0.40). They also concluded that rear-end crashes increased by 58% (CMF 1.58). They conducted a benefit-cost analysis and noted that benefits were greater on higher volume intersections and greater where the ratio of expected right-angle crashes to rear-end crashes is higher.

Another study was performed to establish crash-based warrants for signal installation or removal. It has been observed that twenty-two 3-leg and one hundred 4-leg urban intersections from five U.S. states and Toronto that had been converted to signalized intersections have better improvements in terms of road safety. The result showed that converting a stop-controlled intersection to a signalized intersection resulted in decreases in all crashes, larger decreases in right-angle crashes, and increases in rear-end crashes. Table 1 shows the resulting CMF values (indicated as index of effectiveness). Their results show greater crash decreases at four-leg intersections when compared to three-leg intersections.

	3-leg (22 conversions)			4-leg (100 conversions)		
	All	Right-angle	Rear-end	All	Right-angle	Rear-end
EB estimated after-period expected crashes without conversion.	142.37 (11.32)	22.13 (3.62)	35.02 (3.87)	756.73 (31.77)	314.72 (19.84)	113.22 (8.20)
Injury crashes in the after period.	123	15	53	585	105	157
Index of effectiveness.	0.86	0.66	1.5	0.77	0.33	1.38
VAR.	0.1	0.2	0.26	0.05	0.04	0.15

Table 1. Signal Conversion Crash Modification Factors (R.Srinivasan, B.Lan & D. Carter, 2014).

In Denmark, a study was conducted in order to evaluate the effects of traffic signal installation and 54 intersections were examined by using before and after analysis. It has been concluded in the study that implementation of traffic signals reduces total crashes of 21% (CMF 0.79) at 3-leg intersections and 39% (CMF 0.61) at 4-leg intersections (R.Srinivasan, B.Lan & D. Carter, 2014).

The Highway Safety Manual (2010) provides CMFs related to signal installation in Chapter 14 (Table 14-7). It indicates that converting from stop control to signal control for rural three- and four-leg intersections results in a CMF of 0.56 for total crashes, 0.23 for right angle crashes, 0.40 for left turn crashes, and 1.58 for rear-end crashes. These CMFs are applicable for intersections where the major road annual average daily traffic is 3,200 to 30,000 and the minor road annual average daily traffic is 100 to 10,300 (R.Srinivasan, B.Lan & D. Carter, 2014).

The effects of turn lanes on intersection safety have been evaluated and the study examined two treatments that are relevant i.e. adding left turn lanes to existing signalized intersections and adding left turn lanes to newly signalized intersections (e.g., signalized in conjunction with left turn installation). However, the group of treatment sites was mainly urban. There were no rural sites for which left turn lanes were added to existing signals and only two rural sites where left turn lanes were added to newly signalized intersections. Based on this very limited sample, it has been estimated a 35% decrease (CMF 0.65) in total crashes for adding one left turn lane at rural, four-leg, newly signalized intersections (R.Srinivasan, B.Lan & D. Carter, 2014).

In another study, where the expert panel of researchers tried to recognize the gap in the results of turn lanes on intersection safety**.** It has been concluded by the panel that adding an exclusive left turn lane on one approach at rural signalized intersections results in a CMF for total crashes of 0.82 for four-leg intersections and 0.85 for three-leg intersections. It has also been noted that adding left turn lanes on both approaches at rural four-leg signalized intersections results in a CMF of 0.67. The Highway Safety Manual presents CMFs for exclusive left turn lanes in Part D, Chapter 14 (HSM Tables 14-10, 14-11, 14-12). For rural signalized intersections, the HSM lists the same CMFs as provided by the expert panel. The HSM also provides CMFs for the installation of channelized left turn lanes but does not provide a breakdown according to traffic control type. Additionally, for the scenario addressed by this research project (turn lane installation on the major road), the CMFs provided by the HSM for channelized left turn lanes were not statistically significant. Another study was conducted about safety improvements in Iowa and 11 sites were examined where new traffic signals were installed with the addition of one or more turn lanes. The sites were provided by Iowa DOT, and it has been determined that installing a signal with one or more turn lanes resulted in an average 20% decrease in all crashes. The treatment showed a statistically significant decrease in right angle crashes (63%) and left turn crashes (35%) (R.Srinivasan, B.Lan & D. Carter, 2014).

Apart from this, it is seen in various studies that safety measures have improved while using other ITS applications and it has been observed a significant decrease in the traffic signal violations at the enforcement sites, which varies from 20% to 87%, by introduction of camera enforcement. For example, studies showed that in Scotland the implementation of the enforcement system resulted in an enormous reduction in crashes (Robert P. Maccubbin et. al., 2001). In various countries such as the UK, USA, Australia and Europe, speed cameras have been considered an effective measure in overcoming road crashes and safety issues. For example, by implementing speed cameras, it has been noted that 19 percent of road crashes have been reduced in the USA. In Australia, speed enforcement reduced 41 percent of fatal crashes and in the UK, this enforcement was implemented by the national safety camera program, fatal crashes reduced by 42 percent. While as in Europe and New South Wales, road crash fatalities have been reduced by 50 and 22 percent respectively. In addition to this, in New Zealand, it is seen that the hidden speed cameras are more effective than visible cameras in reducing the speed violations (Ali Humaid Al Darei, 2009). In other studies, the implementation of speed cameras on roads reduced all the crashes by 14 to 72 percent, fatal crashes reduced by 8 to 46 percent and crashes with serious injuries reduced by 40 to 45 percent. Furthermore, studies revealed that the speed cameras are "a promising intervention for reducing the number of road traffic injuries and deaths" (David K. Willis, 2006). In the Netherlands, by introducing automated speed enforcement when combined with the variable message signs, average speed was reduced by 5kmlh i.e. speeding has been reduced by 27 percent while installing such a system. Similarly, by implementation of automated speed enforcement, the number of vehicles in Canada exceeding the speed limit reduced by 50 percent while as in Australia, the number of vehicles travelling at more than 40km/hr. over the speed limit was reduced by 74 percent. In another study, it has been observed that the deployment of mobile speed cameras is an effective tool in reducing the traffic casualties (Ali Humaid Al Darei, 2009).

2.2. Overview of Traffic Signal System

As my focus is to see the impacts of traffic signals in order to provide answers to my main research question and other sub research questions, therefore, I would like to have further insights about traffic signal systems. From the above discussion, intersections play a vital role and movements into the intersections need to be regulated and/or controlled in order to achieve optimal performance and avoid various challenges such as congestion. There are multiple ways for controlling traffic movements at the intersections such as use of 'Stop' signs or 'Yield' signs; Intersection channelization; Pavement markings and the use of traffic signals. It is well known that the traffic signals are standardized devices for controlling and regulating the vehicular traffic, pedestrians, pedal cyclists, which are implemented at the signalized intersections, the signalized pedestrians and the cyclist crossings, the railway crossings and at the locations where the traffic flow needs to be controlled. It is also widely known that the traffic signals are the most efficient means of traffic control at the road intersections (P.T.Adeke, A.A.Atoo & A.E.Zava, 2018). In addition to this, it is believed that the installation of a traffic signal should not only improve the safety level of an intersection, but it should also improve at a level higher than what other measures, non-traffic signal related, would have accomplished. In various studies, it is shown a variety of expected improvements after the installation of a traffic signal. The installation of a traffic signal will result in a general reduction of crashes, but also specific types of crashes, such as right angle and left-turn related crashes, are likely to be reduced more, while other types, such as rear-end, are more likely to increase. Therefore, a decision maker should be able to identify associated benefits and costs from traffic signal installations in order to determine their applicability for the existing conditions (N.Stamatiadis, C.Jones & N. Agarwal, 2008).

Traffic signals are one of the most powerful tools for urban traffic control, which city authorities can utilize and their correct installation can improve both traffic flow and the safety of all road users. In comparison to other traffic improvements, signals are also relatively low capital investment and there is no doubt that time separation of traffic conflicts using traffic signals is one of the most powerful tools for urban traffic control available to city authorities. Consequently, their correct design and operation can improve both traffic performance and safety for all road users. As technology has been improved, informatics and telecommunication develop a new generation of controllers, which are less expensive and optimal that makes modern signaling systems much more cost-effective. In Sweden and other parts of the world while performing experimental investigations, it has been noted that self-optimizing systems have the possibility to reduce traffic costs by around 10-20%. Although politicians and decision makers have shown less interest in such technologies, there are challenges while approving budgets and the investments in such areas are very low irrespective of cost-effective solutions and improvement in traffic performance in urban street networks. Hence, to have sustainable intersections such as safer and environmentally friendly, which focus on effective design and operation. This will assist us in achieving the sustainable solution that would require a high knowledge about the relationships between intersection design, traffic flow, environment, and impacts on traffic performance, safety, and emissions, however, the efforts to study impacts of control strategies on traffic performance are still very limited. To summarize, traffic signal control is a very cost-effective method for the improvement of urban traffic systems in terms of performance, safety and environment and the level of knowledge regarding the impacts of different types of systems and control strategies is insufficient. Therefore, it becomes mandatory to understand various terminologies and performance parameters about traffic signal systems (Al-Mudhaffar, 2006).

2.3. Historical review of Traffic Signal System

In 1868, the first traffic signal was installed in London and they used semaphore ‘arms’ together with red and green gas lamps. It worked almost 50 years before exploding, which resulted in the termination of this sort of control. However, in 1918, the first three-colored light signals were installed in New York and after some time in 1925, the operation of these three-colored light signals were started in Great Britain. In the early 1930s, an attempt was made to introduce “intelligent” traffic signals or simply vehicle responsive signal systems in America by using microphones at the side of the road in which drivers were supposed to sound their horns. This was not that popular, resulting in the introduction of the first traffic detectors, which were electrical and pneumatic in nature. Nowadays, traffic signals are used all over the world with three light signals of green, red, and amber and also by convention, these are normally arranged vertically with red at the top and the green light at the bottom. This arrangement helps people to identify the differences between the lights who are colorblind such as drivers or pedestrians (A. Cannell & G Gardner, 1996).

2.4. Objectives of Traffic Signal System

To evaluate the performance of traffic signal control algorithms, two performance measures were discussed; one is the mobility measure, and another is the sustainability measure. Mobility measures consist of the average total delay, average total throughput, average total travel time, average total number of vehicle stops, and average queue length. While as, sustainability measures consist of emissions and fuel consumption.

2.5. Mobility measures

The basic performance measure to solve an intersection traffic signal control problem (ITSCP) is the delay per vehicle and by minimizing this measure, we can minimize the average waiting time of the vehicles at an intersection due to a red signal. This performance measure is frequently used in ITSCP design by the researchers as indicated by the fact that 61 out of the 72 papers treated delay as the fundamental performance index. Another imperative performance measure in ITSCP is the throughput of the network, which is defined as the number of vehicles passing through the network. Some researchers also considered the total travel time of vehicles as a performance index when solving both a signal setting optimization problem and traffic assignment problem and is defined as the duration of time vehicle moves in the network. They tried to make an effort that the equilibrium pattern flow of a network is intensively related to signal settings. As a mobility measure, minimizing the total number of vehicles stop in a network has also been used and vehicle stops occur due to a red light or accumulated queues, which are directly related to driver satisfaction. The concept of queue length has been used in balancing each traffic signal phase and each direction in an intersection and is defined as the total number of vehicles waiting on the roads at each intersection. Queue length is correlated to the delay or number of stops and as such is typically applied together with these performance measures and the minimization of queue length can lower the variance of vehicle delay in each phase (M. Eom & B. Kim, 2020).

2.6. Sustainability measures

In today's era, the importance of environmental protection has grown, and the researchers investigated the environmental impacts of traffic signalization, therefore, employed a microscopic emissions/fuel consumption model to overcome both exhaust products such as carbon dioxide and fuel consumption to improve sustainability. In order to evaluate emissions/fuel consumption, such models require the assumption of some constraints on vehicular speed, deceleration and acceleration (M. Eom & B. Kim, 2020).

2.6.1. Other measures

In addition to this, various performance indices have been used in accordance with different assumptions and problem-solving methods. For example, in arterial networks, the bandwidth or a portion of a signal cycle has been maximized so that vehicles can progress through the signals without stopping. Some researchers consider cycle-time minimization as a secondary objective, which claim that if two signal time plans generate similar levels and capacity then the plan with the shorter cycle time is better, and in bottleneck links, some authors compared the aggregated average speed of vehicles and the number of vehicles (M. Eom & B. Kim, 2020).

2.7. Signal timing constraints

In the signal timing constraints, we summarize ITSCP constraints regarding cycle length, green phase duration, and phase sequence signal timing constraints. These are defined as below:

2.7.1. Cycle length

Constraints on cycle length can be classified into four types: one is fixed, second is limited minimum length, third is limited maximum length, and finally, fourth is unrestricted. Traffic signals can be optimized while maintaining the total time of one complete phase sequence i.e. keeping the cycle length fixed (M. Eom & B. Kim, 2020).

2.7.2. Green phase duration

The green phase duration can be constrained either by minimum/maximum limit or of any value, and the selection of minimum and maximum green phase durations is dependent on the traffic characteristics of the study area and the space available for vehicles to queue. In green phase duration, a minimum limit is required in order to avoid phase skipping so that pedestrians cross the road safely. This is because the signals from different approaches are collaborated in a single traffic signal system at an intersection and a minimum limit on the green phase duration in one direction can be considered as a minimum limit on the red phase duration in the conflict approaches. Therefore, this red phase should not be too short in order to ensure that the pedestrians can cross the road comfortably. To accommodate the pedestrian crossing, the minimum green time duration needs to be set which depends on the width of the crossing and the assumed walking speed of the pedestrians. In contrast to the maximum time limit on the green phase duration, which is usually defined to limit the green extension for signal groups (M. Eom & B. Kim, 2020).

2.7.3. Phase sequence

The signal phase sequence is a kind of rule that the drivers need to follow. In doing so, some researchers believe that the control system should use a fixed signal phase in order not to confuse drivers while others assume that the phase sequence should not be fixed if we would like to have better performance. During the early days of ITSCP study, researchers were treating the phase sequence as a given parameter and were formulating the problem by using fixed phases. The assumption was that the sequence of phases was fixed which enforced safety and fairness constraints. To ensure compatibility, signal phase groups were predefined and a proper signal phase sequence from among these groups at each rolling horizon was selected by some studies. For instance, a multi-resolution strategy was proposed for updating the elements of the signal plans, which included a cycle-by-cycle signal phase sequence and optimized the current second-by-second green signal timing. While the existing group-based signal as an agent was formulated and a multi-agent system strategy was applied by some studies (M. Eom & B. Kim, 2020). The predefined signal groups have benefits that include a high degree of flexibility when specifying signal plans and the ability to deal with a wide range of traffic patterns in a systematic way. Nowadays, dynamic programming has been widely used to choose phase sequences because the ITSCP can be sorted out recursively without fixed phase constraints within affordable limits of computational complexity. Some researchers believed that any sequence of phases and their associated phase durations could be applied for signal plans if fixed phase sequences were not used. In this scenario, a choice of phase sequence and timings are available for the ITSCP in order to optimize a specified performance index. For instance, at an isolated intersection, traffic flow was simplified as a set of vehicle movements and recognized when to switch the green-red signal for each vehicle movement. Phase pictures were generated by using flexible phase sequences that considers real-time traffic patterns to reduce travel delay, which is caused by inefficient phase formulations (M. Eom & B. Kim, 2020).

2.8. Overview of Traffic Signal Control Methods

In signalized intersections, we use traffic signal controllers that allocate right of way through a sequence of green signals at each approach. Each approach with separate movement is allocated to a phase and a set of non-conflicting phases are grouped into stages. In order to have safer transitions between conflicting phases, we assign inter-green times, which usually consists of flashing green, amber and all red or simply amber and all red. Stages are usually arranged to follow a set of order and a complete series of stages is called a cycle as shown in the figure 1 as below.

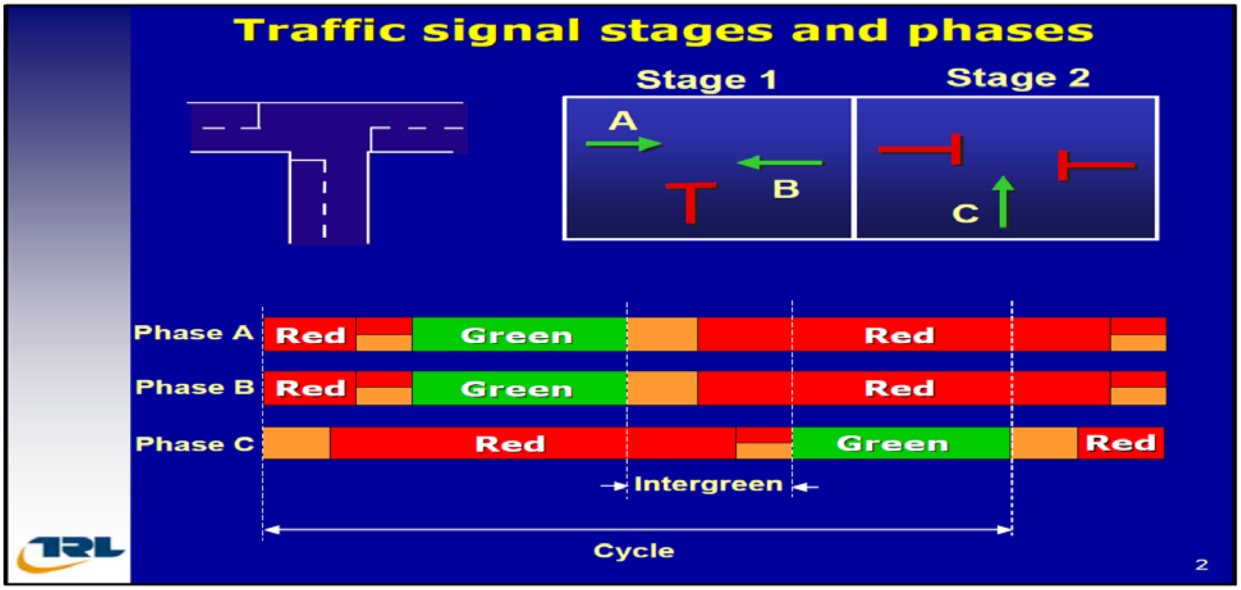


Figure 1. Traffic Signal Cycle Time, Stages and Phases. (Al-Mudhaffar, 2006)

The methods to control the traffic signals can be divided into two main categories; one is to have isolated traffic signal control mode in which the signal timing decisions are based solely on the traffic demand from each approach of the intersection. Another is to have coordinated traffic signal control mode in which the signal timing decisions are taken based on the adjacent traffic signals where the traffic signal controllers of the adjacent intersections are connected to each other to facilitate the traffic flow (Al-Mudhaffar, 2006). To operate the intersections, some researchers have come up with further subdivisions of these control modes as below:

2.9. Isolated Traffic Signal Control

2.9.1. Fixed time signal control (FT)

This is also called a predetermined or time plan in which signal timing from all the approaches is fixed and is calculated in a way to minimize the overall intersection delay for the traffic demand during the studied period. The cycle length for this control mode is fixed and separate time plans can be developed for different periods during the day i.e. morning peak, lunch peak, evening peak and for night in which signal timing is designed (Al-Mudhaffar, 2006).

2.9.2. Vehicle actuated control (VA)

In this control mode, variable green time allocations and cycle time are based on the detection of the traffic demand from the signalized approaches or groups of lanes (signal groups). The decision whether to extend green light or not is based on the conditions i.e. demand for the actual approaches or signal groups served by the ongoing green (Al-Mudhaffar, 2006).

2.9.3. Self-optimized real-time control

In this control mode, green time allocation and cycle time vary as per the real-time demand and optimizes traffic performance from all the signalized approaches within the intersection.

In addition to these signal control methods, traffic signals can be controlled manually usually done by police officers at the intersections or can be switched to flashing/all red mode in case signal is out of service or during the time of accidents that happen at the signalized intersections (Al-Mudhaffar, 2006).

2.10. Strategies for Isolated Traffic Signal Control

Due to IoT, traffic signal control has been influenced by the fast development of computer technology, which makes it possible to use more complex strategies in both isolated and coordinated traffic signal control. Such strategies help us to use self-optimizing strategies in order to improve the performance functions by reducing various parameters such as minimizing the total vehicle delay, the number of stopped vehicles, or a general cost function combining the effects of delay and stopped vehicles. By adding accurate detection of the movements and discharge of all vehicles in the system, we can solve the remaining problem, which can be expensive if we use complex strategies (Al-Mudhaffar, 2006).

In an isolated signal control, it is normally assumed that the arrival of vehicles in the approaches to the intersection is random with a negative exponential time headway distribution.

$f(h)=qe^{-qh}$ (Al-Mudhaffar, 2006)

Where:

h= Headway

q=Traffic flow= $\frac{1}{h}$

2.10.1. Fixed Time Control

In fixed time signal control, the green and cycle times are predetermined with fixed duration. The fixed signal timing calculation is to minimize overall intersection delay for the traffic demand during the studied period. Webster in 1996 introduced a formula for the average delay per vehicle on the arm that is carried out for a variety of flows, saturation flows and signal settings such as cycle as shown below:

$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65 \sqrt[3]{\frac{c}{q^2}} * x^{(2+5\lambda)}$ (F.V.Webster & B.M. Cobbe, 1996)

Where:

d = Average delay per vehicle on the particular arm

q = Traffic flow

c = Cycle time

g = Effective green time

λ= Proportion of the cycle which is effectively green (i.e. g/c)

x = The degree of saturation (i.e. q/λs) (s = saturation flow)

To determine the minimum cycle time, the arms with the highest ratio of flow to saturation flow are selected from each phase. By differentiating the equation for the overall delay, Webster (1966) found that minimization of the overall delay at an intersection with respect to the cycle time could be represented by

$C_{\circ} = \frac{aL+b}{1-y1-y2-\cdots.yn} = \frac{aL+b}{1-Y}$ sec

Where:

y_1-y_2-….y_n = The maximum ratios of flow to saturation flow for phases 1,2….n

Y = ∑y

L = The total lost time per cycle.

a & b are constants

For a certain balance of flows, the values of a & b are 1.5 and 1 respectively.

$C_{\circ} = \frac{1.5L+5}{1-Y}$ sec (F.V.Webster & B.M. Cobbe, 1996)

This cycle time ($c_∘$) is the "Optimum Cycle Time", which under light traffic conditions could be very short. From a practical point of view, including safety considerations, it may be desirable to consider it as lying between 25 and 120 seconds.

It has been observed that for cycle times within the range of three-quarters to one and a half times the optimum value, the delay is never more than 10 to 20 percent above that given by the optimum cycle.

For setting the green times, it was found that the ratio of the effective green times should equal the ratio of the y values, i.e.

$\frac{g1}{g2} = \frac{y1}{y2}$..........

Where g_1 and g_2 are the effective green times of phases 1 and 2 respectively.

If $c_∘$-L is the total effective green time in the cycle, the above rule gives

$g_1 = \frac{y1}{Y}(c_∘-L)$

$g_2 = \frac{y2}{Y}(c_∘-L)$ etc. (F.V.Webster & B.M. Cobbe, 1996)

2.10.2. Vehicle Actuated Control (VA)

In VA-control, all the signalized approaches require detectors in order to detect the vehicle passages or vehicle presence. The information received from these detectors are used for the following purposes:

- To register the demand for green light for vehicles arriving during the red signal on the approach.
- To register the demand for green time extension for vehicles arriving during green light in the approach.
- To register presence of vehicles within the detection area in the approach after the termination of green, i.e. overflow of a queue to the next signal cycle.

Green time extension in VA-control usually occurs with a predetermined extension interval (f), if the time interval between vehicles passing these detectors is shorter than (f) and subject to minimum and maximum green time g (min), g (max) restrictions. In conventional VA-control mode, g (max) is constant, and g (min) is variable as a function of the number of vehicles arriving during red time. The signals return to a state of all red at no demand in order to make a swift change to green possible in any phase when the next vehicle or pedestrian actuates a detector (Al-Mudhaffar, 2006)**.**

The efficiency of two-phase VA-control is primarily a function of the parameters of minimum green (g (min)), maximum green (g (max)) and extension interval (f). Low value of g (min) reduces the average delay (d) at load factors (volume-capacity ratio) below 0.4. For load factors above 0.7, there is a tendency at multilane intersections to obtain demands for very long periods of green. If restrictions of g (max) are not applied, this results in deteriorated control efficiency and for load factors above 0.85 worse performance than at FT (Al-Mudhaffar, 2006).

2.11. Coordinated Traffic Signal Control

2.11.1. Fixed time coordination

This coordinated traffic signal control mode is operated where we keep all the parameters (Cycle time, green time and Offsets) fixed and we prepare a number of time plans throughout the day in order to optimize the traffic. The plans are prepared as per the historic traffic data variations and selection of time plan is also fixed (Al-Mudhaffar, 2006).

2.11.2. Fixed time coordination with traffic actuated time plan selection

This coordinated traffic signal control mode is operated when we keep all the parameters (Cycle time, green time and Offsets) fixed and we prepare a number of time plans throughout the day in order to optimize the traffic. The plans are prepared as per the historic traffic data variations and selection of different time plans is based on the traffic data from selected detectors in the system (Al-Mudhaffar, 2006).

2.11.3. Fixed time coordination with local signal timing adjustment

In this control mode, the local signal timing adjustment is based on the traffic detector inputs from the selected approaches within the intersection. This is done in a way to provide adaptation to the short-term traffic variations through the small adjustments of signal timing within the framework of the fixed time coordination (Al-Mudhaffar, 2006).

2.11.4. Traffic actuated time plan calculation

The time plans in this control mode are re-measured regularly which depends on the information collected from the selected detectors located in the strategic positions (Al-Mudhaffar, 2006).

2.11.5. Dynamic coordination

In the dynamic coordination control mode, all the signal timing events and parameters are calculated in real time, which are based on the input from the traffic detectors of all the approaches that are laid within the signalized intersection (Al-Mudhaffar, 2006). This is shown in figure 2.

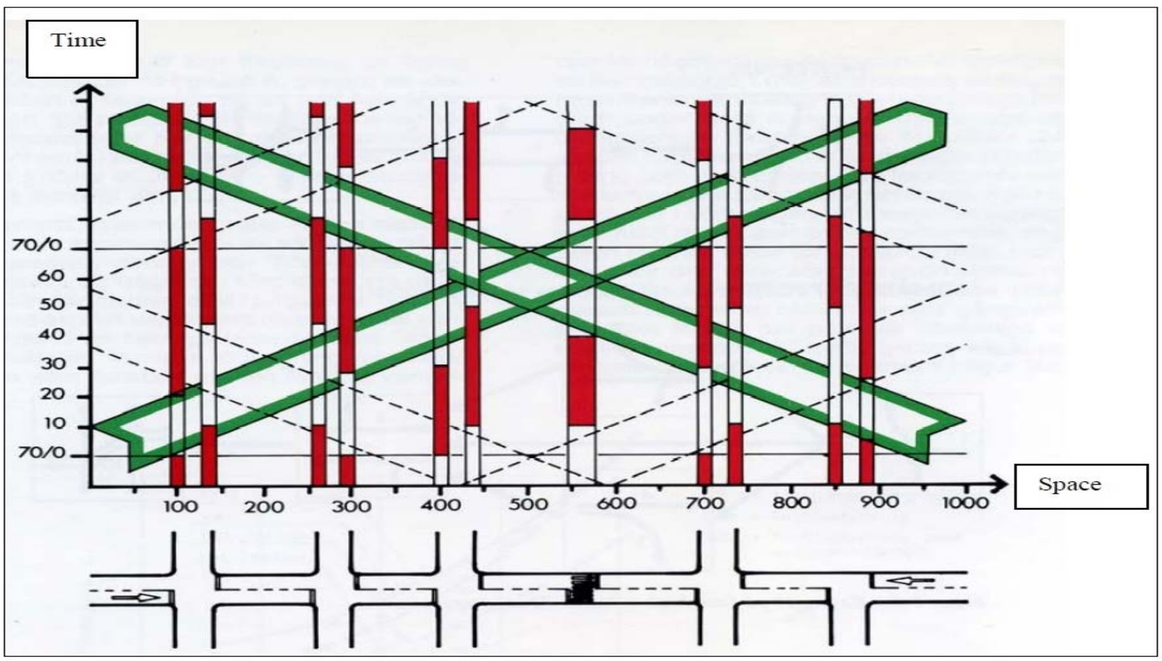


Figure 2. Green Waves in a Coordinated System (Al-Mudhaffar, 2006).

The traffic signal coordination can be applied in two or more adjacent traffic signals within the network in order to reduce travel time and number of stops for commuters. This is also beneficial in terms of environmental perspective by providing better traffic flow. The traffic signal coordination can be achieved either from control center or at a local level with some form of linking between individual intersections. Nowadays, in coordinated systems, fixed control is mainly used where the offset of the green light between adjacent intersections is constant (Al-Mudhaffar, 2006).

2.12. Strategies for Coordinated Traffic Signal Control

In an isolated signal control, it is normally assumed that the arrival of vehicles in the approaches to the intersection is random with a negative exponential time headway distribution. While as in an urban street network, the arrival rates are usually influenced by the queue discharge from the upstream traffic signals, which create vehicle platoons moving along the approach links. The shorter the distance between the signalized intersections, the less these platoons will be dispersed when they arrive at the stop line of the downstream traffic signal, as shown in Figure 3. If adjacent signalized intersections are coordinated in such a way that they operate with the same cycle time along with constant split, and offset. Therefore, it is possible to set these signal timing parameters on a one-way street in such a way that the platoon from the upstream intersection will arrive at the downstream stop-line when this signal is green and this effect is called “green wave” (Al-Mudhaffar, 2006).

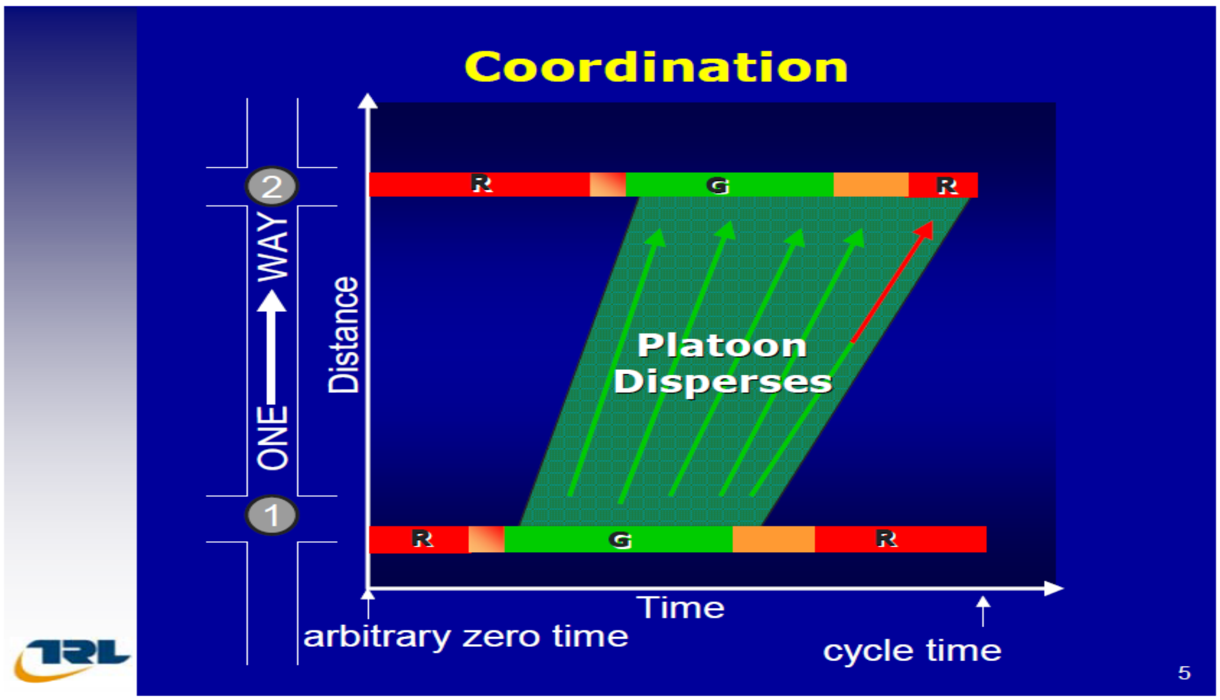


Figure 3. Green Wave or Coordination When Intersections are Close (Al-Mudhaffar, 2006).

For two-way streets, green waves can be accomplished manually by an experienced traffic engineer subject to the signal spacing and cruising speed requirements using time-space diagrams for different time plans, each suited to a typical traffic situation during the day (e.g. morning peak, mid-day, evening peak and low traffic).

For two-way streets, the relationship between cycle time (c), speed (v) and distance (D) is

$$D = v * \frac{c}{2}$$

Or with different speeds in both directions of the street ($v_1$and v_2)

$$\frac{1}{v1} + \frac{1}{v2} = \frac{2}{v}$$

$$D = \frac{v1 * v2}{v1 + v2} *c$$

When cycle time has been determined for every time plan, the green times for the phases are calculated for every intersection by using the formula

$g = \lambda(c-L)$

Where:

G = Effective green time

c = Cycle time

λ = Portion of green time

In the off-peak hours, especially during the nighttime when there is less demand or no demand at all from any of the approaches, we usually break the coordination and operate the signal in an isolated control mode if the signalized intersection is equipped with detectors. If the signalized intersection is not equipped with detectors, then 3-5 fixed reference plans are produced by hand or with some rudimentary computer-aided systems in order to operate the signal in off peak hours (Al-Mudhaffar, 2006).

2.12.1. Off-Line Program TRANSYT

Traffic signals have been used widely all over the world and is considered as one of the most effective ways to resolve conflicting traffic movements of both vehicular and pedestrian particularly at the intersections (S.C.Wong, 1996). At the intersections, congestion problems are predominantly identified especially in urban areas. To overcome this, we need to set a rule that handles the traffic conflicts at the intersections very well either by giving permanent priority to some movements or by alternating the priorities via a traffic signal. The later solution requires some tools that define the timings of each signal and offset between the adjacent signals (R.Fernandez, E.Velenzuela, F.Casanello & C.Jorquera, 2005). In urban areas, distance between adjacent intersections is usually shorter than rural areas, therefore, operational performance of the signal-controlled intersections can be obtained efficiently by considering the interaction between adjacent intersections and this can be determined by calculating the optimum signal settings. Such interaction among the intersections over an area is called area traffic control. To ease congestion in urban areas, a lot of research work has been carried out on the development of area traffic control (S.C.Wong, 1996). It is seen in various studies that the fixed-time coordination of traffic signal settings in a road network provides important benefits. Due to this, several computer programs have been developed in order to have effective solutions for traffic signal coordination. One of the renowned programs that is used globally known as Traffic Network Study Tool (TRANSYT) developed by Transport Research Laboratory Ltd. (TRL) and has issued various versions until date (R.Fernandez, E.Velenzuela, F.Casanello & C.Jorquera, 2005). In an urban road network, TRANSYT is considered as one of the most effective analysis tools for calculating settings for coordinated signals. The TRANSYT program consists of two main modules; one is the traffic model and the second is the signal optimizer. In the traffic model, the movement of traffic through a network is simulated by TRANSYT that considers the effects of platoon dispersion. This provides the means of calculating a performance index that is a weighted linear combination of estimated vehicular delays and stops on all the streets and is used to measure the overall cost of traffic congestion. While the signal optimizer adjusts signal timings and checks whether the adjustment reduces the performance index or not by using the traffic model. By adopting those adjustments, reduce the performance index, which improves the signal timings (S.C.Wong, 1996). The TRANSYT structure with a traffic model and a signal optimizer as shown in Figure 4 as below.

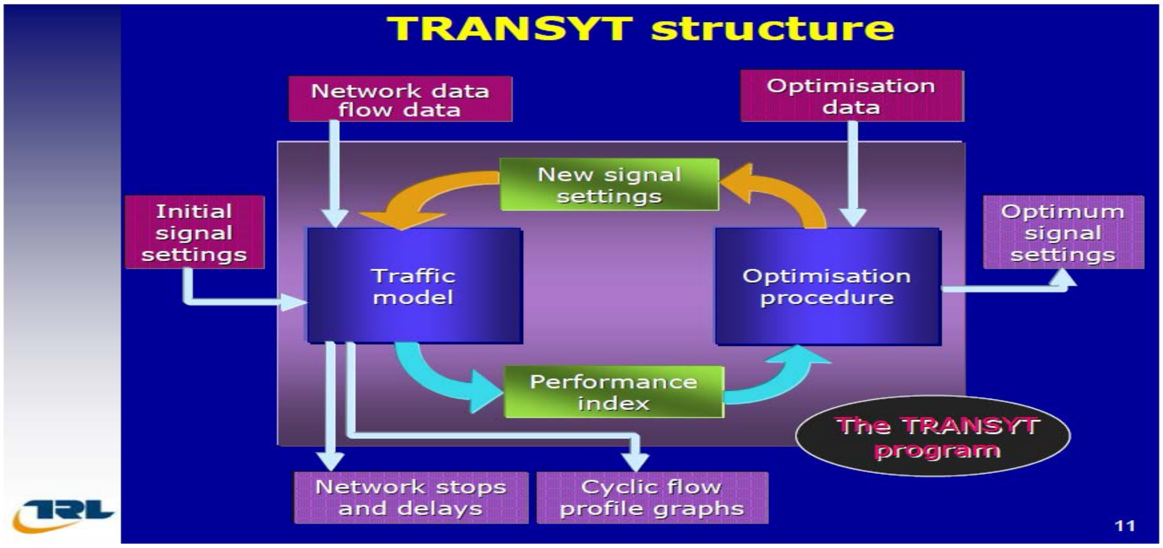


Figure 4. TRANSYT Structure Including Traffic Model and Signal Optimizer (Al-Mudhaffar, 2006).

2.12.2. Automatic Updating of TRANSYT (AUT)

In recent years, fully adaptive on-line systems have been developed such as SCOOT, SCATS and so on. The experimental results from these and several other systems encourage road authorities and research institutes to engage in the development of Automatic Updating of TRANSYT reference plans (AUT). AUT is not a fully adaptive system working in real time instead; it works with a specific number of reference plans that are updated every 24 hours. The AUT control strategy involves time settings that are being automatically adjusted to the variations in the traffic. Using TRANSYT together with two modules i.e. TRAF (deals with traffic data) and AVT (User Friendly TRANSYT), the system is able to work automatically. The basic idea is that the road authority decides the type of effect - minimum exhaust emissions, minimum fuel consumption, minimum travel costs etc. - for which the signal settings are to be optimized. The result of the test area with AUT showed a reduction in fuel consumption of 15% (Al-Mudhaffar, 2006).

2.12.3. Centralized Optimization System SCOOT

In 1973, the Split Cycle Offset Optimization Technique (SCOOT) was developed by the Transport Research Laboratory in the United Kingdom is an online signal timing optimizer and has been implemented into real-world application since 1979. In the early 1980's, SCOOT was continuously developed as an on-line signal control system and has launched several versions till date. For instance, version 3.1 includes bus priority, database facilities and incident detection. Version 4.2 adds estimates of the emission of pollutants. Version 4.5 enables the bus priority to differentiate between different buses (e.g. to give more priority to late buses), MC3 enables the Kernel software to use data safely supplied by packet switched communications systems, provides a congestion supervisor and increases the priority available to the buses by allowing state skipping where it is appropriate. SCOOT is designed for general application within a computerized Urban Traffic Control System and is a method of coordination that adjusts the signal timings in frequent, small increments to match the latest traffic situation. Traffic data from vehicle detectors are analyzed by an on-line computer, which contains programs that calculate traffic flows and predicted queues. It has three optimizers, which are adapted – the amount of green for each approach (Split), the time between adjacent signals (Offset), and the time allowed for all approaches (Cycle Length).

Both SCOOT and TRANSYT employ the traffic model to predict the delay and stops caused by signal settings. In the case of TRANSYT, the model is off-line, and it predicts the average delays that resulted from specified average flows. While the SCOOT model is on-line the predictions of delay are re-calculated every few seconds from the latest measurements of traffic behaviors (nctu, 2007).

SCOOT Traffic Model has an important role in Vehicle Detection, Cycle Flow Profile, Prediction of Queues, Congestion and Measurement of Travel Behavior.

Vehicle Detection:
The vehicle detectors are placed upstream of the stop-line. These detectors are located as upstream as possible from the stop-line. Normally, the distance between detector and stop-line is larger than the maximum potential queue length. If the actual queue length is larger than the distance, then the system would get the warning of congestion, and the corresponding function would be effective (nctu, 2007)**.**

Cyclic Flow Profiles (CFP):
The data from detectors are stored in the SCOOT system in the form of "Cyclic Flow Profiles". The profile patterns tend to be repeated and coupled with new data in a cyclic sequence to avoid large random fluctuation in the profile. The cycle flow profiles contain the information needed to decide how best to coordinate adjacent pairs of signals and cause the signal optimizer to search for a best new timing (nctu, 2007)**.**

Prediction of Queues:
Cruise time is used to predict when the vehicle flows that are recorded in the profile are likely to reach the stop line. Vehicle arrivals at the stop line during the red time are added onto the back of the queue, which usually continues to grow in the next green time until the queue clears. Vehicle discharges from the front of the queue at the specified saturation rate. It will be apparent that these predictions of queue lengths cannot be completely accurate. The prediction errors may become serious; therefore, various validations have been incorporated into SCOOT. If the validation has been accepted, the queue model could be used continuously if the traffic condition is stable in the future (nctu, 2007)**.**

Congestion:
Widespread congestion may occur when the queue grows in length and extends backwards into its upstream junction. The traffic model measures the proportion of cycle time that the detector is occupied by a queue, moreover, the optimizer uses this information to reduce the likelihood of queue blocking the upstream junction (nctu, 2007)**.**

Measures of Traffic Behavior:
It is used to estimate the current size of the queue at the link with the control area. From these estimates, SCOOT calculates an average value for the sum of the queues. This value is used as a measure of the inefficiency of traffic movement and is called Performance Index (PI). The SCOOT optimizer continuously searches for signal settings that make the PI as small as possible. The total number of stops can be weighted and summed with the average queue into the PI. The proportion of a cycle time that vehicles are stationary over detectors can be weighted and summed into the PI (indicate congestion). The degree of saturation is defined as the ratio of the average flow to the maximum flow, which can be passed through the intersection from a particular approach and calculated by the traffic model. Traffic model measures

average travel demand (the sum of the average flows across all the detectors in the area) and the average value of PI. If a large increase in PI without much change in the demand, it is considered as an abnormal event, such as an accident (nctu, 2007).

The space time diagram of the SCOOT traffic model is shown in figure 5 as below:

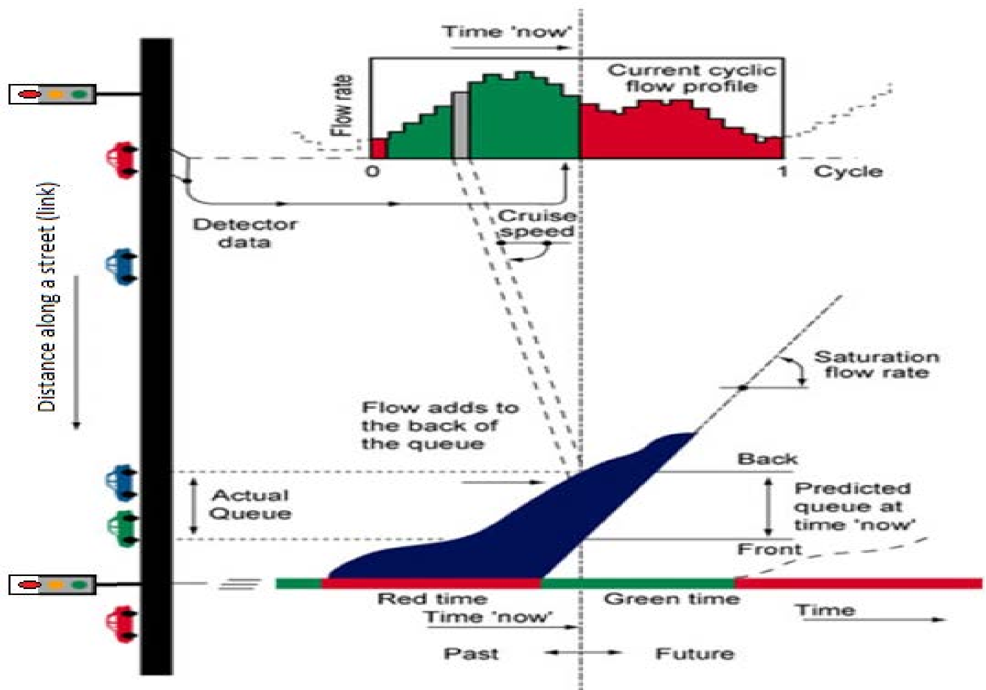


Figure 5. Space-time diagram of the SCOOT Traffic Model (Al-Mudhaffar, 2006).

SCOOT Signal Optimizer:

The system contains a set of parameters that control all the signal settings in the area. If this set of parameters is unchanged, then the associated signals will be controlled by a fixed time plan. However, in normal operations, the optimizer makes frequent changes by small alterations to the parameters to adapt the fixed time plan to variations in the traffic behavior. A few seconds before each stage changes, it estimates every junction whether it is better to make changes earlier, later, or as scheduled. To implement the alternation to minimize the "maximum Degree of Saturation" on the approach of that junction. Calculation is to take account of current queue length; approach congestion measurement and minimum green time constraints. The sequence of installing process is Fix time plan, Split optimizer, Offset optimizer, and Cycle time optimizer (nctu, 2007).

Split Optimizer:

A few seconds (5 secs) before each stage change at every SCOOT intersection is scheduled to occur, the optimizer estimates whether it is better to make the change earlier or later. Any one decision by the optimizer may alter a scheduled stage change time by no more than a few seconds (Maximum allowed changed time). The signal optimizer will minimize the maximum degree of saturation on the approaches at each intersection. Temporary change (e.g. 4 secs) is made to the change of green durations to take account of the cycle-by-cycle random traffic variations. A permanent change (e.g. 1 sec) is made to the stored values of green duration so that longer-term trends in the traffic demands can be followed. Over a period of several minutes, the proportions of green time can be completely revised by SCOOT to meet a new pattern of traffic flows. In Split Optimizer, each junction will be threaded by the split optimizer independently and performed more frequently than other optimizers. For example, in a network of 50 junctions with an average of 3 stages per junction, there will be 150 decisions per cycle. If some decisions are missed, then the split plan will remain unchanged (nctu, 2007).

Offset optimizer:
At each intersection, the offset optimizer makes the offset decision once every cycle. Since the offset of one intersection is altered relative to adjacent intersections, the offset between an adjacent pair of intersections may alter twice per cycle. Decisions are taken during a predetermined stage within every cycle time. To use cycle flow profile information to estimate overall traffic progression in those streets which are immediately upstream and downstream. Offset optimizers are modified when congestion occurs to improve the coordination on shorter streets at the expense of longer streets, since the longer street has a larger queue storage space to prevent potential spillback (nctu, 2007).

Cycle Length Optimizer:
The signal-controlled intersections are grouped into "sub areas" which have pre-set boundaries. All signals within a sub area are operated by SCOOT on a common Cycle Length. Also, some intersections can be operated on one half of the common cycle time of the sub-area; this is referred to as "double cycling" and is of particular value for signal-controlled pedestrian crossings (nctu, 2007).

While SCOOT has been proven to be effective in achieving significant savings in delay, its delay-minimization objective may not be the most effective technique for networks with a high level of congestion. Several new tools have been developed for use in heavily congested situations. These include a 'GATING' facility, which can be used to automatically meter the flow of traffic into a congested area. It has been tested and evaluated in Southampton where significant benefits have been obtained. Another tool is the MONACO program, which can be used in conjunction with SCOOT to monitor, analyze and diagnose congestion in a UTC network and to trigger the introduction of congestion strategies automatically. Early results showed that SCOOT achieved an average saving in delay of about 12% when compared with up to date TRANSYT fixed-time plans. Some researchers suggest that SCOOT is likely to achieve an extra 3% reduction in delay for every year that a fixed-time plan "ages". Since SCOOT is designed to adapt automatically to compensate for aging and incident effects, it is reasonable to expect that, in many practical situations, SCOOT will achieve savings in delay of 20% or more (Al-Mudhaffar, 2006). Due to the limitation of local controllers, SCOOT cannot skip phase or change the phase sequence. The objective function is not sufficient for use in various traffic conditions. SCOOT does not provide good results to deal with congestions, especially for those caused by incidents (nctu, 2007).

SCOOT Benefits and Advantages:
SCOOT provides a fast response to changes in traffic conditions and enables it to respond rapidly to changes in traffic, but not so rapidly that it creates instability. Therefore, it avoids large fluctuations in control behavior because of temporary changes in traffic patterns. SCOOT not only reduces delay and

congestion but also contains other traffic management facilities. For example, in 1995 a new facility was introduced to integrate active priority to buses (link with bus priority) with the common SCOOT UTC system. The system is designed to allow buses to be detected either by selective vehicle detectors or by an automatic vehicle location (AVL) system. Many benefits are obtained from the installation of an effective Urban Traffic Control system utilizing SCOOT, both reducing congestion and maximizing efficiency, which in turn is beneficial to the local environment and economy. In the other words, the characteristics of SCOOT can be summarized as below:

- Customized congestion management.
- Reductions in delay of over 20%.
- Maximize network efficiency.
- Flexible communications architecture.
- Public transport priority.
- Traffic management.
- Incident detection.
- Vehicle emissions estimation.
- Comprehensive traffic information.

SCOOT has shown significant benefits over the best-fixed time operation and is widely used all over the world. Comparisons of the benefits of SCOOT against good, fixed time plans, showed reductions in delays to vehicles of average 27% at Foleshill Road in Coventry - a radial network in Coventry with long link lengths. In 1986, research by Bell suggests that SCOOT is likely to achieve an extra 3% reduction in delay for every year than a fixed-time plan. Further, the effects of incidents have been excluded from many of the survey results to ensure statistical validity. Since SCOOT is designed to adapt automatically to compensate for ageing and incident effects, it is reasonable to expect that, in many practical situations, SCOOT will achieve savings in delay of 20% or more. In 1993, a SCOOT demonstration project in Toronto showed an average reduction in journey time of 8% and vehicle delays of 17% over the existing fixed time plans. During weekday evenings and Saturdays, vehicle delays were reduced by 21% and 34% respectively. In unusual conditions following a baseball game, delays were reduced by 61%, demonstrating SCOOT's ability to react to unusual events (Misagh Ketabdari, 2013).

SCOOT Weak Points

Maintaining a good offset on a short link can be a problem because it is a short link with little storage capacity, the queue in the red will frequently reach the detector. Once a queue has formed over the detector, there is no useful information available from the detector for offset optimization. Consequently, left to its own devices, SCOOT may not control the offset as well on critical short links as on longer ones. However, recently, the congestion-offset facility has been provided to ensure good control and avoid loss of throughput on such links. In addition, users can set a fixed / biased offset on the link to constrain the offset permanently towards the desired value for congested conditions. Another weak point of SCOOT urban traffic control system is it needs a large installation base. In most of the cases, there would be a problem with free space for installation (Misagh Ketabdari, 2013).

2.12.4. Hybrid Centralized Optimization System SCATS

The Roads and Traffic Authority (RTA) of New South Wales, Australia, developed the Sydney Coordinated Adaptive Traffic System (SCATS). It is a real-time area traffic control system, which adjusts signal timing in response to variations in traffic demand and system capacity. The vehicle detectors are in each lane immediately in advance of the stop-line. SCATS uses two levels of control: strategic and tactical. Strategic control determines suitable signal timings for the areas and sub-areas based on average prevailing traffic conditions. Tactical control refers to control at the individual interaction level (Gilbert Gedeon, 2004).

At the strategic level, several signals (from 1 to 10) group together to form a subsystem. Up to 64 subsystems can link together for control by a regional computer. Each traffic signal in a subsystem shares a common cycle time, which is updated every cycle to maintain the degree of saturation around 0.9 (or a user-definable parameter) on the lane with the greatest degree of saturation. Degree of saturation corresponds to an occupancy value measured by the detector. Cycle time can normally vary up to 6 seconds each cycle, but this limit increases to 9 seconds when a trend is recognized. Phase splits vary up to 4 percent of cycle time each cycle to maintain equal degrees of saturation on competing approaches, thus minimizing delay. Offsets selected for each subsystem (i.e., offsets between intersections within the subsystem) and between subsystems linked together (Gilbert Gedeon, 2004).

Tactical operates under the strategic umbrella provided by the regional computer. It provides local flexibility to meet cyclic demand variation at each intersection. For example, any phase (except the main street phase) may be either omitted or terminated earlier or extended. Time saved during the cycle because of other phases terminating early or being skipped may be used by subsequent phases added to the main phase to maintain each local controller at the system cycle length (Gilbert Gedeon, 2004).

SCATS application has been seen in many cities throughout the world and its first application in North America was in conjunction with the Autoscope video detector in Oakland County, Michigan, in the FAST-TRAC project. SCATS currently has three levels of control: local, regional, and central. SCATS distributes computations between a regional computer at the traffic operations center and the field controller. A study by the City of Troy, Michigan, found the benefits in travel time reductions in A.M. Peak by 20%, in Off Peak by 32%, in P.M. Peak by 7% and 20% reduction in stopped vehicle delay (Gilbert Gedeon, 2004).

SCATS Benefits and Advantages:

The benefits of the SCATS system are as follows:

- This system has a small system architecture size.
- This system increases public Health Savings by reducing the amount of emissions because of decreasing traffic congestion.
- This improves operations for all users, especially for transit bus routes. Hence, enhance public transport time and reliability.
- SCATS shows great ability to handle unpredictable changes of traffic volumes and patterns on special days and special times. Demonstrates the ability to provide response to traffic demand dynamically.
- It has the potential to handle the traffic patterns and volumes adequately.
- It would handle long pedestrian clearance time.
- Responsive to day-to-day and time-of-day fluctuations in demand.

- Responds well to traffic congestion resulting from crashes, clears backups quickly.
- Provides an effective maintenance alarm system that reduces traffic delays due to equipment malfunction.
- Eliminates the need (and associated costs) for signal retiming typically performed every three to five years.
- Reduction in Collisions.
- Reduced air pollution.
- Reduced fuel consumption.
- Reduced delays (Misagh Ketabdari, 2013).

SCATS Weak Points:
The SCATS Philosophy is based on optimization in real time by using many distributed computers as processors. The point is although it has libraries of offsets, phase split plans, but there is no comprehensive plan, which is determinable and trustable completely. However, different plans should be checked and be voted to be used for advanced cycles. SCATS is not model based. It relies on incremental feedback. Intersections can be grouped as sub-systems and by accumulation of more sub-systems, it converts to a system. In other words, there is no traffic model in SCATS; the “adaptive” process is completed by the local actual control, which limits the use of an optimization methodology. The other point is changing the phase plans are done manually not automatically which costs time and personnel. This point can cause problems when the system wants to answer to dynamic traffic demand. Another important disadvantage of this system is that it is impossible to currently provide feedback information about the performance of signal progression with the stop line detection philosophy (Misagh Ketabdari, 2013).

2.12.5. UTOPIA
UTOPIA (Urban Traffic Optimization by Integrated Automation) / SPOT (System for Priority and Optimization of Traffic) is designed and developed in the 1980s by FIAT Research Centre, ITAL TEL and MIZAR Automazione in Turin, Italy. The objective of the system is to improve the efficiency of both public and private transportation by performing a real-time optimization of the signal timings to minimize the total socioeconomic cost of the traffic system. Traffic congestion, vehicular emissions, and travel times for public transit vehicles and private traffic are expressed as costs. Depending on the size of the network, the UTOPIA system optimizes the network control strategy over the next 30 to 60 minutes time horizon and updates every 5 minutes. Signal timing optimization at an individual intersection level is performed on the time horizon of the next 120 seconds (Aregay Fkadu Kebede, 2020).

The basic principle of UTOPIA is to perform a real-time optimization of the signal settings in order to minimize the total socio-economic cost of the traffic system, in terms of the avoidance of congestion and decrease the amount of emissions, and the reduction of travel time both for private traffic and for priority vehicles. UTOPIA has a hierarchical and distributed architecture. This architecture consists of a higher level (Central system), which is responsible for setting the overall control strategies, and a lower level (controlled junctions) where the traffic light control is implemented by means of the SPOT software (Misagh Ketabdari, 2013).

Central System:
The central system of Utopia is a higher level that calculates the network-wide optimization strategy and reference control strategies. Based on a LAN of standard computers (servers and workstations), it provides for scale-ability and modularity of all the functions of control, diagnostic, PT priority, monitoring, and user interface. In the following functions that carried out by central level software are:

- Traffic network monitoring.
- System diagnostic.
- Traffic control and public transport priority.
- Co-operative monitoring and control.
- Graphical and interactive user interface (Misagh Ketabdari, 2013).

Roadside Unit:
The second level in the Utopia, which has a lower level compared to the central system part, is based on a network of Roadside Units. This part is equipped with industrial computers, which are running the "SPOT" software, intersection by intersection to control the traffic, calculating the demand etc. In the following, the basic functions carried out by intersection level software "SPOT" are:

- Traffic light controller interface (Actuation).
- Intersection control (Adaptive traffic control and plan selection).
- Intersection status estimation.
- Public transport priority.
- Local level diagnostic (Misagh Ketabdari, 2013).

Communication:
After introducing the two major parts of Utopia, one last important part remains, which is necessary for connecting these two parts together. In order to operate properly, the Roadside Unit needs data from the Central System and data from the adjacent Roadside units. On the other hand, each Roadside Unit locally data (traffic volume and planned control strategy) must be distributed to the adjacent Roadside Unit and to the Control Center (Misagh Ketabdari, 2013).

Regarding improvements to priority, the UTOPIA concept was tested in Gothenburg and Turin. Junction waiting times for public transport improved by 52% in Gothenburg for vehicles with absolute priority, while travel times for both buses with weighted priority and private vehicles were reduced by as much as 15%. Moreover, in Turin, reductions in public transport travel times as high as 14.4% were achieved. Travel times for private cars in Turin were measured in parallel with those made for public transport. An overall reduction of 17% was registered (Misagh Ketabdari, 2013).

UTOPIA Benefits and Advantages:
- Implementation of UTOPIA was shown to give an increase in private traffic speed. In peak times, the speed increases were 35%.
- Public transport vehicles, which were given absolute priority, showed a speed increase of 19.9%.
- UTOPIA/SPOT has been explicitly designed with public transport vehicle priority in mind. Buses and LRT45 vehicles are given absolute priority at junctions, subject to the accuracy in forecasting their arrival time.

- In Turin LRT are given higher priority than buses because they have more passengers, but extra priority can be assigned on a vehicle-by-vehicle basis if required (Misagh Ketabdari, 2013).

UTOPIA Weak Points:

- Longer waiting times for vehicles because of giving priority to buses and preemption.
- Some developments were below the expectations.
- Early termination of some applications.
- Two systems stopped right after the experimentation.
- The main cause of delays, misunderstandings, low profile participation by some parts can be found in the incorrect interpretation of the user needs and in the underestimation of the level of agreement necessary to reach the goals (Misagh Ketabdari, 2013).

2.13. Advantages and disadvantages of Traffic Signal System

Traffic control signals that are properly designed, located, operated, and maintained will have one or more of the following advantages:

- Allows orderly and efficient movement of people for all modes of transportation.
- Effectively maximize the traffic movements served at the intersection.
- Reduce the frequency and severity of certain types of crashes.
- Provide appropriate levels of accessibility for pedestrians and side street traffic.
- Increase the traffic-handling capacity of the intersection if proper physical layouts and control measures are used, and the signal operational parameters are reviewed and updated (if needed) on a regular basis (as engineering judgment determines that significant traffic flow and/or land use changes have occurred) to maximize the ability of the traffic control signal to satisfy current traffic demands.
- Reduce the frequency and severity of certain types of crashes, especially right-angle collisions.
- Can be coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions.
- Used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross (Jim Elgin & et.al, 2021).

The degree to which these benefits are realized is based partly on the design and partly on the appropriate need for a signal. Traffic signals are not always the optimal solution to reducing crashes at intersections. Traffic control signals that are ill designed, ineffectively placed, improperly operated, or poorly maintained, may result in excessive delay, disobedience of the indication, avoidance, and increased frequency of collisions. When properly used, traffic control signals are valuable devices for the control of vehicular and pedestrian traffic. They assign the right-of-way to the various traffic movements and thereby profoundly influence traffic flow. Traffic control signals are often considered a panacea for all traffic problems at intersections. This belief has led to traffic control signals being installed at many locations where they are not needed, adversely affecting the safety and efficiency of vehicular, bicycle, and pedestrian traffic. Traffic control signals, even when justified by traffic and roadway conditions, can be ill designed, ineffectively placed, improperly operated, or poorly maintained. Improper or unjustified traffic control signals can result in one or more of the following disadvantages:

- Excessive delay
- Excessive disobedience of the signal indications
- Increased use of less adequate routes as road users attempt to avoid the traffic control signals
- Significant increases in the frequency of collisions (especially rear-end collisions) (Jim Elgin & et.al, 2021).

A primary objective of signal timing settings is to move people through an intersection efficiently. Achieving this objective requires a plan that allocates right-of-way to the various users. This plan should accommodate fluctuations in demand over the course of each day, week, and year. Because travel demand patterns change over time, the signal-timing plan should be periodically updated to maintain intersection efficiency. There are many traffic signal timing parameters that affect intersection efficiency, including the cycle length (the time needed to serve all movements (signal phases)), movement green time, and clearance intervals. Increasing a traffic movement's green time may reduce its delay and the number of vehicles that stop. However, an increase in one movement's green time generally comes at the expense of increased delay and stops to another movement. A good signal-timing plan is one that allocates time appropriately based on the demand at the intersection and keeps cycle lengths to a minimum (Jim Elgin & et.al, 2021).

The relationship between signal timing and safety is also addressed with specific timing parameters and the design of the intersection. For instance, the intent of the yellow change interval is to facilitate safe transfer of right-of-way from one movement to another. The safety benefit of this interval is most likely to be realized when its duration is consistent with the needs of drivers approaching the intersection at the onset of the yellow indication. This need relates to the driver's ability to perceive the yellow indication and gauge their ability to either stop before the limit line, or travel through the intersection more safely. Their decision to stop, or continue, is influenced by several factors, most notably speed. Appropriately, timed yellow change intervals can reduce driver confusion. Signal timing plans that reduce the number of stops and minimize delays may also provide some additional safety benefits. Traffic signal timing must consider pedestrians, vehicular traffic conditions, change and clearance intervals, and if actuated, detection layout. These signal timing parameter settings may be influenced by adjacent intersections, but are applicable for each intersection considered as an isolated unit. Studies around the country have shown that the benefits of area-wide signal timing outweigh the costs. The benefits of up-to-date signal timing include shorter commute times, improved air quality, reduction in certain types and severity of crashes, and reduced driver frustration (Jim Elgin & et.al, 2021).

Pre-timed (Fixed) control is ideally suited to closely spaced intersections where traffic volumes and patterns are consistent on a daily or day-of-week basis. Such conditions are often found in downtown areas. They are also better suited to intersections where three or fewer phases are needed. Pre-timed control has several advantages. For example, it can be used to provide efficient coordination with adjacent pre-timed signals, since both the start and end of green are predictable. In addition, it does not require detectors, thus making its operation immune to problems associated with detector failure. Finally, it requires a minimum amount of training to set up and maintain. However, pre-timed control cannot compensate for unplanned fluctuations in traffic flows, and it tends to be inefficient at isolated intersections where traffic arrivals are random (Jim Elgin & et.al, 2021).

Semi-actuated control uses detection only for some of the movements at an intersection, typically the minor movements. The phases associated with the major-road through movements are operated as "non-actuated." That is, these phases are not provided detection information. In this type of operation, the controller is programmed to dwell in the non-actuated phases and, thereby, sustain a green indication for the highest flow movements (normally the major street through movement). Minor movement phases are serviced after a call (demand) for their service is received. Semi-actuated control is most suitable for application at intersections that are part of a coordinated arterial street system. Semi-actuated control may also be suitable for isolated intersections with a low-speed major road and lighter crossroad volume. Semi-actuated control has several advantages. Its primary advantage is that it can be used effectively in a coordinated signal system. Moreover, relative to pre-timed control, it reduces the delay incurred by the major-road through movements (i.e., the movements associated with the non-actuated phases) during periods of light traffic. Finally, it does not require detectors for the major-road through movement phases and hence, its operation is not compromised by the failure of these detectors. The major disadvantage of semi-actuated operation is that continuous demand on the phases associated with one or more minor movements can cause excessive delay to the major road through movements if the maximum green and passage time parameters are not appropriately set. Alternatively, because the major street has no detection and is thus guaranteed a minimum green time regardless of the presence of traffic, there can be unnecessary delay to the minor movement traffic in off-peak hours. Another drawback is that detectors must be used on the minor approaches, thus requiring installation and ongoing maintenance (Jim Elgin & et.al, 2021).

Fully actuated control refers to intersections for which all phases are actuated and hence, it requires detection for all traffic movements. Fully actuated control is ideally suited to isolated intersections where the traffic demands and patterns vary widely during the course of the day. There are several advantages of fully actuated control. First, it reduces delay relative to pre-timed control by being highly responsive to traffic demand and to changes in traffic pattern. In addition, detection information allows the cycle time to be efficiently allocated on a cycle-by-cycle basis. Finally, it allows phases to be skipped if there is no call for service, thereby allowing the controller to reallocate the unused time to a subsequent phase. The fully actuated control requires initial and maintenance costs (Jim Elgin & et.al, 2021).

2.14. Conclusion of Literature Review

In conclusion, traffic congestion can be reduced on the road networks, which in turn reduces the excessive delays at the intersections by deploying the traffic signals in efficient ways. This means, we need to use proper traffic signal design with optimum phasing arrangement at the intersections and will surely reduce the existing traffic congestion that will save time and cost for the road users. Moreover, the bottlenecks at the intersections will be overcome and road intersections will have positive impacts on mobility such as less delays at the intersections, decrease in travel time. Not only this, but have positive impacts on the environment as well such as less emission of harmful pollutants, decrease in noise pollution, decrease in fuel consumption. Thus, the capacity of the road network will be optimized and the losses in terms of economies caused by traffic congestion can be improved significantly. Another important point is that the traffic signal is a better option for effective transportation and is the best possible way to control the vehicle movements at the intersections without any accidents and conflicts. Traffic signals are one of the most effective and flexible active controls of traffic and are widely used all over the world. By deploying traffic signals at the intersections, total crashes, which includes injury, and fatal crashes will be reduced and is the safer option as well in order to avoid any type of chaos. The installation of a traffic signal will result in a general reduction of crashes, but also specific types of crashes, such as right angle and left-turn related crashes, are likely to be reduced more. In addition to this, it is concluded that the installation of a traffic signal will not only improve the safety level of an intersection but it will also improve at a level higher than what other measures, non-traffic signal related, would have accomplished. Hence, the traffic signals are one of the most powerful tools for urban traffic control, which city authorities can utilize, and their correct installation can improve both traffic flow and the safety of all road users. In comparison to other traffic improvements, traffic signals are also relatively low capital investment and there is no doubt that time separation of traffic conflicts using traffic signals is one of the most powerful tools for urban traffic control available to city authorities. Consequently, their correct design and operation can improve both traffic performance and safety for all road users. As technology has been improved, informatics and telecommunication have developed a new generation of controllers, which are less expensive and optimal that makes modern signaling systems much more cost-effective. Therefore, the traffic signal deployment at the intersections will provide sustainable solutions such as better traffic flow, less emission of harmful pollutants in the environment, and optimized traffic performance and moderate safety.

By these types of results, I am sure that deploying the traffic signal control in my hot spot area will reduce the traffic problems and improve safety. Therefore, I will perform traffic analysis by using VISSIM software in the next section to see the practical implications.

3. RESEARCH PLAN: SURVEY SETUP

In order to be able to analyze more in depth how the traffic signals at the intersections influence commuters a survey needs to be conducted. The objective of this research is to examine how the traffic signals at the intersections can influence autonomous drivers in terms of traffic safety and driver behavior. This chapter describes all the steps that need to be undertaken to create and distribute the survey. This survey will target a variety of categories of drivers including young novice and older experienced drivers. The survey has been circulated to all drivers' age categories. The following chapters indicate the survey design, how the questions should be defined and why the chosen questions are the most appropriate. Further, the goal of the survey chapter will try to document why this survey is necessary to be conducted and what are the expected outcomes of the whole procedure.

3.1. Goal of the Survey

The main goal of the survey is to gain knowledge of people regarding traffic signals at the intersections. What do they know about the specific subject? What do they believe about it? Do they have any similar experience? What is their opinion about traffic safety, traffic congestion and queues? Will they ever feel safe under signalized control at the intersections? How do they perceive intersections with different control modes? By implementing proper traffic management initiatives such as proper traffic signal design with optimum phasing arrangement, connection with centralized control room and so on, what do they think about the capacity of the roads at the intersections? The report from the survey in combination with the literature review part will give us a clearer picture about the usage of traffic signals at the intersections.

3.2. Questionnaire

The questionnaire consists of 21 questions, divided into 5 main parts scattered inside the survey. The first part gains inside the demographics of the responders, asking questions about the gender, age, living current area and country, the owning of a car and a driving license, the current profession and which means of transport they are using. The second part tries to investigate/ explore individual knowledge about what they think about traffic signals. The third part deals with the safety and behaviors, what the drivers perceive about deployment of traffic signals in terms of traffic safety and driver behaviors. The last part is related to the travel time, congestions, queues and traffic accidents that what commuters believe about traffic signals in terms of travel time and queues when signalized intersections are highly denser. This also deals with the implementation of proper traffic management initiatives such as what commuters believe about traffic signals whether it is a best option to control vehicle movements or not, and whether the centralization system optimizes performance measures such as delays, capacity and various others.

3.2.1. Demographic Questions

Demographic questions are one of the most important parts of each questionnaire. These questions help us to make the comparison between age groups, living areas, groups, gender etc. In this survey, the demographic questions are crucial to distinguish the difference in perspective between age groups. Experienced individuals with car have better understanding about driver behavior and other human factors at the intersections than those who do not have a car. In the paragraphs below, we will discuss the different demographic questions.

The first question refers to the gender of the responder. Males and females have different perspectives on driving and it will be interesting to analyze their answers. The next question refers to age, it is an important parameter and used to compare different perspectives between individuals. Answers can vary depending on age. Regarding the age of the participants, I decided to create five different age groups, and not to have an open question about the age. The age groups are separated as shown below:

- 16 – 24
- 25 – 34
- 35 – 44
- 45 – 65
- 65+

Next two questions refer to the living area of individuals in order to be able to have an idea where the responders mainly live. First, a question about the country is asked so that we will have a fair idea about the deployment of traffic signals and what initiatives have been taken in their countries. Therefore, the specific question is crucial to understand individuals' background. Second question refers to the living area of individuals. There are three choices for the respondent as below:

- Urban area
- Suburban area
- Rural area

These choices have been defined to get a more general overview whether the responder lives in a city or outside the city. For example, people living in a village may not have had the opportunity to get involved or just to know about the traffic signal system. Next two questions ask about the ownership of a car and the ownership of a driving license. Responders, who own a car and a driver's license, are more likely to have better understanding about different parameters such as traffic congestions at the intersections than the individuals who do not own a car or a driver's license. For these two questions, "Yes" and "No" choices are available for the responder. Finally, the last two questions refer to the responder's profession and the means of transport that is used for his/ her everyday movement. For the first question, three choices are available for the responder:

- Student
- Employee
- Unemployed

It is important to know the profession of each responder. For example, a student who does not own a car or a driver's license has less knowledge about traffic signals than a student who owns a car. For the above-mentioned, we can clearly see that we must consider multiple factors of each responder, in order to have a clearer view. Finally, a question regarding the means of transport that the responder uses has been asked. The same explanation counts as for the parameter about the "Current Profession". For this question, four choices are available for the responder:

- Car

- Public Transport
- By foot
- Other means of transport (e.g., bicycle)

3.2.2. Traffic Signals knowledge questions

After the demographic questions, we can see the knowledge questions, to see if the responders know what traffic signal refers to. Likewise, a question is being asked about operational modes. As we know, operational modes are critical factors when we speak about efficiency of traffic. For this part, I used closed questions with answering categories. I preferred to use seven possible answers (Likert scale) which are shown below:

- Totally disagree
- Disagree
- Rather disagree
- Neither disagree nor agree
- Rather agree
- Agree
- Totally disagree

All the questions of the specific part try to determine the level of knowledge of each participant but also their perspective about the operations. In addition to this, I also tried to have logical transitions among the questions in order to have a meaningful conclusion.

3.2.3. Traffic safety and Behavior questions

In this part, questions that have been included are about traffic safety. How they feel about traffic signals than stop signs at the intersections in terms of safety. Are traffic signals assist us in controlling driver behaviors such as careless driving? Are traffic accidents increasing traffic congestion at the intersections? Responders who are frequent commuters know this scenario well and are in a better position to give their feedback. For this part, I used a Liker scale with seven possible answers as well as I used for the previous parts.

3.2.4. Responders' perspective questions

This part consists of most questions compared to the other parts and is related with the travel time, congestions, queues and traffic accidents that what commuters believe about traffic signals in terms of travel time and queues when signalized intersections are highly denser. This also deals with the implementation of proper traffic management initiatives such as what commuters believe about traffic signals, whether it is a best option to control vehicle movements or not, and does the centralization system optimize performance measures such as delays, capacity and various others. From this specific part, we can draw very useful conclusions about the perspective of the users regarding traffic signals. Here, I also used a Liker scale with seven possible answers.

4. SURVEY ANALYSIS AND INTERPRETATION OF THE RESULTS

In order to create the survey and collect the data, QUALTRICS XM survey application has been used. The specific software also offers analysis of basic statistics and relative percentages, which are enough for this research work. QUALTRICS will help us to create additional figures in case something is not provided from the software. Besides, the raw data and the set of questions used for the survey as shown in the annex 09. In this chapter, the results from the survey are presented as below.

4.1. Demographics Interpretation

A total number of 103 people participated in the survey. From the 103 people's participation in my research survey, among these five participants chose not to continue further. The analysis of the collected responses will be presented as below:

From the 98 participants, 78% were male and 22% were female responders. As we can see, participants were mostly male as shown in the figure 6 as below:

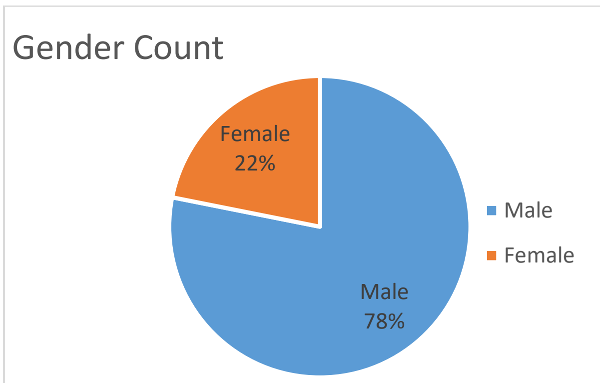


Figure 6: Demographics- Gender (Qualtrics, Own edit, 2023)

It is important to mention here that among 98 participants, 86 participants have driving licenses, 11 participants do not own driving licenses and 1 participant did not mention driving license status. This is shown in the figure7 as below:

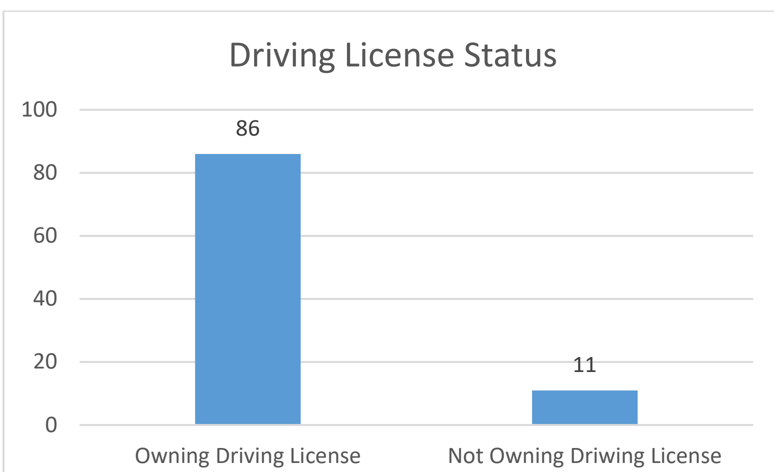


Figure 7: Demographics- Driving licenses Owning *(Qualtrics, Own edit, 2023)*

As we can observe from the following figure 8, we have participants from all the categories. 12% of the participants belong to the first age category, 36% of the responders belong to the second age category i.e. higher percentage of participants belong to this category, 29% belong to the third age category (35-44) i.e. in this part, good number of participants are well experienced that is good for my analysis. Fourth age category has 22% responders and 1% belongs to the last category i.e. fifth category. This means overall participants are well experienced that have taken part in this survey, which is quite interesting and the outcome of the survey will be more ethical and sensible.

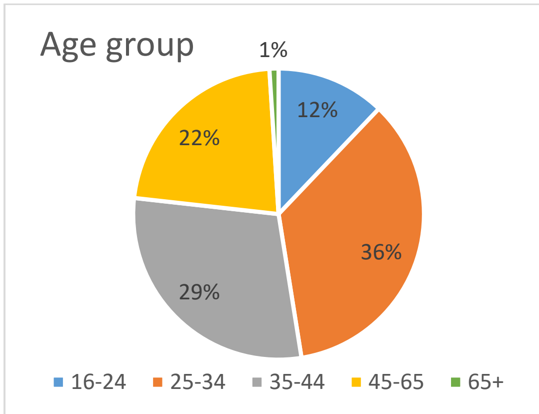


Figure 8: Demographics-Age Categories *(Qualtrics, Own edit, 2023).*

Regarding the living country, I created an open question and only 57 participants were able to write about s their living country. Since QUALTRICS was not able to create any visualization, I exported the raw data on excel sheet (see annex 9.4) in order to create a graph according to my data to see the perspectives of each individual and the good thing is majority of participants are from well developed countries. This means that the outcome, which I will be provided with, would have better quality and effective as well. This is shown in the figure 9 as below:

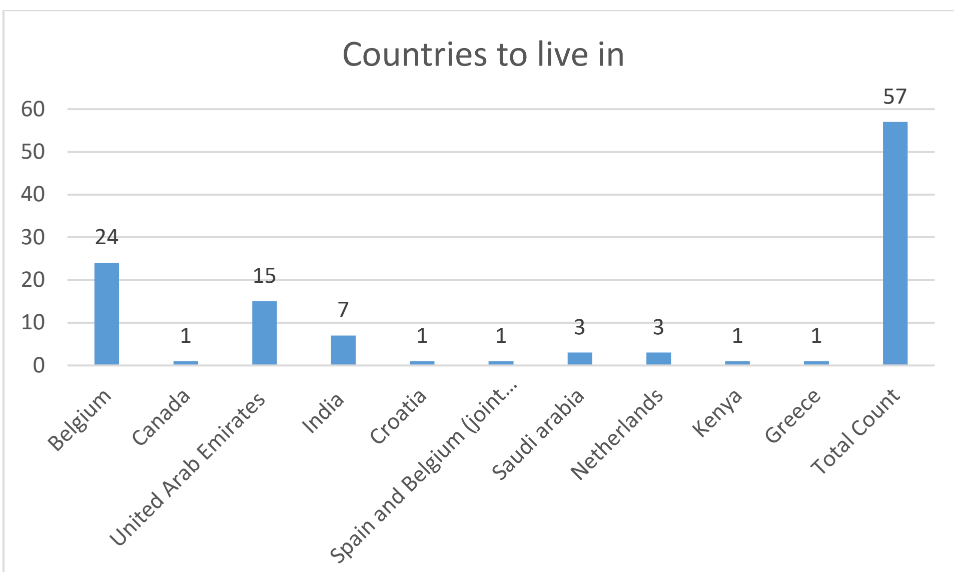


Figure 9: Demographics-Living Country *(Qualtrics, Own edit, 2023).*

Next question has to do with the living area of the responder. Observing figure 10, we see that 73% of the respondents live in an urban area. 18% of the respondents live in a suburban area and the rest 9% lives in a rural area. This means that the majority of the participants live in an urban area, therefore, they have better observation about denser traffic as the urban area is denser than suburban and rural areas.

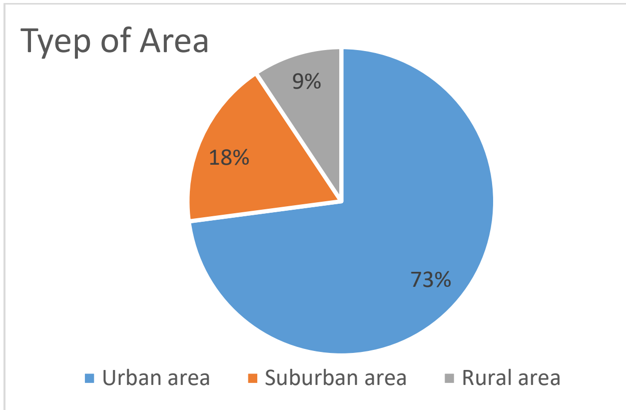


Figure 10: Demographics-Living Area *(Qualtrics, Own edit, 2023).*

The next question has to do with the ownership of a driver's license. It is really important to know the percentage of people who own a driving license because the perspective and knowledge about signalized intersections is a fundamental concern to know the impacts of intersections with signalized and non-signalized control modes. According to people's answers, we see that 86 participants out of 97 participants own a driving license and 11 participants do not have driving licenses. From this figure, the probability for valuable data and hence effective results will have more. This is shown in the figure 11 as below:

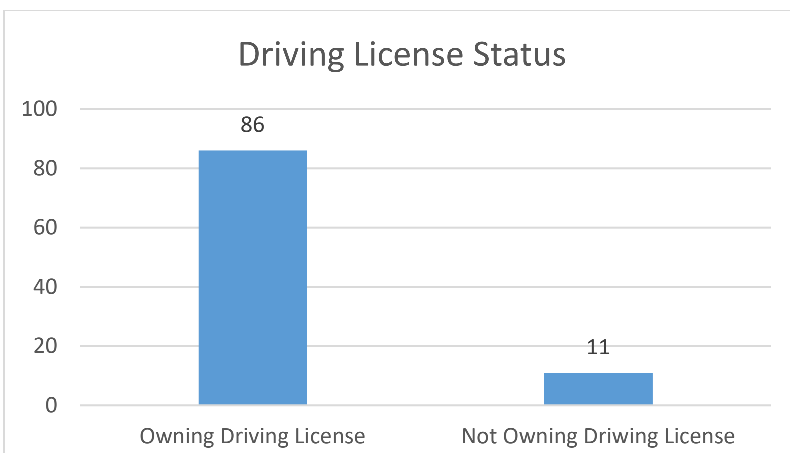


Figure 11: Demographics-Driving License Owning *(Qualtrics, Own edit, 2023)*

Next question is also important and it is related to the previous one. It deals with car ownership in which 78% participants own a car. This is again an interesting figure in which our validated data will have more weightage. Hence, as per survey participants, the results will be much more authentic as the users who own a car have better observations and experience about different parameters of the road. This is shown in the figure 12 as below:

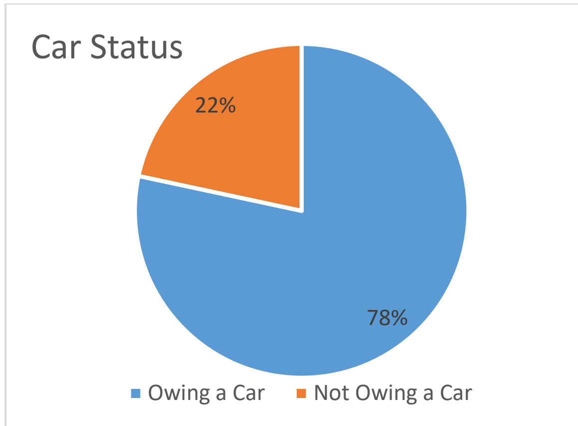


Figure 12: Demographics-Car Owning *(Qualtrics, Own edit, 2023)*

Regarding the current profession, 76% respondents are employees, 21% are students and the remaining participants i.e. 3% respondents are unemployed. This is really encouraging because the employees who have car understand the situation of traffic especially during peak and off-peak hours, driver behaviors and various others very well. This means, again we will have very good results later in the survey because of the more informed responders.

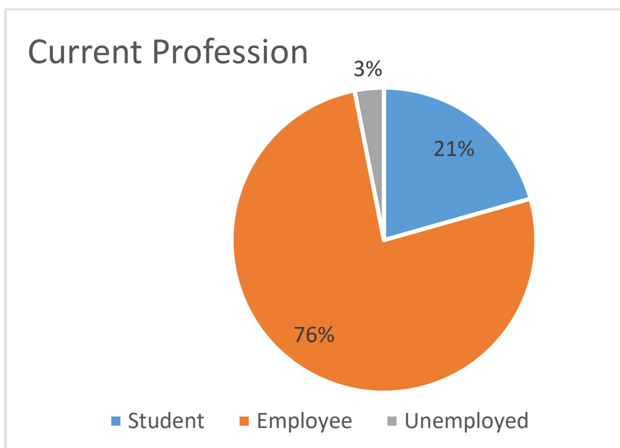


Figure 13: Demographics-Current Profession *(Qualtrics, Own edit, 2023)*

The last demographic question has to do with the means of transport, how participants use to go to the university or at the office etc. Most of the participants i.e. 66% use the car for their daily movement. Public transport is used by 19%, 11% participants use other means of transport, for example bicycle or taxi etc. Finally, only 4% of the participants prefer to walk to their job or to the university. It is remarkable here and looking at the car-owning figure, we see that almost all the individuals who own a car use it every day for their daily movements and they do not prefer to use any other means of transport. Again, this will be really helpful in analyzing the intersections in the later part of this and we will have much more authentic results.

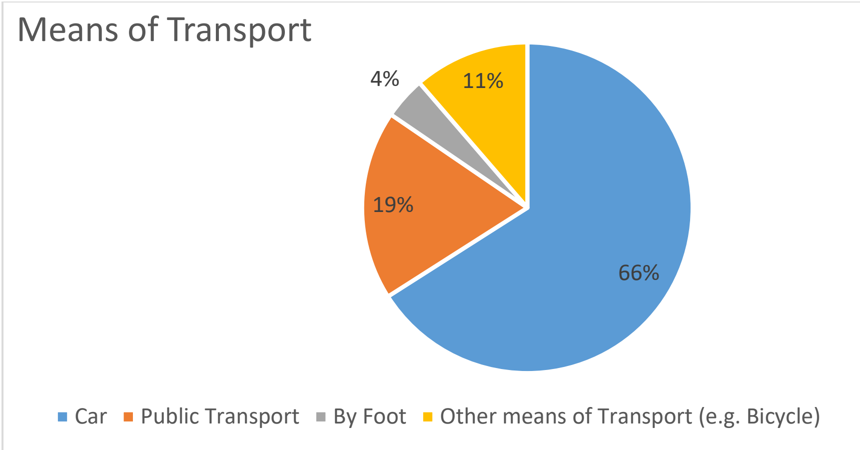


Figure 14: Demographics-Means of Transport *(Qualtrics, Own edit, 2023)*

To summarize the demographics results, all numbers, answers and percentages depicted in the table 2 are as below:

Age Category	16-24	25-34	35-44	45-65	65+	Total
Answers	12	35	29	22	1	99
Percentage	12.12%	35.35%	29.29%	22.22%	1.01%	100%
Living Area	**Urban**	**Suburban**	**Rural**			
Answers	70	17	9			96
Percentage	72.92%	17.71%	9.38%			100%
Driving License	**Yes**	**No**				
Answers	86	11				97
Percentage	88.66%	11.34%				100%
Car Owning	**Yes**	**No**				
Answers	76	21				97
Percentage	78.35%	21.65%				100%
Employment Status	**Student**	**Employee**	**Unemployed**			
Answers	20	74	3			97
Percentage	20.62%	76.29%	3.09%			100%
Means of Transport	**Car**	**Public Transport**	**By Foot**	**Other**		
Answers	64	18	4	11		97
Percentage	65.98%	18.56%	4.12%	11.34%		100%

Table 2: Demographics Results *(Qualtrics, Own edit, 2023).*

4.2. Knowledge, Traffic Safety and Behavior Questions about Signalized and Non-signalized intersections

The second part of the questions are important in order to understand what responders know, perceive and think about traffic safety regarding signalized and non-signalized intersections. In this chapter, I will interpret all the questions and answers given by the responders. As the responders participated in different way like some clicked only on one statement and some clicked on all the statements i.e. all the three statements in each question. Therefore, I will choose that bar who has more participants and will analyze accordingly.

4.2.1. Traffic Signal Knowledge

This question, after explaining to responders the definition of traffic signals, tries to extract information related to their knowledge. What they know about the specific topic. Have they ever heard about operational modes of traffic signals? The full question is "Traffic Signals (TS) are standardized devices for controlling and regulating the vehicular traffic, pedestrians, pedal cyclists, which are implemented at the signalized intersections, the signalized pedestrians and the cyclist crossings, the railway crossings and at the locations where the traffic flow needs to be controlled. To what extent do you agree with the following statement?

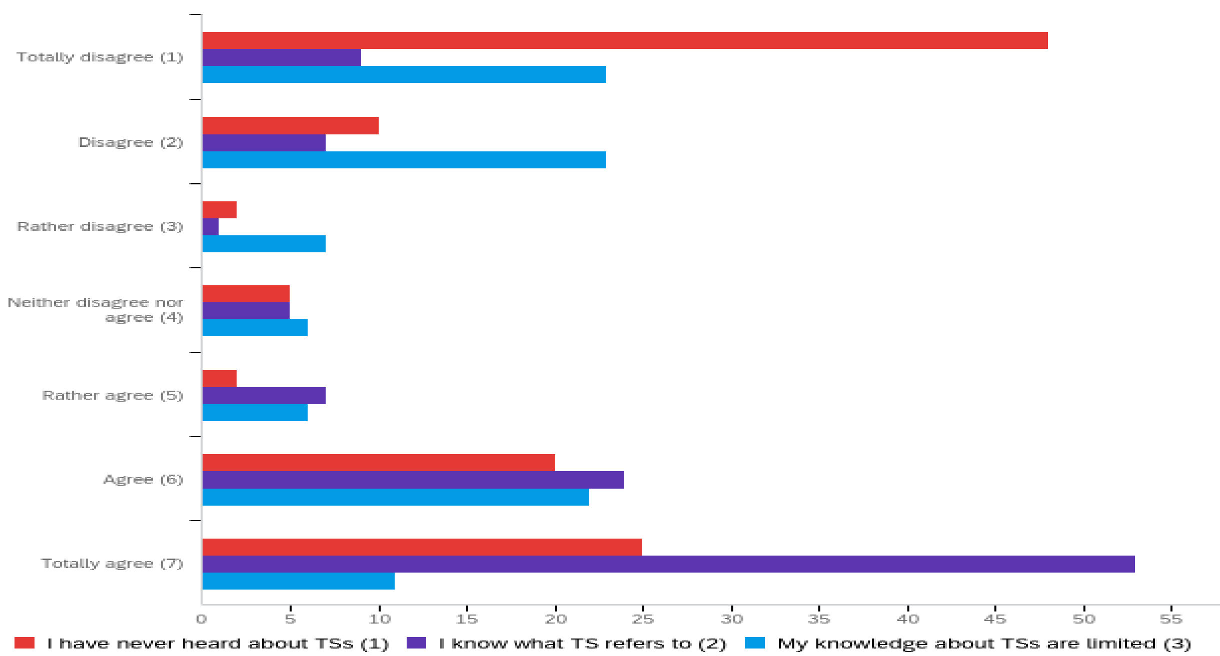


Figure 15: Traffic Signal Knowledge *(Qualtrics, Own edit, 2023)*

In this question, 90 participants ticked totally agree bar in which 54 participants have heard about TS and totally agreed as well i.e. 60% of the participants are well aware about TS. 25 participants have totally agreed that they never heard about TS i.e. 27.77% of the participants stated they do not know what TS refers to. Finally, 11 participants totally agreed that they have limited knowledge about TS i.e. 12.22% of the responders stated that their knowledge about TS is limited. What we can conclude from the specific questions is that most of the respondents have enough knowledge about TS and hence it is easier for them to respond to further questions that are related toTS. This is shown in figure 15 as above.

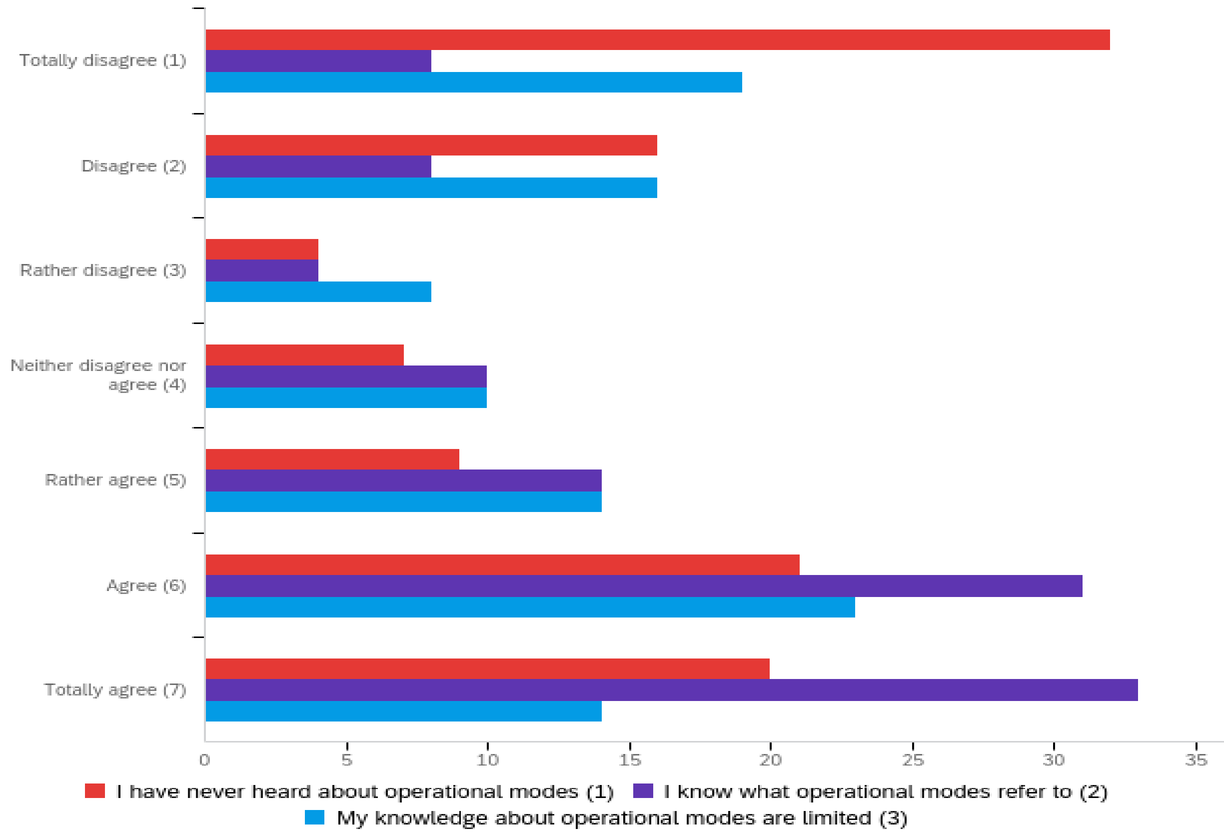


Figure 16: Traffic Signal Operational modes *(Qualtrics, Own edit, 2023)*

This question is related with operational modes such as fixed, vehicle actuated or centralized modes of traffic signals. 68 participants ticked totally agree bar in which 34 participants have totally agreed that they have heard about operational modes of TS i.e. 50% of the participants are well aware about operational modes of TS. 20 participants have totally agreed that they have never heard about operational modes TS i.e. 29.41% of the participants stated they do not know what operational modes of TS refer to. Finally, 14 participants totally agreed that they have limited knowledge about operational modes of TS i.e. 20.58% of the responders stated that their knowledge about operational modes of TS are limited. What we can conclude from the specific questions is that half of the respondents have enough knowledge about operational modes of TS. This is shown in figure 16 as above.

4.2.2. Traffic Safety and Behaviors

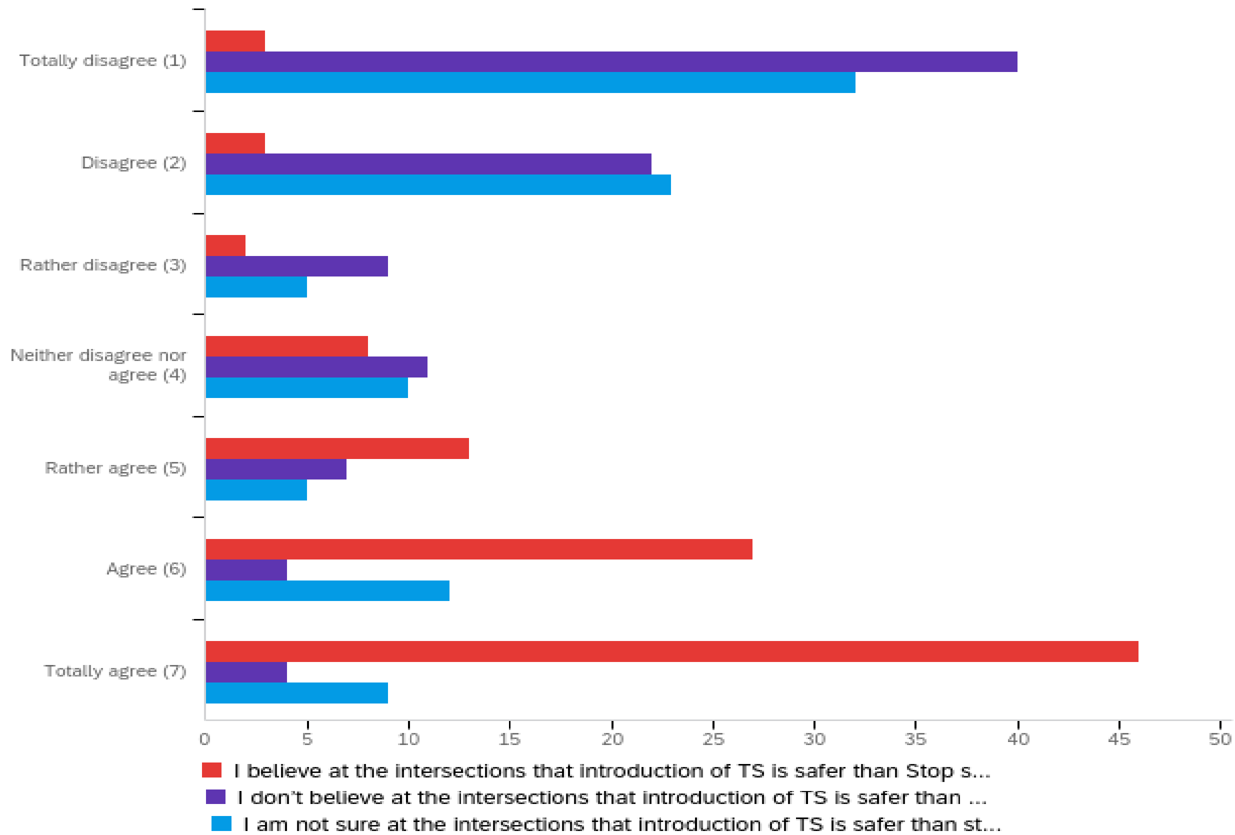


Figure 17: Traffic safety at Signalized intersections *(Qualtrics, Own edit, 2023)*

This question enquires about the introduction of traffic signal control mode at the intersection whether it is safer or not. 59 participants clicked the totally agree bar in which 46 participants have totally agreed that they believe that introduction of traffic signals at the intersections is safer while driving than stop sign control mode i.e. 77.96% of the participants are feeling safer under traffic signal control mode. 9 participants have totally agreed that they are not sure whether introduction of traffic signals at the intersection is safer or not than stop sign control mode i.e. 15.25% of the participants stated they are not sure that introduction of traffic signal mode is safer than stop sign control mode. Finally, 4 participants totally agreed that they do not believe the introduction of traffic signals at the intersection is safer than stop sign control mode i.e. 6.77% of the responders stated that they are not safer while using traffic signals at the intersections. Hence, from this question, the majority of the respondents feel safer under signalized mode at the intersection. This is shown in figure 17 as above.

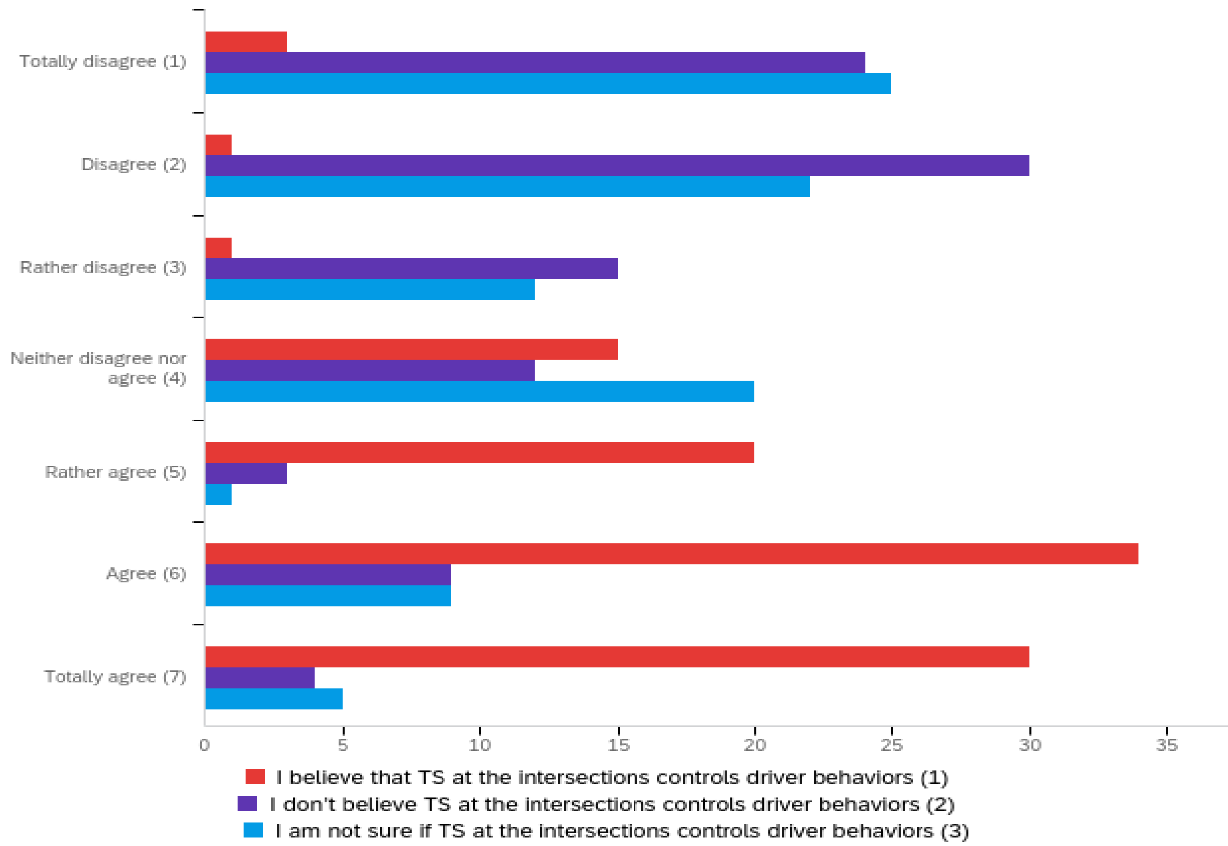


Figure 18: Driver behavior with Traffic Signals *(Qualtrics, Own edit, 2023)*

This question enquires about the introduction of traffic signals at the intersections whether it helps us to control driver behavior such as careless driving or not. In this survey question, 52 participants voted in agree bar in which 34 participants agreed that they believe that introduction of traffic signal at the intersections controls driver behavior than stop sign control mode i.e. 65.38% of the participants are believing that driver behavior is controlled with the signalized intersections than non-signalized intersections. 9 participants have agreed that they are not sure whether introduction of traffic signal at the intersection controls driver behavior or not than stop sign control mode i.e. 17.30% of the participants stated they are not sure that introduction of traffic signal mode controls driver behavior than stop sign control mode. Finally, 9 participants agreed that they do not believe the introduction of traffic signals at the intersection controls driver behavior more than stop sign control mode i.e. 17.30% of the responders stated that driver behavior is controlled while using traffic signals at the intersections. Hence, from this question, the majority of the respondents feel that traffic signal controls driver behaviors at the intersection rather than by using stop sign control mode. This is shown in figure 18 as above.

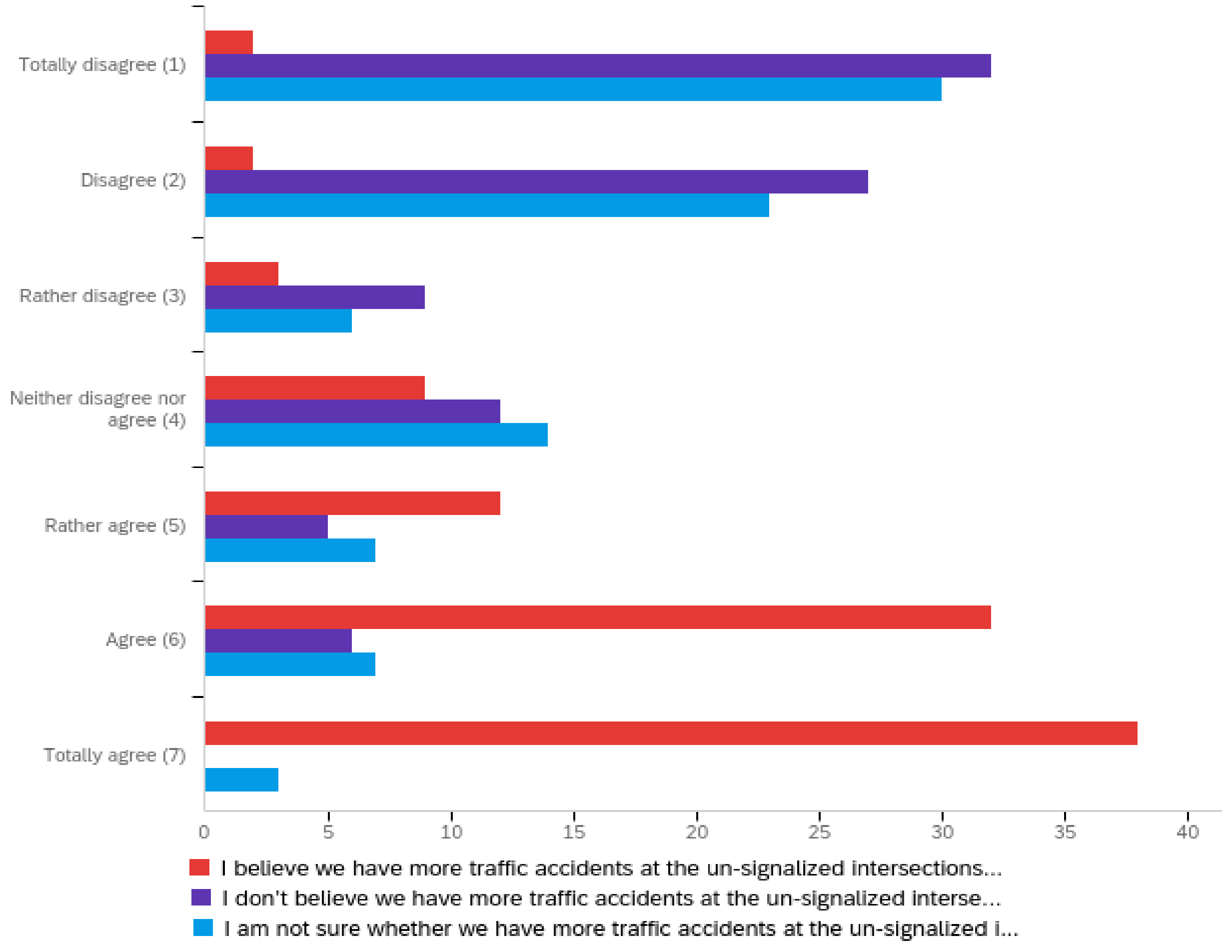


Figure 19: Traffic accidents at the signalized intersections. *(Qualtrics, Own edit, 2023)*

This question tries to have insights about traffic accidents whether we have more traffic accidents at the non-signalized intersection or not. In this question, 64 participants voted in totally disagree bar in which 32 participants totally disagree that they do not believe that traffic accidents are more at the non-signalized intersections than signalized intersections i.e. 50.00% of the participants are disagreeing about more traffic accidents at the signalized intersections than non-signalized intersections. 30 participants totally disagree that they are not sure whether traffic accidents are more at the non-signalized intersections than signalized intersections or not i.e. 46.87% of the participants totally disagree that they are not sure whether traffic accidents are more at the non-signalized intersections than signalized intersections. Finally, 2 participants totally disagree that they believe there are more traffic accidents at the non-signalized intersections than signalized intersections i.e. 3.12% of the responders believe that traffic accidents are more at the signalized intersections. Hence, from this question, the majority of the respondents feel that traffic accidents are more at the non-signalized intersections than at signalized intersections. This is shown in the figure19 as above.

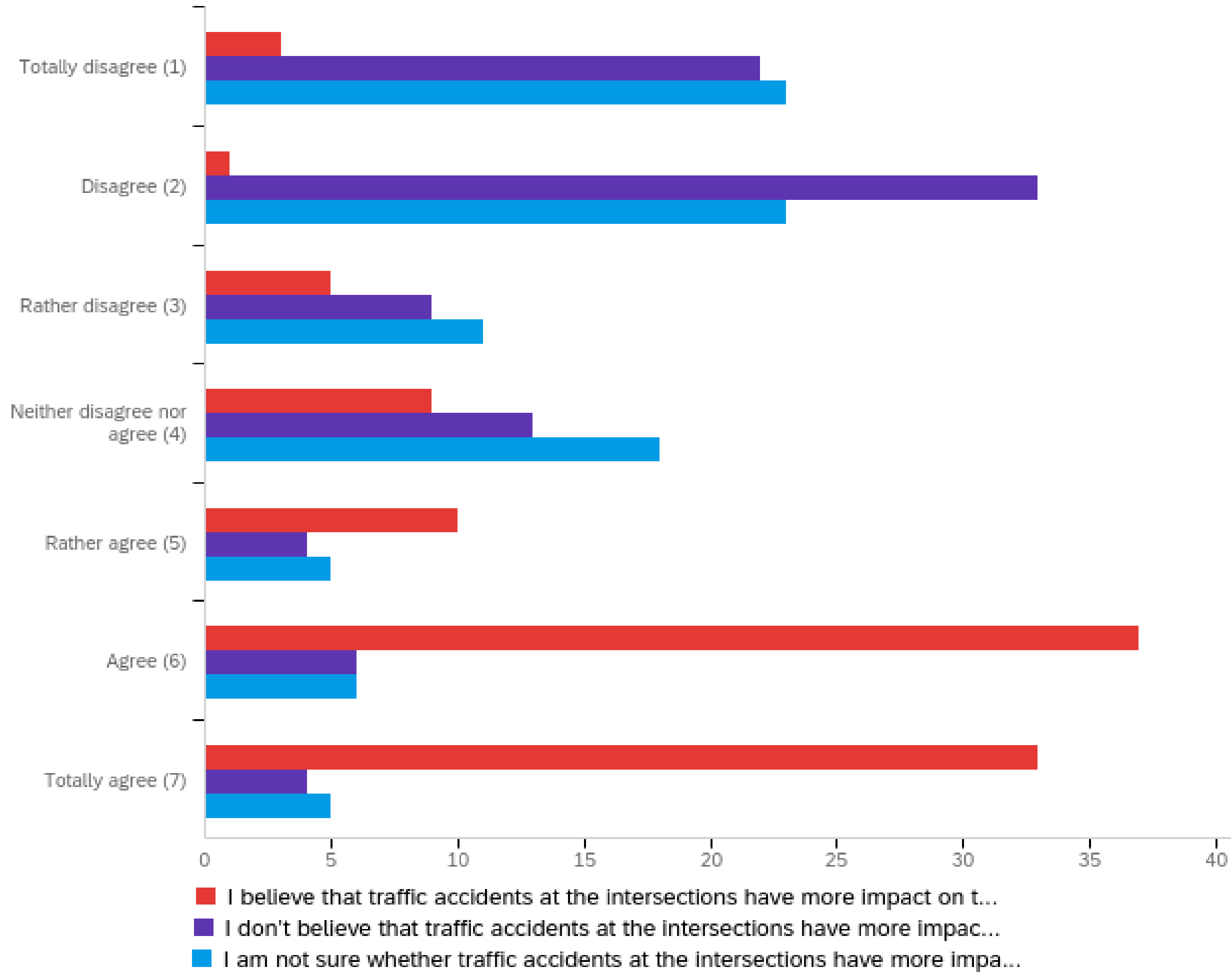


Figure 20: Traffic congestion impact at the signalized intersections. *(Qualtrics, Own edit, 2023)*

This question elaborates further about traffic accidents whether traffic accidents have more impacts on traffic congestions at the intersections or not. In this question, 49 participants ticked in agree bar in which 37 participants agreed that they believe that traffic accidents have more impact on traffic congestions i.e. 75.51% of the participants are believing that traffic accidents build more traffic congestions at the intersections. 6 participants have agreed that they are not sure whether traffic accidents build traffic congestions or not i.e. 16.21% of the participants stated they are not sure whether traffic accidents are more at the intersections or not. Finally, 6 participants agreed that they do not believe traffic accidents build traffic congestions at the intersections i.e. 16.21% of the responders agreed that traffic accidents do not build traffic congestions at the intersections. Hence, from this question, majority of the respondents feel that traffic accidents build traffic congestions at the intersections. This is shown in figure 20 as above.

4.2.3. Traffic Management initiatives and Efficiency/Traffic flow

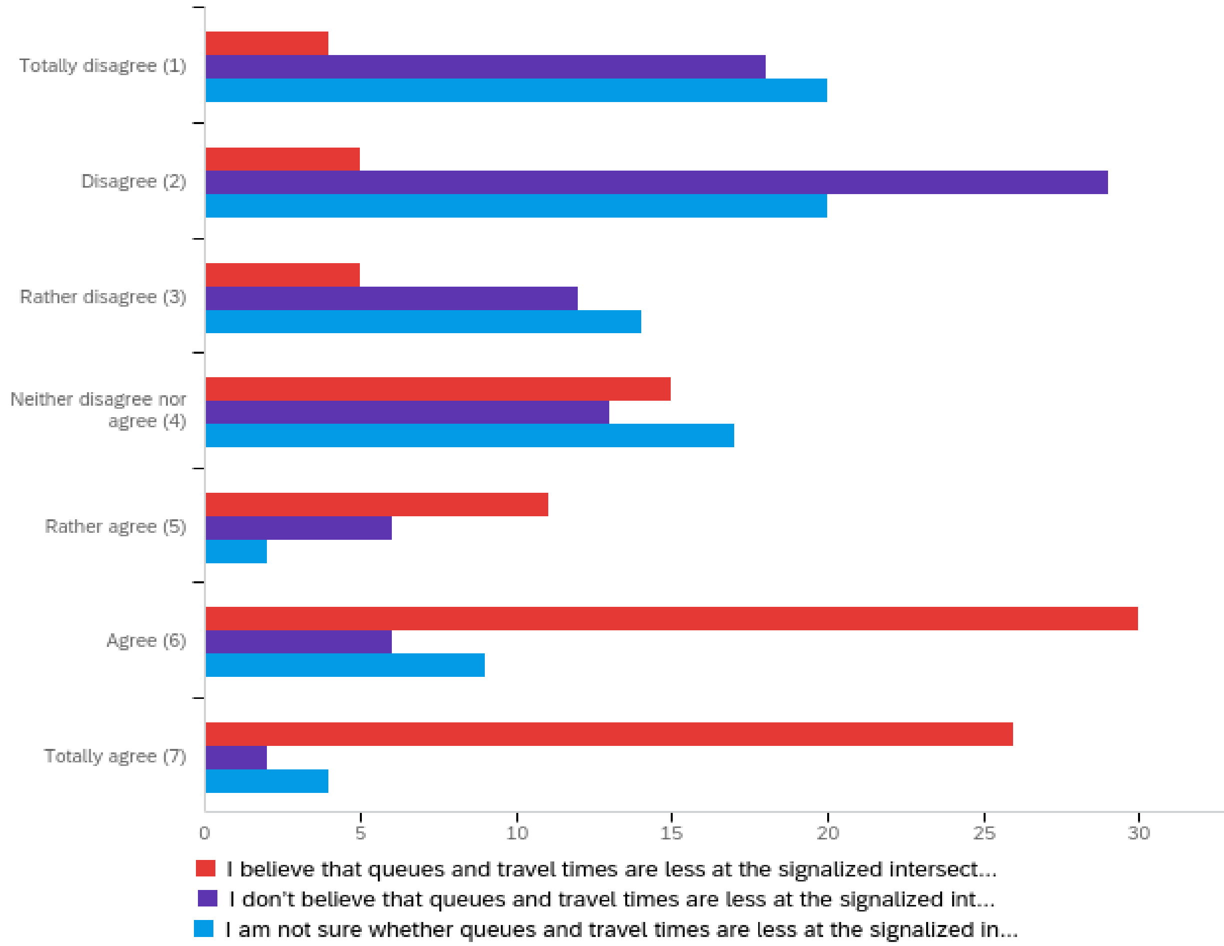


Figure 21: Queues and Travel Times impacts at the signalized intersections. *(Qualtrics, Own edit, 2023)*

This question is related with queues and travel times whether we have less queues and travel times at the signalized intersections or not than non-signalized intersections. In this question, 45 participants ticked in agree bar in which 30 participants agreed that they believe that queues and travel times are less at the signalized intersections than non-signalized intersections i.e. 66.66% of the participants are believing that queues and travel times are less at the signalized intersections than non-signalized intersections. 9 participants have agreed that they are not sure whether queues and travel times are less at the signalized intersections than non-signalized intersections or not i.e. 20.00% of the participants stated they are not sure whether queues and travel times are less at the signalized intersections or not. Finally, 6 participants agreed that they do not believe queues and travel times are less at the signalized intersections i.e. 13.33% of the responders agreed that queues and travel times are not less at the signalized intersections than non-signalized intersections. Hence, from this question, majority of the respondents feel that queues and travel times are less at the signalized intersections than non-signalized intersections. This is shown in the figure 21 as above.

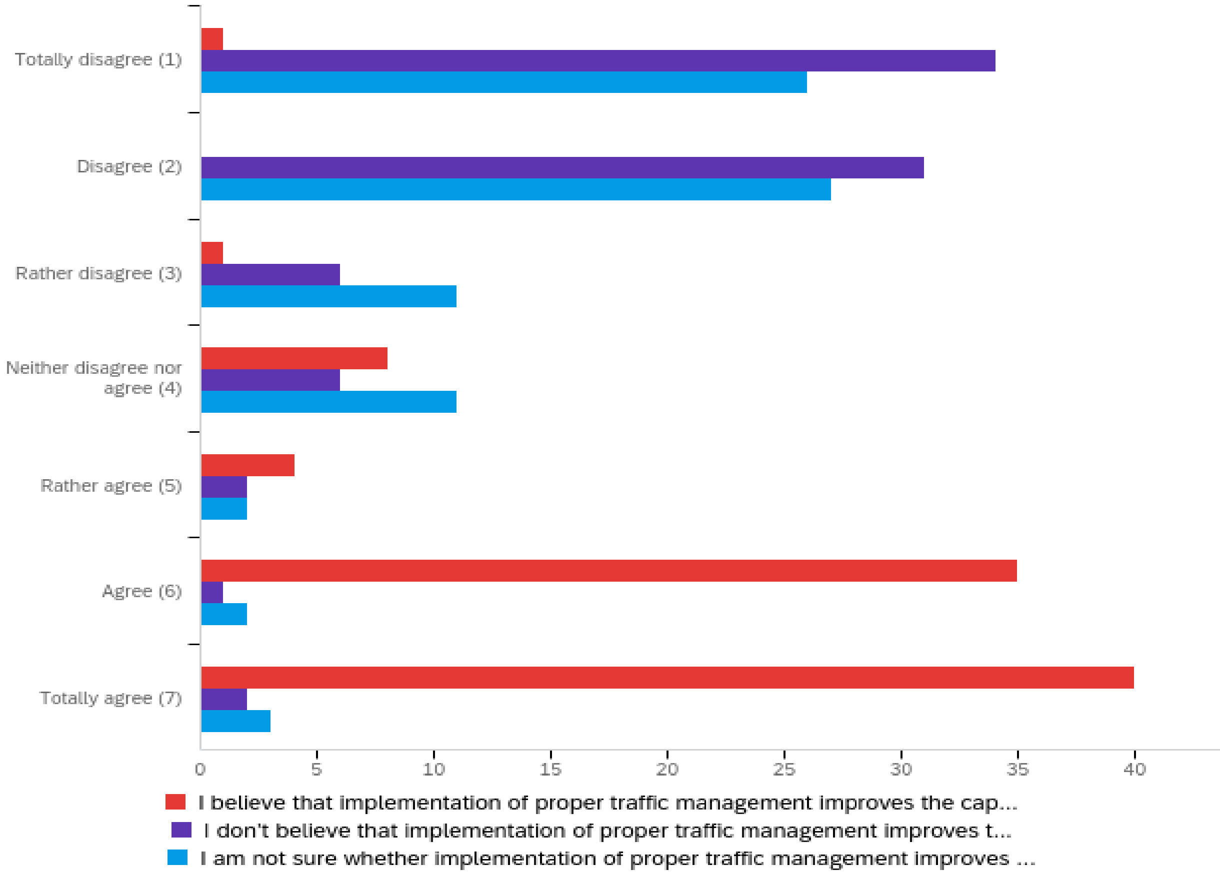


Figure 22: Road capacity impact by traffic management. *(Qualtrics, Own edit, 2023)*

This question describes whether implementation of proper traffic management improves the capacity of the roads particularly at the intersections or not. In this survey question, 45 participants clicked in the totally agree bar in which 40 participants totally agreed that they believe implementation of proper traffic management improves capacity of the roads at the intersections i.e. 88.88% of the participants believe that capacity is improved by implementing proper traffic management initiatives. 3 participants have agreed that they are not sure whether implementation of proper traffic management initiative improves capacity of the roads at the intersections or not i.e. 6.66% of the participants stated they are not sure whether proper traffic management initiative at the intersections improves road capacity or not. Finally, 2 participants agreed that they do not believe capacity of roads at the intersections is improved by the implementation of proper traffic management initiatives i.e. 4.44% of the responders totally agreed that capacity is not improved by proper traffic management initiatives. Hence, from this question, the majority of the respondents feel that the capacity of roads at the intersections is improved by proper traffic management initiatives. This is shown in figure 22 as above.

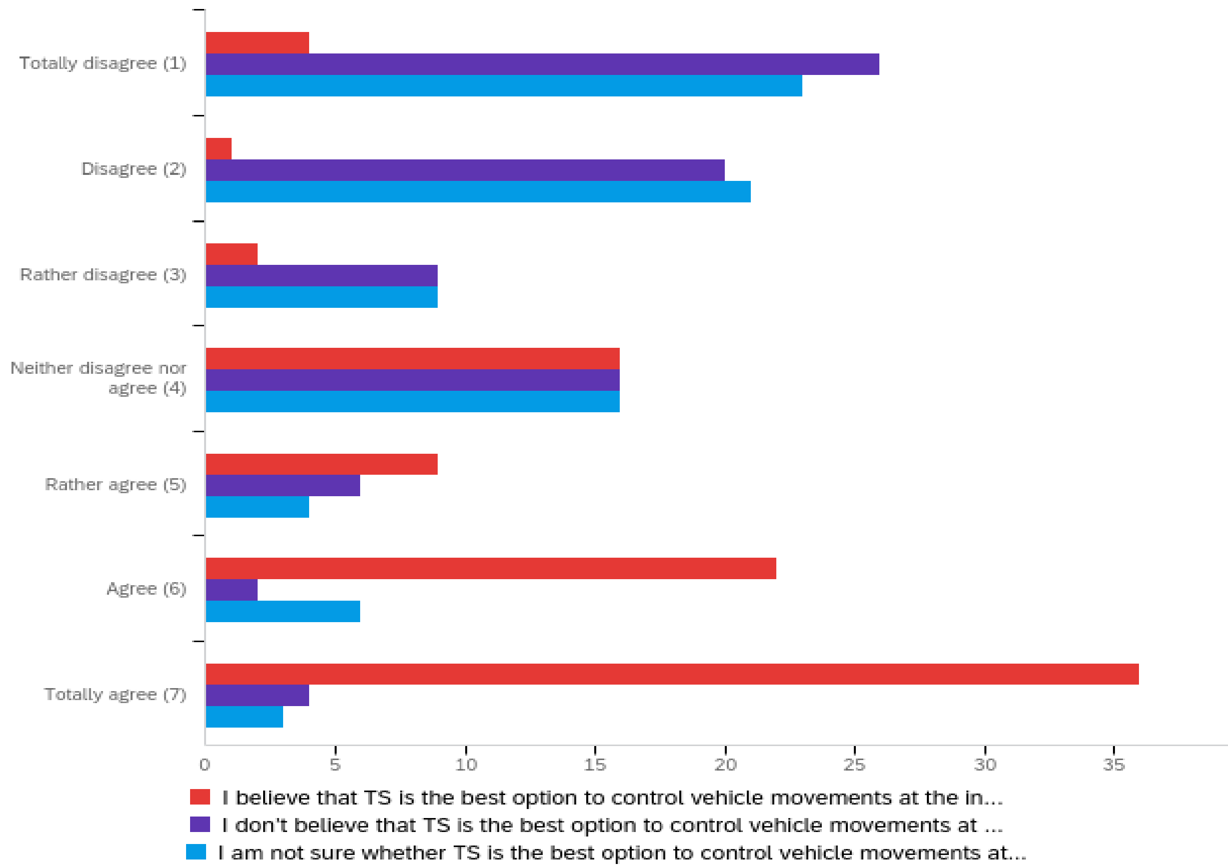


Figure 23: Vehicle movements at the signalized intersections. *(Qualtrics, Own edit, 2023)*

This question tries to fetch the answer about vehicle movements whether a traffic signal is the best option to control vehicle movement or not. In this survey question, 43 participants clicked in totally agree bar where 36 participants totally agreed that they believe traffic signal is the best option for effective transportation at the intersection and controls vehicle movements without conflicts and accidents i.e. 83.72% of the participants are believing that traffic signal is controlling vehicle movements at the intersections without conflicts and accidents. 3 participants have totally agreed that they are not sure whether traffic signals controls vehicle movements at the intersections or not i.e. 6.97% of the participants stated they are not sure whether traffic signals controls vehicle movements or not at the intersections. Finally, 4 participants totally agreed that they do not believe traffic signals at the intersections control vehicle movements i.e. 9.3% of the responders totally agreed that traffic signals are not controlling vehicle movements without traffic accidents and conflicts. Hence, from this question, the majority of the respondents feel that traffic signal controls vehicle movements without accidents and conflicts at the intersections. This is shown in figure 23 as above.

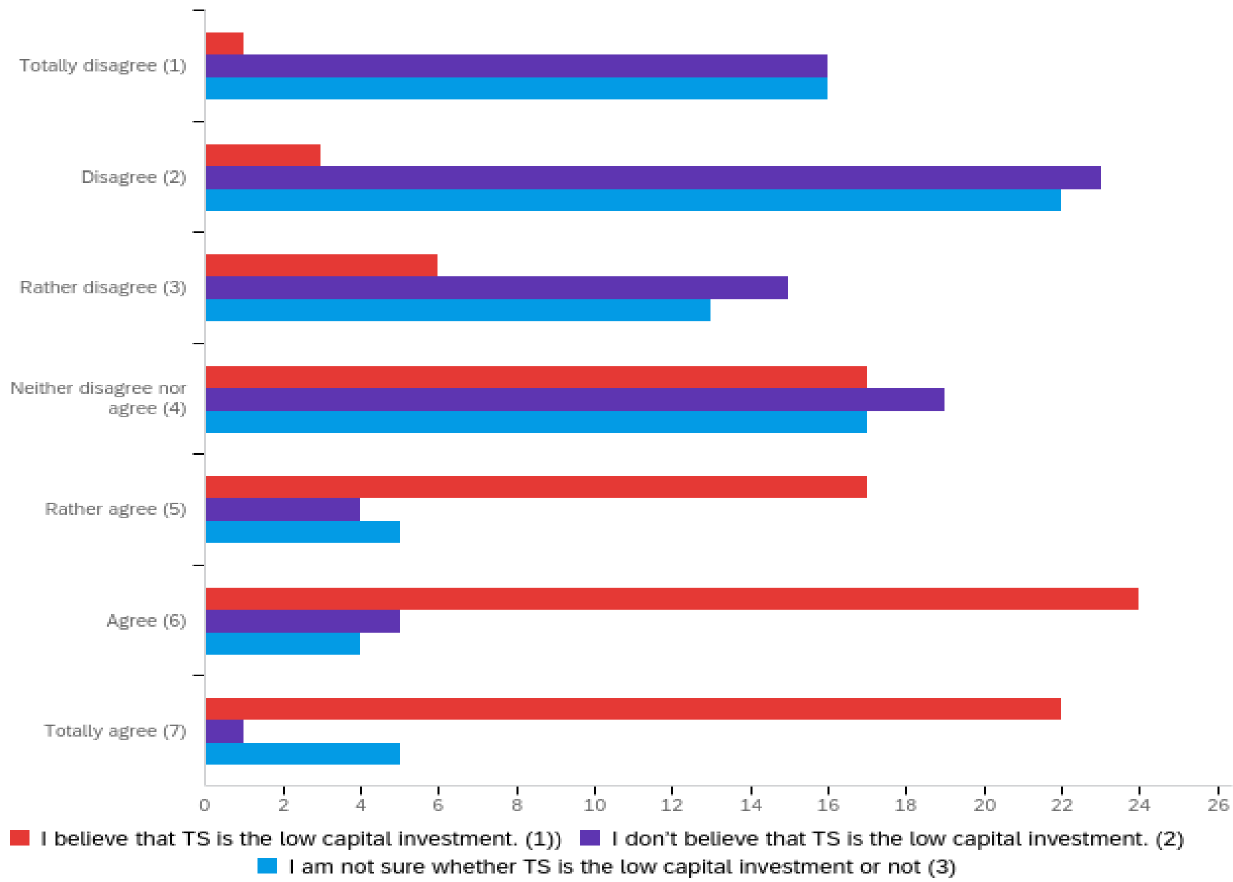


Figure 24: Traffic signal as capital investment. *(Qualtrics, Own edit, 2023)*

This question explains about capital investment whether traffic signals are low capital investment or not. In this survey question, 50 participants ticked in the disagree bar where 3 participants disagreed that traffic signal is low capital investment than other forms i.e. 6.0% of the participants disagreeing on believing that traffic signal is low capital investment than other forms such as bridges. 23 participants disagree that they are not sure whether traffic signals are low capital investment or not i.e. 46.00% of the participants disagreed that they are not sure whether traffic signals are low capital investment or not. Finally, 24 participants disagreed that they do not believe traffic signals are low capital investment i.e. 48.00% of the responders believe that traffic signals are low capital investment. Hence, from this question, the majority of the respondents feel that traffic signal investment is not more expensive than other forms. This is shown in figure 24 as above.

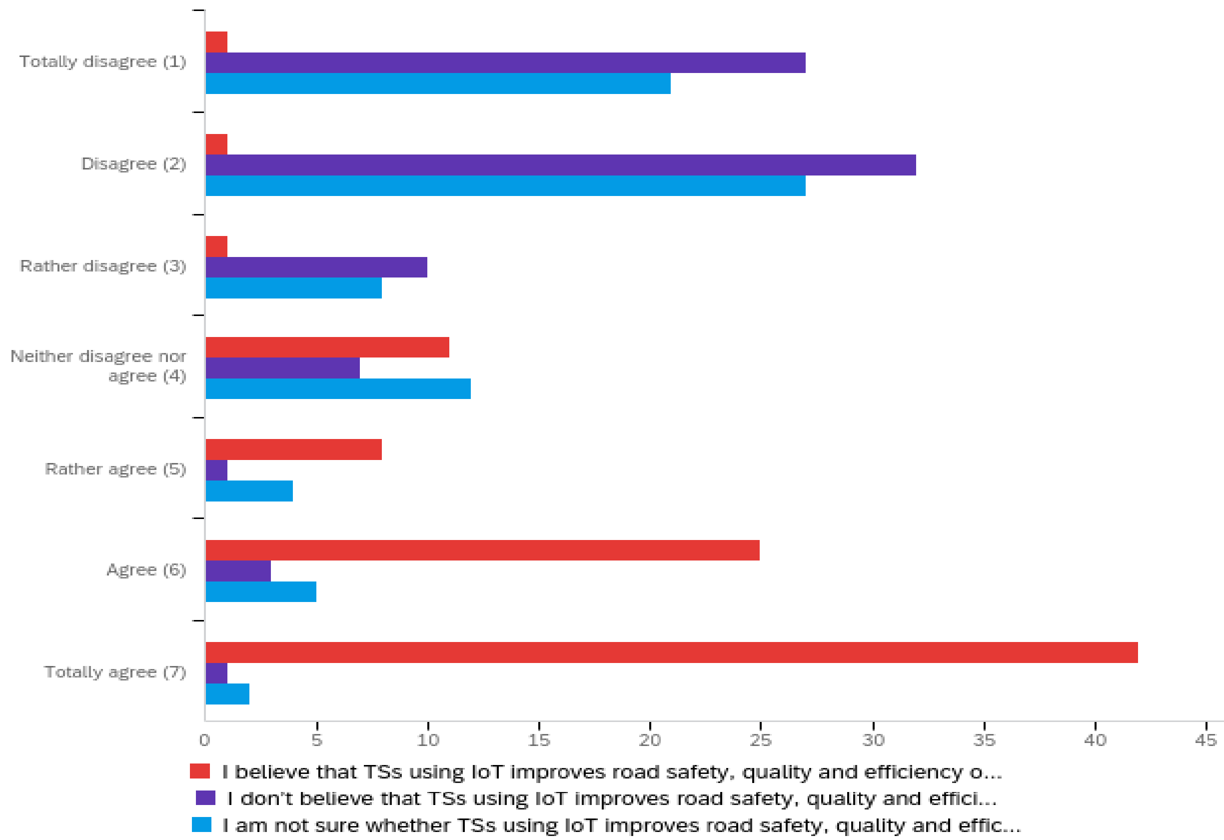


Figure 25: Traffic signal using IoT impacts. *(Qualtrics, Own edit, 2023)*

This question explains the importance of traffic signals by using IoT whether important parameters such as road safety, quality and efficiency are improved or not. In this survey question, 45 participants voted in the total agree bar where 42 participants totally agreed that they believe traffic signals using IoT improves road safety, quality and efficiency of the road network i.e. 93.33% of the participants believe that traffic signals using IoT improves road safety, quality and efficiency of the road network. 2 participants have totally agreed that they are not sure whether traffic signals using IoT improves road safety, quality and efficiency of road network or not i.e. 4.44% of the participants totally agreed that they are not sure whether traffic signals using IoT improves traffic safety, quality and efficiency of the road network or not. Finally, 1 participant totally agreed that they do not believe traffic signals using IoT improves road safety, quality and efficiency of the road network i.e. 2.22% of the responders totally agreed that traffic signals using IoT are not improving road safety, quality and efficiency of the road network. Hence, from this question, the majority of the respondents feel that traffic signals using IoT improves road safety, quality and efficiency of the road network. This is shown in figure 25 as above.

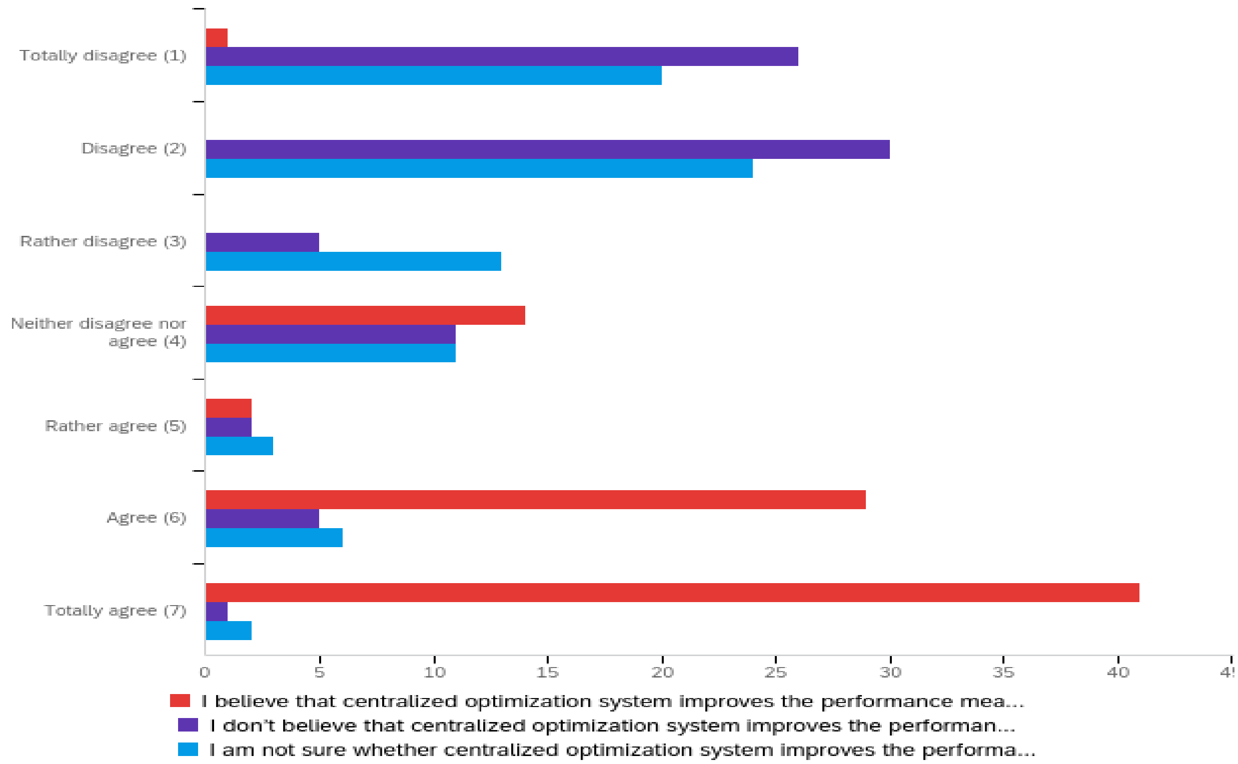


Figure 26: Centralized optimization system impact on performance measures. *(Qualtrics, Own edit, 2023)*

This question elaborates further about whether the centralization optimization system improves the performance measures or not. In this survey question, 44 participants voted in total agree bar, 41 participants totally agree that they believe centralized optimization system improves the performance measures i.e. 93.18% of the participants are believing that centralized optimization system improves the performance measures such as delay, travel time and so on. 2 participants have totally agreed that they are not sure whether a centralized optimization system improves the performance measures or not i.e. 4.54% of the participants stated they are not sure whether a centralized optimization system improves the performance measures or not. Finally, 1 participant totally agreed that he does not believe a centralized optimization system improves the performance measures i.e. 2.22% of the responders totally agreed that a centralized optimization system does not improve the performance measures. Hence, from this question, the majority of the respondents feel that a centralized optimization system improves the performance measures. This is shown in figure 26 as above.

4.3. Survey analysis conclusion

In conclusion, all the age group categories participated in this survey as per the demographics results with major participants' ages ranging from 25 to 65 years i.e. 86.86%. In this survey, urban participants have a much higher share i.e. 72.92% than suburban and rural areas. All the participants mostly have driving licenses with cars and the percentage value share for driving licenses and cars are 86.66% and 78.35% respectively. In this survey, I try to figure out the employment status and the percentage value for employees who are higher than students and unemployed participants, which is 76.29%. In addition to this, I try to figure out the means of transport so that I will have effective results and the private car transport has a major share than public transport, by foot and others that is 65.98%.

From the knowledge, Traffic safety and behavior results, almost 60% participants know what a traffic signal means with 50% having the knowledge of operational modes. In terms of traffic safety and behavior, 77.96% participants are feeling safer while using traffic signals at the intersections and 65.38% participants believe that driver behavior is controlled at the signalized intersections than non-signalized intersections. In terms of traffic accidents, 50% disagree about more traffic accidents occur at the signalized intersections than non-signalized intersections and 46.87% participants are not sure whether traffic accidents at the signalized intersections than non-signalized intersections are less or not. Only 3.12% participants believe that more traffic accidents at the signalized intersections than non-signalizedintersections. In terms of traffic congestion and efficiency, 75.51% participants believe that traffic accidents build more traffic congestions at the intersections, 66.66% participants believe that queues and travel times are less at the signalized intersections than non-signalizedintersections. In terms of capacity of road, 88.88% participants believe that capacity of the road network is improving by implementing proper traffic management initiatives, 83.72% participants believe that traffic signal is controlling vehicle movements without conflicts and traffic accidents. In terms of capital investment, 48% believe that traffic signals are lower capital investment than other forms. 93.33% participants believe that road safety, quality and efficiency of the road network are improved by using IoT with the traffic signals. The last part of the survey deals with performance measures by using a centralization optimization system with the signals and 93.18% participants believe that performance measures are improved by using a centralization optimization system with the signals.

Apart from this, I have a chance to meet the director of traffic engineering department at Sharjah Roads and Transport Authority whose name is Dr. Eng. Mohsin Ali Balwan. He has done his PhD in ITS at Austria and has enormous experience in traffic engineering as well around 20 years. He is also a member of Sharjah Police committee where he discusses road issues frequently with his members. While discussing with him, he agrees on all the survey questions and has replied that traffic signals should be operated in an optimal way if not then there will be delay and congestion. He also mentioned that implementation of traffic signals at the intersections reduce traffic accidents drastically than stop sign control modes by controlling driver behavior. With the result, improves traffic flow of the roads and adjacent to this intersection as well. He also said that traffic signals are much better option if there is budget constraint during the project proposal phases and importantly we need to take care of the optimization system. By deploying such systems at the traffic signals, we improve performance measures exponentially (Balwan, 2023).

5. INTERSECTION ANALYSIS AND INTERPRETATION OF THE RESULTS

5.1. Data analysis

To see the effectiveness of the intersection by deploying different control modes such as stop signs or traffic signals at the intersections by using the VISSIM microsimulation tool. I have undertaken a three-way approach intersection at Muntazah area near Sharjah corniche, UAE usually called as "Al-Muntazah Junction or Junction number 04" by Sharjah Roads and Transport Authority (SRTA). SRTA is a government entity situated in Sharjah emirate of UAE that deals with road and transport affairs in order to facilitate the road users. The figure 27 shows the geometry of the intersection.

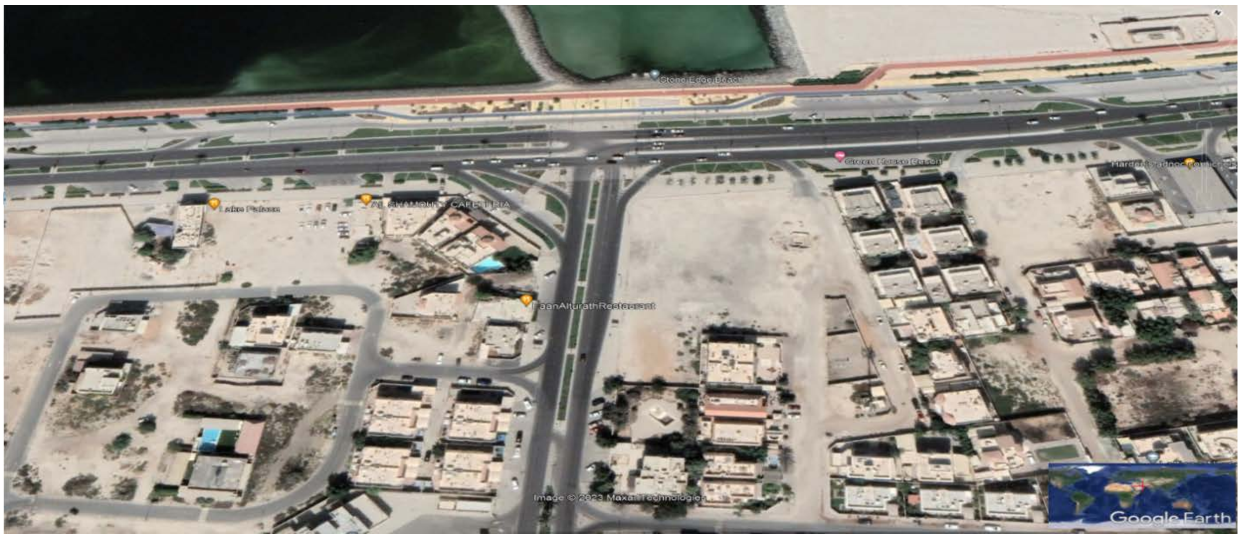


Figure 27: Geometry of Al-Muntazah Junction (Jn04) (Google Earth Pro, 2023)

To work on VISSIM software, I need to have real traffic data for this intersection, therefore, coordinated with the Traffic Engineering department of SRTA where I was provided the data which the study team had taken in February of 2022. While analyzing the real time data, leg1 is from the West side, leg2 is from South side and leg3 is from the East side. Leg1 comprises free right, straight and left movements, Leg2 comprises left and free right movements, and leg3 comprises left and straight movements. The real time data with the legs is shown in the figures 28 and 29 as below

Sharjah Roads and Transport Authority

Traffic Counts

Survey Date:	07.02.2022
Survey Time:	24 Hours
Survey Location:	Al Muntazah T-Junction (J4)
Notes:	Turning Movement Counts

Time	leg-1											
	U-turn				Straight				Right			
	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total
12.00 - 01.00	66	0	0	66	524	0	0	524	92	0	0	92
01.00 - 02.00	19	0	0	19	173	0	1	174	115	0	0	115
02.00 - 03.00	13	0	0	13	158	0	0	158	31	0	0	31
03.00 -04.00	17	0	0	17	103	0	2	105	27	0	0	27
04.00 - 05.00	12	0	0	12	67	0	0	67	10	0	0	10
05.00 - 06.00	4	0	0	4	55	0	0	55	11	0	0	11
06.00 - 07.00	17	0	0	17	203	0	5	208	65	0	0	65
07.00 - 08.00	47	0	0	47	520	0	15	535	110	0	0	110
08.00 - 09.00	58	0	0	58	477	0	12	489	66	0	0	66
09.00 - 10.00	43	0	0	43	656	0	18	674	102	0	0	102
10.00 - 11.00	71	0	0	71	500	0	13	513	111	0	0	111
11.00 - 12.00	44	0	0	44	472	0	10	482	85	0	0	85
12.00 - 13.00	54	0	0	54	697	0	19	716	120	0	0	120
13.00 - 14.00	49	0	0	49	707	0	22	729	113	0	0	113
14.00 - 15.00	53	0	0	53	809	0	24	833	109	0	0	109
15.00 - 16.00	30	0	0	30	910	0	19	929	90	0	0	90
16.00 - 17.00	61	0	0	61	1012	0	22	1034	67	0	0	67
17.00 - 18.00	66	0	0	66	1184	0	21	1205	111	0	0	111
18.00 - 19.00	87	0	0	87	1129	0	26	1155	110	0	0	110
19.00 - 20.00	74	0	0	74	1046	0	15	1061	86	0	0	86
20.00 - 21.00	80	0	0	80	1079	0	12	1091	115	0	0	115
21.00 - 22.00	69	0	0	69	1039	0	12	1051	117	0	0	117
22.00 - 23.00	66	0	0	66	871	0	8	879	132	0	0	132
23.00 - 24.00	61	0	0	61	741	0	6	747	112	0	0	112

Time	leg-2								leg-3								Leg1	Leg2	Leg3
	Left				Right				Straight				Left				T.	T.	T.
	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Count	Count	Count
12.00 - 01.00	19	0	0	19	177	0	0	177	316	0	3	319	191	0	0	191	682	196	510
01.00 - 02.00	0	0	0	0	131	0	0	131	197	0	2	199	56	0	0	56	308	131	255
02.00 - 03.00	5	0	0	5	47	0	0	47	108	0	0	108	45	0	0	45	202	52	153
03.00 -04.00	12	0	0	12	32	0	0	32	83	0	0	83	44	0	0	44	149	44	127
04.00 - 05.00	11	0	0	11	30	0	0	30	40	0	0	40	29	0	0	29	89	41	69
05.00 - 06.00	15	0	0	15	28	0	0	28	26	0	0	26	31	0	0	31	70	43	57
06.00 - 07.00	29	0	0	29	62	0	0	62	300	0	5	305	206	0	8	214	290	91	519
07.00 - 08.00	182	0	4	186	170	0	3	173	826	0	12	838	254	0	6	260	692	359	1098
08.00 - 09.00	147	0	8	155	193	0	4	197	652	0	10	662	189	0	4	193	613	352	855
09.00 - 10.00	92	0	6	98	149	0	2	151	523	0	10	533	151	0	3	154	819	249	687
10.00 - 11.00	108	0	8	116	192	0	5	197	515	0	12	527	107	0	4	111	695	313	638
11.00 - 12.00	67	0	4	71	127	0	3	130	428	0	9	437	164	0	5	169	611	201	606
12.00 - 13.00	82	0	5	87	229	0	3	232	562	0	12	574	169	0	8	177	890	319	751
13.00 - 14.00	61	0	5	66	246	0	5	251	618	0	16	534	241	0	9	250	891	317	784
14.00 - 15.00	101	0	10	111	457	0	4	461	638	0	20	658	232	0	22	254	995	572	912
15.00 - 16.00	214	0	12	226	633	0	8	641	744	0	14	758	171	0	17	188	1049	867	946
16.00 - 17.00	213	0	14	227	625	0	6	631	718	0	10	728	237	0	14	251	1162	858	979
17.00 - 18.00	153	0	10	163	704	0	9	713	1146	0	22	1168	400	0	19	419	1382	876	1587
18.00 - 19.00	164	0	9	173	646	0	6	652	827	0	10	837	251	0	15	266	1352	825	1103
19.00 - 20.00	179	0	10	189	621	0	10	631	678	0	10	688	260	0	12	272	1221	820	960
20.00 - 21.00	184	0	8	192	709	0	10	719	726	0	6	732	286	0	15	301	1286	911	1033
21.00 - 22.00	152	0	6	158	662	0	8	670	714	0	6	720	270	0	10	280	1237	828	1000
22.00 - 23.00	95	0	2	97	509	0	8	517	489	0	4	493	198	0	8	206	1077	614	699
23.00 - 24.00	66	0	0	66	270	0	2	272	417	0	4	421	208	0	8	216	920	338	637

Figure 28: Real time data of Al Muntazah Junction (Jn04) (SRTA, Excel, own edit , 2022).

Figure 29: Direction indication of Al Muntazah Junction (Jn04) (SRTA, Excel, own edit , 2022).

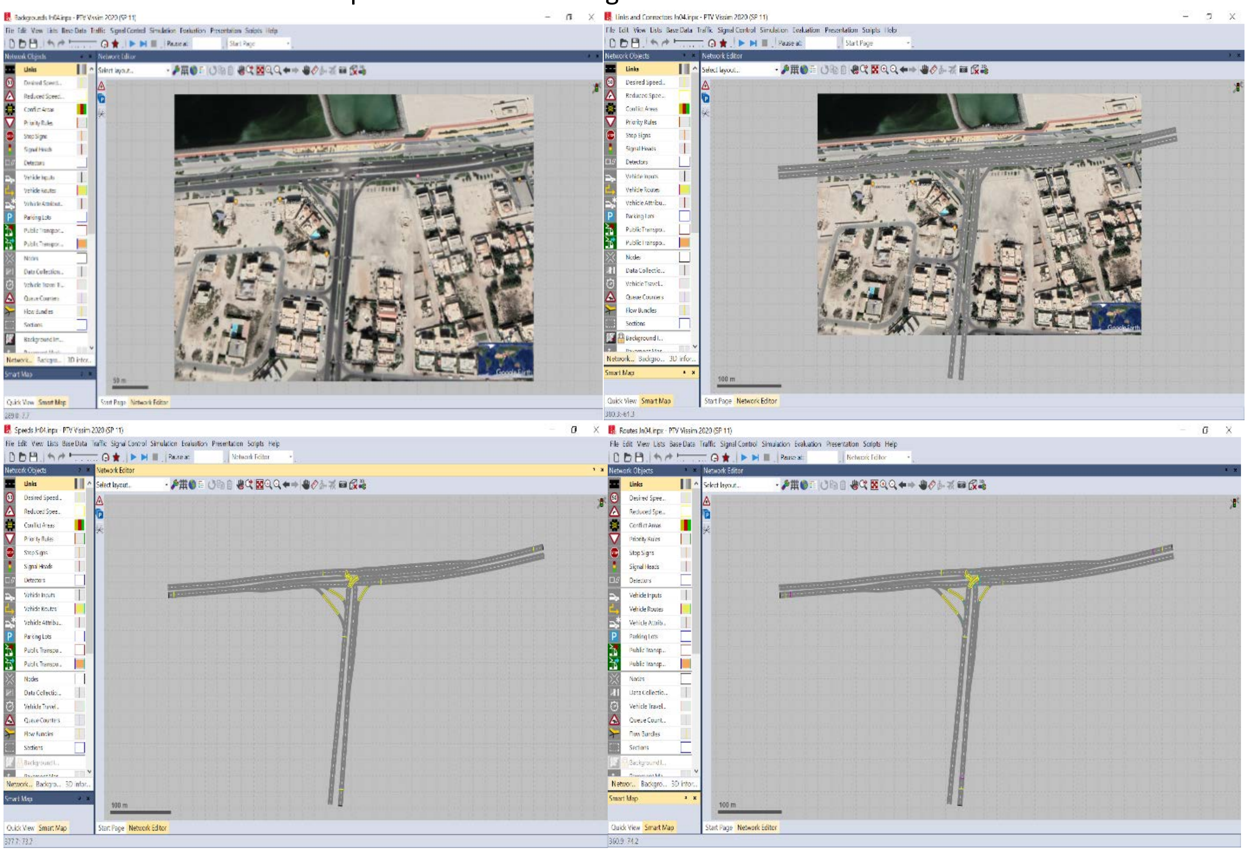
Intersection analysis with stop signs using VISSIM software:

I have performed all the necessary steps in order to define all the parameters in VISSIM simulation software by considering geometry, traffic data and various others. The steps that I have done in VISSIM analysis with stop signs are as below:

- Configured graphical user interface and uploaded background image.
- Added links in the intersection from all the approaches and joined with the connectors.

- Introduced speed limits as per the road.
- Added input data from the real time data provided by the traffic engineering department.
- Defined routing for all the three approaches.
- Defined conflicts in non-signalized mode.
- Added three stop line control signs; one before the U turn movement from West to West, second before the left turn movements from East towards South side and third before the left turn movements from South towards East side while straight movements kept uncontrolled as these have higher priority.
- Added queue and travel time parameters for these three turn movements.
- Defined simulation and evaluation parameters.
- Finally, run the simulation, and collected the queue and travel time results for all the three turn movements in the excel sheet.

The screen shots of these steps are shown in the figure 30 as below:



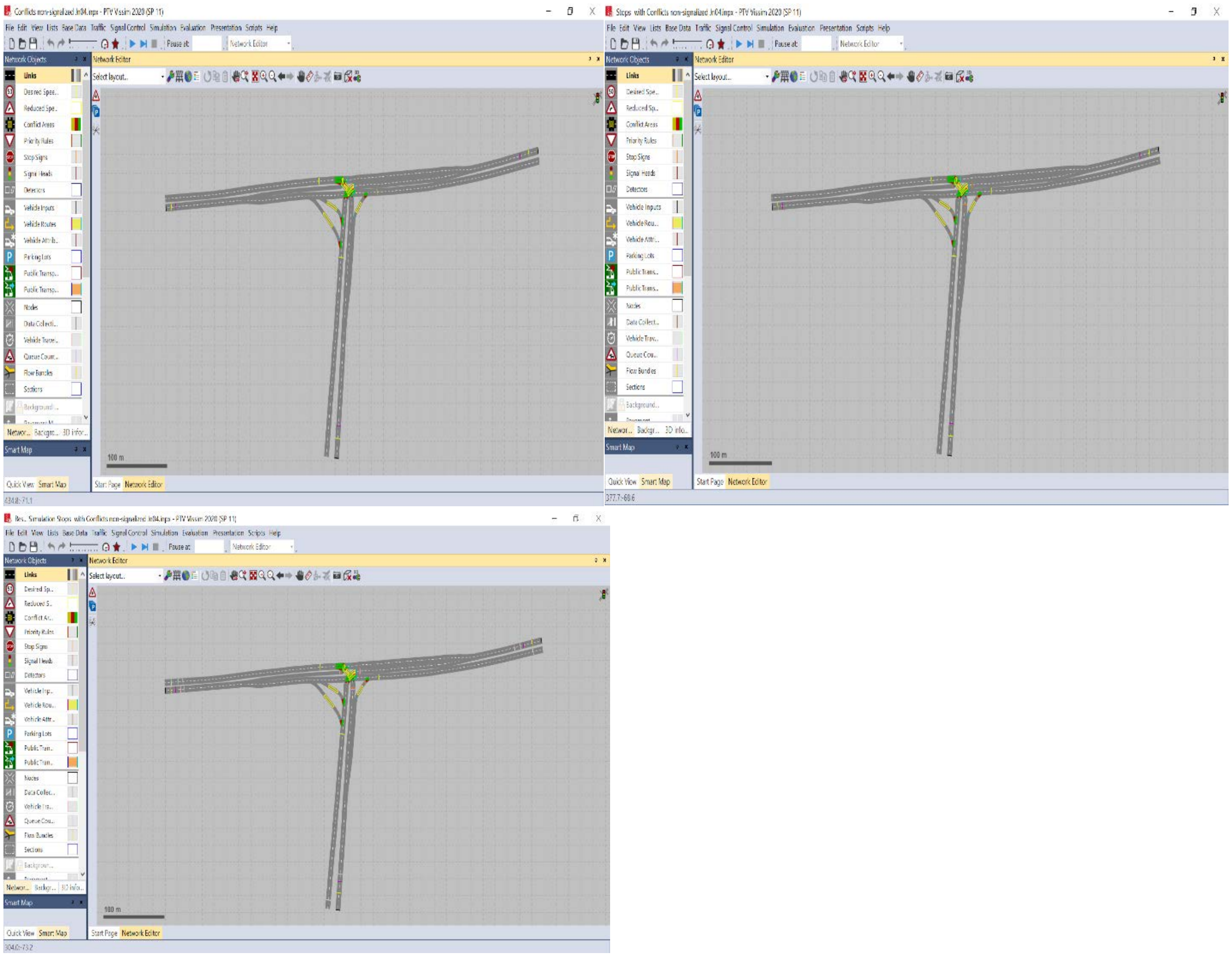


Figure 30: VISSIM analysis with stop signs at three turn movements (VISSIM, Own data, 2023)

Intersection analysis with traffic signals using VISSIM software:

Before performing VISSIM analysis, I have collected the phasing and staging data as ST950 Siemens controller has been deployed for this intersection. In Siemens traffic signal controllers, we use phases and stages, which are shown in the figure 31 as below:

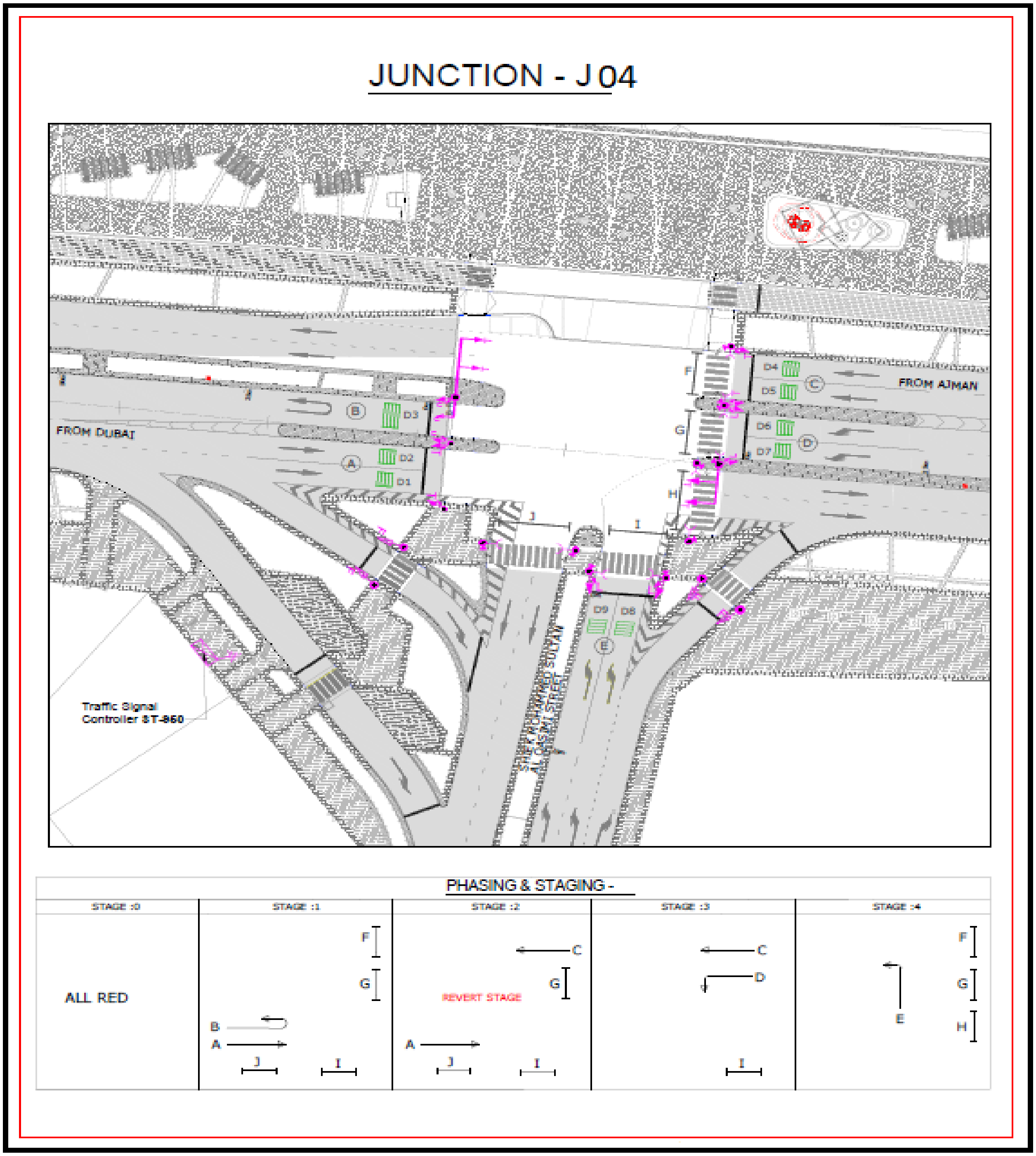


Figure 31: Phasing and Staging of Al-Muntazah Junction (Jn04) (SRTA, 2022).

The traffic signal timing of Al-Muntazah Junction for all the plans throughout the day is shown in figure 32 as below:

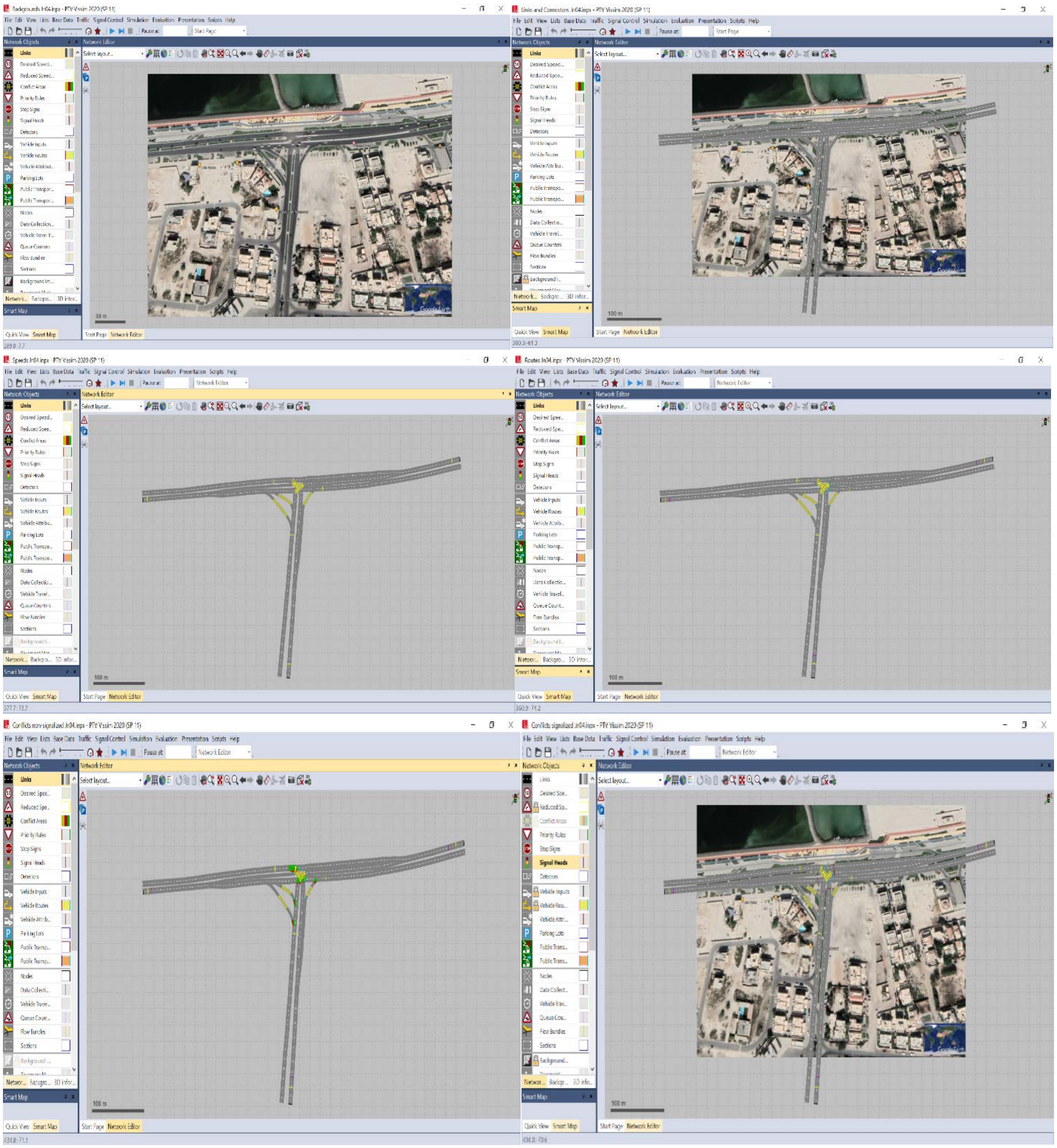
Signal timing details for Muntazah Rd. T - Junction (Jn04)							Controller :- ST950
S. No.	**Program**	**Switching Time**	**From Radisson Blue- A,B- (Stg-1)**	**From Straight Traffic - A,C- (Stg-2)**	**From Ajman - C,D- (Stg-3)**	**From Shk. Muh. Sultan Al Qasimi Stg. E (Stg-4)**	**Cycle time (in Second)**
1	**MAX SETA**	**6:00 to 12:00**	**35**	**10**	**45**	**20**	**110**
2	**MAX SETB**	**12:00 to 18:00**	**45**	**10**	**35**	**20**	**110**
3	**MAX SETC**	**18:00 to 23:00**	**45**	**10**	**35**	**20**	**110**
4	**MAX SETD**	**23:00 to 6:00**	**35**	**10**	**45**	**20**	**110**

Figure 32: Traffic signal timing of Al-Muntazah Junction (Jn04) (SRTA, 2022).

The steps that I have done in VISSIM analysis with traffic signals are as below:

- Configured graphical user interface and uploaded background image.
- Added links in the intersection from all the approaches and joined with the connectors.
- Introduced speed limits as per the road.
- Added input data from the real time data provided by the traffic engineering department.
- Defined routing for all the three approaches.
- Defined conflicts in non-signalized mode.
- Added five traffic signal heads: one for straight movement from the West side, second for U turn movement from West side, third for straight movement from East side, fourth for left turn movement from East side and fifth for left turn movement from South side.
- Added queue and travel time parameters for these three turn movements, as I did not introduce these on straight movements because straight movements have free flow traffic while operating under stop signs control mode. Therefore, cannot compare these straight movements under stop and signal control modes.
- Defined simulation and evaluation parameters.
- Finally, run the simulation, and collect the queue and travel time results of all the three turn movements in the excel sheet.

The screen shots of these steps are shown in the figure33 as below:



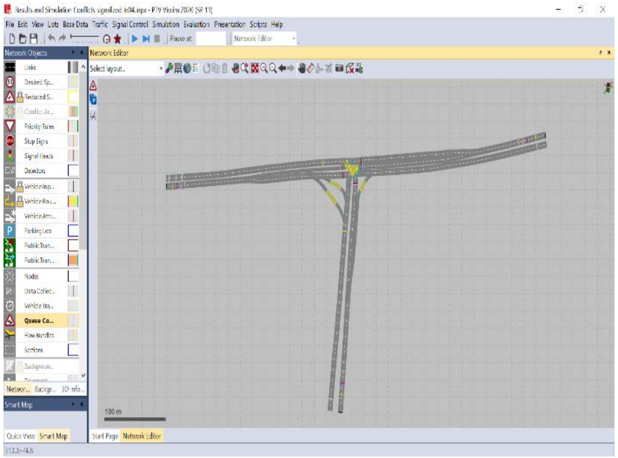


Figure 33: VISSIM analysis with traffic signals at three turn movements (VISSIM, Own data, 2023).

Simulation results of stop and traffic signal control modes:

After performing VISSIM analysis, I have defined two important parameters to get simulation results in VISSIM software; one is queue parameters and another is travel time parameters, which are fundamental parameters in traffic engineering. In my analysis segment i.e. at the t-intersection, I have considered three key locations where I defined these parameters so that I can compare the results with different control modes i.e. Stop and Signal control modes. The three key locations are U-turn movements from West to West side, left turn movements from East to South side and finally left turn movements from South to West side. Throw movements I did not prefer because for free movements with priority we do not add stop sign if the control mode is stop sign so that I will have balanced analysis and hence effective results. This is shown in figure 34 as below:

Figure 34: Key locations for turn movements (Googel Eart Pro, Own data, 2023).

Queue Results with stop and signal control modes at three turn movements:

While performing VISSIM analysis, the queue results for all the three turn movements are lesser in stop sign control mode than signal control mode. This is shown in figure 35 as below:

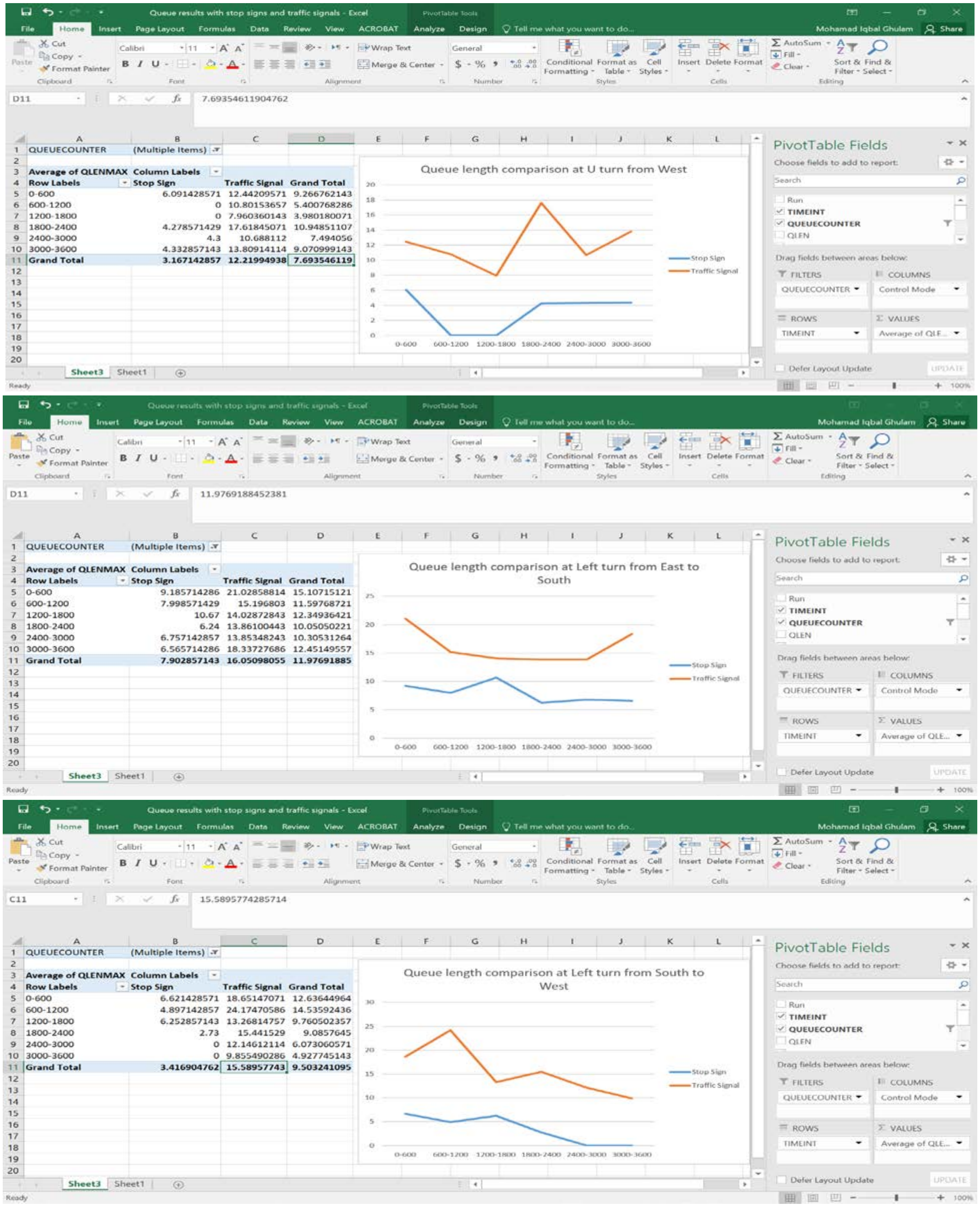
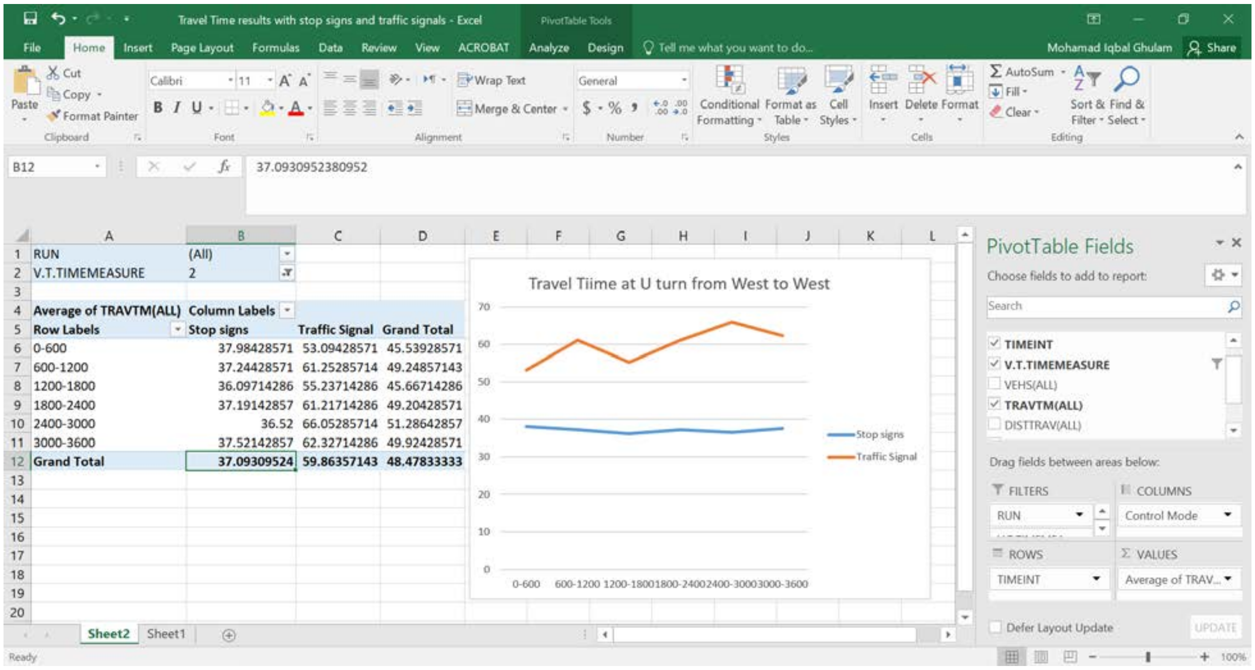


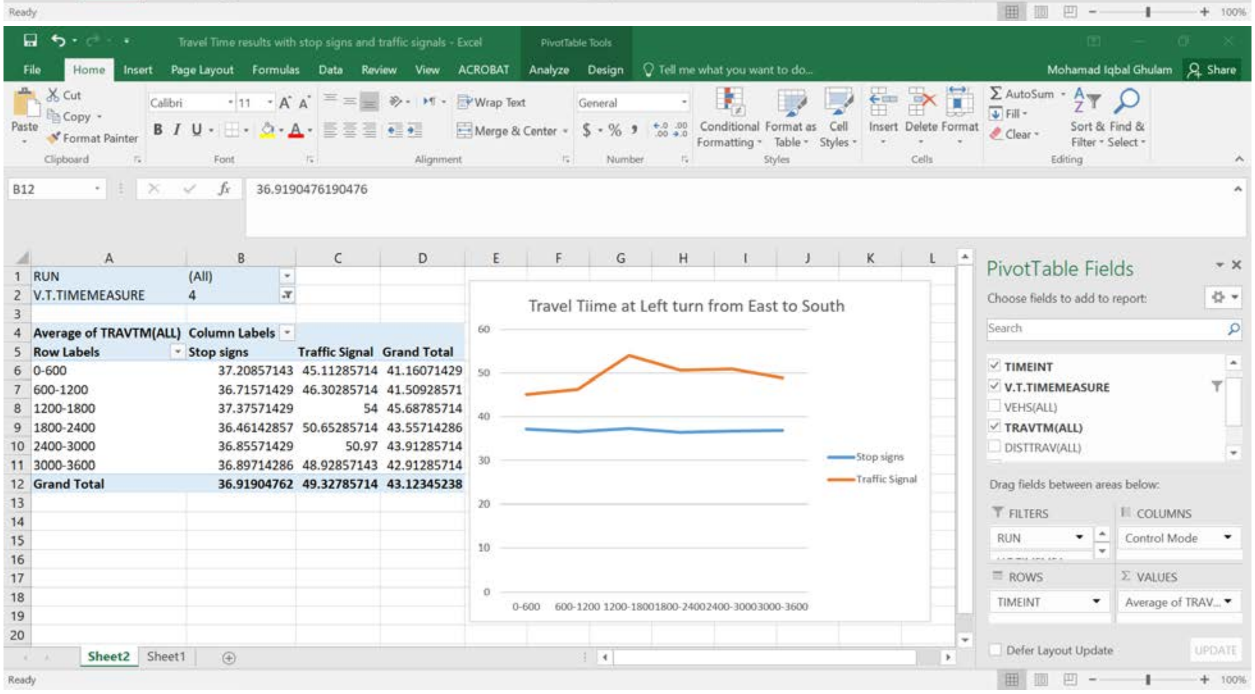
Figure 35: Queue results with stop and signal control modes at three turn movements (VISSIM, Own data, 2023).

Travel Time Results with stop and signal control modes at three turn movements:

While performing VISSIM analysis, the travel time results for all the three turn movements are lesser in stop sign control mode than signal control mode. This is shown in figure 36 as below:



Average of TRAVTM(ALL)	Column Labels		
Row Labels	Stop signs	Traffic Signal	Grand Total
0-600	37.98428571	53.09428571	45.53928571
600-1200	37.24428571	61.25285714	49.24857143
1200-1800	36.09714286	55.23714286	45.66714286
1800-2400	37.19142857	61.21714286	49.20428571
2400-3000	36.52	66.05285714	51.28642857
3000-3600	37.52142857	62.32714286	49.92428571
Grand Total	37.09309524	59.86357143	48.47833333



Average of TRAVTM(ALL)	Column Labels		
Row Labels	Stop signs	Traffic Signal	Grand Total
0-600	37.20857143	45.11285714	41.16071429
600-1200	36.71571429	46.30285714	41.50928571
1200-1800	37.37571429	54	45.68785714
1800-2400	36.46142857	50.65285714	43.55714286
2400-3000	36.85571429	50.97	43.91285714
3000-3600	36.89714286	48.92857143	42.91285714
Grand Total	36.91904762	49.32785714	43.12345238

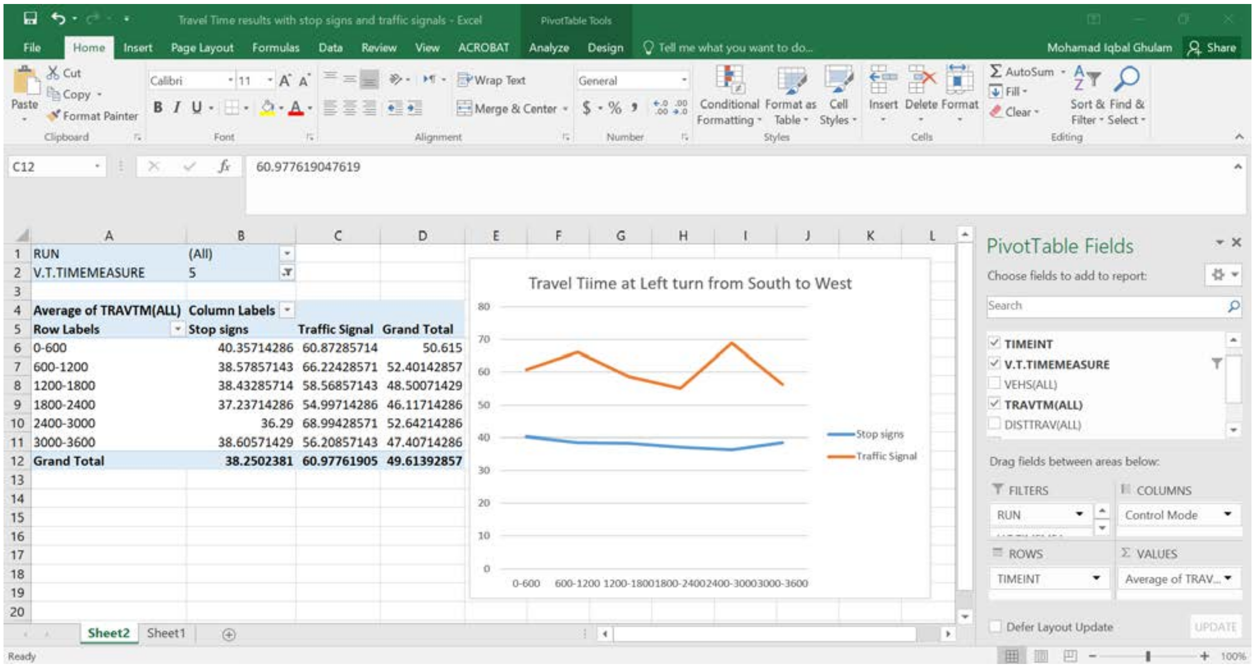


Figure 36: Travel Time results with stop and signal control modes at three turn movements (VISSIM, Own data, 2023).

Assuming Increase in U-turns and left turns from all the sides:

To make sure the results, which I collected are correct, I considered another scenario where I increased turn movements double than the real turn movements from 07:00 am to 01:00 pm time switch plans. This is shown in figure37 as below.

Sharjah Roads and Transport Authority

Traffic Counts with increase in U and left turns.

Survey Date:	07.02.2022
Survey Time:	24 Hours
Survey Location:	Al Muntazah T-Junction (J4)
Notes:	Turning Movement Counts

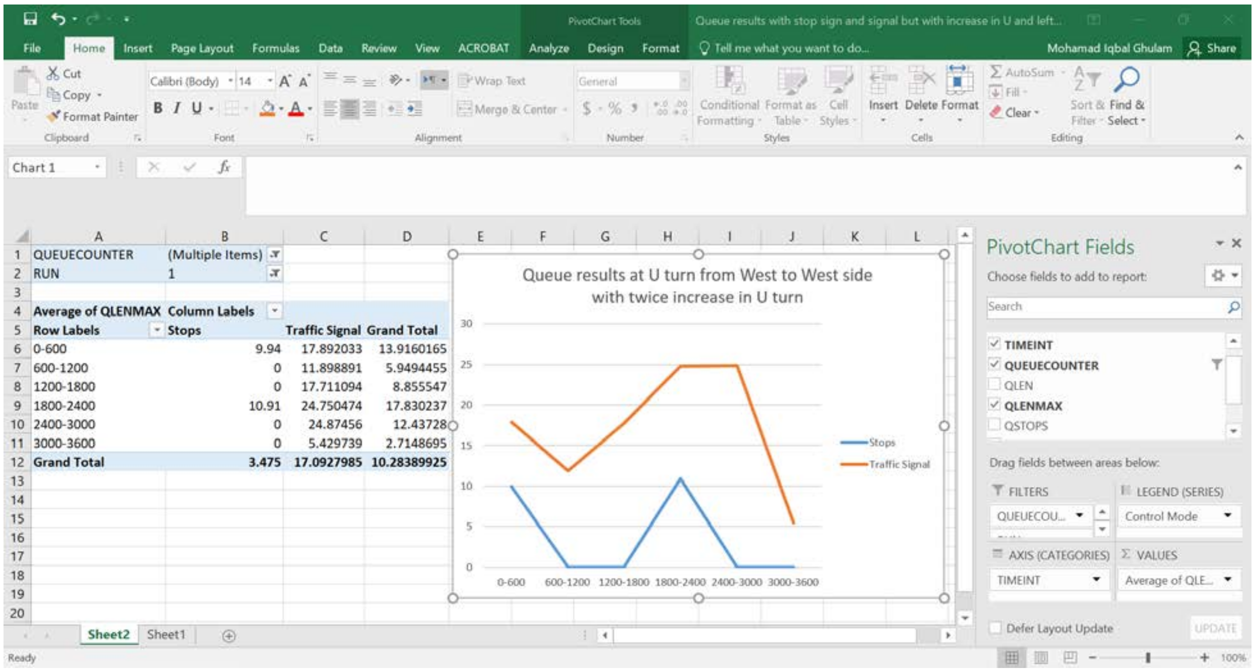
Time	leg-1												leg-2								leg-3								Leg1	Leg2	Leg3
	U-turn				Straight				Right				Left				Right				Straight				Left				T.	T.	T.
	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Lv	Hv	Bus	Total	Count	Count	Count
12.00 - 01.00	66	0	0	66	524	0	0	524	92	0	0	92	19	0	0	19	177	0	0	177	316	0	3	319	191	0	0	191	682	196	510
01.00 - 02.00	19	0	0	19	173	0	1	174	115	0	0	115	0	0	0	0	131	0	0	131	197	0	2	199	56	0	0	56	308	131	255
02.00 - 03.00	13	0	0	13	158	0	0	158	31	0	0	31	5	0	0	5	47	0	0	47	108	0	0	108	45	0	0	45	202	52	153
03.00 -04.00	17	0	0	17	103	0	2	105	27	0	0	27	12	0	0	12	32	0	0	32	83	0	0	83	44	0	0	44	149	44	127
04.00 - 05.00	12	0	0	12	67	0	0	67	10	0	0	10	11	0	0	11	30	0	0	30	40	0	0	40	29	0	0	29	89	41	69
05.00 - 06.00	4	0	0	4	55	0	0	55	11	0	0	11	15	0	0	15	28	0	0	28	26	0	0	26	31	0	0	31	70	43	57
06.00 - 07.00	17	0	0	17	203	0	5	208	65	0	0	65	29	0	0	29	62	0	0	62	300	0	5	305	206	0	8	214	290	91	519
07.00 - 08.00	94	0	0	94	520	0	15	535	110	0	0	110	364	0	8	372	170	0	3	173	826	0	12	838	508	0	12	520	739	545	1358
08.00 - 09.00	116	0	0	116	477	0	12	489	66	0	0	66	294	0	16	310	193	0	4	197	652	0	10	662	378	0	8	386	671	507	1048
09.00 - 10.00	86	0	0	86	656	0	18	674	102	0	0	102	184	0	12	196	149	0	2	151	523	0	10	533	302	0	6	308	862	347	841
10.00 - 11.00	142	0	0	142	500	0	13	513	111	0	0	111	216	0	16	232	192	0	5	197	515	0	12	527	214	0	8	222	766	429	749
11.00 - 12.00	88	0	0	88	472	0	10	482	85	0	0	85	134	0	8	142	127	0	3	130	428	0	9	437	328	0	10	338	655	272	775
12.00 - 13.00	108	0	0	108	697	0	19	716	120	0	0	120	164	0	10	174	229	0	3	232	562	0	12	574	338	0	16	354	944	406	928
13.00 - 14.00	49	0	0	49	707	0	22	729	113	0	0	113	61	0	5	66	246	0	5	251	618	0	16	534	241	0	9	250	891	317	784
14.00 - 15.00	53	0	0	53	809	0	24	833	109	0	0	109	101	0	10	111	457	0	4	461	638	0	20	658	232	0	22	254	995	572	912
15.00 - 16.00	30	0	0	30	910	0	19	929	90	0	0	90	214	0	12	226	633	0	8	641	744	0	14	758	171	0	17	188	1049	867	946
16.00 - 17.00	61	0	0	61	1012	0	22	1034	67	0	0	67	213	0	14	227	625	0	6	631	718	0	10	728	237	0	14	251	1162	858	979
17.00 - 18.00	66	0	0	66	1184	0	21	1205	111	0	0	111	153	0	10	163	704	0	9	713	1146	0	22	1168	400	0	19	419	1382	876	1587
18.00 - 19.00	87	0	0	87	1129	0	26	1155	110	0	0	110	164	0	9	173	646	0	6	652	827	0	10	837	251	0	15	266	1352	825	1103
19.00 - 20.00	74	0	0	74	1046	0	15	1061	86	0	0	86	179	0	10	189	621	0	10	631	678	0	10	688	260	0	12	272	1221	820	960
20.00 - 21.00	80	0	0	80	1079	0	12	1091	115	0	0	115	184	0	8	192	709	0	10	719	726	0	6	732	286	0	15	301	1286	911	1033
21.00 - 22.00	69	0	0	69	1039	0	12	1051	117	0	0	117	152	0	6	158	662	0	8	670	714	0	6	720	270	0	10	280	1237	828	1000
22.00 - 23.00	66	0	0	66	871	0	8	879	132	0	0	132	95	0	2	97	509	0	8	517	489	0	4	493	198	0	8	206	1077	614	699
23.00 - 24.00	61	0	0	61	741	0	6	747	112	0	0	112	66	0	0	66	270	0	2	272	417	0	4	421	208	0	8	216	920	338	637

Figure 37: Traffic data with twice increase in turn movements than actual turn movements (SRTA, Own edit, 2023).

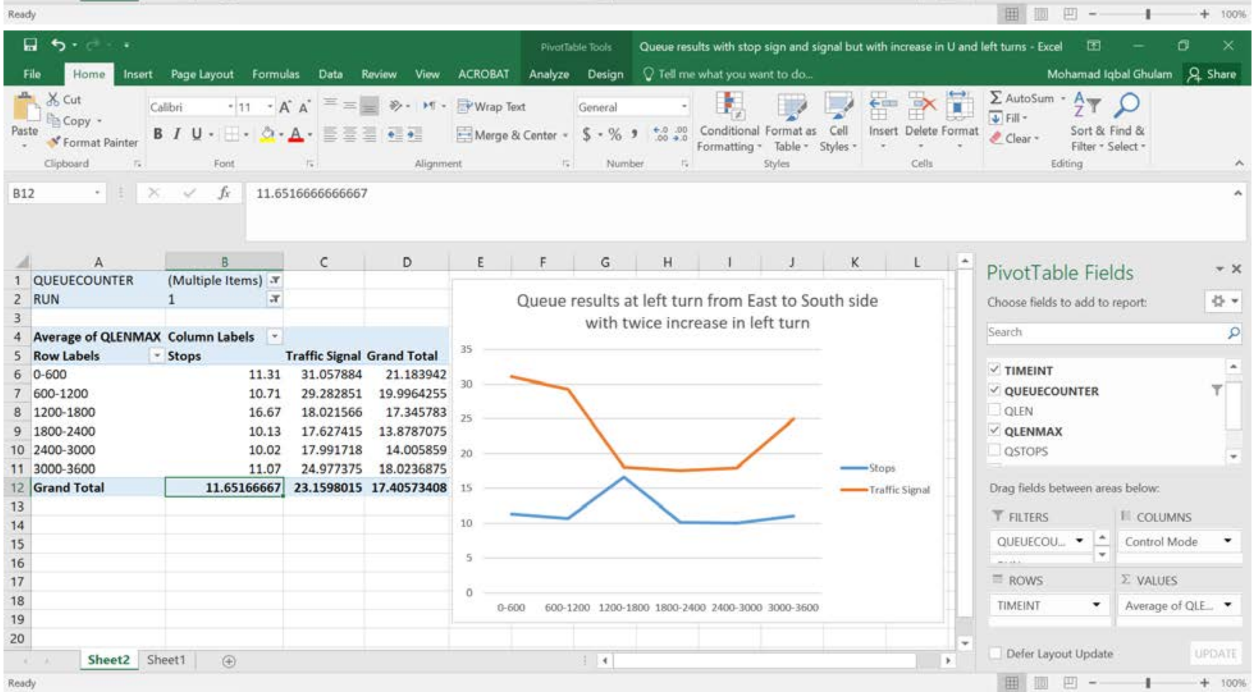
Simulation results of stop and traffic signal control modes with twice increase in turn movements:

Queue Results with stop and signal control modes with increase in turn movements:

While performing VISSIM analysis, the queue results with increase in turn movements for all the three turn movements are lesser in stop sign control mode than signal control mode. This is shown in figure 38 as below:



Average of QLENMAX	Stops	Traffic Signal	Grand Total
0-600	9.94	17.892033	13.9160165
600-1200	0	11.898891	5.9494455
1200-1800	0	17.711094	8.855547
1800-2400	10.91	24.750474	17.830237
2400-3000	0	24.87456	12.43728
3000-3600	0	5.429739	2.7148695
Grand Total	3.475	17.0927985	10.28389925



Average of QLENMAX	Stops	Traffic Signal	Grand Total
0-600	11.31	31.057884	21.183942
600-1200	10.71	29.282851	19.9964255
1200-1800	16.67	18.021566	17.345783
1800-2400	10.13	17.627415	13.8787075
2400-3000	10.02	17.991718	14.005859
3000-3600	11.07	24.977375	18.0236875
Grand Total	11.65166667	23.1598015	17.40573408

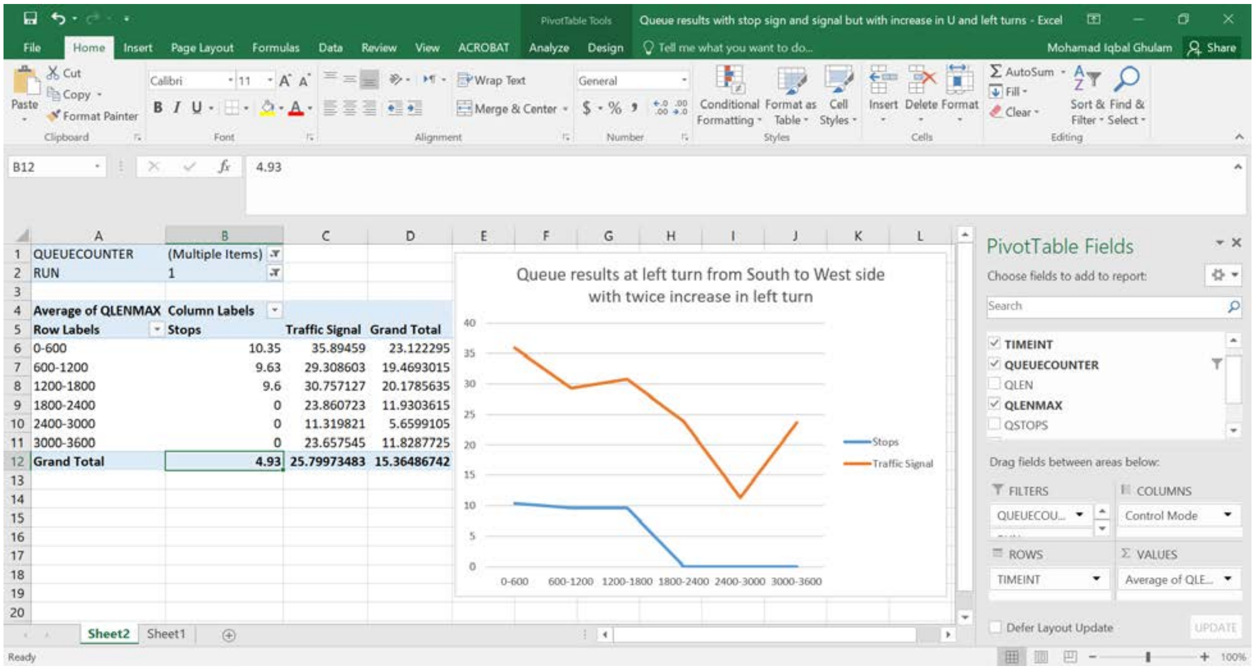
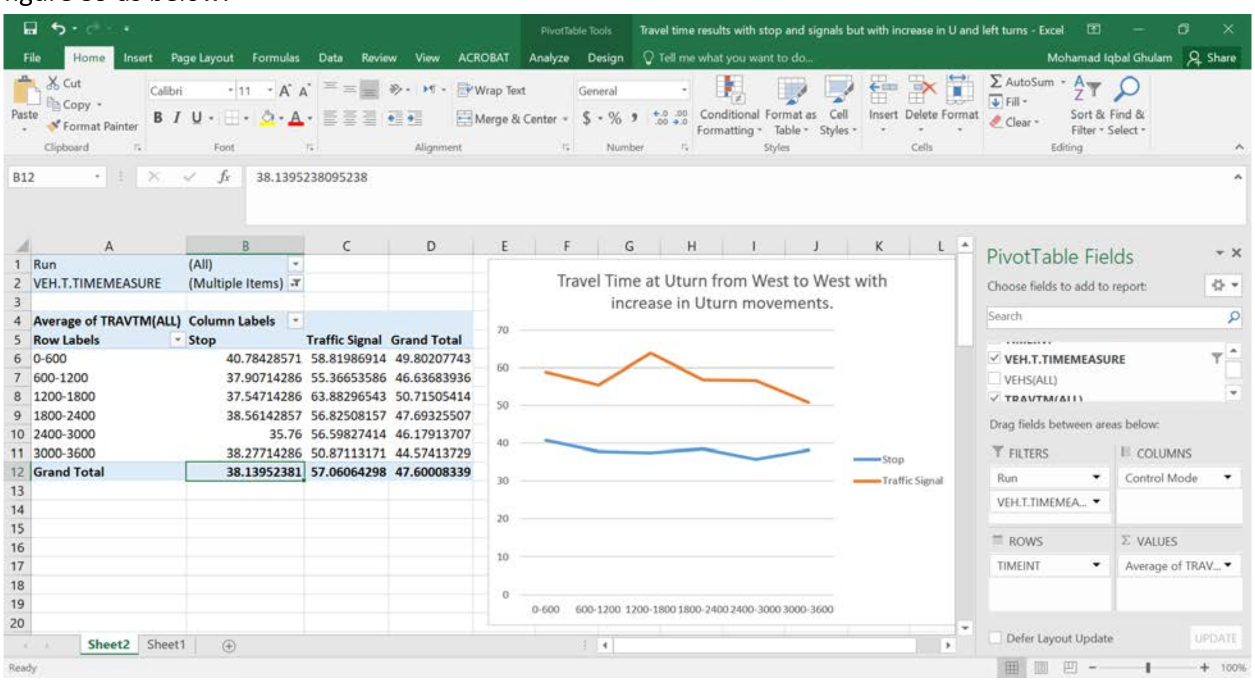


Figure 38: Queue results with stop and signal control modes with twice increase in turn movements (VISSIM, Own data, 2023).

Travel Time Results with stop and signal control modes with twice increase in turn movements:
While performing VISSIM analysis, the travel time results with twice increase in turn movements for all the three turn movements are lesser in stop sign control mode than signal control mode. This is shown in figure 39 as below:



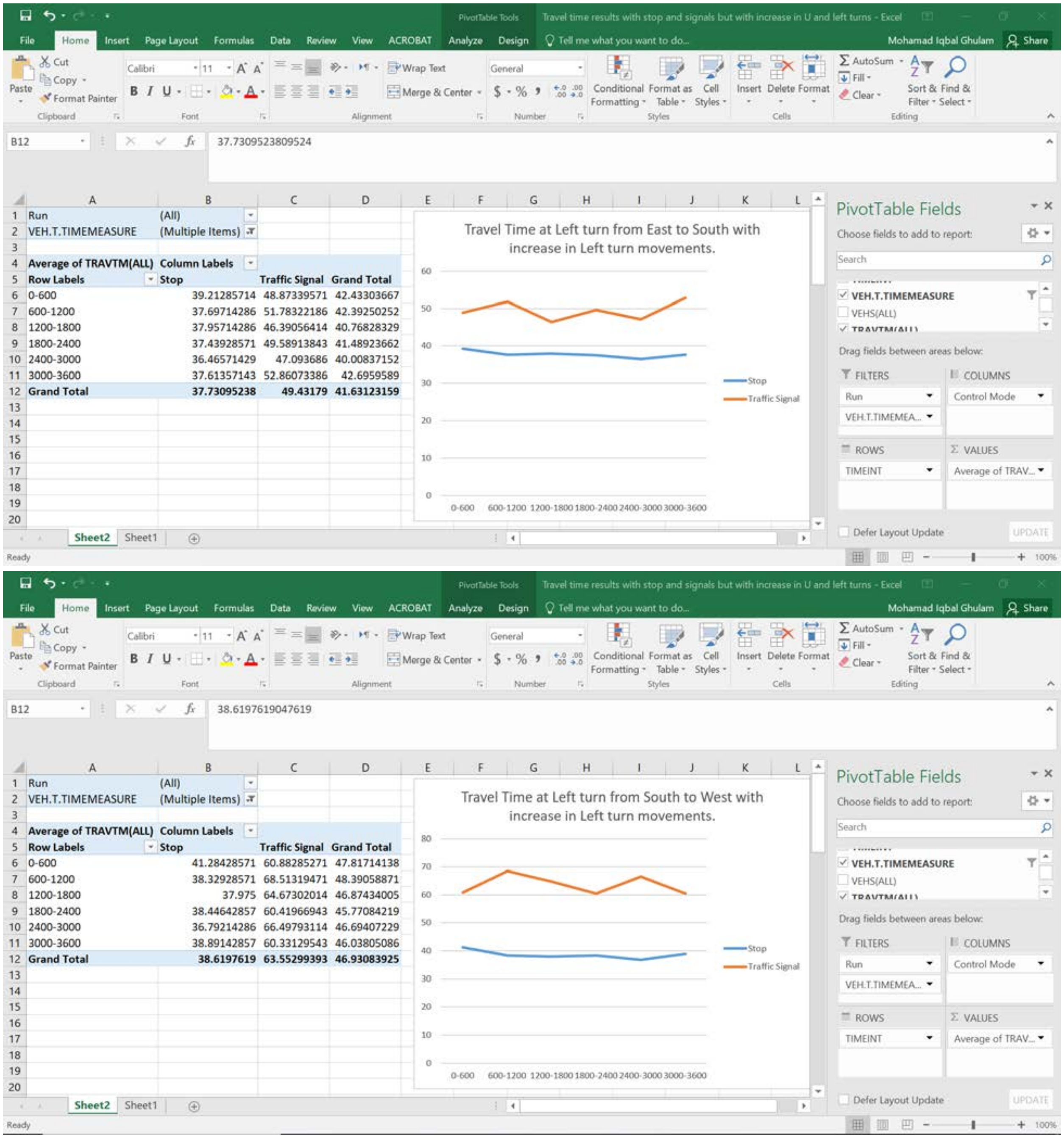


Figure 39: Travel Time results with stop and signal control modes, twice increase in turn movements (VISSIM, Own data, 2023).

5.2. Data analysis conclusion

To sum-up from data analysis by using VISSIM software, I have drawn a conclusion that Queue and Travel Time results at this intersection are better while operating in stop sign control mode than traffic signal control mode. However, these results are in ideal conditions, as I did not include the impacts of traffic collisions at the turn movements. In addition to this, I did not include the driver's behavior such as careless driving, tailgating and so on. Apart from this, these results are not certain for other intersections as the data interpretation results vary due to the volume of traffic. In this particular intersection, if we analyze the real traffic data we do not have denser traffic particularly at the turn movements even if we increase the turn movements as shown in the above figure37. Hence, it is not certain whether we have less or high queues and similarly with the travel times at this t-intersection due to impacts of driving, human behavior and so on, therefore, these parameters might vary than the actual ground conditions.

6. LIMITATIONS

Regarding this study, I must highlight a few limitations of my study. The first one is the people's participation in my survey. From the beginning of my research, I was not certain whether I will have a huge number of participants or not and after survey results, participation is limited. As we know in research, the greater the number of participants the better the outcome. The survey was mainly distributed using an email that was sent to all students at Hasselt University and to all of my colleagues. Moreover, the survey was distributed using social media especially WhatsApp, LinkedIn, where most of my connections are relevant to the transportation sector. Although the survey was sent to quite a large number of potential responders, I am not sure if the participants are familiar with traffic signal concepts or not. In addition to this, some participants are students and their experience in such systems might be limited if not zero. They might not have better observation about careless driving at the intersections as they use mostly public transport services.

Another limitation is to make automatic accident detection and notification systems more effective, this could have been achieved by connecting different hardware, especially sensors of the enforcement system with the Internet of Things (IoT) in order to make this information available to the relevant authorities such as the police and medical emergencies. However, due to cost and time constraints, at this moment, it is not possible to find a sponsor who can invest in this. Moreover, time constraint is another limitation if let us suppose sponsor is available, we need to implement hardware such as sensors, communication medium and so on, which requires time but due to less time span of this research, it is not possible to try this feature. Finally, the accessibility of this signal with centralized traffic management control center is limited as this is not accessible due to privacy concerns from the concerned authorities in order to see the impacts of centralized system. However, this signal is integrated with SRTA TMC and has automatic detection system if crashes or mishaps occur. In addition to this, actual traffic accident data is not published and is not accessible at all. In doing so, we need to apply officially where we have to follow various procedures which is again a time-consuming process.

7. CONCLUSION

This research tries to find an answer to the main research question "Which system needs to be deployed at the intersections in order to mitigate the problems such as speeding, careless driving, tailgating that monitor and enforce the ITS features?" In order to answer this main research question, a number of sub-questions need to be answered that were formulated in the first part of my thesis. To evaluate the above-mentioned sub-questions, three strategies have been implemented.

The first strategy deals with literature review where I focused on safety impacts of traffic signal system, overview of traffic signal systems and historical review of traffic signals system. Moreover, I focused on mobility measures, sustainability measures and other measures, signal timing constraints and overview of traffic signal control methods. Further to this, I focused on isolated and coordinated traffic signal controls, and advantages and disadvantages of traffic signal systems in order to have a clearer picture about the impacts on the daily lives of the people at the intersections. The second strategy deals with the conduction of the survey that investigates traffic safety and human behavior, since traffic safety and human behavior are important factors especially at the intersections. It is important to know how commuters feel about traffic signals at the intersections in terms of safety rather than stop signs. Are traffic signals assist us in controlling driver behaviors such as careless driving? Are traffic accidents increasing traffic congestion at the intersections? This survey targeted a variety of categories of drivers including young novice and older experienced drivers. Furthermore, it is crucial to know what people think about traffic signal systems and centralized optimization systems. The last strategy is a VISSIM analysis where I have used two control modes namely stop sign and traffic signal control modes at the t-intersection in order to figure out how these control modes impact performance measures such as queue level and travel time.

The first sub-question, "How can we evaluate the existing situation based on the available data? Are there chances for improvement?" investigates the volume of the problem and possibilities for the mitigation of such aberrant behaviors and other harmful concerns. To obtain all the necessary information, I have performed a software analysis in VISSIM by putting real traffic data in order to figure out the magnitude of the problem. While using VISSIM analysis, I have estimated Queue and Travel Time results at the T-intersection in Sharjah, UAE and concluded that Queue and Travel Time results at this intersection are better while operating in stop sign control mode than traffic signal control mode. However, these results are in ideal conditions, as I did not include the impacts of traffic collisions at the turn movements. In addition to this, I did not include the driver's behavior such as careless driving, tailgating and so on. Apart from this, these results are not certain for other intersections as the data interpretation results vary due to the volume of traffic. In this particular intersection, if we analyze the real traffic data we do not have denser traffic particularly at the turn movements even if we increase the turn movements as shown in the above figure37. Hence, it is not certain whether we have less or high queues and similarly with the travel times at this t-intersection due to impacts of driving, human behavior and so on, therefore, these parameters might vary than the actual ground conditions.

For the second question, "Does an intervention have a positive impact on drivers and surroundings under the enforcement of traffic signals at the intersection?" A literature review was performed to see the impacts on the daily lives of the people. In addition to this, I have conducted surveys in order to see how the drivers behave at the intersections with different ages ranging from young novice to old- experienced drivers. From the literature review, I have concluded that traffic congestion can be reduced on the road networks, which in turn reduces the excessive delays at the intersections by deploying the traffic signals in efficient ways. Deployment of traffic signals is an effective transportation option and is the best possible way to control the vehicle movements at the intersections without any accidents and conflicts. Traffic signals are one of the most effective and flexible active controls of traffic and are widely used all over the world. In addition to this, it has been noted that the installation of a traffic signal will not only improve the safety level of an intersection but it will also improve at a level higher than what other measures, non-traffic signal related, would have accomplished. Hence, the traffic signals are one of the most powerful tools for urban traffic control, which city authorities can utilize, and their correct installation can improve both traffic flow and the safety of all road users. In comparison to other traffic improvements, traffic signals are also relatively low capital investment and there is no doubt that time separation of traffic conflicts using traffic signals is one of the most powerful tools for urban traffic control available to city authorities. Consequently, their correct design and operation can improve both traffic performance and safety for all road users. In survey analysis, the results which I received that majority of the participants are feeling safer while using traffic signals at the intersections and also believe that driver behavior is controlled at the signalized intersections than non-signalizedintersections. In addition to this, majority of the participants believe that traffic signal is controlling vehicle movements without conflicts and traffic accidents.

In the third sub question “Is it possible to evaluate the effectiveness of traffic signals in terms of reduction in crash frequency and the net economic benefit?” In this sub-question, I have conducted literature review and survey analysis as it was not possible to apply before and after study methodology to this sub-question in order to compare the results, as I need to wait for some time to see the impacts of traffic signals at the intersections. In the literature review, I have concluded that we need to use proper traffic signal design with optimum phasing arrangement at the intersections and will surely reduce the existing traffic congestion that will save time and cost for the road users. Moreover, the bottlenecks at the intersections will be overcome and road intersections will have positive impacts on mobility such as less delays at the intersections, decrease in travel time. Not only this, but have positive impacts on the environment as well such as less emission of harmful pollutants, decrease in noise pollution, decrease in fuel consumption. Thus, the capacity of the road network will be optimized and the losses in terms of economies caused by traffic congestion can be improved significantly. By deploying traffic signals at the intersections, total crashes, which includes injury, and fatal crashes will be reduced and is the safer option as well in order to avoid any type of chaos. The installation of a traffic signal will result in a general reduction of crashes, but also specific types of crashes, such as right angle and left-turn related crashes, are likely to be reduced more. In the survey analysis, the majority of the participants believe that there are less traffic accidents at signalized intersections than non-signalizedintersections. In terms of capital investment, the majority of the participants believe that traffic signals are a lower capital investment than other forms.

In the fourth sub-question, “How to make automatic accident detection and notification systems more effective?” This could have been achieved by connecting different hardware, especially sensors of the enforcement system with the Internet of Things (IoT) in order to make this information available to the relevant authorities such as the police and medical emergencies. However, due to cost and time constraints, during my research period, it was not possible to find a sponsor who would invest in this. Moreover, time constraint was another limitation if let us suppose a sponsor was available but to implement hardware such as sensors, communication medium and so on, required time. Therefore, due to less time span of this research, it was not possible to try this feature and hence relied only on survey outcome. In the survey analysis, the majority of the participants believe that traffic signals by using IoT improves road safety, quality and efficiency of the road network.

Finally, the last sub-question, "Is it possible to integrate traffic signals with the traffic control center?" which is related to the integration of the enforcement system with the traffic management control center (TMC). The TMC is to collect and analyze road traffic condition related data and provide real-time feedback to users, such as on traffic congestion, detour suggestions due to severe weather and road maintenance works or traffic incidents. The data will strengthen their ability to manage the development and maintenance of the network and allow more effective long-term planning.
Data from traffic monitoring has three primary functions in network operations:

- Capacity modeling of road links and junctions.
- Incident detection.
- Congestion monitoring.

Real-time information about traffic conditions and travel times contributes strongly to the improvement of traffic efficiency. It enables road operators to understand how well the road network is operating and enables the timely detection of incidents. For example, the TMC may wish to measure the performance of its road network to provide tangible evidence that the methods to reduce congestion and improve the consistency of journey times are having a positive effect. Therefore, we have to see whether this is possible at the implementation area or not, such as the availability of TMC and availability of data communication in that region. Further to this, I will also perform survey analysis to see the impacts of centralized adaptive systems. Once all the answers and sub-questions have been provided, the answer to the main research question will be answered. The accessibility of this signalized intersection with a centralized traffic management control center is limited as this is not accessible due to privacy concerns from the concerned authorities in order to see the impacts of the centralized system. However, this signal is integrated with SRTA TMC and has an automatic detection system if crashes or mishaps occur. To see the impacts of a centralized system, I have tried to post this in the survey questionnaire and noted that the majority of the participants believe that performance measures improve by using a centralized optimization system with the signals.
In conclusion, vehicular travel has been increasing at a tremendous rate. The growth of traffic volumes at many intersections has necessitated many changes in the control devices employed to regulate the intersecting traffic flows. The control devices most often used when the volumes are low are stop or yield signs. At high volume at-grade intersections, however, a traffic signal is required to regulate the intersecting traffic flows to reduce congestion and delay. Since the traffic signal is the control device employed to regulate traffic at high-volume intersections, it has been assumed by much of the motoring public to be a cure-all for intersection problems, including safety (G.W.Schoene, H.L.Michael, 2023). Further to this, I have attached traffic accident statistics of 2007 published by the U.S Department of Transportation, Federal Highway Administration where it is clearly indicating that there are more traffic

accidents at the non-signalizedintersections than signalized intersections (FHA, 2023). This is shown in figure 40 as below.

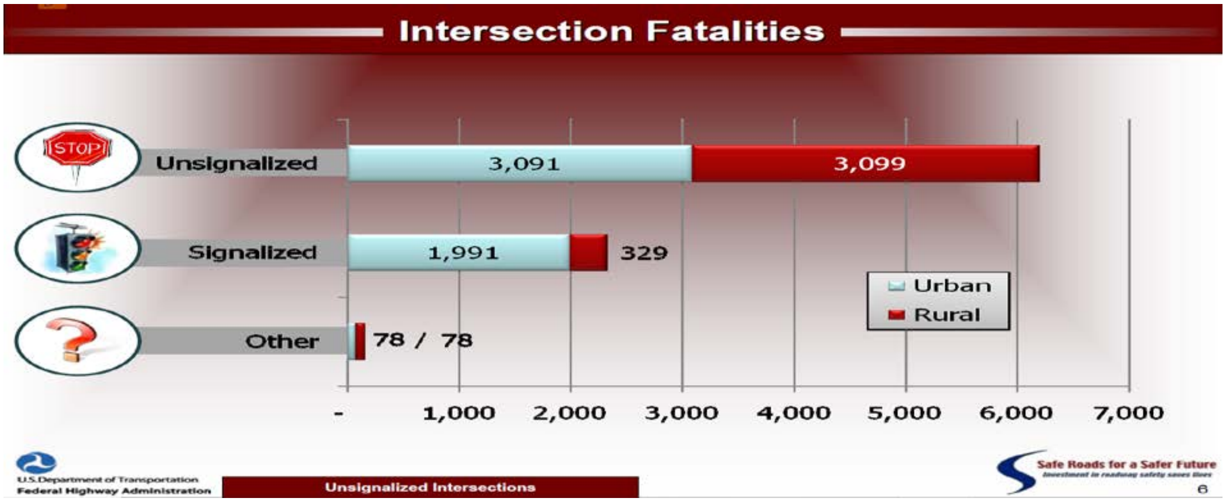


Figure 40: Intersection fatalities statistics (FHA, 2023)

8. PRACTICAL RECOMMENDATION AND FUTURE RESEARCH

Three methodologies discussed in this research, literature review, a survey and an analysis of intersection data by using VISSIM analysis. All of these methodologies could be used in further research but with some changes. The changes have to do with 2 of the 3 methodologies that have been used, survey and VISSIM analysis. Regarding the survey, the aim would be to involve more people related to the subject and people who have experience in similar fields. In this survey, the majority of the participants are transport professionals but the number is not that much. Hence, a greater number of participants should be involved and this can be achieved by involving different alumni of the transport sector and professionals as well from different regions. Regarding intersection data using VISSIM analysis, as I mentioned before, the limitation of data was the biggest constraint and the safety features are not included in this analysis. This can be achieved by keeping the data available to everyone particularly for the academic people. By highlighting these points in my master thesis, at least I can see more possibilities in my future research to have scent percent results such as possibility for safety analysis at the intersections, analysis for driver behaviors and various others.

In terms of practical level, I have learned how to set up a survey and how to take the best answers from participants to have the best results. Moreover, the analysis of the survey data is crucial to depict the results. The specific thesis is a very good effort and the recommendations are feasible to be carried out in order to achieve the best possible results on traffic management and enforcement of road traffic infrastructures such as traffic signals at the intersections.

9. ANNEXES

9.1. Annex 1: Survey

Management and Enforcement of Road Traffic Infrastructures using ITS (IoT-based)

Start of Block: Default Question Block

Q1.1 My name is Mohmad Iqbal Mir and I am pursuing a master's degree in Transportation Sciences at University of Hasselt via distance learning. The objective of this research is to examine how automatic accident detection and notification systems using IoT-based vehicular environment such as Advanced Monitoring, Management and Enforcement of Road Traffic Infrastructures can influence traffic flow in terms of road safety, traffic congestion. The survey will take approximately 8 minutes to complete and you can be assured that all information will be kept private and confidential. Before starting the survey, please read the information below thoroughly. I have read the above information about this study. I understand the purpose of this study as well as what is expected of me during the study. I understand that my participation in this study is voluntary and I have the right to discontinue my participation at any time during the intake (by closing the browser window). I do not need to give a reason for this and I know that there will be no harm at all in doing so. I understand that the results of this research may be used for scientific purposes and may be published. My name will not be published and the privacy of my data is guaranteed at every stage of the research. I know that the results of this research will be kept for 5 months, starting 5/18/2023, and will be deleted after this period. For questions I know I can contact after my participation: mohmadiqbal.mir@student.uhasselt.be. By submitting this survey form, you are indicating that you have read the purpose of the study and that you agree to the terms. Many thanks in advance for your participation. Click to write the question text

O I agree and would like to fill in the survey (1)

O I disagree and would not like to fill in the survey (2)

Skip To: End of Survey If My name is Mohmad Iqbal Mir and I am pursuing master's degree in Transportation Sciences at Unive... = I disagree and would not like to fill in the survey (2)

End of Block: Default Question Block

Start of Block: Block1

Q2.1 What is your gender?

O Male (1)

O Female (2)

Q2.2 What age group do you belong to?

- 16-24 (1)
- 25-34 (2)
- 35-44 (3)
- 45-65 (4)
- 65+ (5)

End of Block: Block1

Start of Block: Block 2

Q3.1 In which country do you live in?

- Click to write Choice 1 ____

Q3.2 In what kind of area do you live in?

- Urban area (1)
- Suburban area (2)
- Rural area (3)

End of Block: Block 2

Start of Block: Block 3

Q4.1 Do you own a driving license?

- Yes (1)
- No (2)

Q4.2 Do you own a car?

- Yes (1)
- No (2)

End of Block: Block 3

Start of Block: Block 4

Q5.1 What is your current profession?

- Student (1)
- Employee (2)
- Unemployed (3)

Q5.2 You go to work/university by using...

- Car (1)
- Public Transport (2)
- By Foot (3)
- Other means of Transport (e.g. Bicycle) (4)

End of Block: Block 4

Start of Block: Block 5

Q6.1 Traffic signals (TSs) are standardized devices for controlling and regulating the vehicular traffic, pedestrians, pedal cyclists, which are implemented at the signalized intersections, the signalized pedestrians and the cyclist crossings, the railway crossings and at the locations where the traffic flow needs to be controlled.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I have never heard about TSs (1)	O	O	O	O	O	O	O
I know what TS refers to (2)	O	O	O	O	O	O	O
My knowledge about TSs are limited (3)	O	O	O	O	O	O	O

Q6.2 Traffic signals (TS) can be operated under various operational modes such as fixed, vehicle actuated or centralized mode.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I have never heard about operational modes (1)	O	O	O	O	O	O	O
I know what operational modes refer to (2)	O	O	O	O	O	O	O
My knowledge about operational modes are limited (3)	O	O	O	O	O	O	O

End of Block: Block 5

Start of Block: Block 6

Q7.1 At the intersections, introduction of TS control mode is safer than non-signalized control modes such as stop signs.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe at the intersections that introduction of TS is safer than Stop signs (1)	O	O	O	O	O	O	O
I don't believe at the intersections that introduction of TS is safer than stop signs (2)	O	O	O	O	O	O	O
I am not sure at the intersections that introduction of TS is safer than stop signs (3)	O	O	O	O	O	O	O

Q7.2 At the intersections, introduction of TS helps us to control driver behaviors such as careless driving.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that TS at the intersections controls driver behaviors (1)	O	O	O	O	O	O	O
I don't believe TS at the intersections controls driver behaviors (2)	O	O	O	O	O	O	O
I am not sure if TS at the intersections controls driver behaviors (3)	O	O	O	O	O	O	O

End of Block: Block 6

Start of Block: Block 7

Q8.1 We have more traffic accidents at the non-signalized intersections than signalized intersections.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe we have more traffic accidents at the non-signalized intersections than signalized (1)	O	O	O	O	O	O	O
I don't believe we have more traffic accidents at the non-signalized intersections than signalized (2)	O	O	O	O	O	O	O
I am not sure whether we have more traffic accidents at the non-signalized intersections than signalized or not (3)	O	O	O	O	O	O	O

Q8.2 At the intersections, traffic accidents have more impact on traffic congestions.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that traffic accidents at the intersections have more impact on traffic congestions (1)	o	o	o	o	o	o	o
I don’t believe that traffic accidents at the intersections have more impact on traffic congestions (2)	o	o	o	o	o	o	o
I am not sure whether traffic accidents at the intersections have more impact on traffic congestions or not (3)	o	o	o	o	o	o	o

End of Block: Block 7

Start of Block: Block 8

Q9.1 We have less queues and less travel times at the signalized intersections than non-signalized intersections in highly dense traffic condition.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that queues and travel times are less at the signalized intersections than non-signalized intersections in highly dense traffic condition (1)							
I don't believe that queues and travel times are less at the signalized intersections than non-signalized intersections in highly dense traffic condition (2)							

I am not sure whether queues and travel times are less at the signalized intersections than non-signalized intersections in highly dense traffic condition or not (3)	

End of Block: Block 8

Start of Block: Block 9

Q10.1 By implementing proper traffic management initiatives such as proper traffic signal design with optimum phasing arrangement, connection with centralized control room and so on, capacity of the roads at the intersections can be improved significantly.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that implementation of proper traffic management improves the capacity of the roads at the intersections. (1)							
I don't believe that implementation of proper traffic management improves the							

capacity of the roads at the intersections. (2)	
I am not sure whether implementation of proper traffic management improves the capacity of the roads at the intersections or not (3)	

Q10.2 Traffic signals are a better option for effective transportation and is the best possible way to control the vehicle movements at the intersections without any accidents and conflicts.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that TS is the best option to control vehicle movements at the intersections without accidents and conflicts. (1)							
I don't believe that TS is the best option to control vehicle movements at the intersections without							

accidents and conflicts. (2)	
I am not sure whether TS is the best option to control vehicle movements at the intersections without accidents and conflicts or not (3)	

Q10.3 Traffic signals (TSs) are relatively low capital investment than other forms such as building of bridges.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that TS is the low capital investment. (1))							
I don't believe that TS is the low capital investment. (2)							
I am not sure whether TS is the low capital							

investment or not (3)	

End of Block: Block 9

Start of Block: Block 10

Q11.1 Traffic signals using Intelligent Transportation System (ITS) based on advanced telecommunication and information technology (IoT) provides great support in improving road safety, quality and efficiency of transport networks.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that TSs using IoT improves road safety, quality and efficiency of transport networks. (1)							
I don't believe that TSs using IoT improves road safety, quality and efficiency of transport networks. (2)							

I am not sure whether TSs using IoT improves road safety, quality and efficiency of transport networks or not (3)

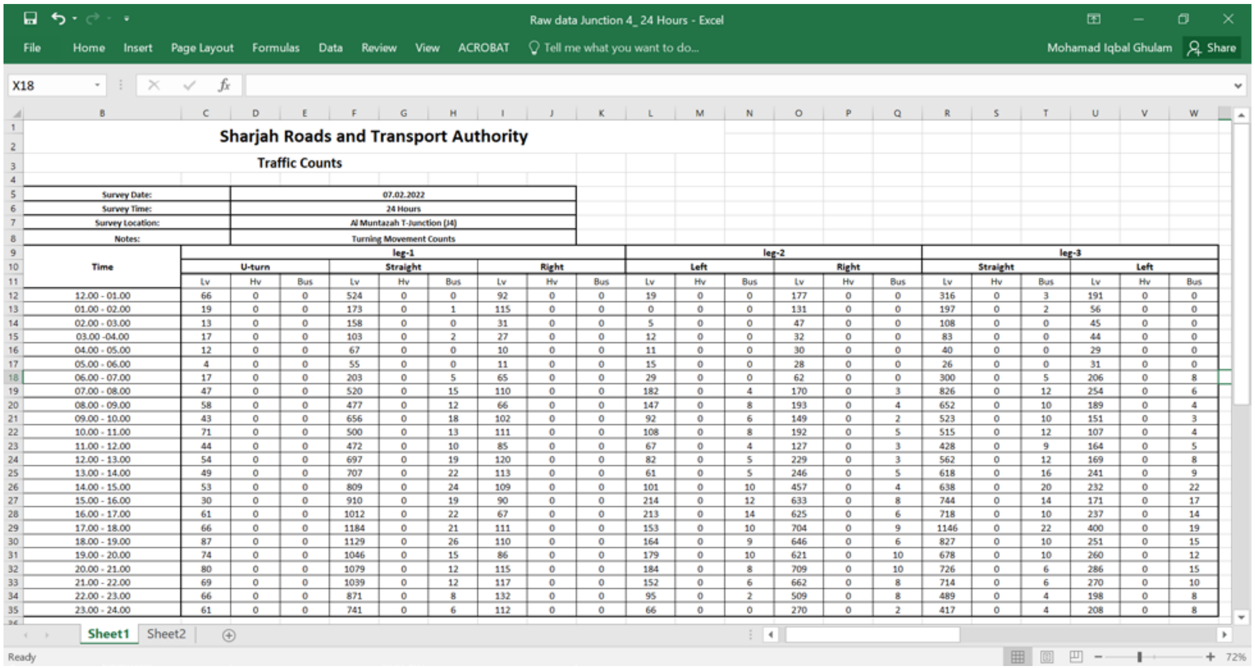
Q11.2 Centralized optimization system is designed for general application within a computerized Urban Traffic Control System and is a method of coordination that adjusts the signal timings in frequent, small increments to match the latest traffic situation. Traffic data from vehicle detectors are analyzed by an on-line computer, which contains programs that calculate traffic flows and predicted queues. This control mode helps us to improve the performance measures (delay, travel time, congestion and so on) in an effective way.

To what extent do you agree with the following statements?

	Totally disagree (1)	Disagree (2)	Rather disagree (3)	Neither disagree nor agree (4)	Rather agree (5)	Agree (6)	Totally agree (7)
I believe that centralized optimization system improves the performance measures. (1)	O	O	O	O	O	O	O
I don't believe that centralized optimization system improves the performance measures. (2)	O	O	O	O	O	O	O
I am not sure whether centralized optimization system improves the performance measures or not. (3)	O	O	O	O	O	O	O

End of Block: Block 10

9.2. Annex 2: T-intersection raw data



Sharjah Roads and Transport Authority

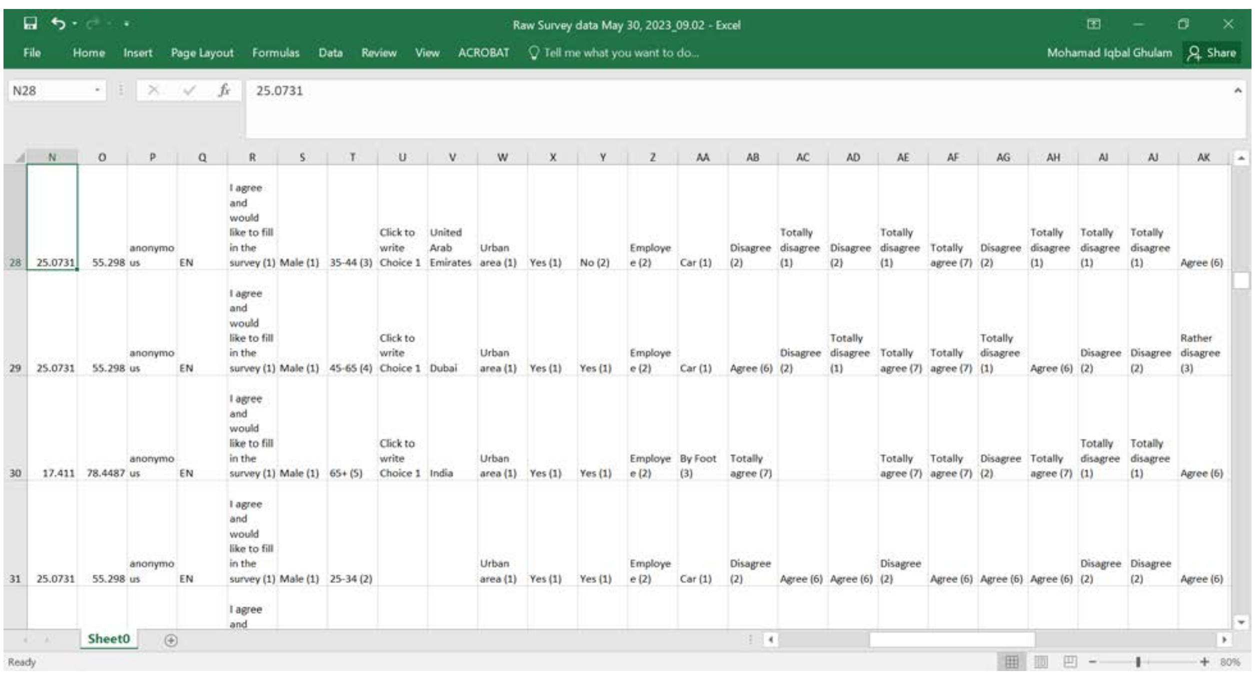
Traffic Counts

Survey Date:	07.02.2022
Survey Time:	24 Hours
Survey Location:	Al Muntazah T-Junction (J4)
Notes:	Turning Movement Counts

Time	leg-1									leg-2						leg-3					
	U-turn			Straight			Right			Left			Right			Straight			Left		
	Lv	Hv	Bus	Lv	Hv	Bus	Lv	Hv	Bus	Lv	Hv	Bus	Lv	Hv	Bus	Lv	Hv	Bus	Lv	Hv	Bus
12.00 - 01.00	66	0	0	524	0	0	92	0	0	19	0	0	177	0	0	316	0	3	191	0	0
01.00 - 02.00	19	0	0	173	0	1	115	0	0	0	0	0	131	0	0	197	0	2	56	0	0
02.00 - 03.00	13	0	0	158	0	0	31	0	0	5	0	0	47	0	0	108	0	0	45	0	0
03.00 -04.00	17	0	0	103	0	2	27	0	0	12	0	0	32	0	0	83	0	0	44	0	0
04.00 - 05.00	12	0	0	67	0	0	10	0	0	11	0	0	30	0	0	40	0	0	29	0	0
05.00 - 06.00	4	0	0	55	0	0	11	0	0	15	0	0	28	0	0	26	0	0	31	0	0
06.00 - 07.00	17	0	0	203	0	5	65	0	0	29	0	0	62	0	0	300	0	5	206	0	8
07.00 - 08.00	47	0	0	520	0	15	110	0	0	182	0	4	170	0	3	826	0	12	254	0	6
08.00 - 09.00	58	0	0	477	0	12	66	0	0	147	0	8	193	0	4	652	0	10	189	0	4
09.00 - 10.00	43	0	0	656	0	18	102	0	0	92	0	6	149	0	2	523	0	10	151	0	3
10.00 - 11.00	71	0	0	500	0	13	111	0	0	108	0	8	192	0	5	515	0	12	107	0	4
11.00 - 12.00	44	0	0	472	0	10	85	0	0	67	0	4	127	0	3	428	0	9	164	0	5
12.00 - 13.00	54	0	0	697	0	19	120	0	0	82	0	5	229	0	3	562	0	12	169	0	8
13.00 - 14.00	49	0	0	707	0	22	113	0	0	61	0	5	246	0	5	618	0	16	241	0	9
14.00 - 15.00	53	0	0	809	0	24	109	0	0	101	0	10	457	0	4	638	0	20	232	0	22
15.00 - 16.00	30	0	0	910	0	19	90	0	0	214	0	12	633	0	8	744	0	14	171	0	17
16.00 - 17.00	61	0	0	1012	0	22	67	0	0	213	0	14	625	0	6	718	0	10	237	0	14
17.00 - 18.00	66	0	0	1184	0	21	111	0	0	153	0	10	704	0	9	1146	0	22	400	0	19
18.00 - 19.00	87	0	0	1129	0	26	110	0	0	164	0	9	646	0	6	827	0	10	251	0	15
19.00 - 20.00	74	0	0	1046	0	15	86	0	0	179	0	10	621	0	10	678	0	10	260	0	12
20.00 - 21.00	80	0	0	1079	0	12	115	0	0	184	0	8	709	0	10	726	0	6	286	0	15
21.00 - 22.00	69	0	0	1039	0	12	117	0	0	152	0	6	662	0	8	714	0	6	270	0	10
22.00 - 23.00	66	0	0	871	0	8	132	0	0	95	0	2	509	0	8	489	0	4	198	0	8
23.00 - 24.00	61	0	0	741	0	6	112	0	0	66	0	0	270	0	2	417	0	4	208	0	8

Figure 41: Raw traffic data of T-intersection (SRTA, 2022)

9.3. Annex 3: Qualtrics raw data



	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
28	25.0731	55.298	anonymous	EN	I agree and would like to fill in the survey (1)	Male (1)	35-44 (3)	Click to write Choice 1	United Arab Emirates	Urban area (1)	Yes (1)	No (2)	Employee (2)	Car (1)	Disagree (2)	Totally disagree (1)	Disagree (2)	Totally disagree (1)	Totally agree (7)	Disagree (2)	Totally disagree (1)	Totally disagree (1)	Totally disagree (1)	Agree (6)
29	25.0731	55.298	anonymous	EN	I agree and would like to fill in the survey (1)	Male (1)	45-65 (4)	Click to write Choice 1	Dubai	Urban area (1)	Yes (1)	Yes (1)	Employee (2)	Car (1)	Agree (6)	Disagree (2)	Totally disagree (1)	Totally agree (7)	Totally agree (7)	Totally disagree (1)	Agree (6)	Disagree (2)	Disagree (2)	Rather disagree (3)
30	17.411	78.4487	anonymous	EN	I agree and would like to fill in the survey (1)	Male (1)	65+ (5)	Click to write Choice 1	India	Urban area (1)	Yes (1)	Yes (1)	Employee (2)	By Foot (3)	Totally agree (7)			Totally agree (7)	Totally agree (7)	Disagree (2)	Totally agree (7)	Totally disagree (1)	Totally disagree (1)	Agree (6)
31	25.0731	55.298	anonymous	EN	I agree and would like to fill in the survey (1)	Male (1)	25-34 (2)			Urban area (1)	Yes (1)	Yes (1)	Employee (2)	Car (1)	Disagree (2)	Agree (6)	Agree (6)	Disagree (2)	Agree (6)	Agree (6)	Agree (6)	Disagree (2)	Disagree (2)	Agree (6)

Figure 42: Survey Raw Data in Excel *(Excel, Own data, 2023)*

9.4. Annex 4: Raw data about the living Country

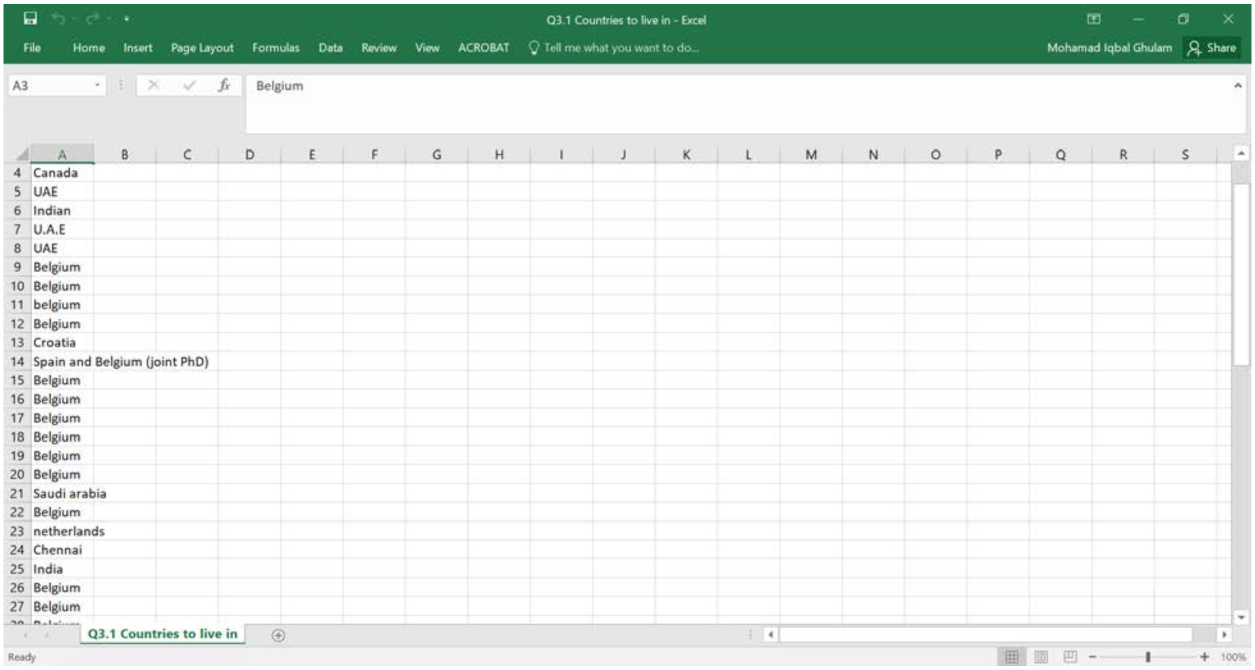


Figure 43: Raw Living Country Data in Excel *(Excel, Own data, 2023)*

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