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College of Engineering

Civil Engineering Department

A Traffic Simulation Study for Changing Roundabout into Signalized Intersections

A Thesis Submitted to the Council of the Faculty of the Engineering/University of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Infrastructure Engineering

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

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الْعِلْمَ دَرَجَاتٍ

صدق الله العلي العظيم

(المجادلة: من الآية 11)

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A Traffic Simulation Study for Changing Roundabout into Signalized Intersections

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Abstract

Karbala governorate is regarded as one of the most well-known governorates in Iraq for its religious and tourist attractions, which polarized many visitors, resulting in a growing need for transportation system services. As a result, congestion is common in many streets and intersections. In particular, at the roundabouts that are suffering from significant congestion. This research aims to study traffic operations due to various performance measures at the roundabout. Furthermore, study the roundabout after change it to signalized roundabouts and signalized intersections. Then, traffic growth after five years is studied due to those measures.

The research unit is focus on three high-traffic roundabouts in the center of Karbala district (CKD) (Al-Tarbia, Said Al-Assar, and Al-Mohafada). A video recording is obtained from the Karbala Police Department, through which the traffic volumes required in the study are calculated during (7:30AM-8:30AM), (12:30-13:30), and (19:30-20:30) during peak hours. The Planung Transport Verkehr Vissim 2022 program is relied upon to create a model that simulates reality.

The results showed a significant delay in the studied roundabouts, with a level of service F for all roundabouts. Due to converting the roundabout to a signalized roundabout and a signalized intersection, the level of service LOS shifted (from F to D and C) and (from F to E and D), when the average delay decreased at signalized roundabouts by 40% and decreased by 66% at signalized intersections, and the average queue length decreased by 16% and 27% respectively.

The results of the effect of traffic volumes on the performance of the roundabout and comparing the three cases that have been studied (roundabout,

signalized roundabout, and signalized intersections) indicate that traffic arrival rates of 0.2 v/s/l are achieved, after which it is preferable to convert the roundabouts to a signalized roundabout. Moreover, it is preferable to convert the roundabout to signalized intersections at 0.29 v/s/l.

The study of the effect of the growth rate of traffic volumes showed that most signalized intersections would return to the level of service F in a few years that do not exceed five years. Changing roundabout into signalized roundabout and signalized intersection shows an apparent effect on the environmental parameters CO, NOx, VOC, and fuel consumption, as all factors decreased in different proportions

Undertaking

I certify that research work titled "**A Traffic Simulation Study for Changing Roundabout into Signalized Intersections**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged/referred.

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Ali Fadhlallah Hussein

Date: / / 2023

Dedication

I dedicate this work:

To the beloved Mustafa Muhammad, peace and blessings be upon him

To whom I proudly bear his name; my dear Father

To whom did she drink the cup of misery to drink me nectar of happiness, dear mother

To my dear wife Zainab, who helped me and encouraged me, and to my family in general

To all my dear friends, exceedingly Eng.Diaa Mazal, Eng.Abbas Jalal Kaaishish and Eng. Sajjad firas

For they always being there for me through all of my ups and downs, without even a sigh.

Finally, to those who gave their lives in order for us to live; Martyrs of Iraq

Acknowledgements

All praise and glory to Almighty Allah for providing me with the health and strength to finish this work and do something that will benefit humanity.

I would like to express my sincere gratitude to my supervisors, **Prof.Dr Hussein Ali Ewadh** and **Asst.Prof.Dr. Raid R. A. Almuhanna,** for their guidance, advice, and encouragement throughout my study in general and my research in particular.

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List of Abbreviations

AIMSUN	Advanced Interactive Microscopic Simulator for Urban and Nonurban Networks
AIMSUN	Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks
CA	Cellular Automaton
CKD	Centre Karbala District
FFS	Free Flow Speed
GA	Genetic Algorithm
HCM	Highway Capacity Manual
LOS	Level of Service
MMAS	Multi-Stream Minimum Acceptable Space
MUTCD	Manual of Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
PTV	Planung Transport Verkehr
SIDRA	Signalized & Unsignalized Intersection Design and Research Aid
SSAM	Surrogate Safety Assessment Model
Vissim	Verkehr in Städten – Simulations model

List of Symbols

ari	Clearance Interval
C	Cycle Length
Co	Optimal Cycle Length in Seconds
d	Delay (S/Vet)
d1	Uniform Delay(S/Vet)
d2	Incremental Delay(S/Vet)
d3	Initial Queue Delay(S/Vet)
Dat	Density on The Link at Time T
$\mathbf{d_{ia}}$	Delay of Vehicle I
G	Green Interval
$\mathbf{g_i}$	Effective Green Time for One Phase
L	Sum of All Wasted Time
Qat	Vehicles on The Link at Time I
Ri	Red Interval
$\mathbf{t^{fa}}$	Base Travel Time
$\mathbf{t_i}$	The Total Effective Green Time
$\mathbf{t_{ia}}$	Actual Travel Time
v/c	Volume/Capacity
V/s	Design Flow Rate to Saturation Flow Rate for Each Phase's Critical
yi	Change Interval

Chapter One:

Introduction

Chapter One
Introduction

1.1 General

As Iraq's population continues to grow at a rapid rate, all areas of life are being impacted, particularly transportation networks. The significant increase in population directly correlates to a rise in the number of vehicles utilizing the traffic networks.

Overcrowding has become one of the biggest problems for transportation networks in Iraq in general and Karbala in particular. Karbala has witnessed a significant increase in population in recent years because people from all over Iraq have moved here because of its religious history and the relative improvement of services compared to other governorates, which is thought to be a major reason for the migration.

Consequently, with the population increase in the governorate, the traffic network began to lose its capability to accommodate the significant increasing in traffic volume. The essential parts of the traffic network that are greatly affected by the significant increase in traffic volumes are the roundabouts, which are facing major congestion that delays the smooth flow of traffic volumes. Instead of being a smooth point between roads, it has become a congestion point that takes much time to get past.

In many areas, the roundabouts are considered intersections with traffic policeman stands to regulate the large volume of traffic that faces them, especially at peak times when it begins to lose the ability to control the traffic volume, as it was designed for different traffic volumes than what it is now (Rodrigues 2014).

1.2 Traffic Volumes in Iraq

The population of Iraq has increased in general, and Karbala, in particular, has a direct and linear relationship with the number of vehicles entering service, which has significantly increased in recent years.

Where the number of vehicles has increased dramatically, there is a direct and linear relationship with the congestion that has become increasingly evident in Karbala in recent years. The Ministry of Planning-the Central Bureau of Statistics has published the main indicators of the number of private sector cars, and all types of plates (permanent, Mnafist, new plates) registered at the Directorate of Traffic for the years 2016–2020. It is noted the increase in leaps in numbers was from a few years ago (Iraq 2020).

Figure1-1 shows that the growth rate in the number of cars in Iraq has reached 15% during the past five years, bringing the total number of cars to 7 million, with one car for every six people.

The density of cars in the paved streets was 154 cars per km, knowing that the average rate to avoid traffic jams should be less than 100 cars per km paved.

With the continuation of this rate of growth in the number of cars, it is expected that the number of cars in 2036 will reach more than 12 million, and the density of cars on paved streets will reach 203 cars per km paved. (Iraq 2020).

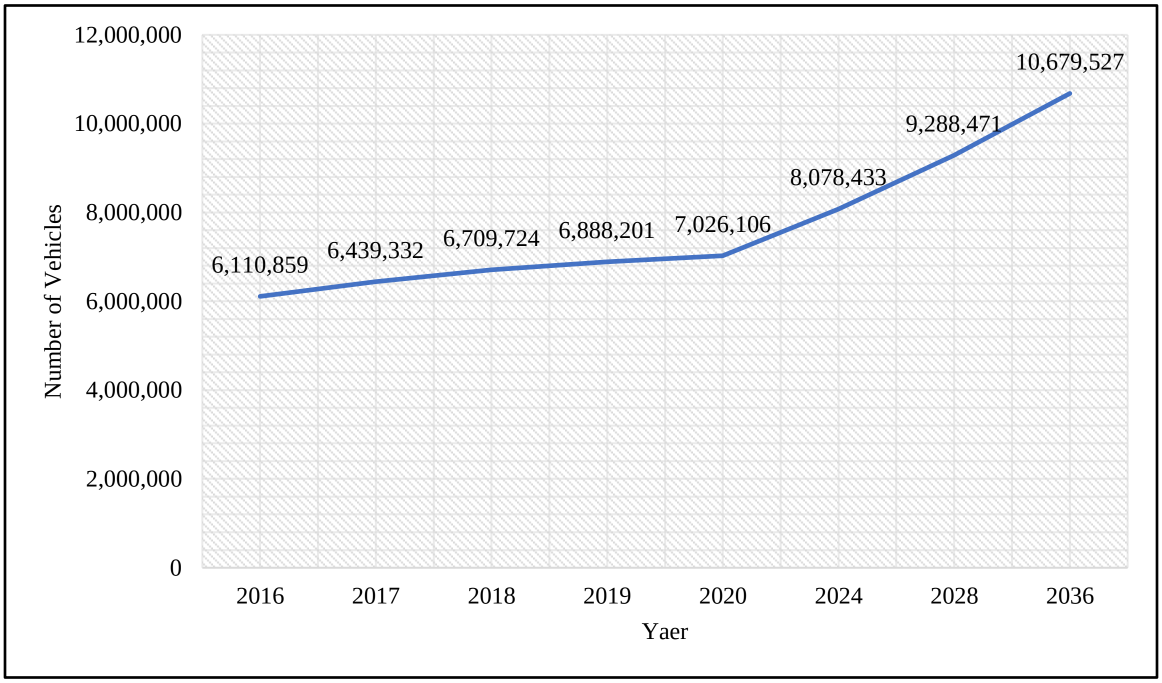


Figure 1-1 Increase in Number of Vehicles From 2016 - 2036

Figure 1-2 shows the first thing that helps more people buy cars is when the economy grows, when more people own cars, fewer people use public transportation, and when fewer people are using public transportation, operators may respond by raising prices, cutting service, or both. These steps make driving a car even more appealing than before, making more people want to buy cars and speed up the cycle (Rodrigues 2014).

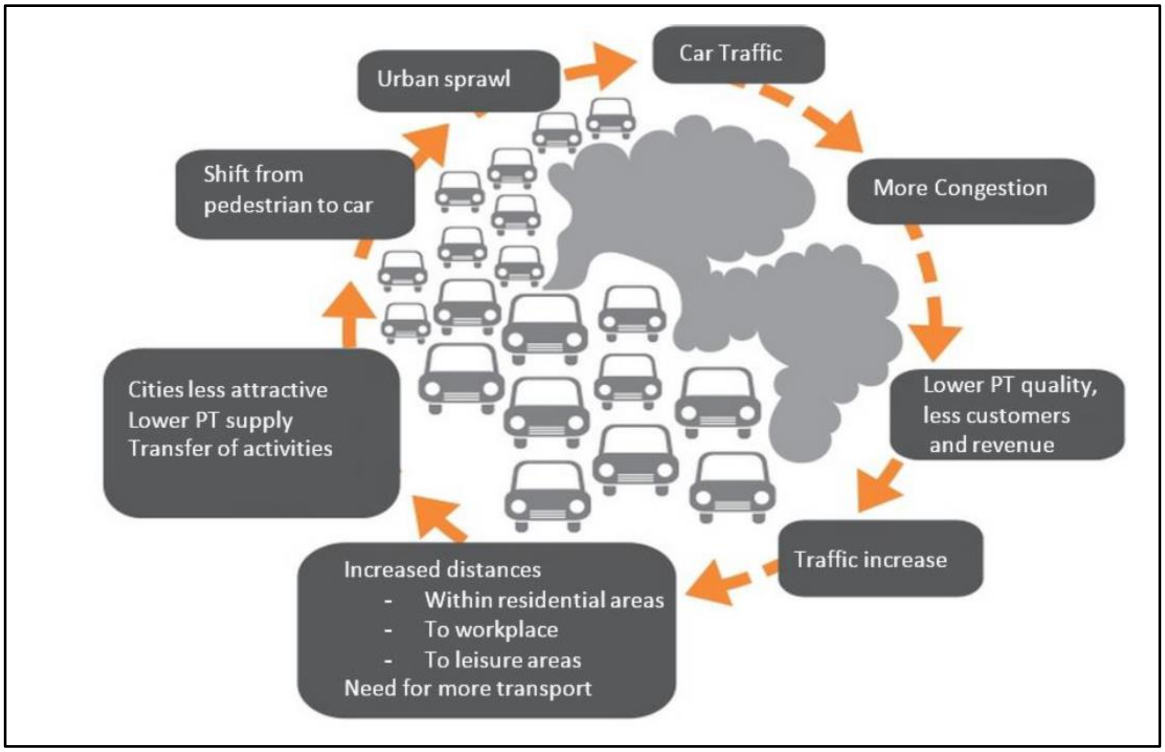


Figure 1-2 Vicious Circle of Urban Decline (Rodrigues 2014).

1.3 Simulation Concept

The simulation aims at the existence of an alternative available to study the various traffic and transportation problems by designing a model close to reality through which the problems and obstacles facing movement can be studied, such as congestion, delay, level of service, and performance of the traffic network. Traffic simulation programs have become an essential and indispensable part of analyzing and evaluating traffic movement in all its details. Furthermore, follows are the essential features that simulation programs provide.

- Get rid of old and traditional methods that drain effort, money, and time.
- Forecast the future traffic movements of a particular network based on the current traffic and population growth rate(Saleh 2021)

- Simulate projects planned to be implemented in the future and evaluate their expected performance.
- Ability to simulate traffic with all its complexities and interlocking interaction of different vehicles with each other (Abed and Ewadh 2021)

1.4 Problem Statement

When navigating Karbala roundabouts, it will be observed that there is a lot of traffic congestion, especially at peak times, which sometimes requires the intervention of the traffic police to manage congestion and try to reduce it. This point shows that the roundabout is not doing what it is supposed to do (moving cars through the roundabout smoothly and without stopping) at many times of the day, especially at peak times.

The study of traffic in developing countries, particularly those with diverse and heterogeneous traffic conditions, has been insufficient, creating a significant research gap. Most of the researchers studied the traffic movement in its standard homogeneous form. Therefore, there is a strong rationale for addressing this gap and conducting comprehensive research in this area.

1.5 Scope of Study

- A comparison of the functional performance of the roundabouts, signalized roundabouts, and signalized intersections studies according to the Karbala governorate's traffic volumes.
- Determining the specific value of the arrival rate, after which it is preferable to use the signalized roundabouts during peak times
- Determining the specific value of the arrival rate, after which it is preferable to use the signalized intersections during peak times
- Studying the quality of converting the roundabout into signalized intersection according to the growth rate in traffic volumes

- Giving a clear decision on the quality of changing the studied roundabout intersections into signalized intersections
- Explaining the possibility of the Vissim program to display and simulate traffic congestion at roundabouts and traffic signalized intersections in developing countries where the behavior of traffic is heterogeneous.
- Studying the impact of changes on environmental and economic parameter

1.6 Limitation of Study

- All roundabouts were studied in the October, and it is considered a working month, which is appropriate for study
- The process of identifying the circles was done with the help of specialists in the Karbala Police Directorate to identify the roundabouts that suffer from severe congestion
- Some incidents intersected in the process of calculating the traffic volumes, as there was a religious event in the Education Roundabout with normal traffic volumes in the remaining roundabouts as a result of the normal traffic volumes during the working hours.
- The specific days of the study were determined to cover the representation of all cases of the week between holidays and working hours
- The program has been calibrated to simulate traffic in countries with heterogeneous traffic
- Heavy vehicle traffic and pedestrian traffic were neglected

1.7 Thesis Structure

The thesis contains five chapters:

Chapter One:

The first chapter summarises how traffic is getting worse in Iraq and how that is related to the number of cars on the road going up. It also explains the general concept of simulation, its essential features, and what this concept provides to the users of simulation programs.

Chapter Two :

Chapter two is a research literature review and a general description of the different types of roundabouts and signal intersections and their pros and cons. It also gives a general description of Planung Transport Verkehr PTV Vissim,

Chapter Three :

The third chapter explains the Vissim program's details, how it works, and how to collect traffic volumes. A detailed clarification of the study areas and how to calibrate the program to approximate reality as much as possible.

Chapter Fourth :

The fourth chapter analyses all the data produced from the simulation of reality in the PTV Vissim program within the simulation models.

Implement analysis of the traffic behavior at the roundabout after changing it to the signalized roundabout and signalized intersections, and compare the outputs with reality to come up with the results closest to the reality.

Chapter Five :

The fifth chapter contains the research's most critical conclusion and recommendations to decision-makers to reduce congestion at roundabouts and signalized intersections.

It clarifies the essential points that researchers should start with in future studies to treat those not included in this study.

Chapter Two:

Literature Review

Chapter Two

Literature Review

2.1 Introduction

In the world, transportation networks face many obstacles that reduce the quality of movement from one place to another, and the critical problems they face are the high traffic volumes, which may reach hours in some areas. These obstacles are faced by many methods to reduce their effects on the transportation process, such as determining the numbers of cars (odd-even) for specific days per week, or converting some roundabouts to signalized intersections according to the determinants and circumstances of the place.

With the progress of time and the development of computer software, many simulation programs were introduced, which began to facilitate the process of predicting the forms of traffic according to the data supplied by the user. One of the most famous programs that provide many features and characteristics for the user is the PTV Vissim 2022 program, which was developed for the first time in 1992, and many copies rolled until the year 2022.

this section reviews previous research and studies related to traffic operations in roundabouts and signalized intersections. It examines the findings and conclusions of previous studies, discussing their relevance to the current research.

2.2 Roundabout

Roundabouts are generally defined as a circular intersection in which the speed is limited and cannot be exceeded. Likewise, the vehicle does not stop moving, but its speed decreases significantly, according to the determinants designated for this type of intersection

The vehicles revolve around a median island, they head as they rotate towards the a specific exits at the intersection, and the roundabouts are designed in general, through several steps composed of the following steps:

- The roundabout is identified as the best traffic solution.
- The determination of the number of lanes at an intersection following the required capacity and level of service
- Prepare the initial designs of the roundabout.
- The design process will include considerations such as vehicle swept path design, fastest path analysis, and visibility performance checks.
- If the results of the performance checks are consistent with the design recommendations, a detailed roundabout design can be developed. Since the initial roundabout geometry design elements are not independent, it is necessary to ensure they are compatible (Ahac and Dragčević 2021).

2.2.1 Advantages of Roundabout

Compared to other types of intersections, roundabouts frequently provide more excellent safety and operational advantages. A brief discussion of these advantages is provided in this section (Rodegerdts, Blogg et al. 2007).

2.2.1.1 Safety

When the National Cooperative Highway Research Program (NCHRP) Report 572: Roundabouts in the United States was published in 2007, it corroborated prior results showing intersections converted to roundabouts had lower collision rates. This report found that roundabouts have reduced crash rates in particular, injury crash rates in a wide range of area (urban, suburban, and rural) when compared to previous forms of traffic control, except all-way stop control, where no statistically significant difference was found (Rodegerdts, Blogg et al. 2007).

Roundabouts tend to become more tempting as an option when the safety benefits of using them are considered. Additionally, roundabouts have proven to be a considerably more cost-effective option than signalized intersections in certain situations when bridge widening or another road widening would have been required under a signalized alternative.

2.2.1.2 Operations

Generally, a roundabout experiences less delay than a signalized intersection with comparable traffic volumes. At signal warrant volume thresholds specified in the Manual of Uniform Traffic Control Devices (MUTCD), a vehicle travelling through roundabout experiences approximately 12 seconds less delay than a vehicle travelling through a traffic signal with comparable turning volumes. Additionally, drivers in the United States appear to use roundabouts less efficiently than drivers in other countries, suggesting that operations will continue to improve as drivers become more familiar with roundabouts(Rodegerdts, Blogg et al. 2007).

Roundabouts tend to become more tempting as an option when the safety benefits of using them are considered. Additionally, roundabouts have proven to be a considerably more cost-effective option than signalized intersections in certain situations when bridge widening or another road widening would have been required under a signalized alternative(Pochowski and Myers 2010).

2.2.2 Disadvantage of Roundabout

2.2.2.1 Suitability

Roundabouts, like other forms of intersections, are inappropriate in several situations. Therefore, roundabouts should be used with extreme caution in the following types of sites :

- The Roundabout located near signalized intersection, where the congestion at the traffic light will move to the roundabout, causing congestion at the ring intersection as well.
- Roundabout within a high-quality arterial system will cause a general delay in the system
- Roundabout with high traffic volumes on the main street versus little traffic volumes on the secondary street
- Highly complex intersections, both geometrically and physically
- Roundabout with unsuitable geographical terrain due to their complexity, such as a severe slope, may cause a decrease in visibility, which leads to problems in its construction.
- Roundabout with high numbers of motorcycles and bicycles.
- Roundabout with a high population density, where the pedestrian density is high(Rodegerdts, Blogg et al. 2007).

2.2.2.2 Cost

The cost considerations play a role in slowing the expansion of roundabout development. Roundabouts are generally more expensive than alternatives such as signalized intersections (Pochowski and Myers 2010). As a result, it might not be easy to persuade public agencies to build roundabouts when another solution is equally capable of performing its function. Rather than solely comparing the construction costs of roundabouts with other alternatives, many municipality directorates now conduct life-cycle cost studies. These studies analyze the costs associated with roundabouts and other alternatives throughout their entire lifespan. (Pochowski and Myers 2010). Figure 2-1 shows the main parts of a typical four-approach roundabout from the center island and the radius included in the roundabout.

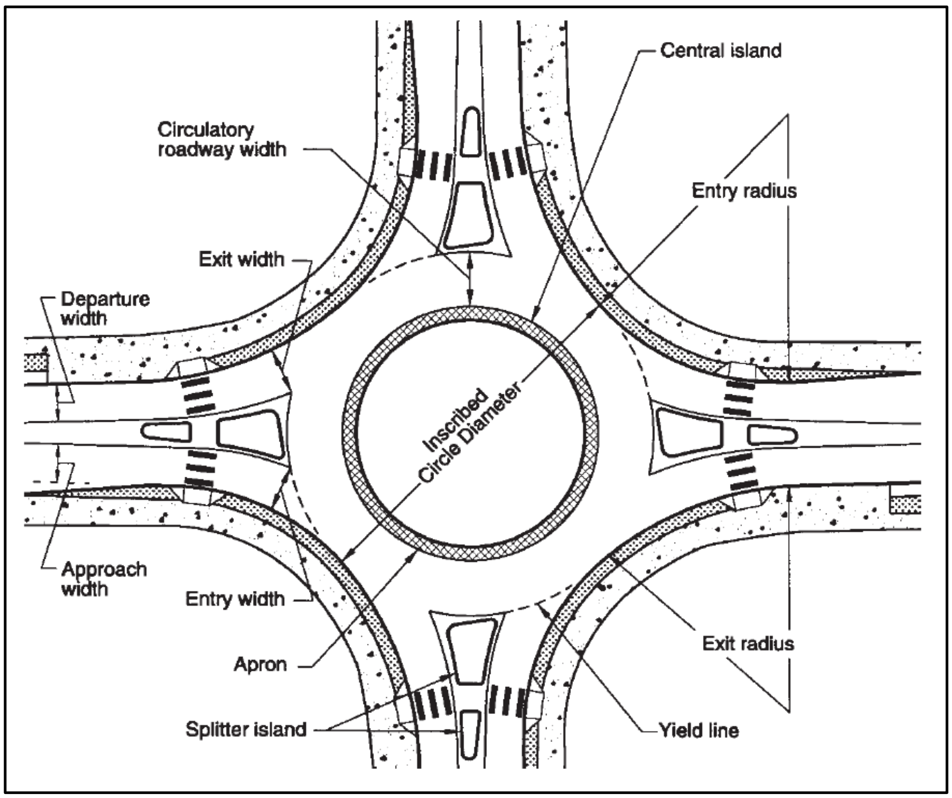


Figure 2-1 Roundabout Terminology (Ahac and Dragčević 2021)

2.3 Type of Roundabout

There are several types of roundabouts based on their design and features. The main types of roundabouts include:

- Single-Lane Roundabout: This is the most common type of roundabout, featuring a single circulating lane around a central island. It typically has one entry lane and one exit lane for each approach. Single-lane roundabouts are suitable for low to moderate traffic volumes and are often used in residential areas or smaller intersections.

- Multi-Lane Roundabout: Multi-lane roundabouts have multiple circulating lanes and additional entry and exit lanes. They can accommodate higher traffic volumes compared to single-lane roundabouts. Multi-lane roundabouts utilize lane markings and signage to guide drivers in choosing the correct lane based on their desired exit. They provide increased capacity and smoother traffic flow(Ahac and Dragčević 2021).
- Turbo-Roundabout: Turbo-roundabouts are a type of multi-lane roundabout that feature additional geometric elements to manage complex traffic patterns and high volumes of vehicles. They may have extra circulating lanes and entry/exit lanes located outside the central island. Turbo-roundabouts help reduce conflicts and improve traffic flow, particularly in busy intersections.
- Dogbone Roundabout: Dogbone roundabouts, also known as peanut roundabouts, have a unique shape resembling a double teardrop or a peanut. They consist of two roundabouts interconnected by a narrower section. Dogbone roundabouts allow for efficient traffic movement and are particularly useful for managing traffic at major intersections or high-demand areas.
- Mini-Roundabout: Mini-roundabouts are smaller in diameter compared to traditional roundabouts. They are typically found in urban areas with limited space. Mini-roundabouts provide a compact solution for managing traffic while maintaining lower speeds. They are effective in residential neighborhoods and areas with lower traffic volumes(Ahac and Dragčević 2021).

2.4 Warrants of Insulation Traffic Signals

The MUTCD handbook provides nine traffic signal warrants that cover a wide range of intersection conditions. The significant criterion influencing the installation of signal devices is traffic volume, specified in the MUTCD from its initial version in 1935. Student requirements are limited to school crossing zones, whereas pedestrian requirements describe the sorts of pedestrian crossing facilities that should be supplied under specific traffic and site conditions. Crossings between highways and railroads are similarly hazardous to vehicle traffic, and traffic lights at grade crossings reduce collisions. However, these primarily provide a first decision, traffic signal restrictions should not be installed if none of the criteria is fulfilled(Imran and Ewadh 2020).

2.5 Signalized Roundabout

Signalized roundabouts are quite similar to regular roundabouts with the addition of traffic lights to control the approach. In most cases, the roundabouts without traffic lights or traffic lights are separated, to combine the two common systems, it was not easy to obtain previous studies to know the expected performance of the system resulting from them, as did Yadeta (Chimdessa, Kassa et al. 2013). Yadeta found in his study that the use of traffic signals with roundabouts may work very well in medium traffic volumes before reaching high traffic volumes. Therefore, he advised using the combined system between controlling traffic lights and circuits in places where the traffic volume is medium or close to high to solve the problems generated in the roundabouts before converting them into signalized intersections.

2.6 Signalized Intersection

An intersection is an area where two or more streets join or cross at-grade. All modes of transportation are accommodated at intersection, including pedestrians, bicyclists, motorists, and public transportation. Thus, the intersection includes the pavement area, the adjacent sidewalks, and pedestrian curb-cut ramps. The term "intersection" refers to any alterations (for example, turning lanes) to the otherwise typical cross sections of the intersecting streets at location. Intersections play a critical role in street design for several reasons:

- Tourist attractions and shopping destinations are often located near intersections where there is a lot of activity..
- Intersections are areas where different types of traffic movements converge, which can lead to conflicts between them. For example, pedestrians may cross the street while vehicles are turning or crossing, creating a complex and potentially hazardous traffic environment.
- Transportation management at intersections and traffic control devices such as yield signs, stop signs, and traffic signals are used to direct the movement of people. Traffic control result in a delay to users traveling along the intersecting roadways, but helps to organize traffic and decrease the potential conflict.

- Traffic control at intersections frequently restricts the capacity of intersecting highways, defined as the number of users who may be accommodated in a particular period on a specific road segment (Rodegerdts, Nevers et al. 2004). Figure2-2 shows the main parts of a typical four-approach signalized Intersection of the major and minor streets, road markings, corner radius, and crossing places

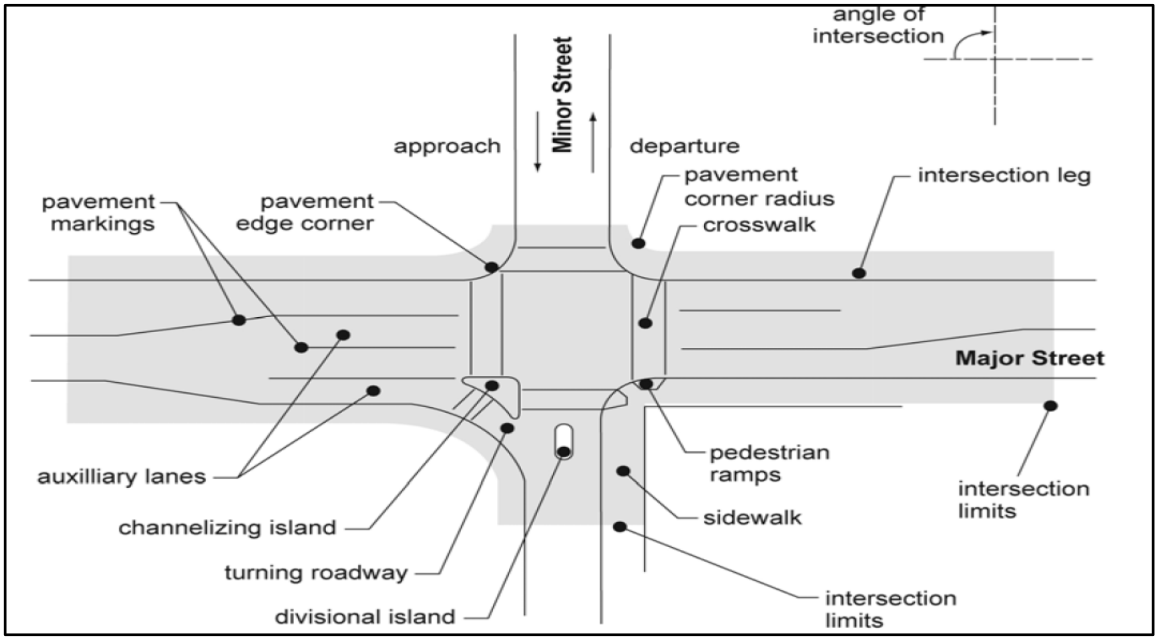


Figure 2-2 Intersection Terminology (Rodegerdts, Nevers et al. 2004)

2.6.1 Traffic Signal

In the transportation industry, traffic signals are electrically driven traffic control devices that give road users the signal to proceed with their journeys by assigning right-of-way to each approach and movement on a route. Traffic signals are a typical method of traffic control that is utilized to handle concerns related to roadway operations and safety on public roadways. Because they separate conflicting movements in time and allocate delay, it enable the shared use of road space. They can also improve the mobility and safety of particular movements by separating them in time and allocating delay(Rodegerdts, Nevers et al. 2004).

2.6.1.1 Advantages and Disadvantages of Traffic Control Signals

Traffic control signals are valuable devices for vehicular and pedestrian traffic control when properly used. It assign the right-of-way to various traffic movements, thereby profoundly influencing traffic flow(Ni 2020).

2.6.1.2 Advantages of Traffic Control Signals:

- Provides orderly movement of traffic.
- Increases intersection capacity with proper physical layouts and control measures.
- Operational parameters are regularly reviewed and updated to meet current traffic demands.
- Reduces frequency and severity of right-angle collisions.
- Enables continuous or nearly continuous traffic movement at a definite speed along a given route under favorable conditions.
- Used to interrupt heavy traffic at intervals to allow for crossing by other vehicular or pedestrian traffic(Ni 2020).

2.6.1.3 Disadvantages of Traffic control signals

- Traffic control signals can cause excessive delays As a result of the delay in the light signal.
- Road users may choose less-than-ideal routes to avoid signals and disobey signal indications.
- The use of traffic signals has resulted in a significant increase in the number of rear-end collisions(Ni 2020).

2.7 Conflict Point

In traffic engineering, a conflict point refers to a location within an intersection where the paths of different vehicles or pedestrians intersect, potentially leading to conflicts or collisions. Conflict points are identified and analyzed to understand the safety and operational aspects of an intersection. They can be categorized based on the type of conflicts that may occur, such as vehicle-vehicle conflicts, vehicle-pedestrian conflicts, or vehicle-bicycle conflicts. Identifying and managing conflict points is crucial for designing safe and efficient intersections. The main difference in conflict Points between a Roundabout and a Signalized Intersection explained as follows:

Roundabout: In a roundabout, conflict points are reduced compared to a signalized intersection. This is because vehicles in a roundabout are constantly moving in a counterclockwise direction, and conflicts are primarily limited to merging points where vehicles enter or exit the roundabout. The number of potential conflict points is minimized due to the absence of conflicting signal phases or opposing traffic movements. Roundabouts generally have fewer conflict points, resulting in improved safety compared to signalized intersections.

Signalized Intersection: A signalized intersection has multiple conflict points due to the presence of signal phases that control the movement of vehicles. Conflict points occur at locations where different traffic streams cross each other, such as during green signal phases for one direction and red signal phases for another. For example, conflicts can arise between vehicles traveling straight and vehicles making left or right turns, or between vehicles and pedestrians at crosswalks. Signalized intersections typically have more conflict points than roundabouts, which can increase the potential for collisions.

The key difference between the conflict points in a roundabout and a signalized intersection lies in the nature of traffic movement. Roundabouts promote continuous traffic flow with yielding and merging, resulting in fewer conflicts. In contrast, signalized intersections have controlled traffic movements with conflicting phases, leading to a higher number of conflict points.

It's important to note that the specific number and location of conflict points can vary depending on the design, layout, and size of the roundabout or signalized intersection. Proper intersection design and management practices aim to minimize conflict points and optimize safety for all road users (Rodegerdts, Nevers et al. 2004).

2.7.1.1 Components of a Signal Cycle

The terms below describe the major and minor parts of the signal cycle(Roess, McShane et al. 1998). The most fundamental unit in signal design and timing is the cycle, as defined here.

- Cycle: A signal cycle is one complete cycle containing all the traffic lights that are displayed at the intersection.
- Cycle length: The duration of one complete cycle of indicators is the cycle length, measured in seconds.
- Interval time :The interval is a time when there are no changes to the signal indication. It is the shortest time interval that may be specified in a signal cycle. Throughout a signal cycle, there are many interval types:

Change interval: The "yellow" indicates the changing period " It is a component of the change from "green" to "red," In signalized intersections, movements that are expected to lose their "green" signal are assigned a "yellow" signal, while all other movements receive a "red" signal.

The timing enables a car that can't safely stop when the "green" is removed to safely cross the junction.

Clearance interval: A given set of movements' transition from "green" to "red" also includes the clearing interval. The "red" indication is present for all moves throughout the clearing interval. It is timed to let a car approaching the crossing legally on the "yellow" " cross the intersection before the unsafe release of opposing flows.

Green interval: Throughout the signal cycle, there is one green" period for each movement. The motions that are allowed have a "green" light during a green interval, whereas all prohibited movements have a "red" light.

Red interval: during the signal cycle, each motion has a red interval. Any actions that are not permissible have a "red" light, while those that are approved have a "green" light. For all other motions in the junction, the red interval overlaps the green, yellow, and all red intervals.

- phase: It is a series of periods that allow a specific movement or group of motions to flow and safely stop before the release of a competing set of movements. A signal phase consists of a green interval followed by change and clearing intervals (Roess, McShane et al. 1998).

2.8 Traffic Simulation Models

Traffic simulation models are frequently categorized according to the level of modeling detail. The classifications of macroscopic, microscopic, and mesoscopic models are widely employed.

2.8.1 Traffic Microsimulation Concept

Over the last few years, traffic microsimulation packages have become necessary as a modeling tool for a wide range of transportation planning, design, and operations applications. According to Algers et al. (1997), a study conducted in 1997 identified more than fifty different commercially available traffic microsimulation packages, and there is no doubt that this number has increased significantly since then. As a result, traffic microsimulation models in various transportation applications are becoming increasingly common; therefore, transportation professionals must understand the concepts underlying these models and the statistical methods that can be used to analyze their output.

In traffic microsimulation models, the interaction between the physical system (e.g., the supply: roads, intersections, traffic control) and the users are attempted to be modeled (e.g., the demand: routes, driver characteristics). As the name implies, these models are called micro since they function on a per-unit basis (e.g., vehicles, people). Furthermore, because they attempt to mimic the system's internal processes (e.g., drivers' behavior , car characteristics, traffic signal operations), rather than simply the system's output, they are referred to as simulations. Finally, they are often used because the systems they depict are so complex that more classic macroscopic models are insufficient to represent them accurately (Spiegelman, Park et al. 2016).

2.8.2 Macroscopic Simulation Concept

Model Traffic flow is simulated by macroscopic models, which consider traffic flow, speed, and density and their relationships to each other. They can be used to determine the size and order of traffic jams caused by traffic demand or accidents in a network, but they can't be used to model how vehicles interact in different design configurations. The Macroscopic simulation takes place section by section rather than following individual vehicles. Instead, macroscopic models use equations to show how flow is conserved and how traffic problems send shockwaves through the system. At first, these models were made to simulate traffic on different kinds of transportation sub-networks, like corridors with freeways and parallel arterials, surface-street grid networks, and rural highways(Rodrigues 2014).

2.8.3 Mesoscopic Simulation Concept

Mesoscopic models are the third type of traffic simulation model. The level of detail in these models is between how little detail there is in macro models and how much detail there is in microscopic models. One way to model is to use relationships between speed and flow, like in a macroscopic model, to show how individual vehicles move, like in a microscopic model. Mesoscopic modeling techniques can simulate networks that are bigger than what can be done with microscopic models and are more accurate than what can be done with macroscopic models. Dynamic traffic assignment is an example of an application where this property is essential. Traffic simulation models like contram(Taylor 2003), dynameq(Florian, Mahut et al. 2006), and mezzo are all examples of mesoscopic models(Burghout 2004).

In the work shown in this thesis, microscopic traffic simulation models were made and studied. From now on, traffic simulation will be used as a short-form traffic micro-simulation(Tapani 2008).

2.9 Macroscopic, Mesoscopic, and Microsimulations Different

The main difference between microscopic, mesoscopic, and macroscopic are three levels of analysis used to model traffic flow. Microscopic models analyze the individual behavior of vehicles and drivers, while mesoscopic models analyze traffic flow at an intermediate level of detail. Macroscopic models analyze traffic flow at a high level of abstraction and are used for simulating traffic phenomena that occur over large spatial and temporal scales. Each level of analysis is useful for simulating different aspects of traffic flow and can be applied to transportation planning and policy analysis(Rodrigues 2014).

2.10 Classification Modeling Simulation

According to a study conducted by Brackstone and McDonald (Brackstone and McDonald 1999), car following models can be divided into five categories:

- Gazis–Herman–Rothery (GHR) Model
- Collision-Avoidance Model
- Linear Model,
- Psychophysical or Action-Point Model (AP)
- Fuzzy Logic-Based Model.

Hussein Dia and Sakda Panwai (Panwai and Dia 2005) use a variety of traffic simulators to investigate and evaluate car-following behavior (advanced interactive microscopic simulator for urban and nonurban networks)

(AIMSUN), parallel microscopic simulation (PARAMICS), and Verkehr in Stadten—simulation (VISSIM)]. The results showed that the Gipps-based models implemented in AIMSUN had lower error values, while the psychophysical spacing models used in PTV VISSIM and PARAMICS had similar error values. As a result, the PTV Vissim was the best option for studying within the available programs.

2.11 Vissim Program Software

The main program adopted in this study is PTV Vissim 2022, an accurate simulation program that briefly explains as follows.

2.11.1 Theoretical Background of PTV VISSIM Software

According to the PTV Group (2022), PTV VISSIM software is the industry-standard microscopic traffic and transportation planning tool based on modeling and simulation techniques. According to the PTV Group (2022), this software can be used in the following areas:

- Traffic Flow Simulation – It is possible to use traffic flow simulation software to assist in the decision-making process for developing an environmentally friendly transport network (Muchlisin and Widodo 2019)
- Advanced Traffic Management Systems – The use of software may assist in minimizing the negative effects of the transportation system (Xing, Lu et al. 2014)
- Multimodal Systems – The use of software facilitates the analysis of various types of transportation, including pedestrians.(Wu, Radwan et al. 2018)
- Autonomous Vehicles and New Mobility – Software supports the modeling and simulation of the effects of autonomous driving (Songchitruksa, Sunkari et al. 2017)

- Virtual Reality Traffic Simulation – The software assists in creating microscopic traffic simulations. The development of the number of VISSIM software-related papers published in the Web of Science and Scopus databases between 1994 and 2019 is depicted in figure 2-3. After entering the keyword "VISSIM" in the field "subject" of the Web of Science (2020) database, articles were searched for in the field "topic" (1195 articles were found in total). After entering the keyword "VISSIM" in all fields of the Scopus (2020) database, articles were searched for in all fields of the database (4123 articles were found in total) (Kučera and Chocholáč 2021) .

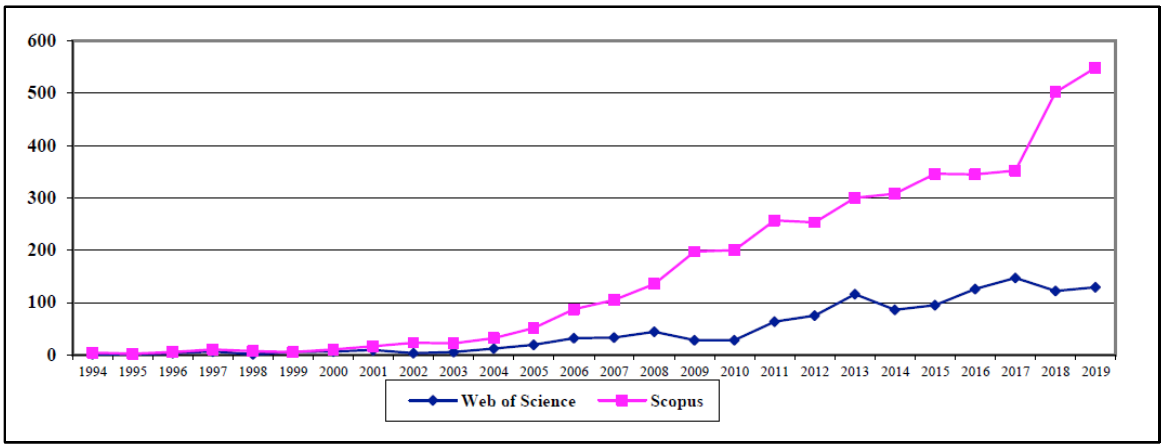


Figure 2-3 Number of VISSIM Software-Related Papers Published in The Web of Science and Scopus Databases Between 1994 and 2019

2.11.2 Vissim Model

VISSIM's car-follow model is based on psychophysical models described in (Wiedemann 1974)and (Wiedemann 1991). These models work on the notion that a driver can be in one of four states as follows: -

- Free-driving mode, in which no influence is imposed by the vehicles in front. The driver attempts to reach and maintain the desired speed in this mode.
- The approaching mode when the driver of the following car consciously recognizes that is approaching a slower vehicle in front .
- Following mode, in which the headway for a pair of vehicles is between the following maximum headway and the safe following headway Figure 2-4. While operating in this mode, the following vehicle can accelerate or decelerate in response to the car in front of it.
- Braking mode is when the distance between two cars falls below a predetermined safety distance.

To simulate longitudinal vehicle movement, the VISSIM traffic model employs a psychophysical automobile following model, while lateral vehicle movement is handled by a rule-based algorithm (lane changing). The behavior of car-following changes from one mode to another in response to specified perceptual limited levels, which serve as the basis for the psychophysical models of the activity. It has been determined that these limitations are a mix of speed and headway differences (Wiedemann 1974), (Wiedemann 1991). In VISSIM, each driver–vehicle unit is referred to as a driver–vehicle element to distinguish it from another driver–vehicle Element (DVE). which illustration demonstrates the interaction between two vehicles in which DVEj travels faster than and approaches a slower vehicle DVEi as shown in Figure 2-4. First, driver j begins to decelerate until he reaches a personal limit, a function of the permissible speed difference and space between cars in front of him. When other limits are achieved, the driver accelerates again (Fellendorf 1994). The driver then maintains a speed equal to or lower than the current speed of DVEi until other thresholds are hit again.

One of the difficulties in developing a simulation model is calculating the psychological variables of traffic movement. To calibrate the model realistically, it is necessary to take continuous measurements of various traffic circumstances. Therefore, the thresholds depicted in Figure 2-4 are defined further. (Fellendorf 1998). It is possible to model driver-specific perceptive abilities and individual risk behavior by assigning random values to each model's parameters.

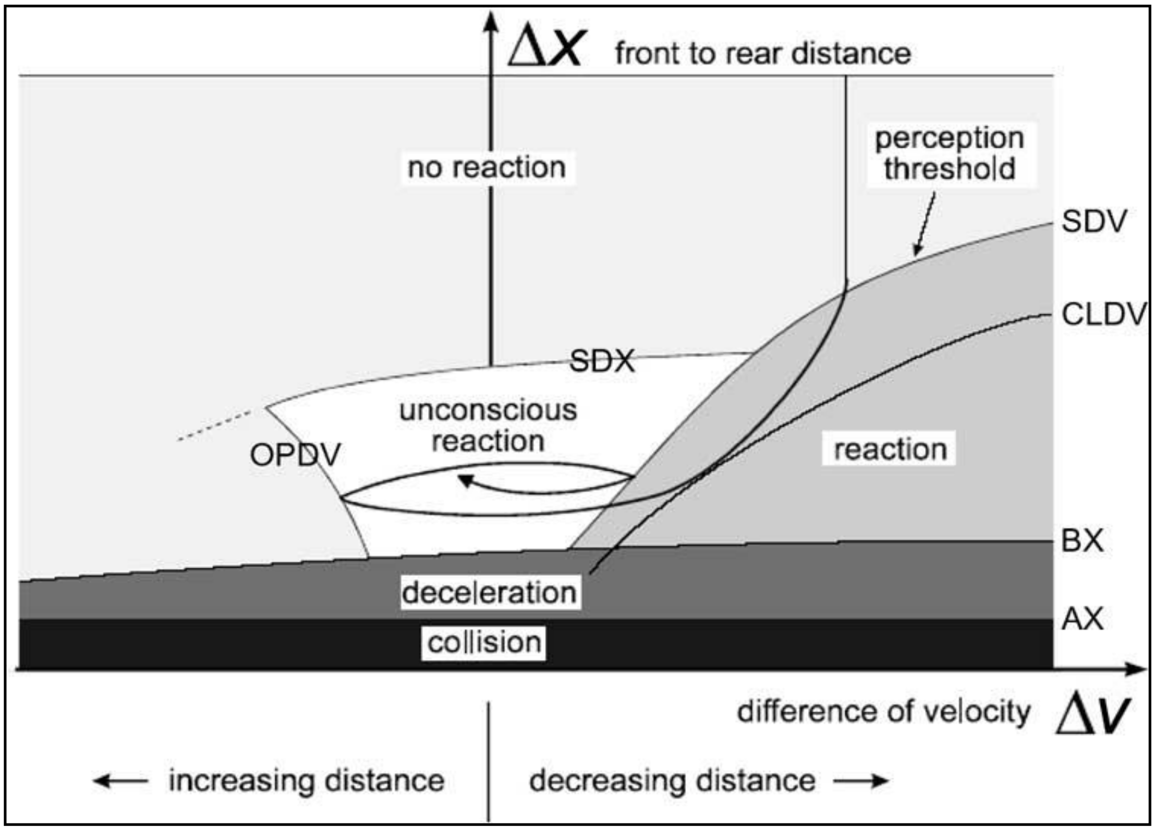


Figure 2-4 Car-Following Model By Wiedemann(GROUP 2022).

AX Desired separation between the front ends of the two following vehicles in a vertical line of cars.

BX Minimum deceleration between two vehicle

ABX Minimum desired following distance as a function of AX, safety distance, and speed.

SDV When a driver notices a slower car coming, they take action. With rising speed differences, SDV rises. In Wiedemann's original study (Wiedemann 1974), an extra limit is used to simulate deceleration caused by brakes.

OPDV When drivers of following cars realize they are moving slower than the leading vehicles, they must accelerate again.

SDX The greatest following distance is around 1.5–2.5 times ABX, and the perception limit is used to simulate it.

When the gap between the two cars hits 150 meters, a driver reacts to the leading vehicle. The minimal rate of acceleration and deceleration is 0.2 m/s2. The technical characteristics of the vehicle determine the maximum acceleration rates. The model also provides a rule for exceeding the maximum deceleration rate in an emergency. (Panwai and Dia 2005).

2.12 Delay Concept

The term "total delay" refers to the total amount of time that is lost by a vehicle or group of vehicles while traveling from their origin to their destination. It is a measure of the inefficiencies and disruptions experienced by drivers on the road network, which can be caused by various factors such as traffic congestion, traffic control devices, accidents, road works, and weather conditions. To calculate the total delay for a specific period, such as rush hour or a day, the actual travel time and the base travel time for each vehicle on a given route or network are measured. The actual travel time is the time taken by a vehicle to travel from its origin to its destination, including any delays caused by congestion, traffic control devices, or other factors. The base travel time, on the other hand, is the time that it would take a vehicle to travel the same distance without any congestion or traffic control devices. the delay can be calculated using Equation 2-1.

$d_{ia}=t_{ia}-t_a^f$ *(Spiegelman, Park et al. 2016)* $i=1,.....N$ $a=1,....N$ ....*Equation 2-1*

where:

d_{ia} Delay of Vehicle i

t^{fa} Base Travel Time (it is recommended that a free-flow travel time be used to analyze the interchange or roundabout.)

t_{ia} Actual Travel Time.

2.12.1 Delay at Roundabout

The roundabouts' delays might be specified separately for each entering approach. Any entry approach's delay value is made up of two independent parts:

- Queue Delay
- Geometric Delay.

Vehicles slowing down as they cross roundabouts causes a geometric delay. In addition, when drivers wait for a suitable opening in the moving traffic, delays occur (Hummody 2007).

The HCM 2000 defines control delay as the number of times drivers spends slowing down to join a line, standing in line, waiting for a sufficient opening in the line to pass, and then accelerating away from the line (D.C 2005).

There are many different delays, but the control delay is when the driver waits at the front of the line for an appropriate opening in the traffic flow. Exponentially increasing control delays based on traffic levels as they approach capacity

According to approach and exit cruise speeds, control delay can be thought of as the total amount of time lost during a trip through an Intersection (including all acceleration and deceleration delays, delays due to cruising at a lower speed, and stopped delay). In addition, when there are no other vehicles present, a vehicle navigating an intersection will face a geometric delay (Akçelik 2009).

2.12.2 Delay at Signalized Intersection

Control delay is used to measure the level of service at signalized intersections. It is because delay shows how much time drivers lose and how frustrated and uncomfortable they are. The level of service at a signalized intersection is based on the control or signal delay, which is part of the total delay that the control facility causes. It includes the time it took to slow down at the start, move up in the queue, speed up at the end, and stop.

Even though the (v/c) ratio is as high as 0.9, getting good service with short cycle lengths is still possible. It is because when the effect of signal coordination changes, it can get different levels of service for the same (v/c) ratio. It is because signal coordination cuts down on delay(Garber and Hoel 2019).

The Highway Capacity Manual (HCM) of 2010 suggested this method for figuring out control delay. It is based on counting the number of cars in line at an intersection. As shown in Equation 2-2, the average control delay is equal to the delay that all vehicles that arrive during the evaluation duration

$$d = d1 + d2 + d3$$ *(Garber and Hoel 2019)……………………………Equation 2-2*

where

d Delay (s/veh),
d1 Uniform Delay (s/veh)
d2 Incremental Delay (s/veh)
d3 Initial Queue Delay (s/veh)

2.13 Level of Service

Levels of Service (LOS) is a qualitative measure used to describe the operational performance of transportation facilities such as roads, highways, and public transit systems. The LOS is generally defined using a set of letter grades, from A to F, which correspond to different levels of travel time, speed, reliability, and comfort experienced by users(Roess, Prassas et al. 2004).

For highways and roads, LOS is typically determined based on the average speed of traffic, the volume of traffic, and the density of vehicles on the road. For example, LOS A represents a very high-quality level of service, with high speeds and little delay, while LOS F represents a very low-quality level of service, with slow speeds and long delays.

In public transit systems, LOS is typically determined based on factors such as the frequency of service, the average travel time, and the availability of seats and standing room. For example, LOS A represents a very high-quality level of service, with frequent service, short waiting times, and plenty of seating, while LOS F represents a very low-quality level of service, with infrequent service, long waiting times, and crowded conditions.

LOS is an important tool for transportation planners and policymakers to evaluate the performance of transportation systems and to identify areas for improvement. It can also be used to set performance targets and monitor progress toward achieving those targets over time(Roess, Prassas et al. 2004).

2.13.1 Level of Service of Roundabouts

The level of service (LOS) of a roundabout is a measure of its operational performance, which is determined based on several factors such as the traffic volume, circulating and entering speeds, and delays experienced by drivers. (Taylor J.L. 2012).

Table 2-1 outlines the level of service LOS requirements for vehicles operating in roundabouts. If the volume-to-capacity ratio of a lane is greater than 1.0, regardless of the control delay, LOS F will be assigned to that lane. Control delay is the main factor considered while determining LOS at the approach and Intersection levels (Washington 2010).

Table 2-1 LOS for Roundabout (Washington 2010).

Control Delay (s/veh)	LOS by Volume to Capacity Ratio v/c≤ 1.0	LOS by Volume to Capacity Ratio v/c> 1.0
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	E
>50	F	F

The level of service is not the same at the roundabout as it is at signalized intersections because of the various conditions and the drivers' perceptions of those factors (Washington)

2.13.2 Level of Service of Signalized Intersection

The LOS of a signalized intersection is a measure of its operational performance, which is determined based on several factors such as the volume of traffic, the cycle time of the signal, and the delay experienced by drivers. The LOS of a signalized intersection is usually represented by a letter grade, ranging from A (best) to F (worst). The grade is determined based on the level of delay experienced by drivers at the intersection during peak traffic periods. Table 2-2 displays the LOS for a signalized Intersection(Washington 2010).

Table 2-2 LOS for Signalized Intersection (Washington 2010).

Control Delay (s/veh)	LOS by Volume to Capacity Ratio v/c≤ 1.0	LOS by Volume to Capacity Ratio v/c> 1.0
<10	A	F
>10-20	B	F
>20-35	C	F
>35-55	D	F
>55-80	E	F
>80	F	F

2.14 Previous Studies of Roundabouts and Traffic Light Intersections

Experts in the field of statistical physics have become interested in traffic congestion. Several approaches can be used to investigate and explain the phenomenon of traffic, including the cellular automaton (CA), the car-following method, and the fluid-dynamical method. In general, the simulation program provides a way to use this different model to analyses the actual case in the best way(Nagel and Schreckenberg 1992, Nagatani, Nakanishi et al. 1998).

In the city, the mobility of cars is constrained by the vehicular traffic at the intersection (for example, due to congestion or the loss of energy), and this constrained motion is mainly dependent on the control mechanisms that include traffic lights, a traffic circle, and a roundabout. The roundabout is a unique intersection that has attracted the interest of researchers among the various kinds of intersections since it assures smooth transportation and has a bigger capacity. Therefore, it has been extensively researched using various models(Fouladvand, Sadjadi et al. 2004, Ke-Zhao, Hui-Li et al. 2010).

Chen and Lee 2011 demonstrate queue duration and delay in multi-lane roundabouts depending on Vissim, Sidra, and Rodel, which were calibrated as field data and found to be dependent on the characteristics of the roundabout. All three software systems grossly underestimated the capacity. Both SIDRA and VISSIM significantly underestimated delay and queue lengths. At most entries, RODEL significantly exaggerated the delay and queue lengths.

Al-Ghandour and Rasdorf 2011 demonstrate the delay in single-lane roundabouts dependent on Vissim that without calibrated (default) and discovered that the average delay and circulating conflict volumes in a roundabout with a slip lane are related exponentially to slip lane volumes up to a saturation point.

Gallelli and Vaiana 2012 explain the delay that would occur in a single lane of the roundabout depending on Vissim's calibration. Based on the published works, Vaiana and Gallelli (Vaiana and Gallelli 2011) discovered. The stop-line delay has a significant relationship with the value of the assumed time gap. The relationship between the stop-line delay and the time gap is even more pronounced when there is a high traffic volume; the approach speed does not appear to have any particular influences on the stop-line delay when there is a consistent traffic volume. The findings of the micro simulator are susceptible to the geometric variables of each scenario

Yadeta et al. 2013 demonstrate the performance of a multilane intersection to determine the optimal design, as traffic congestion is becoming a global concern. A Multi-stream Minimum Acceptable Space (MMAS) Cellular Automata (CA) model is utilized for modelling vehicle traffic at double-lane roundabouts and cross intersections. A comparison is conducted between roundabouts with and without traffic lights and signalized intersections based on their ability to reduce traffic congestion. In addition, Yadeta utilized computer simulations to suggest critical arrival rates to reduce intersectional traffic congestion and segregate the aforementioned modes.

Based on the study's results, the cross intersections with traffic lights perform the best. Therefore, for maximum operational efficiency in areas with a high traffic arrival rate larger than 0.64 v/s/l, roundabouts must be replaced by cross Intersection s. Where typical arrival rates are 0.64 v/s/l, however, it is sufficient to put part-time traffic light signals at the entrance to the roundabout to ensure smooth traffic flow. In contrast, un signalized double-lane roundabouts are no longer advised when recorded arrival rates surpass 0.1 v/s per lane since queues begin to form .

Mohamed, Ci et al. 2020 demonstrate the safety of the mega elliptical roundabout interchange. The mega elliptical roundabout interchange was compared to eight other interchange designs. They use the VISSIM software version 4.30 and the surrogate safety assessment model (SSAM) software version 3.

Based on the study's results, a mega elliptical roundabout interchange was one of the best interchanges regarding the number of total conflicts and the number of crossing conflicts .

Fabianova, Michalik et al. 2022 demonstrate how the VISSIM program could be used to design and test an intersection model with traffic lights. First, the traffic at the chosen busy intersection is modeled and simulated in its current state. Then, two models are made with changes meant to make the intersection move more quickly. Finally, the queue length is used to measure the throughput of an intersection. Both changes have led to a significant drop in cars waiting to get to the places with the most traffic. In the first model, the average length of the lines was decreed by 75%, and in the second model, the changes made it easy for right-turning vehicles to move through and made the lines for vehicles going in other directions much shorter.

Prasetyo, Setiawan et al. 2022 demonstrate the traffic congestion was conducted by measuring the length of the vehicle line at the roundabout and using PTV VISSIM by inputting vehicle volume information and other variables.

Based on simulation results on the Jl. Thamrin N-S, the queue length was measured at 461.69 meters. For parts on Jl. Sudirman S-N, the distance is 482.13 meters. After the projection, the simulation provides two possibilities for the present queue length: road expansion and underpass. Therefore, the queue length may be calculated based on the forecasts and options—the alternate underpass for the queue length on Jl. Thamrin N-S is 0 meters in length, whereas on Jl. Sudirman S-N it is 356.20 meters. Jl. Thamrin N-S measures 407.10 m, whereas Jl. Sudirman S-N measures 444.98 m . Table 2-3 shows a summary of previous studies related to the research.

Table 2-3 Summary of previous studies

Researcher	Year	Methodology	Results	Software Used
Al-Ghandour	2011	Analysis of roundabout Performance When Introducing Slip Lanes	discovered that the average delay and circulating conflict volumes in a roundabout with a slip lane are related exponentially to slip lane volumes up to a saturation point	PTV VISSIM
Chen and Lee	2011	Evaluation of the performance of Congested Multi-Lane Roundabouts by three simulation programs	Both SIDRA and VISSIM significantly underestimated wait times and line lengths. RODEL significantly exaggerated the wait times and line lengths at the majority of the entries	Vissim Sidra, Rodel
Gallelli	2012	Evaluation of roundabout Performances Using a Micro-Simulation Software	The delay has a significant relationship with the value of the assumed time gap and it is even more pronounced when there is a high volume of traffic	PTV VISSIM
Yadeta and Semu	2013	Study the efficiency of roundabouts as compared to roundabouts with and without traffic lights and signalized intersections based on their ability to reduce traffic	The cross intersections with traffic lights perform best, and when the arrival rate becomes more than 0.64 v/s/l, roundabouts must be replaced by signalized intersections. Where the arrival rate is 0.1 v/s/l, it is better to use traffic light signals at the entrance to the roundabout to ensure smooth traffic flow	MMAS, CA
Mohamed AIZ	2020	Evaluate the safety performance of the new mega elliptical roundabout interchanges and compare them to eight other interchange designs	A mega elliptical roundabout interchange was one of the best interchanges when it came to the number of total conflicts and the number of crossing conflicts	PTV VISSIM, SSAM
Fabianova, J	2022	Design and evaluation of two intersection models to minimize congestion	Both models have led to a significant drop in cars waiting to get to the places with the most traffic. The average queue length of the lines was decreed by 75%	PTV VISSIM
Harwidyo	2022	Study the performance of queue length of vehicles on the Roundabout after two changes in road expansion and underpass	The queue length was at 461.69 and 482.13m in the normal roundabout and became 0 and 356.20 m for the first case study and become, 407.10 m, and 444.98 m for the second case study	PTV VISSIM

2.15 Gap of knowledge

The implementation of roundabouts and signalized intersections in developing countries with heterogeneous traffic behavior poses several significant challenges. Firstly, there is a notable absence of established vehicle arrival rate thresholds that can serve as reliable benchmarks for decision-making processes. This lack of standardized guidelines complicates the determination of when to opt for a roundabout or a signalized intersection. Moreover, there is a considerable dearth of research investigating the effectiveness of signal installation at roundabouts in such developing countries. The variability in traffic behavior further emphasizes the need for empirical studies that specifically examine the outcomes of introducing traffic signals within roundabout configurations. Additionally, the long-term impact of time and population gro wth on proposed traffic control solutions remains insufficiently understood. As these factors dynamically evolve over time, it is crucial to assess the scalability and sustainability of the selected traffic management measures. Finally, the influence of environmental factors on the changes resulting from the implementation of signalized intersections has not been adequately explored. Factors such as climate, road conditions, and surrounding infrastructure play integral roles in determining the effectiveness and efficiency of traffic control interventions. Addressing these research gaps and comprehensively understanding the complexities associated with implementing roundabouts and signalized intersections in developing countries are imperative for developing context-specific and effective traffic management strategies.

Chapter Three:

Methodology and Data Collection

Chapter Three

Methodology and Data Collection

3.1 Introduction

Congestion in roundabouts is causing significant delays in transportation time, reducing road efficiency, and impacting overall road service. This is a major problem that needs to be addressed by finding alternatives that can reduce congestion and improve roundabout performance

PTV Vissim enables accurate simulation and performance assessment of roundabouts, including their transformation into signalized roundabouts or intersections. Collecting and inputting relevant data into the simulation program is vital for achieving realistic results

. This is because the model used in the program is designed to create a virtual reality that closely mirrors the real-world situation being studied. By inputting accurate data, the simulation can accurately predict how the system will perform under different conditions and help identify potential issues or solutions. Therefore, data collection is a critical component of creating an effective simulation.

3.2 Study Area

The roundabouts located in the center of Karbala governorate are known to be highly congested and are considered problem areas for traffic flow. The study focused on three roundabouts, all of which had four and three arms and varied in size. The aim was to investigate how the size of a roundabout affects congestion levels. All of the roundabouts were situated in the urban center Kerbala Distract (CKD) area and experienced high traffic volume. Figure 3-1 shows the roundabouts studied in the research and its location in relation to Karbala and Iraq

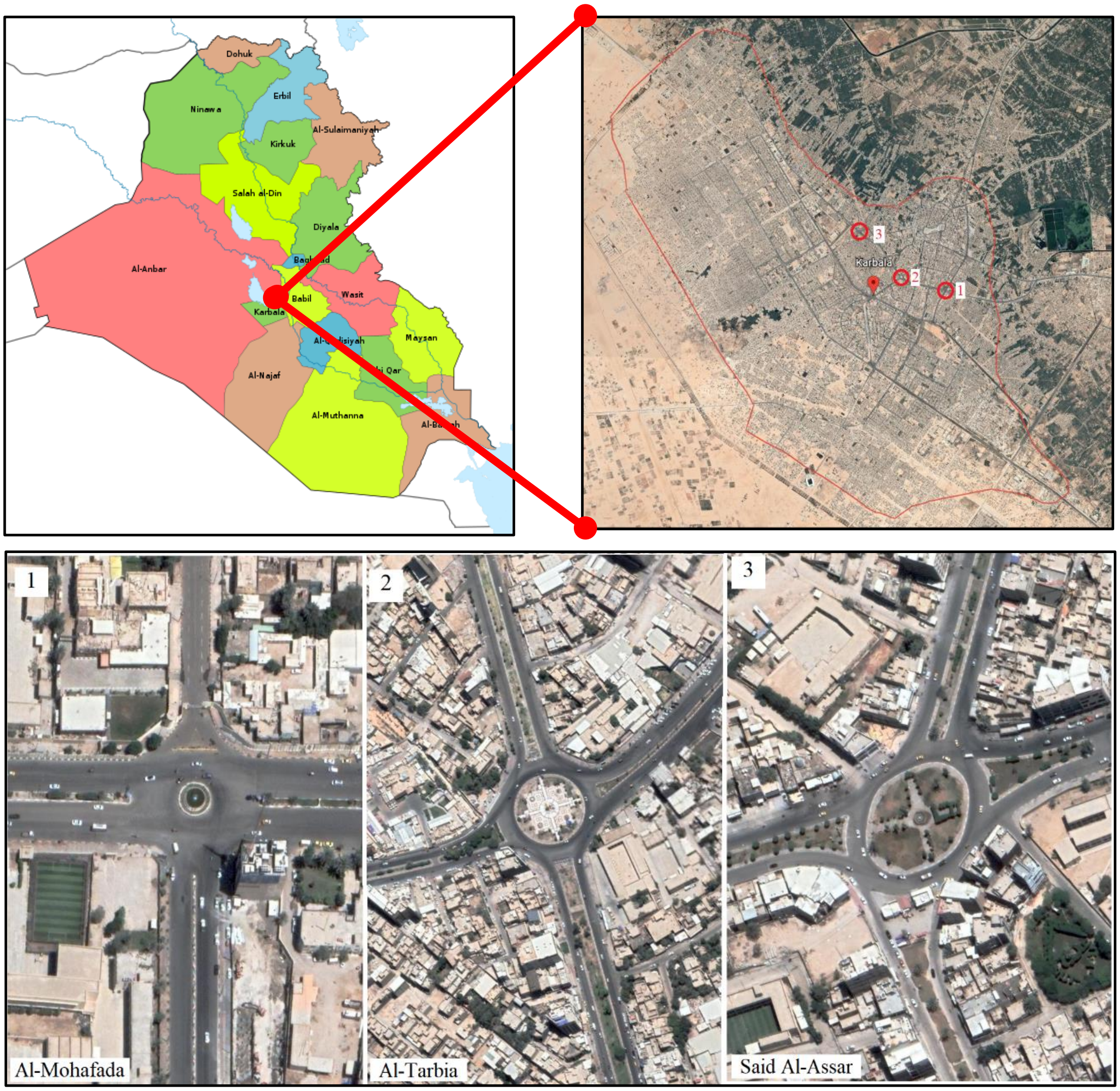


Figure 3-1 Layout of Studied Roundabout In Kerbala Center Districts

3.3 Characteristics of Selected Roundabout

Many characteristics are included in the design of the roundabouts, which significantly affect the performance of the roundabout, and as much as possible, it is necessary to know most of the details that help to make a simulation model in the Vissim program are as follows :

- All roundabout directions are at one level from sea level
- No heavy truck traffic in the roundabouts
- Pedestrian crossings are not specified on all roundabouts
- There is no car park near any roundabout

According to geometric and traffic characteristics data, the models are built in the PTV Vissim program. Table 3-1 shows the name, coordinates, and number of approaches to the roundabout.

Table 3-1 Name, Number of Approaches, and Coordinates of Studied Roundabout

Name of Roundabout	No. Approach	Location	
		Latitude	Longitude
Al-Tarbia	4	32.6068567 ^{o}	44.0264503 ^{o}
Said Al-Assar	4	32.6053037 ^{o}	44.030273 ^{o}
Al-Mohafada	3	45.9935502 ^{o}	0.3456173 ^{o}

3.4 Data Source

Accurate data is crucial for creating a simulation model as it forms the foundation of the virtual world recreated within the program's system. Therefore, comprehensive and detailed data must be utilized for all components of the system.

The most critical data that will be studied to build the simulation model is the following

- first Step: Traffic Volume Data
- Second Step: Geometric Data
- Three Step: Calibration Data
- Four Step: Validation of Data

The first step involves collecting traffic volume data to determine the volume of traffic that passes through the roundabout. The second step is to collect geometric data, such as the size and shape of the roundabout and the number of approaches. The third step involves calibration data, which helps adjust the simulation model to match real-world conditions accurately.

The fourth step is essential to ensure the quality of the data used in the simulation model. Finally, the data obtained from the simulation model is compared to the field data, and the confirmation step is used as a reference point to compare the traffic movement in the model simulation to reality.

3.5 Methodology of Calibration

It is necessary to use unique calibration processes when calibrating a microsimulation model for mixed traffic due to the unique characteristics of this type of traffic.

Therefore, an approach is given that consists of three steps:

- Modeling of Cars.
- Modeling of Geometry.
- Modeling of Traffic.

They are followed by multi-parameter sensitivity analysis, selecting their ranges heuristically, and determining parameter values using an optimization model. The traffic depiction takes into account several distinguishing characteristics of mixed traffic. As depicted in Figure 3-2, the proposed methodology is provided in the form of a flow chart. First, the model should be simulated with the default settings (before calibration) to determine whether or not calibration is required. The delay values should then be acquired to determine if calibration is required. Finally, this set of values is compared to field values; if the error is insignificant (usually improbable), the model with default settings can be accepted without needing additional adjustment. If the inaccuracy is considerable, it is necessary to do the calibration procedures (GA Genetic Algorithm).

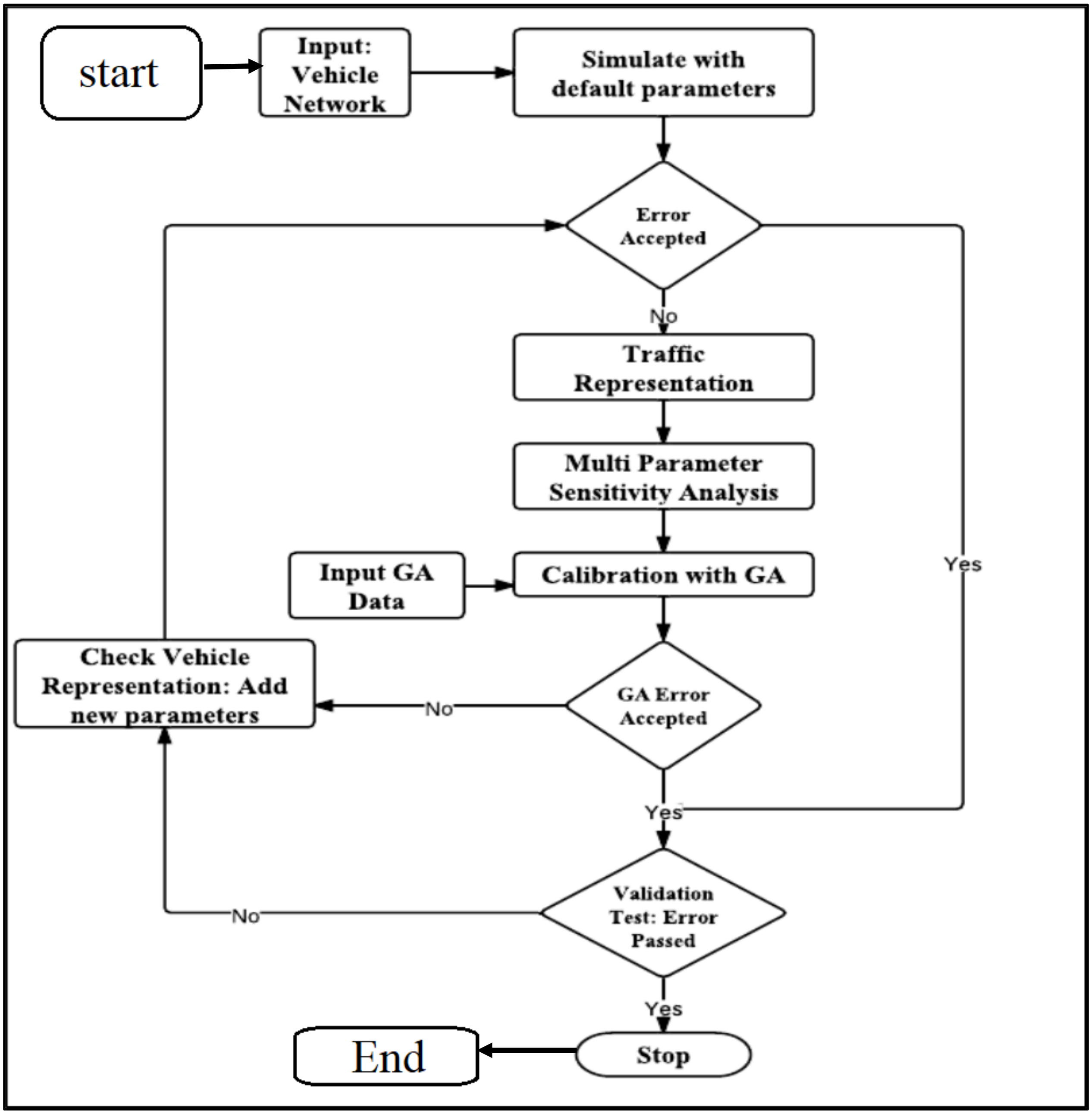


Figure 3-2 Methodology of Calibration

3.6 Methodology of Research

Figure 3-3 illustrates the sequential progression of steps involved in a project aimed at transforming an existing intersection into a roundabout. It encompasses the process of gathering the necessary study requirements, implementing the conversion to a roundabout with the addition of traffic lights, evaluating the effectiveness of the conversion, and ultimately transitioning the roundabout into a fully functional intersection with traffic signals. Each stage of the project presents an opportunity to assess the impact and variances introduced by the modifications.

The project commences with an assessment of the current state of the intersection, which serves as the foundation for subsequent decisions. Extensive research and analysis are conducted to determine the specific requirements for the study. Factors such as traffic volume, peak hours, existing road conditions, and surrounding infrastructure are thoroughly examined to inform the subsequent steps.

Based on the study requirements, the project advances to the implementation phase, where the existing intersection is converted into a roundabout. The conversion entails careful planning and execution, including the installation of appropriate traffic lights within the roundabout. This combination of a roundabout and traffic signals aims to regulate traffic flow more efficiently and ensure smoother transitions for vehicles entering and exiting the intersection.

Following the implementation of the roundabout with traffic signals, a comprehensive evaluation is conducted to gauge the effectiveness of the conversion. Various performance metrics are considered, such as traffic throughput, average waiting times, congestion levels, and safety measures.

Comparisons are made between the previous state of the intersection and the modified roundabout configuration to assess the improvements achieved.

Based on the findings from the evaluation stage, the project proceeds with a final transformation. The roundabout is completely replaced with a traditional intersection equipped with traffic lights. This shift allows for a direct comparison between the two types of traffic management systems, highlighting the differences in traffic flow, efficiency, and overall effectiveness.

Throughout each stage of the project, careful attention is given to monitor and analyze the impact of the changes made. Data collection, analysis, and modeling techniques are employed to gather meaningful insights and inform subsequent decisions. By systematically studying the modifications introduced at each stage, the project aims to optimize traffic management and contribute to safer and more efficient road networks.

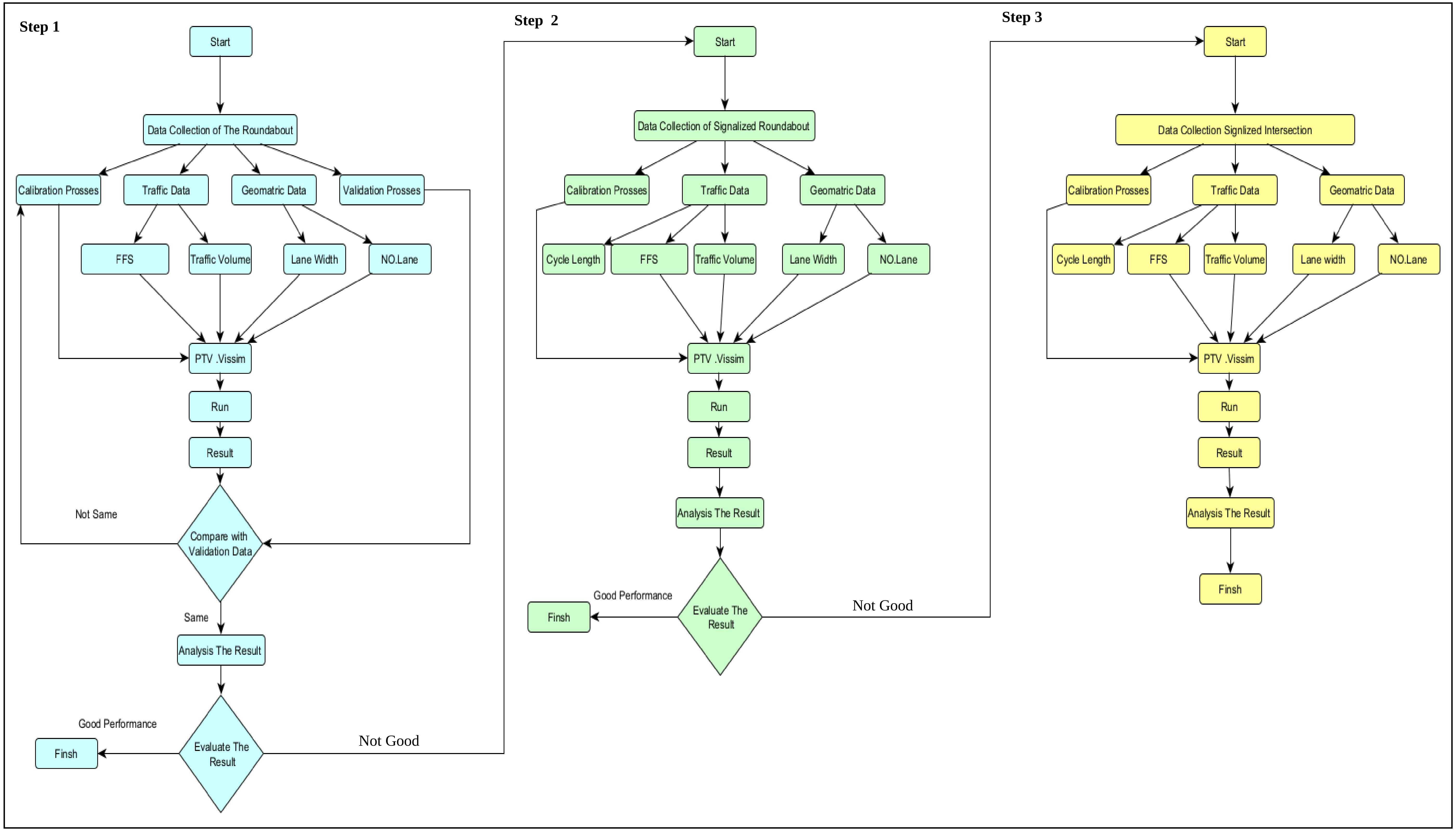


Figure 3-3 Methodology of Research

3.7 Vehicle Representation

Simulation models are designed to provide standard vehicle types such as trucks, cars, motorcycles, buses, and others. However, in real-life traffic scenarios, non-standard vehicles occupy a significant portion of the streets. Thus, it becomes imperative to model these non-standard vehicles in simulation models to improve their accuracy. This can be achieved by approximating the vehicles' characteristics, such as acceleration, length, and width, to build a more realistic model.

While the Vissim program provides some standard vehicle types, it does not include three-wheeled vehicles or motorcycles, which are commonly found in the studied area. To enhance the simulation accuracy, it was necessary to obtain the required models for these vehicles. After consulting with several experts, itis approached to Mayank Kanani, a Civil Engineer with a Master's degree in Transportation Engineering and the owner of the Civil Engineering Skills YouTube channel who provided us with the necessary file.

The study employed four types of vehicles: private cars, motorcycles, buses, and three-wheeled vehicles. The images in Figure 3-4 show these vehicles and their dimensions and other relevant characteristics that were incorporated into the simulation program. By incorporating these non-standard vehicles into the simulation model, the accuracy of the simulation was improved, and a more realistic traffic scenario was created.

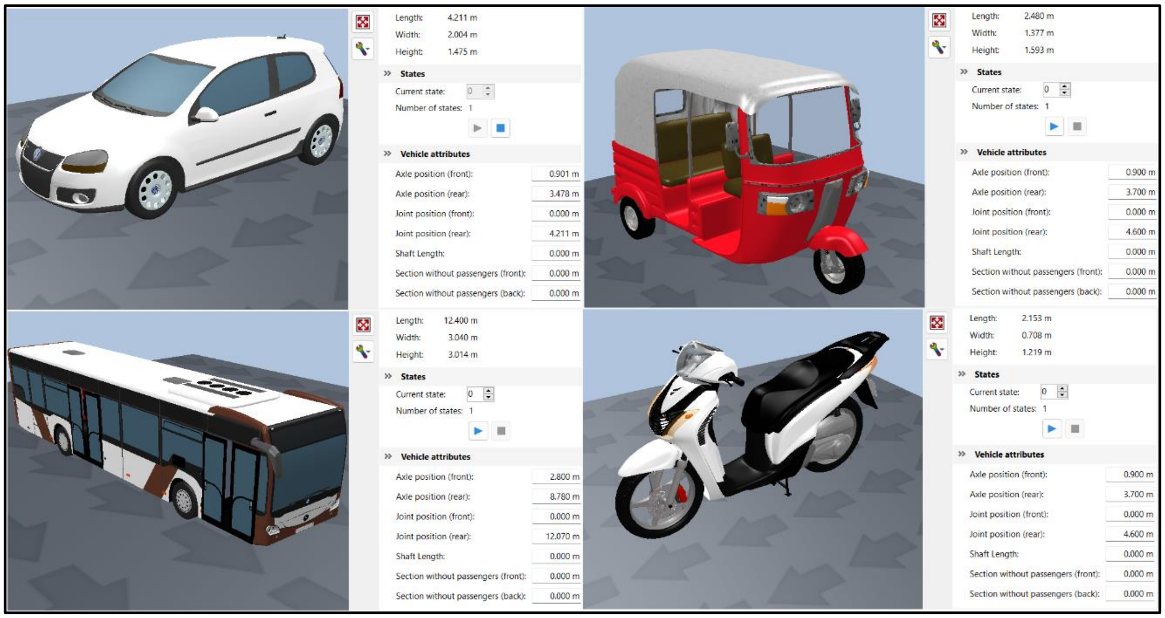


Figure 3-4 Vehicles Used in the Simulation Process

3.8 Geometric Representation

To accurately model the intersection, it is crucial to ensure that its geometry is represented with precision. This includes the number of approaches, the width of each approach, and the turning space required for each turning movement within the intersection. Table 3-2 presents all the necessary geometric details for simulating the three roundabouts in the study, including the approach direction, start and end points, the number of lanes on the approach, lane width, roundabout diameter, center island diameter, number of lanes within the roundabout, and lane width for each roundabout.

Furthermore, Figure 3-5, Figure 3-6, and Figure 3-7 depict the layout and movement direction of the three roundabouts as they exist in reality without any modifications. By incorporating these precise geometric details, the simulation model can be more accurately replicate real-life traffic scenarios, resulting in more reliable and effective outcomes.

Table 3-2 Geometric Representation of Roundabout in the Study Area

Roundabout Name		Approach Direction	Approach Start	Approach End	No.Lane	Width of Lane (m)
Roundabout Name	Al-Tarbia	NE	Imam Hussein	Al-Tarbia R	3	4
		NW	AL-mohafada	Al-Tarbia R	3	3.5
		ES	Al-Tarbia S	Al-Tarbia R	5	3
		WS	Al-dariba S	Al-Tarbia R	3	3.5
	Said Al-Assar	NW	Al-Mamalaje S	Said alassar R	3	3.5
		WS	Ramadan NH	Said alassar R	2	3.5
		E	Al-Roudatain S	Said alassar R	3	3.5
		ES	Al-Jameaa S	Said alassar R	3	4
	Al-Mohafda	NE	Al-Tarbia S	Al-mohafda R	5	2.5
		ES	AL-jaer S	Al-mohafda R	4	3
		WS	Imam Abass s	Al-mohafda R	3	3
Roundabout Name			Roundabout Diameter (m)	Center Island(m) Diameter	No.Lane of Roundabout	Width of Lane of Roundabout
Al-Tarbia			91	77	5	3
Said alassar			78	66	3	4
Al-mohafda			45	30	5	3

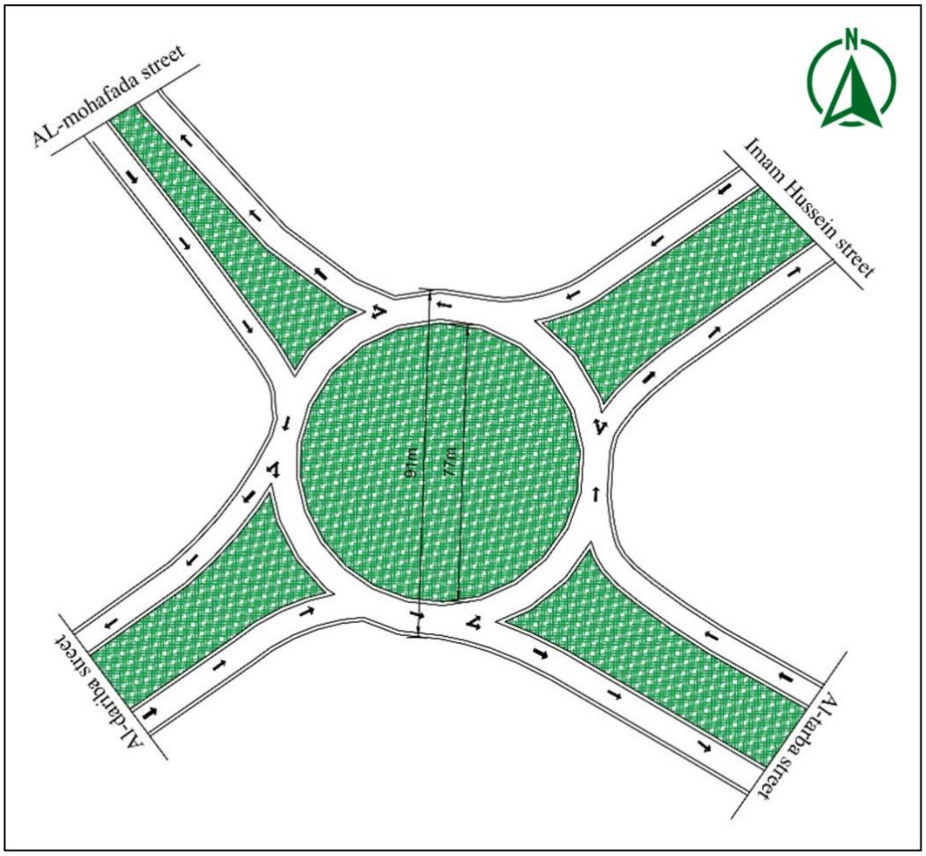


Figure 3-5 Al-Tarbia Roundabout Layout

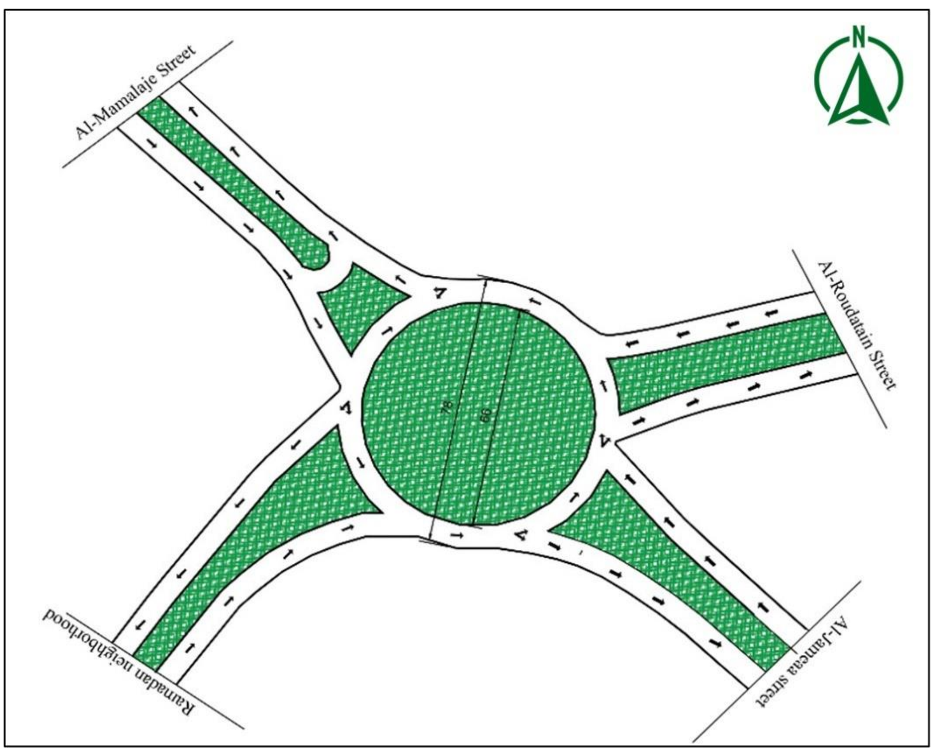


Figure 3-6 Said Al-Assar Roundabout Layout

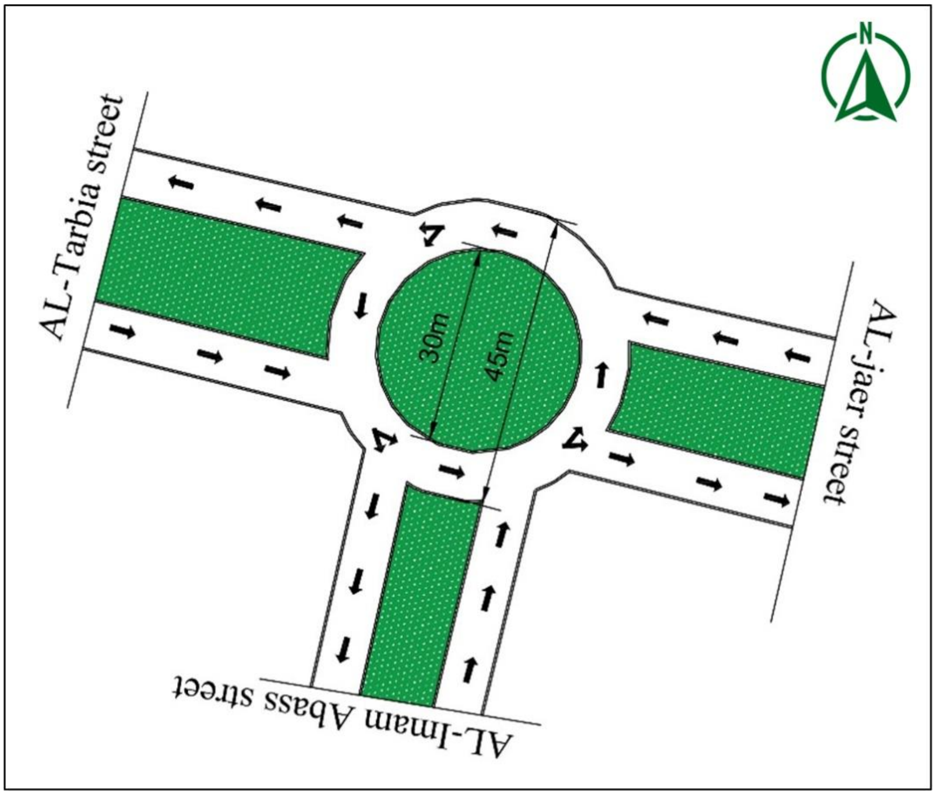


Figure 3-7 Al-Mohafada Roundabout Layout

3.9 Traffic Signal Warrants

"It defines the minimum traffic conditions that should be present before a traffic signal is installed"(Hawkins Jr and Carlson 2006) , and the MUTCD mentions this warrant in Table 3-3

Table 3-3 Texas MUTCD Traffic Signal Warrants(Hawkins Jr and Carlson 2006)

Warrant Number and Title	Basis for Analysis
Eight-Hour Vehicular Volume	Eight-hour vehicular volumes
Four-Hour Vehicular Volume	Four-hour vehicular volumes
Peak Hour	Vehicular volume and delay on the minor street
Pedestrian Volume	Pedestrian volumes and gaps
School Crossing	Number of school children and gaps
Coordinated Signal System	Vehicular volumes and road classification
Crash Experience	Crashes and Warrants 1 or 4
Roadway Network	Projected volumes and Warrants 1, 2, or 3

3.10 Signal Control System Representation

The cycle length refers to the total time of a traffic light cycle, including green, yellow, and red times, as well as any transition times between signal changes. In general, longer cycle lengths result in a higher number of vehicles entering the intersection. However, this also leads to an increase in delay at the intersection.

The highway capacity manual, ITE manual on traffic signal design, and ITE transportation and traffic engineering handbook cover many ways to determine cycle durations. **Webster's empirical formula** to reduce intersection delay:

$C_o = \frac{1.5*L+5}{1-\sum\frac{V}{S}}$ *(Chakroborty and Das 2017)…………………………………… …Equation 3-1*

C_o Optimal cycle length in seconds, generally round to the nearest 5 seconds
L Sum of all wasted time, mainly intergreen intervals (sec)
V/s Design flow rate to saturation flow rate for each phase's critical approach

$t_g = C_O - L_t$ *(Chakroborty and Das 2017)………… …………….……………Equation 3-2*
$gi = \left[\frac{V_C}{\sum_{i=1}^{N} VC}\right] * t_g$ *(Chakroborty and Das 2017)…………….…………….……Equation 3-3*

t_g The total effective green time
gi Effective green time for one phase

And the design of the cycle length is detailed in Appendix-A

3.11 Geometric Representation of Signalized Intersection

The conversion of the roundabouts into signalized intersections is illustrated in Figure 3-8, Figure 3-9, and Figure 3-10. In this conversion process, the geometric characteristics of the approach were kept the same, including the dimensions and number of lanes. The only change made was to alter the geometry of the roundabout island to that of a signalized intersection. The final layout of the proposed intersections in PTV Vissim can be found in Appendix-C.

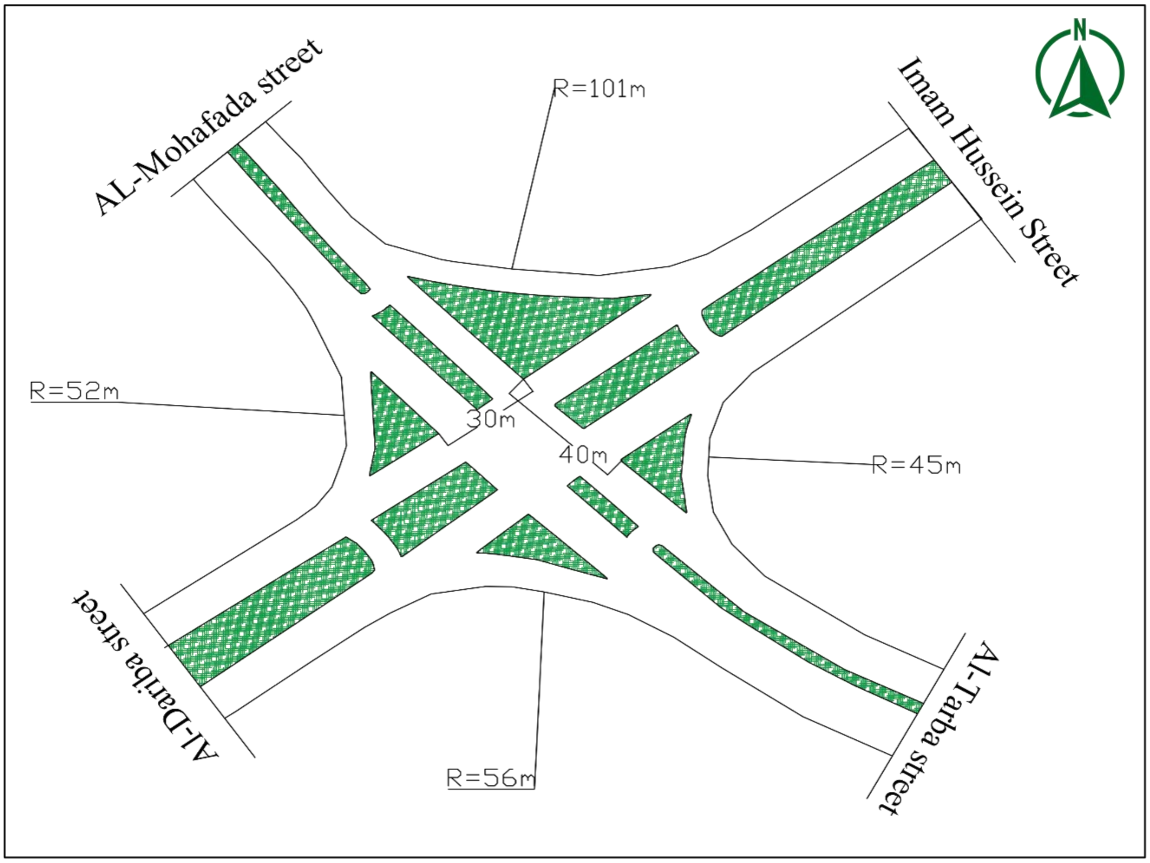


Figure 3-8 AL-Tarbia Signalized Intersection Proposed Layout

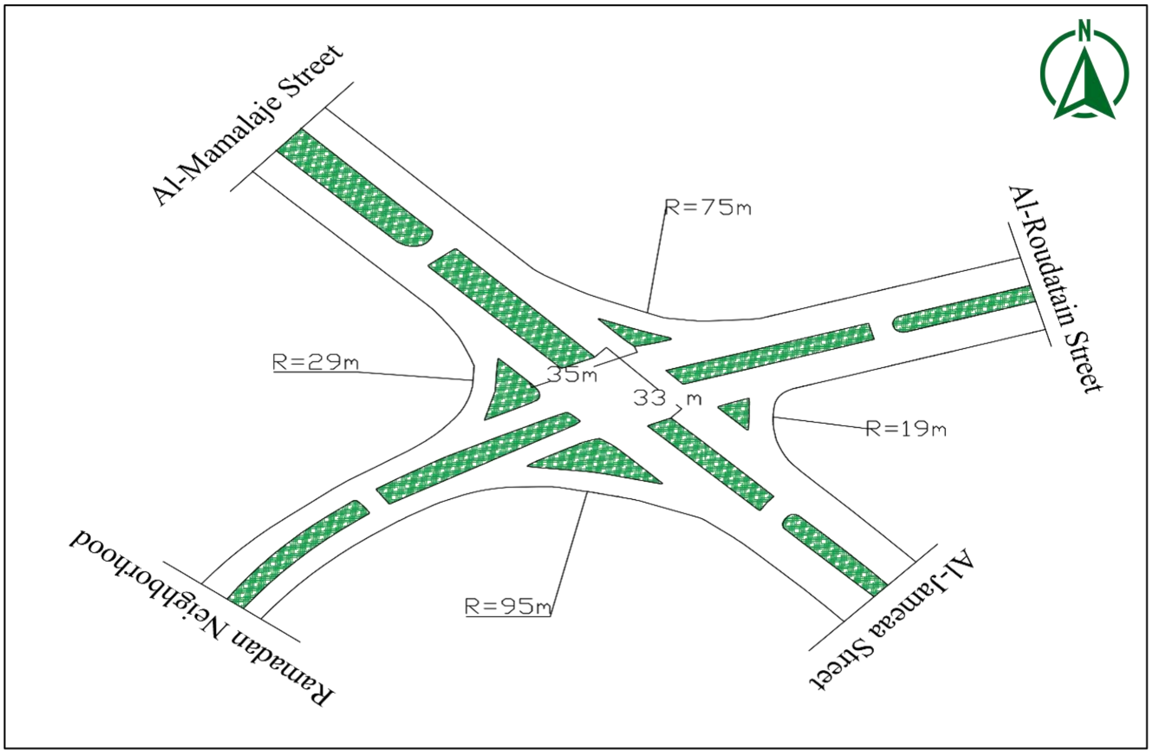


Figure 3-9 Said Al-Assar Signalized Intersection Proposed Layout

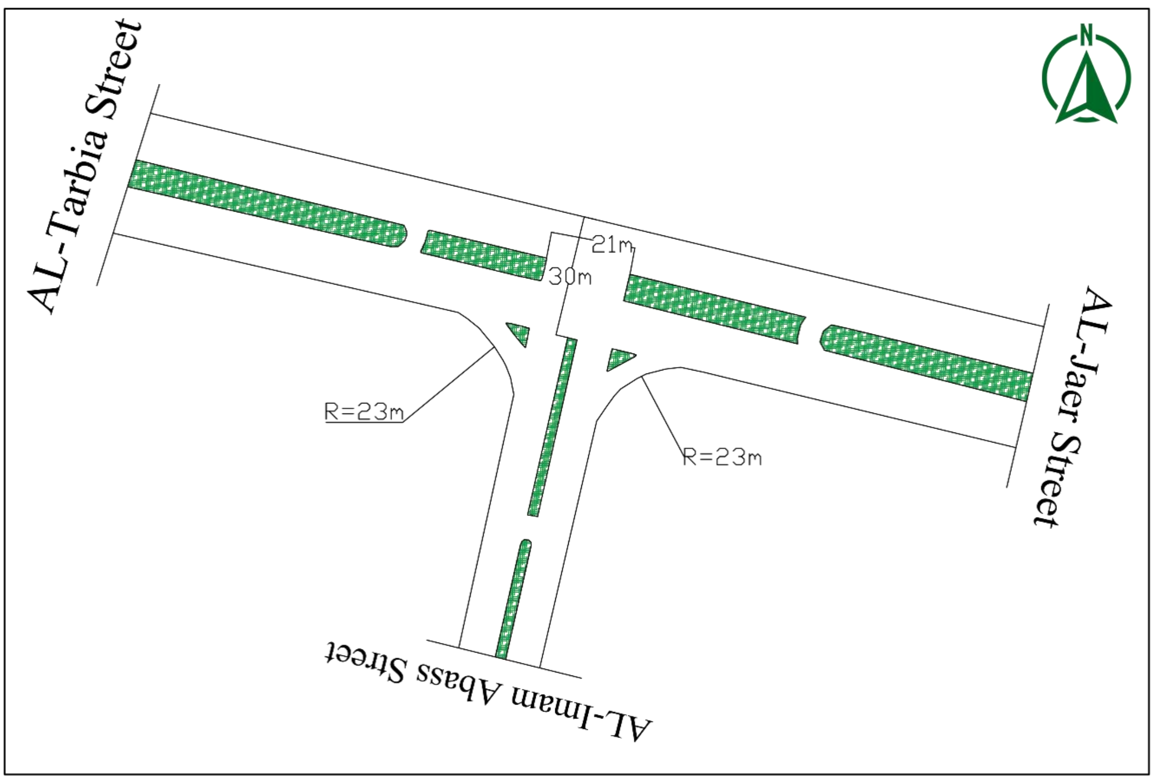


Figure 3-10 AL-Mohafada Signalized Intersection Proposed Layout

3.12 Traffic Representation

This aspect of the simulation involves identifying and defining the characteristics of local traffic behavior in the studied roundabout to create a realistic representation. The studied roundabout exhibits some unusual movements, such as sudden path changes and small vehicles passing through narrow gaps between larger vehicles. While it may not be possible to account for all of these small details in the simulation models, the flexibility of the built model can enable the approximation of the traffic simulation model as closely as possible to the actual situation.

3.13 Data Collection

The collection of traffic volume data is a crucial step in the process of simulating traffic reality. To achieve this, cameras were installed at the beginning of all streets leading to the roundabout. Five cameras were placed strategically to ensure complete coverage of the roundabout. A video recording is obtained from the Karbala Police Department, The traffic volumes were calculated during peak hours, which were between 07:30 to 8:30 AM, 12:30 to 13:30, and 19:30 to 20:30, over a period of four days. This period spanned from Saturday, October 1, 2022, to Friday, October 7, 2022, and included three working days and one day off.

The peak hour volume of traffic in the studied roundabouts is illustrated in Figure 3-11, Figure 3-12, and Figure 3-13, showing the distribution of traffic volume against the times and days of the week. For instance, the peak hour volume of traffic in the Al-Tarbia Roundabout was recorded between 19:30 to 20:30 on Thursday, reaching nearly 7939v/h. The Said Al-Assar Roundabout, on the other hand, had the highest peak hour volume of traffic between 19:30 to 20:30 on Sunday, which was about 6059v/h. Lastly, the Al-

Mohafada Roundabout had the highest peak hour volume of traffic at 12:30 to 13:30 on Sunday, with approximately 5878v/h of traffic movement.

In order to provide a detailed analysis of the traffic movement, Table 3-4, Table 3-5, and Table 3-6 were prepared, which present the peak hour traffic volume data for each quarter of an hour separately. These tables provide a comprehensive overview of the traffic patterns and volume at different times during the peak hours of the day.

Moreover, Figure 3-14, and Figure 3-15 were included in the report to give a visual representation of the installed cameras at the entrances of the roundabouts and on the roundabout lanes. These figures provide insight into the type of cameras used to collect the traffic data, as well as their positioning to ensure full coverage of the roundabouts.

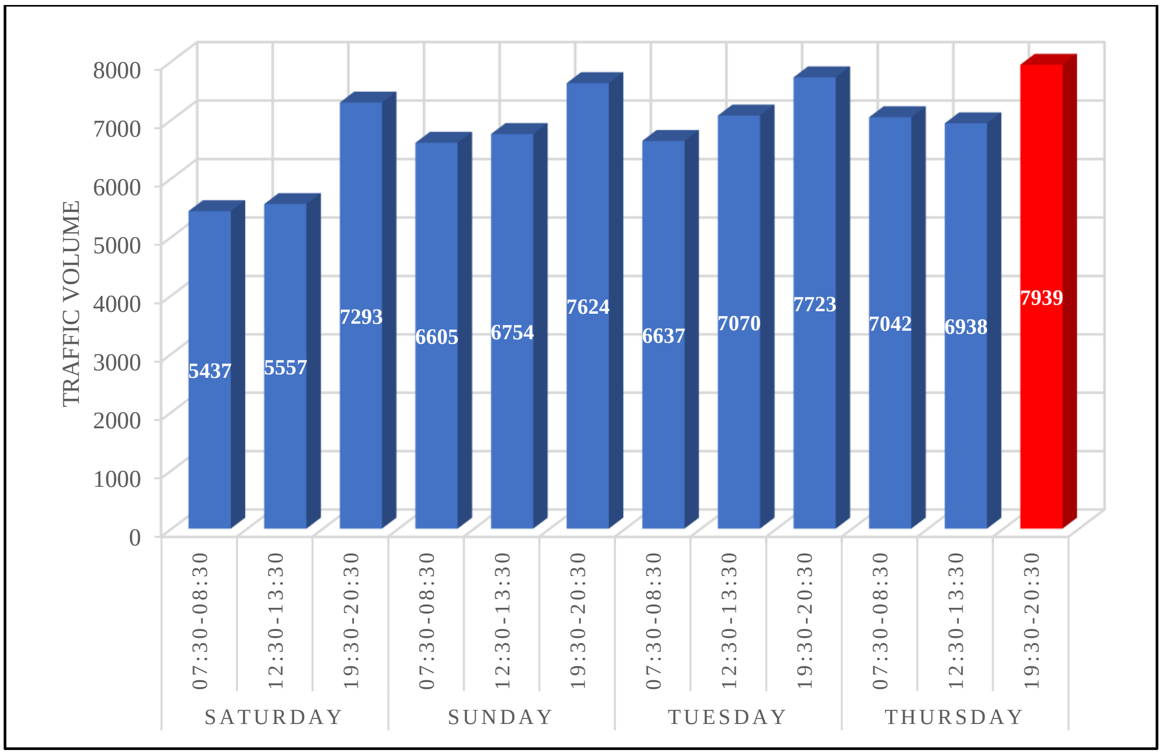


Figure 3-11 Traffic Volume of Al-Tarbia Roundabout from 1:7-OCT-2022

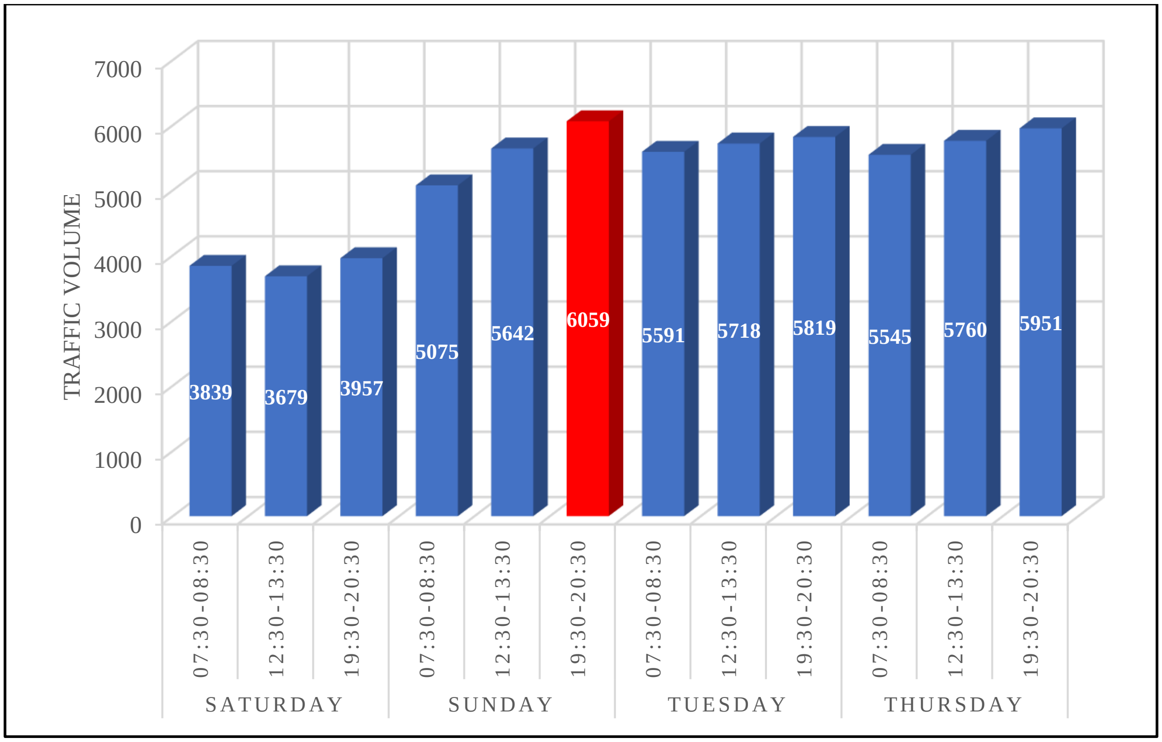


Figure 3-12 Traffic Volume of Said Al-Assar Roundabout from 1:7-OCT-2022

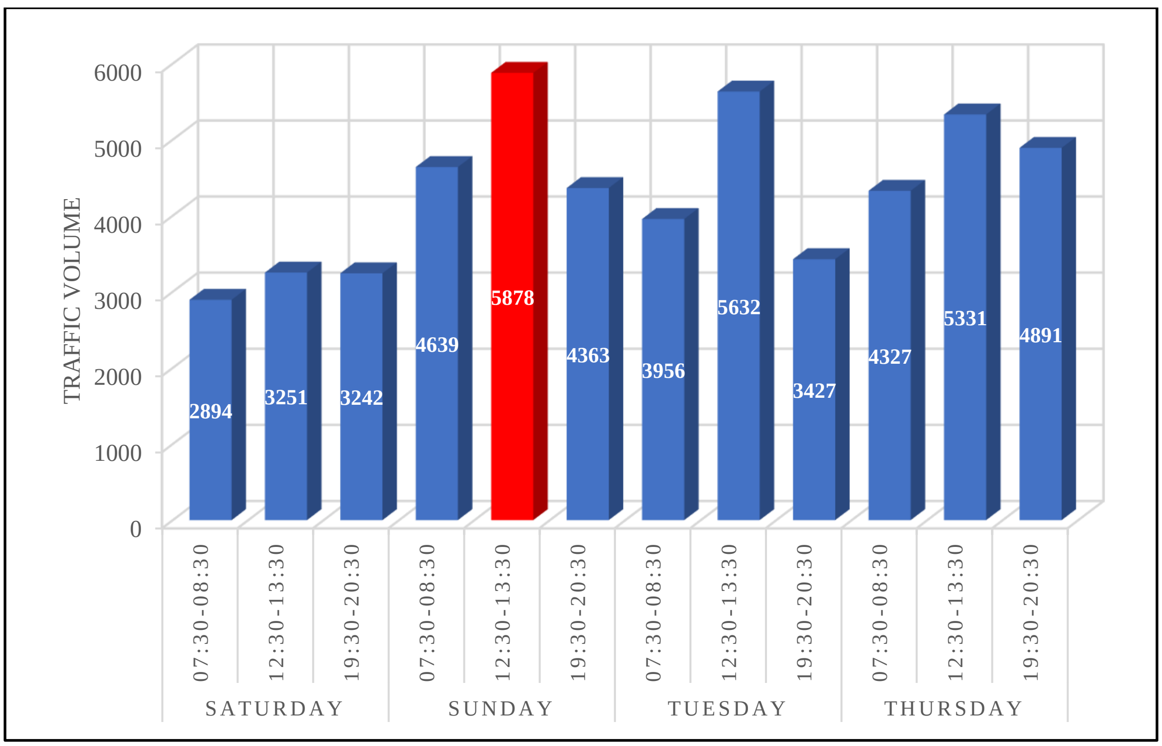


Figure 3-13 Traffic Volume of Al-Mohafada Roundabout from 1:7-OCT-2022

Table 3-4 Peak Traffic Volume of Al-Tarbia Roundabout 6/10/2022 (Thursday)

Video Record Time	Almohafada Street (veh)	Al-Dareba Street (veh)	Al-Tarbia Street (veh)	Imam Hussein Street (veh)	Total (veh)
19:30-19:45	462	479	494	463	1898
19:45-20:00	499	506	502	474	1981
20:00-20:15	467	469	599	485	2020
20:15-20:30	498	483	586	473	2040
Total(veh)	1926	1937	2181	1895	7939

Table 3-5 Peak Traffic Volume of Said Al-Assar Roundabout 2/10/2022 (Sunday)

Video Record Time	Al-Jameaa Street (veh)	Al-Roudatain Street (veh)	Al-Mamalaje Street (veh)	Ramadan NH (veh)	Total (veh)
19:30-19:45	362	399	610	85	1456
19:45-20:00	327	380	540	97	1344
20:00-20:15	304	346	580	87	1317
20:15-20:30	298	305	636	75	1314
Total(veh)	1291	1430	2366	344	6059

Table 3-6 Peak Traffic Volume of Al-Mohafada Roundabout 2/10/2022 (Sunday)

Video Record Time	Imam Abass Street(veh)	Al-Tarbia Street(veh)	Al-Jaer Street(veh)	Total (veh)
12:30-12:45	238	561	435	1234
12:45-13:00	320	578	465	1363
13:00-13:15	270	589	490	1349
13:15-13:30	420	583	525	1528
Total(veh)	1248	2310	1915	5878

Figure 3-14 Video Screenshot of Traffic Movements at Al-Roudatain Street In Said Al-Assar Roundabout

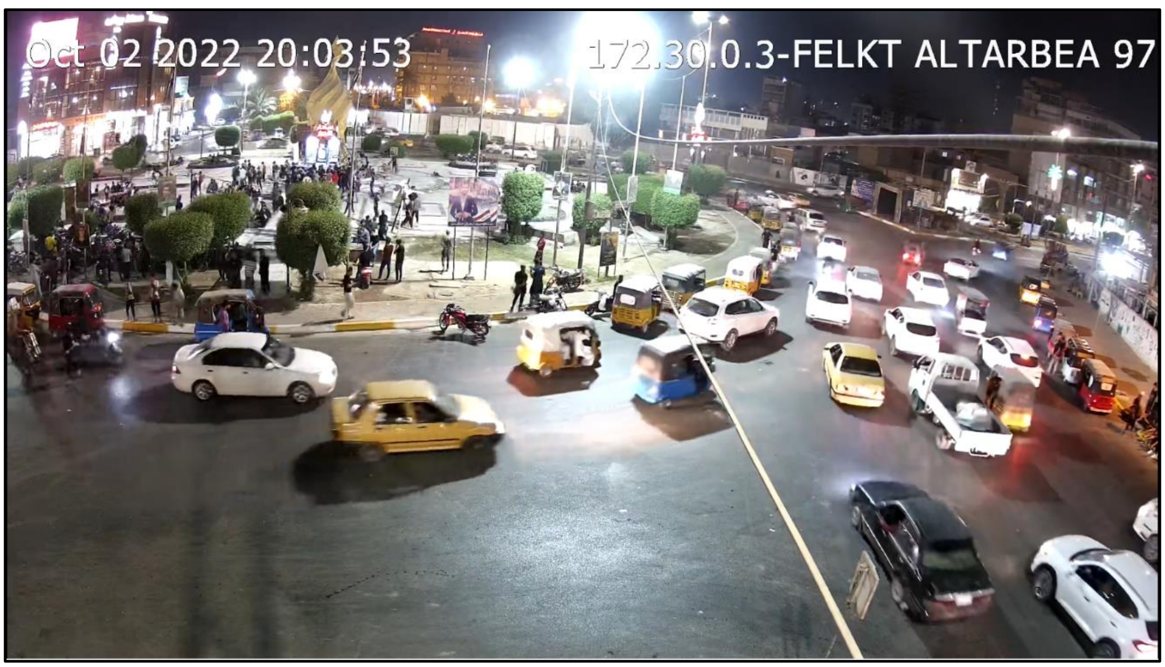


Figure 3-15 Video Screenshot of Traffic Movements at Al-Tarbia Roundabout

3.14 Distribution of Peak Hour Volume at the Studied Roundabout

Table 3-7, Table 3-8, and Table 3-9 detail traffic volumes for each roundabout by movement type (right turn, left turn, through, U-turn), providing valuable insight into traffic behavior and aiding in simulation modeling. Appendix-B contains further traffic volume information.

Table 3-7 Peak Hour Volume (19:30-20:30) at Al-Tarbia Roundabout

Approach Name	Al-Mohafada Street(veh)	Al-Dareba Street(veh)	Al-Tarbia Street(veh)	Imam Hussein Street(veh)
Right Turn	598	607	703	485
Left Turn	498	810	609	582
Through	797	506	938	776
U-Turn	100	101	94	97
Peak Hour Volume	1992	2024	2344	1940

Table 3-8 Peak Hour Volume (19:30-20:30) at Said Al-Assar Roundabout

Approach Name	Al-Jameaa Street(veh)	Al-Roudatain Street(veh)	Al-Mamalaje Street(veh)	Ramadan NH (veh)
Right Turn	327	456	210	116
Left Turn	523	380	883	101
Through	405	608	1324	155
U-Turn	52	76	127	16
Peak Hour Volume	1308	1596	2544	388

Table 3-9 Peak Hour Volume (19:30-20:30 P.M) at Al-Mohafada Roundabout

Approach Name	Imam Abass Street(veh)	Al-Tarbia Street(veh)	Al-Jaer Street(veh)
Right Turn	420	589	630
Left Turn	672	706	525
Through	504	943	840
U-Turn	84	117	105
Peak Hour Volume	1680	2356	2100

3.15 Calibration Data

context of Iraq's general traffic conditions, obtaining accurate calibration data poses challenges due to the limited capabilities and lack of devices for studying the psychological state of drivers. As a result, accurately capturing and representing driver behavior in simulation models becomes difficult. The traffic behavior in Iraq is heterogeneous, with weak traffic laws that are not applied by many vehicle drivers, similar to traffic in India and Egypt. To calibrate the PTV Vissim program in this research, the best values for the required variables were obtained from Siddharth, S.P., and G. Ramadurai's detailed study of calibrating India's heterogeneous traffic, which closely resembles traffic behavior in Iraq. Their study yielded a simulation accuracy of 91.81% with present errors of 8.19%, relying on genetic algorithms in their studies to obtain this accuracy in the results (Siddharth and Ramadurai 2013). Table 3-10 shows the data that was used in the calibration process

Table 3-10 Parameter Calibration Value

parameter	value	parameter	value
Maximum ahead distance	100.00 m	Acceleration	40%
Minimum ahead distance	5.00 m	Safety distance	110%
Number of interaction objects	4	Distance	2000 m
Number of interaction vehicles	99	distance for static obstacles:	0.5
Minimum Look back distance	30 m	Average standstill distance:	2 m
Maximum Look back distance	150 m	Additive part of safety distance:	2
Speed	60%	Multiplic. part of safety	3
Maximum deceleration:	-4.00 m/s2	1 m/s2 per distance:	100
Accepted deceleration:	-1.00 m/s2	Waiting time before diffusion:	60 s
Min. clearance (front/rear)	0.5 m	Maximum deceleration	-3.00 m/s2
Maximum speed difference	10.80 km/h	Maximum collision	10 s

3.16 Validation Process

To evaluate the accuracy of the traffic simulation program, it is essential to determine the degree of correlation between the results generated by the PTV Vissim program and the actual values obtained from the field. This is achieved through the use of the regression equation, which calculates the closeness of the simulated results to the real-world situation. The convergence level is then evaluated using the (r^2) equation, under the Transportation Statistics and Microsimulation recommendation(Spiegelman, Park et al. 2016).

To validate the study results, delay values from the program were compared to those observed in the actual Roundabout. This enhances the study's accuracy and overall quality, ensuring precise and reliable findings.

The accuracy of the traffic simulation program was evaluated by comparing its results with actual field data. To assess the level of convergence, a total of 11 sets of data were collected, representing the number of approaches in the three roundabouts under study. For each set, the delay for 90% of the passing vehicles within a five-minute period was calculated. These observed delay values were then compared with the delay values obtained from the simulation program for each direction and for the same five-minute duration.

3.17 Speed Data

The determination of the Free-Flow Speed (FFS) is an essential parameter in transportation system modeling for planning, operational analysis, and performance evaluation. Therefore, it is crucial to determine this parameter accurately in the field. There are various ways to calculate the required speed data, such as using Equation (3-4), which takes into account the length of the segment (L) in feet and the time required to move from one section to another (TR) in seconds(Fatlawy 2019).

$FFS=3600L/5280(TR)$……………………….………….*Equation 3-4(Fatlawy 2019)*

Free-Flow Speed (FFS): The speed at which traffic moves without stopping for intersections (mph)

L: is the length of the segment (feet).
TR: The time required to move from one section to another (second).

Before calculating the FFS, it is necessary to know when traffic volumes will be less than or equal to 200 cars per lane per hour, as this condition is required to obtain the FFS data. It has been observed that traffic speeds decrease to below 200 vehicles per hour after midnight (Fatlawy 2019). To determine the FFS, it is calculated the average speed of standard vehicles at the roundabouts over four days, and a sample of results is presented in Appendix-D.

3.18 Simple Explanation of the Model-Building Steps

Since the Vissim program is the basic program for building a model that simulates the movement of vehicles and how they interact, so it will present a brief and quick summary of the most prominent modeling steps in the Vissim program.

3.18.1 First Step: Linking with Google Maps

Determine the roundabout being studied in the program through the program interface linked in Google Maps, in addition to determine the geomatic characteristics of the roundabout in reality, as shown in Figure 3-16 and Figure 3-17.

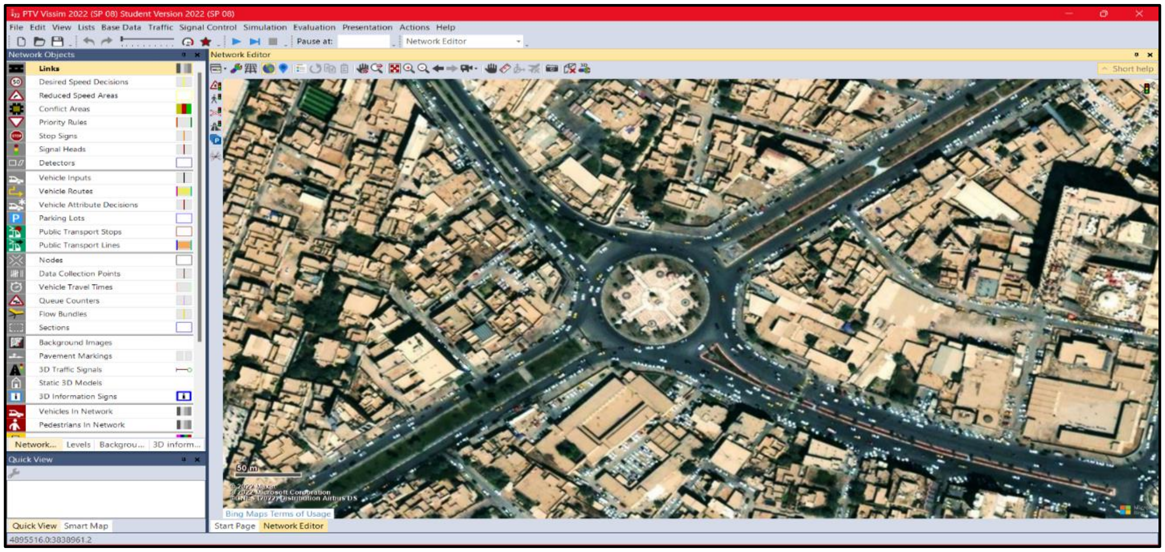


Figure 3-16 A Screenshot of The Street Map Network of VISSIM of Al-Tarbia Roundabout

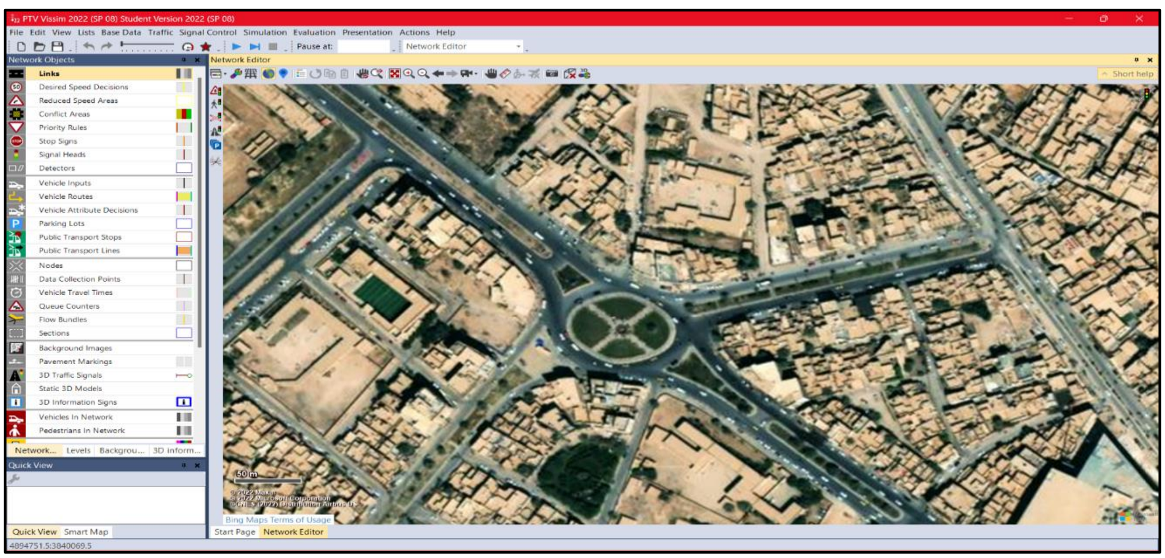


Figure 3-17 A Screenshot of The Street Map Network of VISSIM of Said Al-Assar Roundabout

3.18.2 Second Step: Building the Model

Building streets entering the roundabout from all directions according to the reality are with the same number of lanes. Furthermore, connecting the streets with the main roundabout street, the final geometric shape is identical to the reality of the situation as much as possible, Figure 3-18 shows the difference between links and connectors

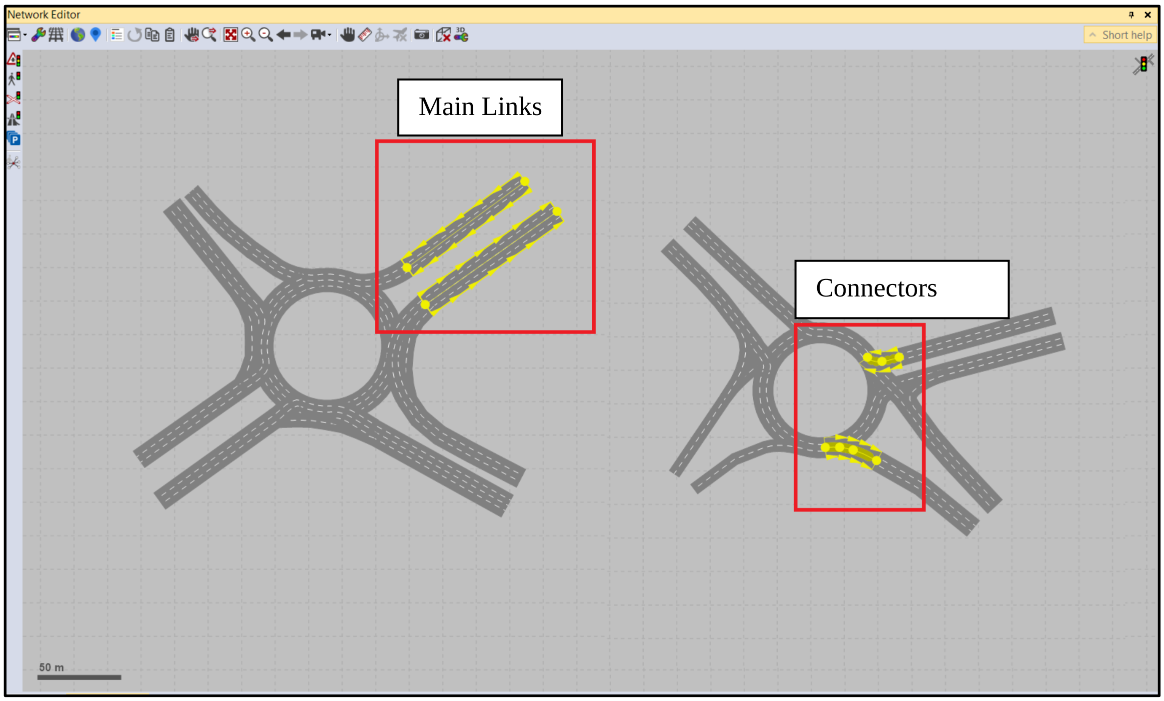


Figure 3-18 A Step of Establishing Links and Connectors of AL-Tarbia Roundabout and Said Al-Assar Roundabout

3.18.3 Third Step: Input Traffic Volumes and Vehicle Types

After linking the streets included in the modeling, traffic volumes and vehicle types are entered according to the type and specifications of each vehicle (bus - taxi - private car – motorcycle - three-wheel vehicle). Summation of all types of vehicles is the final sum of the number of vehicles.

Figure 3-19 shows the method of entering the types, compositions of vehicles and traffic volumes according to each roundabout in proportions that suit.

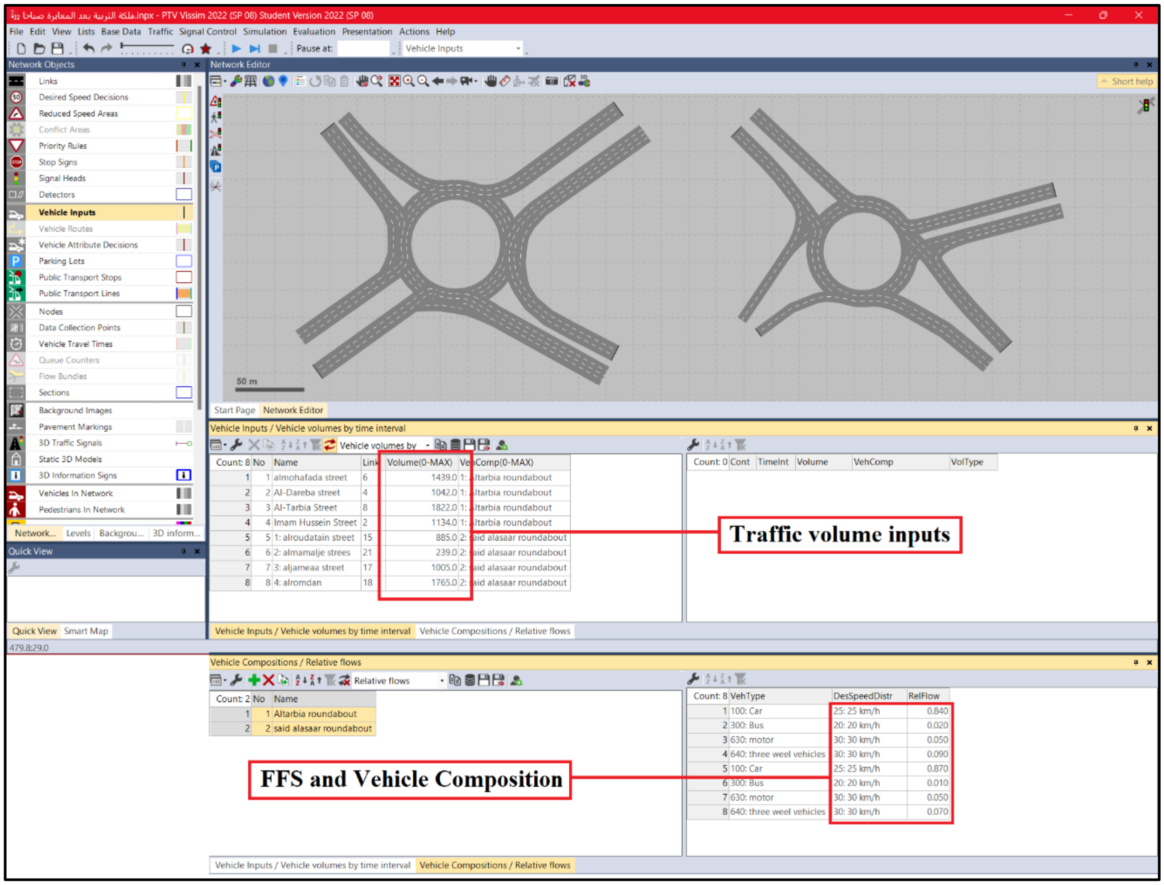


Figure 3-19 Assigning Inputs and Compositions of Vehicles of Al-Tarbia Roundabout and Said Al-Assar Roundabout

3.18.4 Fourth Step: Specified Vehicles Path

The step is determining the path of the vehicles entered in the third step. The path of vehicles that will be walked on is specified from entering the roundabout until they leave it. Each vehicle has a path and destination to which it is heading, where the traffic volumes from the street inside the roundabout are divided into four situations, the sum of these situations is 100% of the total volume entering through this street, and the yellow color shown in the Figure 3-20 represents the path that the vehicle will take from its entry to exit the roundabout

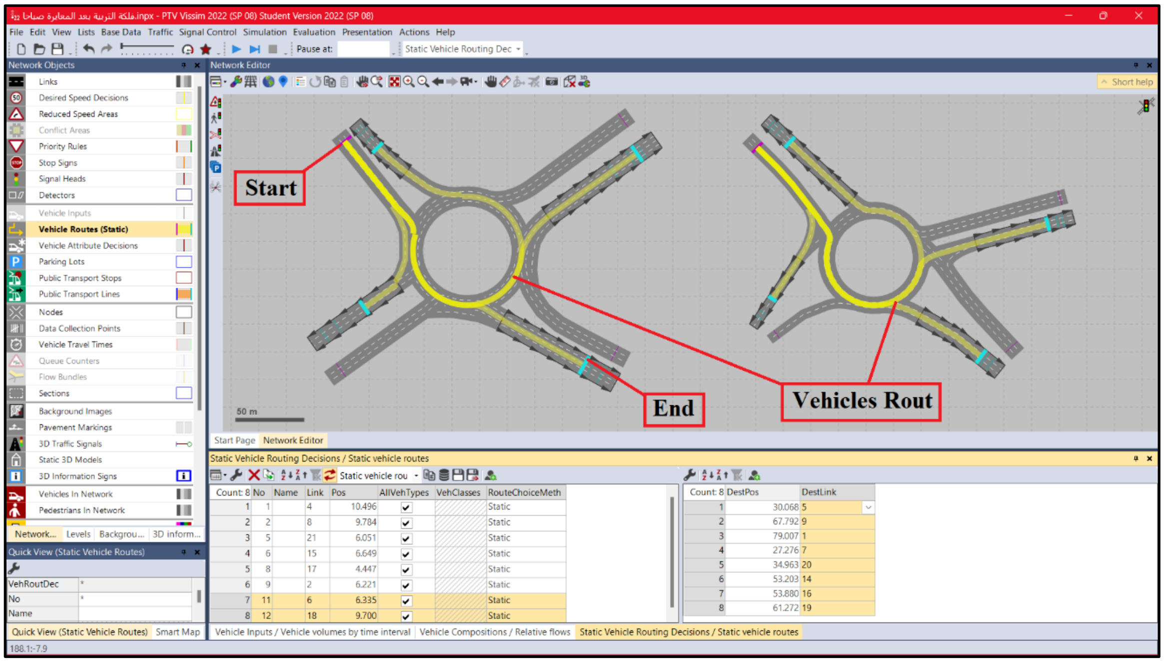


Figure 3-20 Process of Determining Route of The Vehicles of Al-Tarbia Roundabout and Said Al-Assar Roundabout

3.18.5 Fifth Step: Specified Priority Laws

The priority laws must be specified for the vehicles entering the roundabout, where the priority is to cross, and must wait. It is specified in conflict areas where the intersection of the lanes of vehicles occurs

The characteristics of the conflict areas were followed to specify the priority on the road; according to the program's manual recommendations, “It is better to use conflict areas than priority rules to model driving behavior.” (GROUP 2022). Figure 3-21 shows how the vehicles cross the conflict area and has priority in crossing.

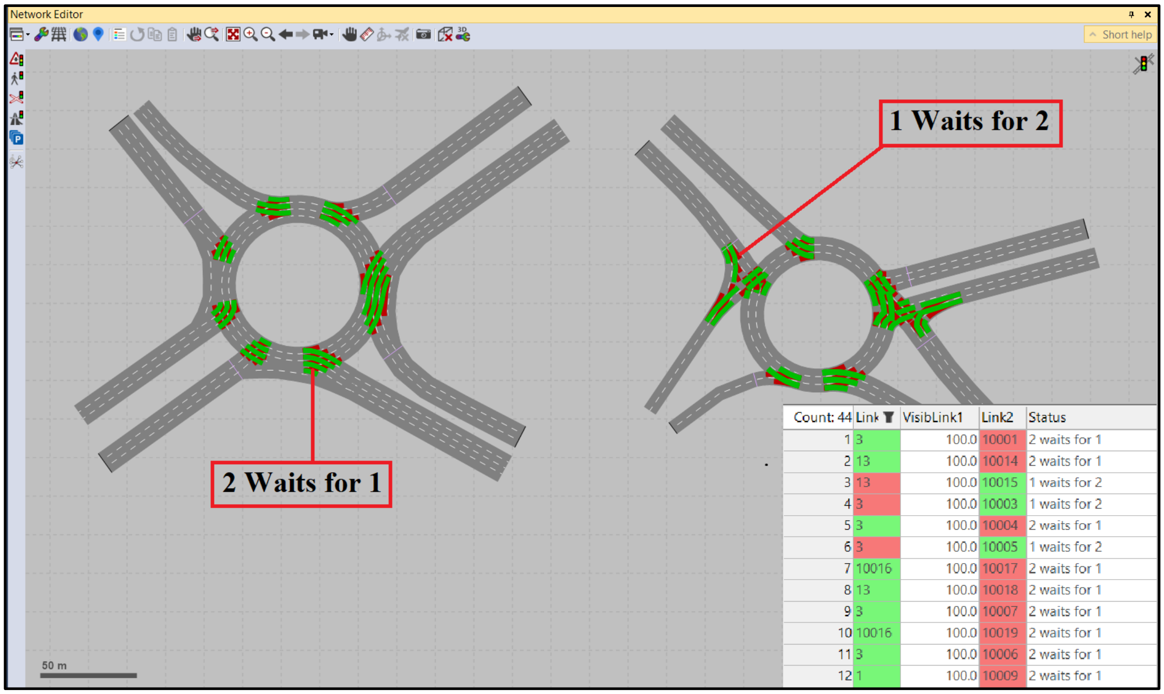


Figure 3-21 The Process of Identifying Conflict Areas to Avoid Collisions for Al-Tarbia Roundabout and Said Al-Assar Roundabout

3.18.6 Sixth Step: Specified Performance Measure

Specifying the performance measure studied and scientifically defined the user's requirements from the program to simulate and present its results. Four variables were studied in this research to evaluate the roundabout before changing it to a signalized roundabout, and signalized intersection, and these variables are

- Delay
- The Level of Service (LOS)
- Queue Length
- Environmental Parameter

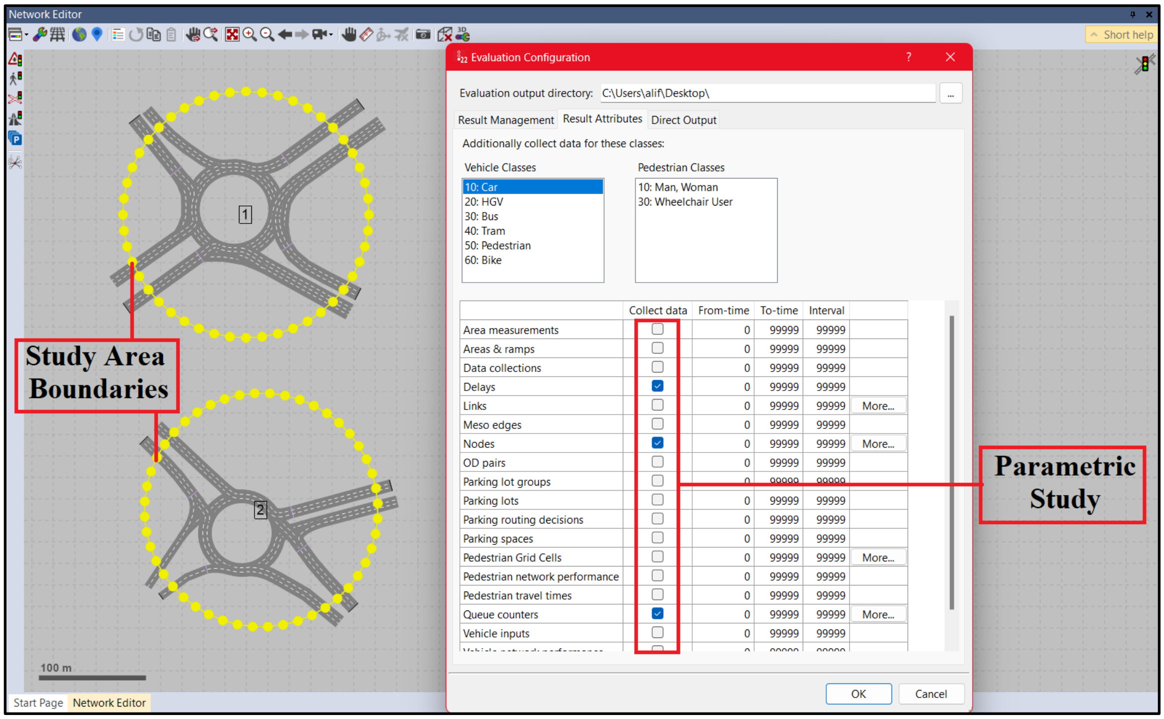


Figure 3-22 Configuration of The Output form of Al-Tarbia Roundabout and Said Al-Assar Roundabout

3.18.7 Seventh Step: Running Process

It is the process of running the program in three-dimensional and two-dimensional forms. The simulation was performed ten times for each model to obtain reliable statistical values and accurately representing the situation's in reality and improve the understanding of traffic driver behavior inside the roundabout. Figure 3-23 shows the final shape of the intersection and how traffic flows at the intersection, and it shows the waiting for vehicles in front of the red light. It also shows the movement of four vehicles in three lanes of the street, a stop of the vehicles on the pavement markings, and a sudden change of direction by one of the vehicles.

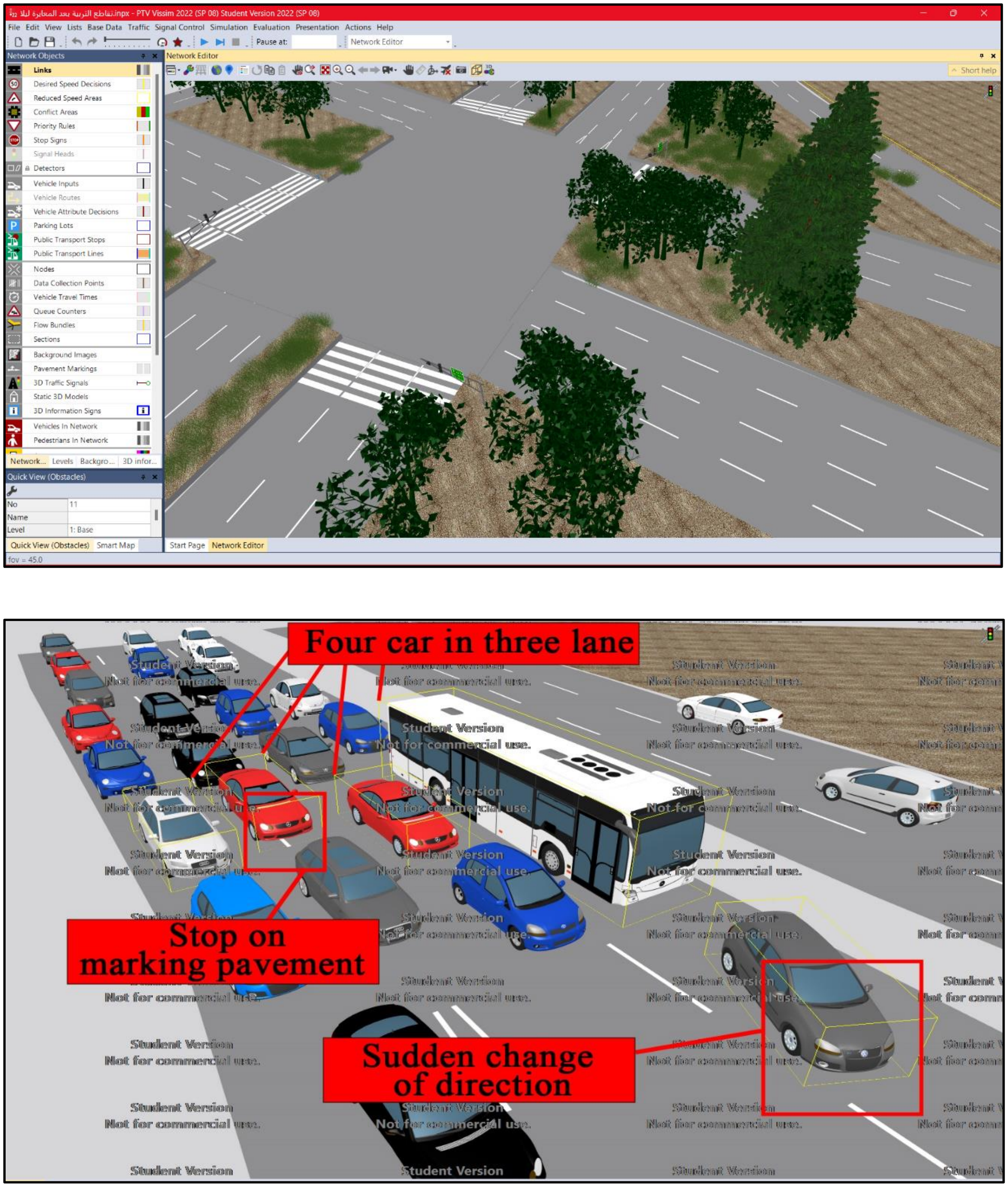


Figure 3-23 A 3D Mode Screenshot Showing The Simulation Run at Al-Tarbia Intersection

3.18.8 Eighth Step: Modelling the Signal Cycle

This step is special for modeling the signalized roundabout and signalized intersection. It simulates the traffic signal cycle at the intersection The process of simulating a traffic intersection is complex, as explained to illustrate the important steps of simulating a traffic signal

- Configure the number of traffic signals equal to the number of streets entering the intersection
- Choose the type of control used at the intersection. The program provides eleven default types of street controls in which the sequence, number, and laws of light signals change.
- Insert the ideal time for the traffic light cycle and determine the time for each of the three red, yellow, and green signals
- specify the stop line for vehicles and their movement at the red and green lights

Figure 3-24, Figure 3-257, Figure 3-26, and Figure 3-27 show how the traffic light cycle works by specifying the number of phases, the duration of the yellow, red, and green colors in each stage, the method of controlling the intersection, and how to link each stage with the other stages

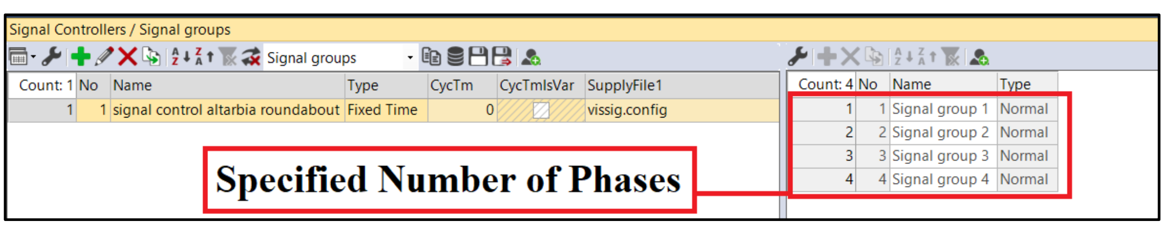


Figure 3-24 Screenshot Illustrating First Stages Modelling Traffic Signal Timing (Specified Number of Phases)

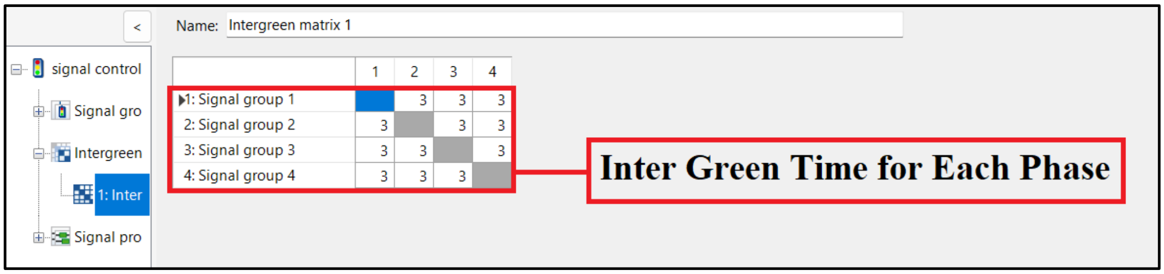


Figure 3-25 Screenshot Illustrating Second Stages Modeling Traffic Signal Timing (Specified Inter Green Time for Each Phase)

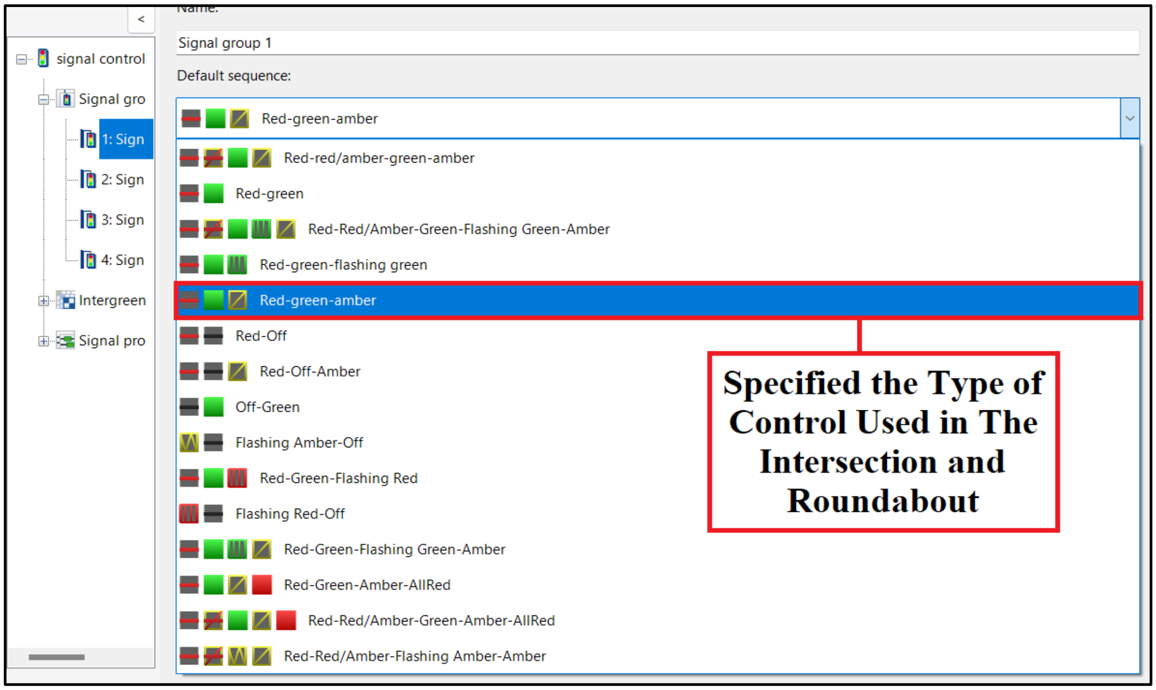


Figure 3-26 Screenshot Illustrating Third Stages Modeling Traffic Signal Timing(Specified The Type of Control Used in The Intersection and Roundabout)

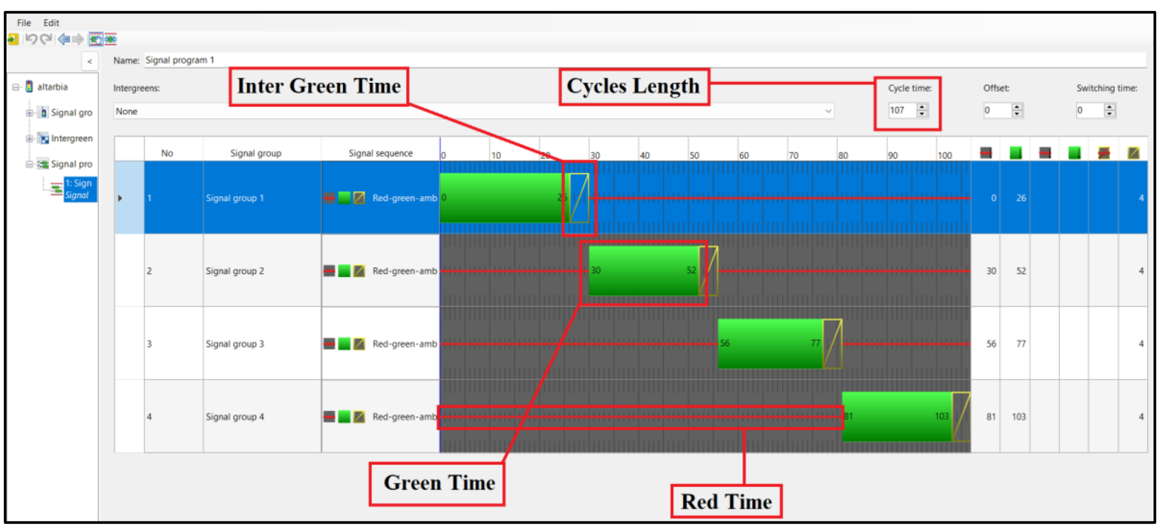


Figure 3-27 Screenshots Illustrating Fourth Stages Modeling Traffic Signal Timing (Insert The Cycles Length Time and Make Connection Between All Approach)

Chapter Four:

Results & Discussions

Chapter Four

Results& Discussions

4.1 Introduction

In this chapter, the results will be divided into two phases

The First Phase is divided into four detailed parts that will be listed as follows separately:

- **Part One:** The roundabout will be analyzed and evaluated as it is, without any change from the reality of the community
- **Part Two:** The warrant traffic lights at the roundabouts will be discussed as the admissibility of changing them to signalized intersections.
- **Part Three:** The roundabout will be analyzed and evaluated after adding a traffic light to it, without changing any geometric element in the shape of the roundabout
- **Part Four:** The performance of the roundabout will be analyzed and evaluated after changing it to an intersection with a traffic signal

The Second Phase will be divided into four parts as follows:

- **Part One**: Evaluate the performance of the roundabout before and after the change and compare each performance with the other.
- **Part Two**: Discuss the performance of the Signalized intersection over five years, with a growth rate of traffic volumes of 3%, based on the Statistics Division of the Ministry of Planning
- **Part Three:** Discuss the relationship between the delay and the arrival rate v/s/l for each roundabout.
- **Part Four:** Discuss the effect of changing the Roundabout on environmental parameters CO, NOx, VOC, and fuel consumption.

4.2 Calculation of Peak Hour Factor (PHF)

As shown in Equation 4-1, the peak hour factor (PHF) is a way to measure the difference between the maximum flow rate for 15 minutes and the hourly flow rate during the peak hour(Roess, Prassas et al. 2004)

$PHF = \frac{Hourly\ volume}{max.rate\ of\ flow}$ *(Roess, Prassas et al. 2004)…………………Equation 4-1*

$$PHF = \frac{Hourly\ volume}{V.15\ \times 4}$$

∴PHF Peak-Hour Factor.
∴V.15 Traffic volume at peak 15 min of the peak hour, on v/15min

Table4-1, Table 4-2 and Table4-3 show the value of PHF for each approach separately

Table 4-1 PHF Values for Al-Tarbia Roundabout

Approach Name	PHF
Imam Hussein Street	0.97
Al-Mohafada Street	0.96
Al-Tarbia Street	0.93
Al-Dariba Street	0.95

Table 4-2 PHF Values for Said Al-Assar Roundabout

Approach Name	PHF
Al-Mamalaje Street	0.93
Ramadan NH	0.88
Al-Roudatain Street	0.89
Al-Jameaa Street	0.98

Table 4-3 PHF Values for Al-Mohafada Roundabout

Approach Name	PHF
Al-Tarbia Street	0.98
AL-Jaer Street	0.91
Imam Abass Street	0.74

4.3 Warrants Results

Traffic signal warrants were applied for three roundabouts in Kerbala city: Al-Tarbia, Said Al-Assar, and Al-Mohafada roundabout. The results show that three warrants of traffic signal satisfied for these roundabouts that can be used as a base to change this roundabout to a signalized intersection, these warrants are (four-hour vehicular volume, peak hour, School Crossing, and network system).

In four hours, warrant the point specified in Figure 4-1(Hawkins Jr and Carlson 2006) (between the collection of two major streets approach traffic flow and one minor approach traffic flow) is above the applicable curve, so it is satisfying and for peak hour warrant, the point specified in Figure 4-2 (Hawkins Jr and Carlson 2006) for one peak hour traffic volume (four periods, each one 15 min consecutive) (between the collection of two major streets approach traffic flow and one minor approach traffic flow) is above the applicable curve, so it is satisfied

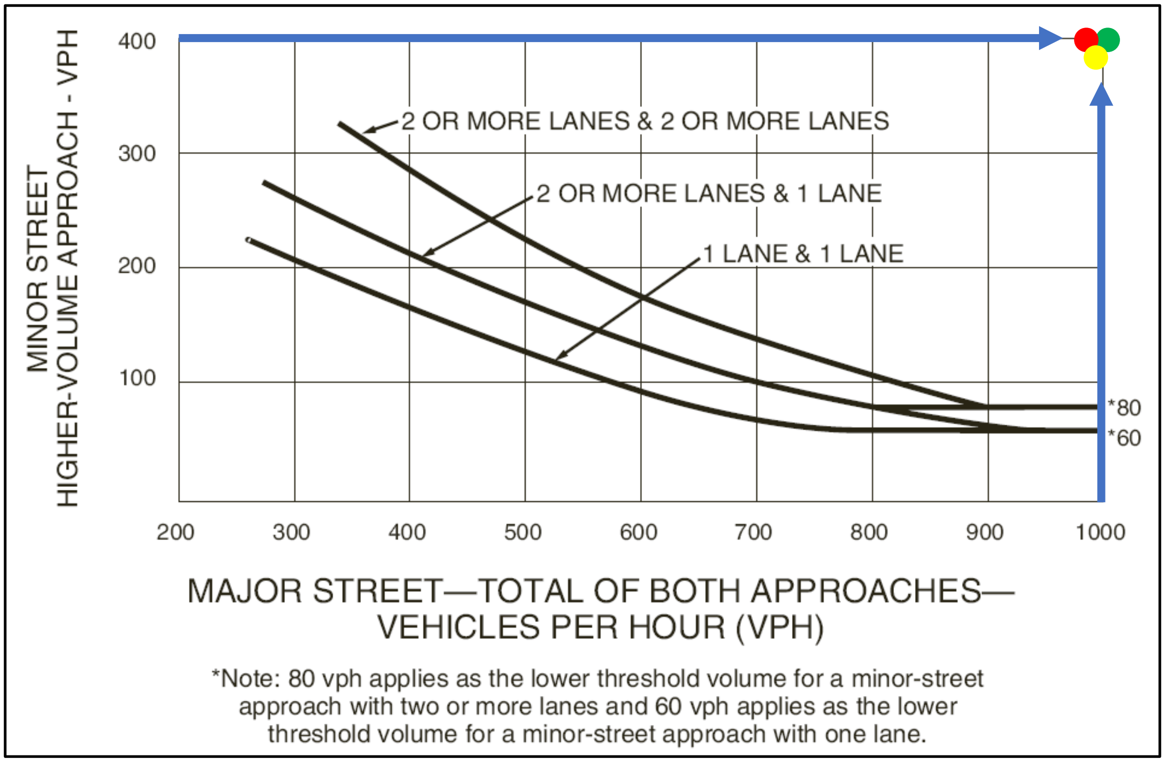


Figure 4-1 Applicable Curve of Warrant 2, Four-Hour Vehicular Volume(Hawkins Jr and Carlson 2006)

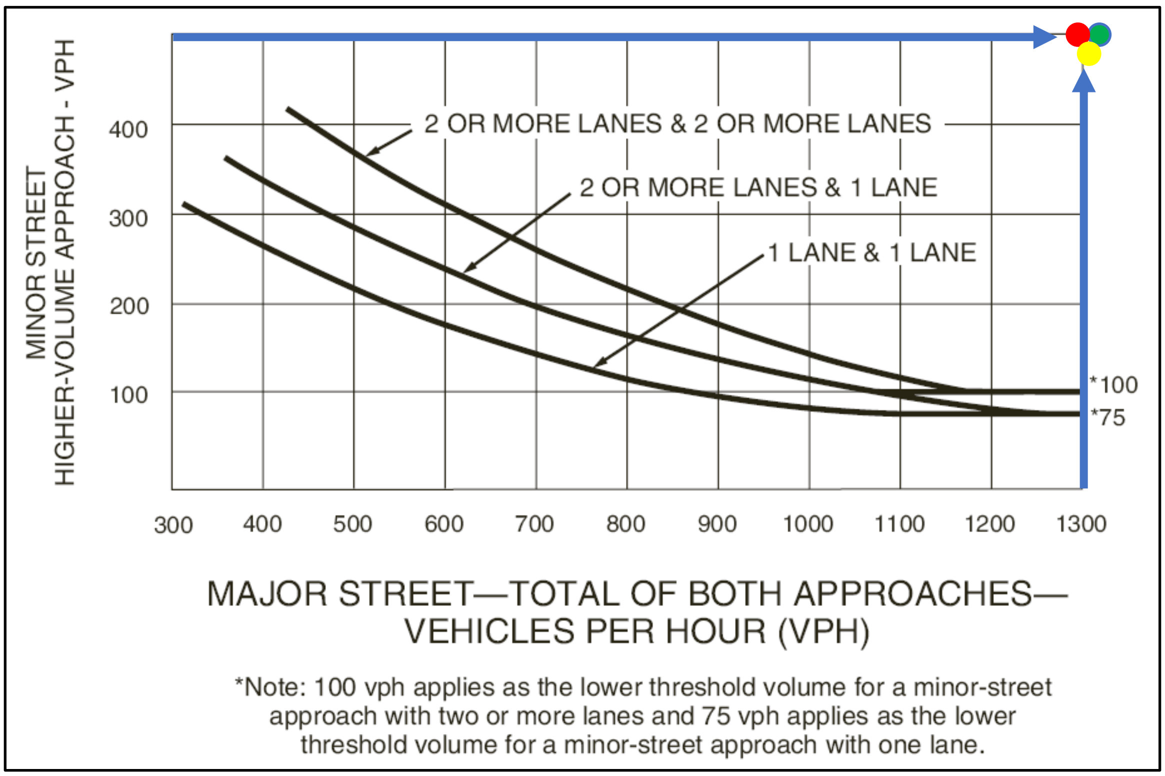


Figure 4-2 Applicable Curve Warrant 3, Peak Hour(Hawkins Jr and Carlson 2006)

Table 4-4 ,Table 4-5 And Table 4-6 shows the results of the Traffic Signal Warrant for all roundabouts, which shows that all roundabouts have sufficient Warrant to convert them to a signalized intersection, as the roundabouts have at least three Warrant to convert them.

Table 4-4 Result of Traffic Signal Warrant for Al-Tarbia Roundabout.

The Warrants	The results
Eight-Hour Vehicular Volume	Not satisfied
Four-Hour Vehicular Volume	Ok, it is satisfied
Peak Hour	Ok, it is satisfied
Pedestrian Volume	Not satisfied
School Crossing	Not satisfied
Coordinated Signal System	Not satisfied
Crash Experience	Not satisfied
Roadway Network	Ok, it is satisfied
Eight-Hour Vehicular Volume	Not satisfied

Table 4-5 Result of Traffic Signal Warrant for Al-Mohafada Roundabout

The Warrants	The results
Eight-Hour Vehicular Volume	Not satisfied
Four-Hour Vehicular Volume	Ok, it is satisfied
Peak Hour	Ok, it is satisfied
Pedestrian Volume	Not satisfied
School Crossing	Ok, it is satisfied
Coordinated Signal System	Not satisfied
Crash Experience	Not satisfied
Roadway Network	Ok, it is satisfied
Eight-Hour Vehicular Volume	Not satisfied

Table 4-6 Result of Traffic Signal Warrant for Said-Al-Assar Roundabout

The Warrants	The results
Eight-Hour Vehicular Volume	Not satisfied
Four-Hour Vehicular Volume	Ok, it is satisfied
Peak Hour	Ok, it is satisfied
Pedestrian Volume	Not satisfied
School Crossing	Ok, it is satisfied
Coordinated Signal System	Not satisfied
Crash Experience	Not satisfied
Roadway Network	Ok, it is satisfied
Eight-Hour Vehicular Volume	Not satisfied

4.4 Cycle Length Design

The cycle length was calculated based on the Webster equation, which provides optimal cycle length with the least lost time and delay. It is a Basic equation in many transportation design books, and the result is shown in Tables 4-7, Table 4-8 and Table 4-9. The optimum cycle length for Al-Tarbia Roundabout is 107 seconds, and the optimum cycle length for Said Al-Assar and Al-Mohafada Roundabout is 100 and 50 seconds

Table 4-7 Result of Cycle Length Calculation of Al-Tarbia Roundabout

Approach Name	Flow(Without Right Turn) Veh/Hr/L	Saturated Flow (Veh)	Cycle Length (Sec)	Lost Time (Sec)	Intergreen Time(Sec)	Green Time (Sec)
Al-Tarbia	329	2400	107	16	4	26
Imam Hussein	474	2400			4	22
AL-Dareba	483	2400			4	22
Al-Mohafada	465	2400			4	21

Table 4-8 Result of Cycle Length Calculation of Said Al-Assar Roundabout

Approach Name	Flow (Without Right Turn) Veh/Hr/L	Saturated Flow(Veh)	Cycle Length (Sec)	Lost Time (Sec)	Intergreen Time (Sec)	Green Time (Sec)
Al-Mamalaje	889	2400	100	16	4	42
Ramadan NH	136	2400			4	6
AL-Roudatain	355	2400			4	19
Al-Jameaa	327	2400			4	17

Table 4-9 Result of Cycle Length Calculation of Al-Mohafada Roundabout

Approach Name	Flow (Without Right Turn) Veh/Hr/L	Saturated Flow(Veh)	Cycle Length (Sec)	Lost Time (Sec)	Intergreen Time (Sec)	Green Time (Sec)
Al-Jaer	326	2400	50	12	3	12
Al-Tarbia	347	2400			3	16
Imam Abass	320	2400			3	10

4.5 Validation Results

The delay values at the roundabout under study were calculated and compared to values obtained from PTV Vissim software. The degree of similarity between the actual values and the program's results was evaluated using regression (r^2) analysis and the results are presented in Figure 4-3. The (r^2) value for the analysis was approximately 87.5%, indicating a high level of convergence between the real-world delay values and those obtained from the software.

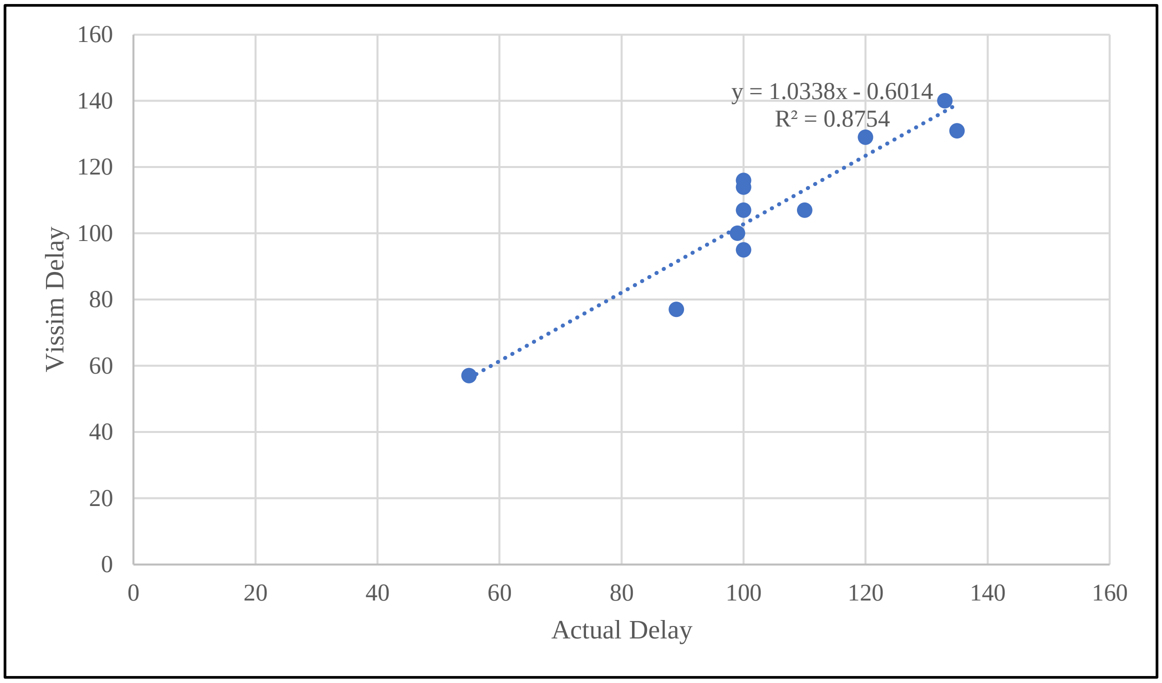


Figure 4-3Validation of the Model with Regression (r^2)

4.6 Evaluation of Traffic Flow Behaviour at Roundabout

The current behaviors of the roundabout was evaluated by PTV Vissim, a simulation program used to build a model close to reality. Table 4-10, Table 4-11 and Table 4-12 show the average delay results obtained from PTV Vissim for Al-Tarbia, Said Al-Assar, and Al-Mohafada Roundabout.

All Roundabout with LOS F with an average delay of 109 seconds for Al-Tarbia Roundabout, as well as 132 and 76 seconds for Said Al-Assar and Al-Mohafada Roundabout, and the Table 4-13, Table 4-14 and Table 4-15 show The value of the queue length minutely of the studied Roundabout and for each approach separately.

Table 4-10 Level Of Service and Delay of Al-Tarbia Roundabout

Approach Name	Approach			Roundabout	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Imam Hussein Street	116	LOS_F	6	109	LOS_F
Al-Mohafada Street	114	LOS_F	6		
Al-Dareba Street	100	LOS_F	6		
Al-Tarbia Street	107	LOS_F	6		

Table 4-11 Level of Service and Delay of Said Al-Assar Roundabout

Approach Name	Approach			Roundabout	
	Vehicle Delay (sec/veh)	LOS	LOS. Values	Vehicle Delay (sec/veh)	LOS
Al-Roudatain Street	129	LOS_F	6	132	LOS_F
Al-Mamalaje Street	140	LOS_F	6		
Al-Jameaa Street	107	LOS_F	6		
Ramadan NH	131	LOS_F	6		

Table 4-12 Level of Service and Delay of Al-Mohafada Roundabout

Approach Name	Approach			Roundabout	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Al-Abass Street	77	LOS_F	6	76	LOS_F
Al-Jayer Street	95	LOS_F	6		
Al-Mohafada Street	57	LOS_F	6		

Table 4-13 Queues Length of Al-Tarbia Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Imam Hussein Street	55	90
Al-Mohafada Street	52	74
Al-Dareba Street	64	94
Al-Tarbia Street	66	85

Table 4-14 Queues Length of Said Al-Assar Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Roudatain Street	33	83
Al-Mamalaje Street	61	80
Al-Jameaa Street	53	91
Ramadan NH	24	58

Table 4-15 Queues Length of Al-Mohafada Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Abass street	41	87
Al-Jayer street	66	99
Al-Mohafada street	43	103

4.7 Evaluation of Traffic Flow Behavior at Signalized Roundabout

After evaluating the roundabouts and according to the results presented in Table 4-10, Table 4-11, and Table 4-12 as expected, it was found that the roundabouts suffer from large traffic jams. Approaches roundabouts at peak time suffer from severe congestion and a significant increase in delay, which indicates a decrease in the level of service to the lowest degree, according to the requirements of HCM2010.

Therefore, the first vision proposed to improve the performance of the roundabout was to convert it to a signalized roundabout that can be controlled by a light signal without changing any geometric characteristics of the roundabout and can be used at peak times. The results of this conversion were as shown in Table 4-16, Table 4-17, Table 4-18, Table 4-19, Table 4-20, and Table 4-21 which explains a relative decrease in the delay value and the queue length, as well as an enhancement in the level of service from F to E in Al-Tarbia and Said Al-Assar Signalized roundabout and from F to D in Al-Mohafada signalized roundabout

Table 4-16 Level of Service and Delay of Al-Tarbia Signalized Roundabout

Approach Name	Approach			Signalized Roundabout	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Imam Hussein Street	65	5	LOS_E	72	LOS_E
Al-Mohafada Street	70	5	LOS_E		
Al-Dareba Street	69	5	LOS_E		
Al-Tarbia Street	85	6	LOS_F		

Table 4-17 Level of Service and Delay of Said Al-Assar Signalized Roundabout

Approach Name	Approach			Signalized Roundabout	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Al-Roudatain Street	59	5	LOS_E	62	LOS_E
Al-Mamalaje Street	75	5	LOS_E		
Al-Jameaa Street	67	5	LOS_E		
Ramadan NH	48	4	LOS_D		

Table 4-18 Level of Service and Delay of Al-Mohafada Signalized Roundabout

Approach Name	Approach			signalized Roundabout	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Al-Abass Street	44	4	LOS_D	47	LOS_D
Al-Jayer Street	44	4	LOS_D		
Al-Mohafada Street	54	4	LOS_D		

Table 4-19 Queues Length of Al-Tarbia Signalized Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Imam Hussein Street	46	85
Al-Mohafada Street	46	68
Al-Dareba Street	63	91
Al-Tarbia Street	60	80

Table 4-20 Queues Length of Said Al-Assar Signalized Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Roudatain Street	25	57
Al-Mamalaje Street	59	73
Al-Jameaa Street	50	84
Ramadan NH	20	40

Table 4-21 Queues Length of Al-Mohafada Signalized Roundabout

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Abass Street	39	67
Al-Jayer Street	50	75
Al-Mohafada Street	37	67

4.8 Evaluation of Traffic Flow Behavior at Signalized Intersections

After presenting the results of the first proposal (converting the roundabout to signalized Roundabout), the second proposal was to completely change the roundabout into a signalized intersection, and the Table 4-22, Table 4-23, Table 4-24, Table 4-25, Table 4-26 and Table 4-27 shows the results obtained from the PTV Vissim program, which shows a significant decrease in the delay values, queue length, and the high level of service for the roundabouts to suitable levels, as Al-Tarbia and Said Al-Assar roundabouts moved from the F to D, and the level of service arrives to C in the Al-Mohafada roundabout.

Table 4-22 Level of Service and Delay of Al-Tarbia Signalized Intersection

Approach Name	Approach			Signalized Intersection	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Imam Hussein Street	26	LOS_C	3	35	LOS_D
Al-Mohafada Street	36	LOS_D	4		
Al-Dareba Street	33	LOS_D	4		
Al-Tarbia Street	42	LOS_D	4		

Table 4-23 Level of Service and Delay of Said Al-Assar Signalized Intersection

Approach Name	Approach			Signalized Intersection	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Al-Roudatain Street	41	LOS_D	4	38	LOS_D
Al-Mamalaje Street	45	LOS_D	4		
Al-Jameaa Street	38	LOS_D	4		
Ramadan NH	29	LOS_C	3		

Table 4-24 Level of Service and Delay of Al-Mohafada Signalized Intersection

Approach Name	Approach			Signalized Intersection	
	Vehicle Delay (Sec/veh)	LOS	LOS. Values	Vehicle Delay (Sec/veh)	LOS
Al-Abass Street	29	LOS_C	3	29	LOS_C
Al-Jayer Street	24	LOS_C	3		
Al-Mohafada Street	33	LOS_C	3		

Table 4-25 Queues Length of Al-Tarbia Signalized Intersection

Approach Name	Queue Length (m)	Queue Length MAX(m)
Imam Hussein Street	35	77
Al-Mohafada Street	36	64
Al-Dareba Street	60	85
Al-Tarbia Street	55	83

Table 4-26 Queues Length of Said Al-Assar Signalized Intersection

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Roudatain Street	20	66
Al-Mamalaje Street	55	70
Al-Jameaa Street	34	80
Ramadan NH	18	47

Table 4-27 Queues Length of Al-Mohafada Signalized Intersection

Approach Name	Queue Length (m)	Queue Length MAX(m)
Al-Abass Street	37	73
Al-Jayer Street	44	76
Al-Mohafada Street	34	83

4.9 Delay Comparison between the Roundabout before and after Changing

The first possible improvement to improve the roundabout is by setting a light signal through which the Roundabout is controlled at specific times (peak hours). The results of delay that were obtained from the PTV Vissim simulation program after converting the Roundabout to signalized Roundabout were presented in Table 4-10, Table 4-11, and Table 4-12.

The second proposal to improve traffic operation is converting the roundabout into a signalized intersection, the results obtained from the PTV Vissim after converting the Roundabout to the signalized intersection are shown in Table 4-22, Table 4-23, and Table 4-24.

During this analysis, the delay values for the roundabout will be compared before and after each proposed change separately. This will allow for a direct comparison of the effectiveness of each proposed solution in improving traffic flow and reducing delays.

4.9.1 Delay Comparison between Al-Tarbia before and after Changing

To make a delay comparison between the three cases Figure 4-4 Explains the difference in delay between cases where the delay decreased by 40%,35%,31%, and 21%, in Imam Hussein, Al-Mohafada, Al-Dareba, and Al-Tarbia Street when changing the roundabouts to signalized roundabouts respectively

Moreover, when comparing the new values of the delay with the LOS requirements of HCM2010, we notice that they did not change much, as they shifted from F to E for (Imam Hussein, Al-Dareba, and Al-Mohafada Street) and still in the same LOS (F) for Al-Tarbia Street. Where it becomes clear that the recent changes in the delay values were not sufficient to cause a significant change in the LOS of the Roundabout

Figure 4-4 also shows the delay values differ between Al-Tarbia roundabout and Al-Tarbia signalized intersection, where it will decrease by 77%, 68%, 67%, and 60% in Imam Hussein, Al-Mohafada, Al-Dareba and Al-Tarbia Street respectively

And when comparing the new values of the delay with the LOS requirements of HCM2010, It was noticed a significant drop in the delay, which converted the level of service (LOS) from F to D for Al-Mohafada, Al-Dareba and Al-Tarbia street approach and from F to C for Imam Hussein Street approach

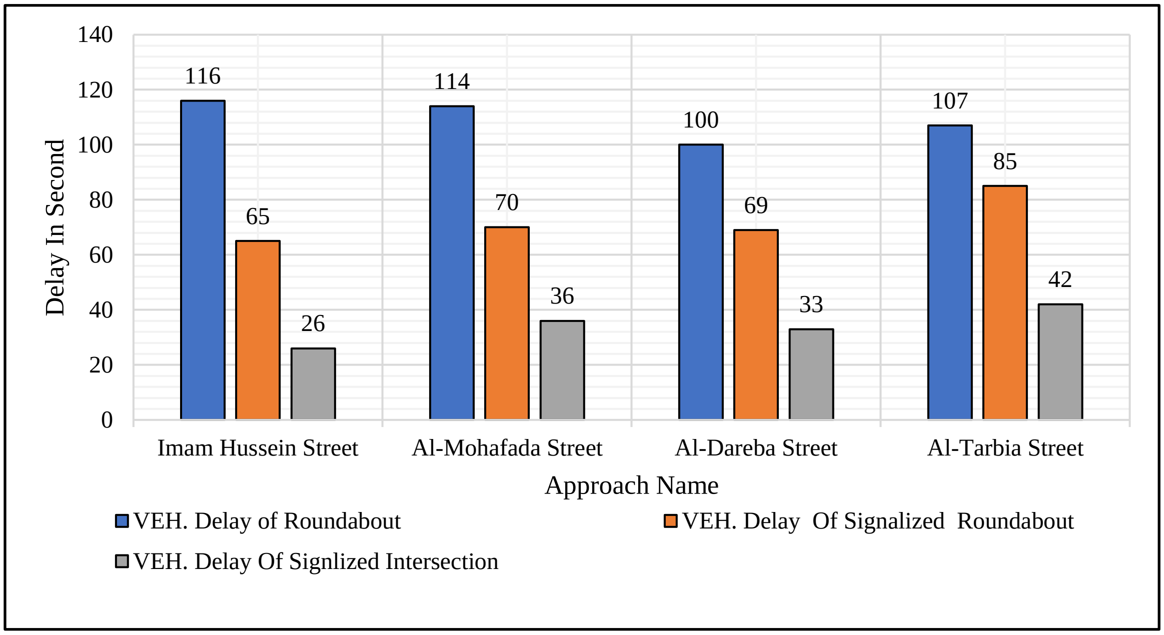


Figure 4-4 Comparison Figure between The Delay in AL-Tarbia Roundabout, Signalized Roundabout and Signalized Intersection

4.9.2 Delay Comparison between Said Al-Assar before and after Changing

Figure 4-5 demonstrate the difference in delay between Said Al-Assar Roundabout, Signalized Roundabout, and Signalized Intersection, where the delay decreased by 54%,46%,37%, and 63% respectively, in Al-Roudatain, Al-Mamalaje, Al-Jameaa street, and Ramadan NH when changing the roundabouts to signalized roundabouts

The new values of the delay compared to requirements of HCM2010, It appears that no significant change has occurred, as they shifted from F to E for (Al-Roudatain, Al-Mamalaje, and Al-Jameaa Street) and it shifted from E to D for Ramadan NH. Therefore, it is clear that the changes that occurred did not cause a significant change in the level of service. It is due to the high value of delay in reality, despite the decrease in delay by up to 63%.

Likewise Figure 4-5 shows the delay values differ between the Said Al-Assar Roundabout, and the Said Al-Assar signalized intersection, where it will decrease by 68%,67%,64%, and77% Al-Roudatain, Al-Mamalaje, Al-Jameaa Street, and Ramadan NH.

After matching the new delay values with the HCM2010 LOS specifications, there was a noticeable reduction in delays, increasing the level of service (LOS) for the Al-Roudatain, Al-Mamalaje, and Al-Jameaa street approach from F to D, and the Ramadan NH approach from F to C.

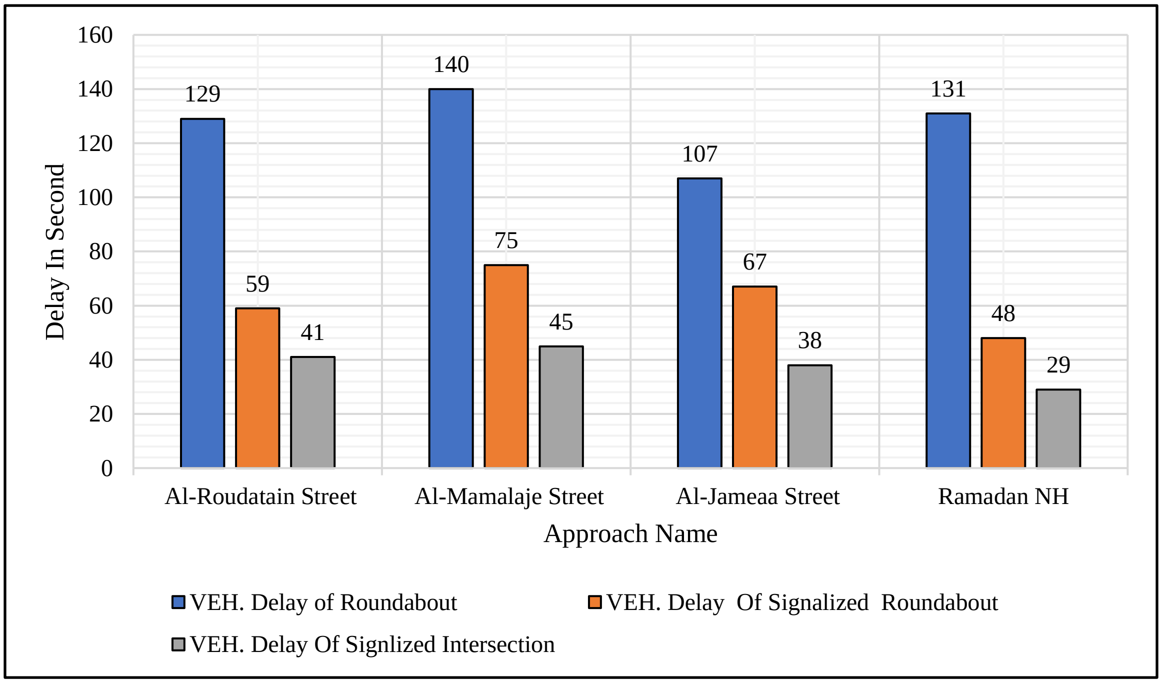


Figure 4-5 Comparison Figure between The Delay in Said Al-Assar Roundabout, Signalized Roundabout and Signalized Intersection

4.9.3 Delay Comparison Between Al-Mohafada Before and After Changing

Figure 4-6 illustrates how the Al-Mohafada roundabout and the Al-Mohafada signalized roundabout have different delay values. The delay decreased by 42%,53%, and 5% respectively in Al-Abass, Al-Jayer, and Al-Mohafada streets when changing the roundabouts to signalized roundabouts.

Furthermore, when comparing the new delay value to the HCM2010 LOS standards, it becomes clear that the transition from F to D has significantly changed the level of service in all approaches.

In the same way, Figure 4-6 shows the delay values differ between the Al-Mohafada Roundabout and Al-Mohafada signalized intersection. Where it will decrease by 62%,73%, and 42% in Al-Abass, Al-Jayer, and Al-Mohafada street

While evaluating the new values of the delay with the LOS requirements of HCM2010, it can be seen that the move from F to C results in a significantly decreased level of service in all approaches.

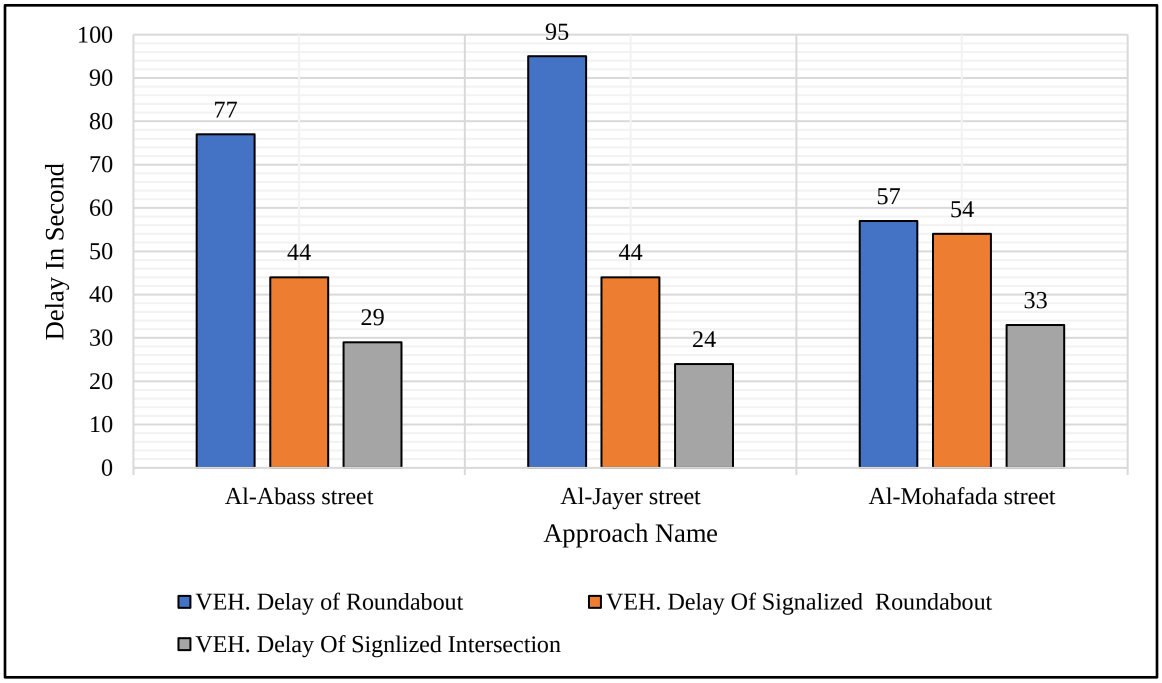


Figure 4-6 Comparison Figure between The Delay in Al-Mohafada Roundabout, Signalized Roundabout and Signalized Intersection signalized

4.10 Average Delay at Roundabouts Before and After Changing

When comparing the average delay in a roundabout generally, an apparent decrease in the average delay in all roundabouts will be noted, as has been explained in Figure 4-7.

- Al-Tarbia roundabout delay decreased when it was converted to the signalized roundabout by 30% and decreased even more than 67% when it was converted to a signalized intersection.
- Said Al-Assar roundabout decreased by 53% when it was diverted to a signalized roundabout, and an apparent decrease appeared when it was converted to a signalized intersection, as the delay decreased by 71%.
- Likewise, what happened to the Al-Mohafada Roundabout, which decreased by 38% when it was converted into a signalized roundabout and decreased by 61% when it was converted directly into a signalized intersection

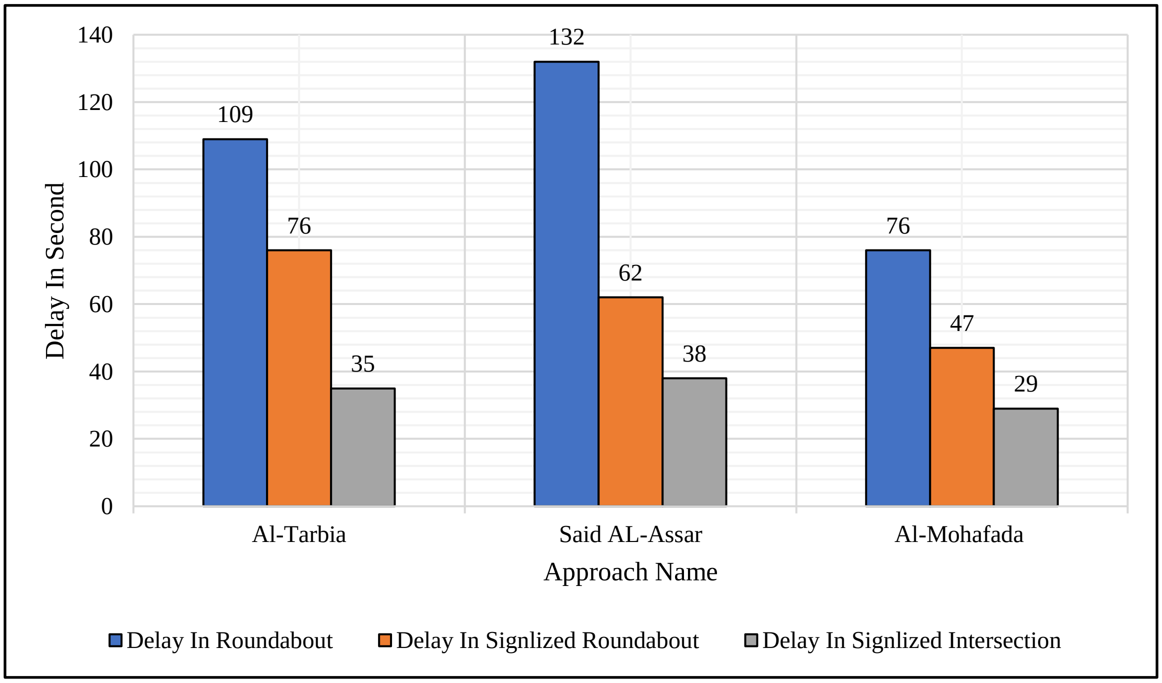


Figure 4-7 Comparison Average Delay in Roundabout Before and After Changing

After observing Figures 4-4, Figures 4-5, Figures 4-6 and Figures 4-7 above, it can be proved the positive effect on the critical indicator in the performance measuring of the roundabout (delay), a decrease was noticed in all the roundabouts when it was converted from the roundabout to a signalized roundabout, although there was no significant change in the level of service due to the delay time occurring at roundabout, the decrease did occur good and acceptable rates with conversion requirements (Install traffic lights)

4.11 Queue Length at Roundabout before and after Changing

The average queue length is an essential indicator at roundabout. therefore, the next section will discuss the queue length in roundabout, signalized roundabout, and signalized intersection for each roundabout separately.

4.12 Queue Length at Al-Tarbia Roundabout Before and After Changing

Figure 4-8 shows the queue length values differ between Al-Tarbia roundabout, signalized roundabout, and signalized intersection, where it displays all approaches of the roundabout separately as follows:

•Imam Hussein Street shows a decrease in the queue length values from 55m to 46m, which has decreased by 16%, While it decreased by 36% when converting it to a signalized intersection

•Al-Mohafada Street shows a decrease in the queue length values from 66m to 46m, which has decreased by 30%, While it decreased by 45% when converting it to a signalized intersection

•Al-Dareba Street shows a decrease in the queue length values from 73m to 63m, Which decreased by about 14%. While it decreased by 18% when converting it to a signalized intersection

•Al-Tarbia Street also show a decrease in the queue length values from 87m to 60, which decreased by about 31%. while it decreased by 36% when converting it to a signalized intersection

When the values of queue length are compared before, and after changing the roundabout into a signalized roundabout and a signalized intersection, it can be seen that the change had a positive impact. The average queue length in the signalized roundabout decreased by about 19%. Furthermore, when it was converted to a signalized intersection decreases by about 33%.

In general, the queue length of the signalized intersection decreased for all approaches, and according to HCM2010, the queue length is not considered a performance measure for the signalized intersection but rather gives a general behavior about the movement of the intersection.

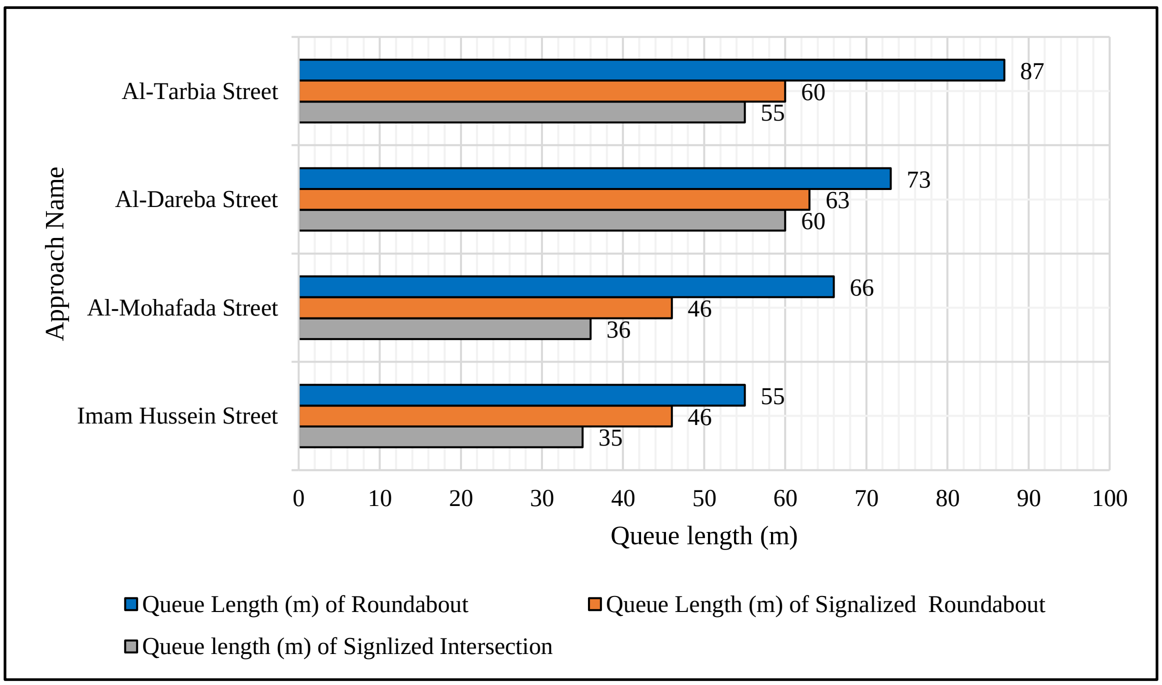


Figure 4-8 Comparison Chart between Queue Length in AL-Tarbia Roundabout, Signalized Roundabout and Signalized Intersection

4.12.1 Queue Length at Said Al-Assar Roundabout before and after Changing

Figure 4-9, the queue length values are displayed separately for each approach to the Said Al-Assar roundabout, signalized roundabout, and signalized intersection.

•Al-Roudatain Street shows a decrease in the queue length from 33m to 25m, which has decreased by 24%, While it decreased by 39% when converting it to a signalized intersection

•Al-Mamalaje Street shows a decrease in the queue length values from 61m to 59m, which has decreased by 3%, While it decreased by 10% when converting it to a signalized intersection

•Al-Jameaa Street shows a decrease in the queue length values from 53m to 50m, which decreased by about 6%, While it decreased by 35% when converting it to a signalized intersection

•and Ramadan NH also shows a decrease in the queue length values from 24m to 20, which only decreased by about 16%. While it decreased by 25% when converting it to a signalized intersection

when comparing the values with the Queue length before and after changing the roundabout into Signalized Roundabout and Signalized Intersection it will be noted the positive effect of the change, where the average queue length in the roundabout decrees by about 13% when converted to a signalized roundabout and decrease by about 27% when convert it to signalized intersection.

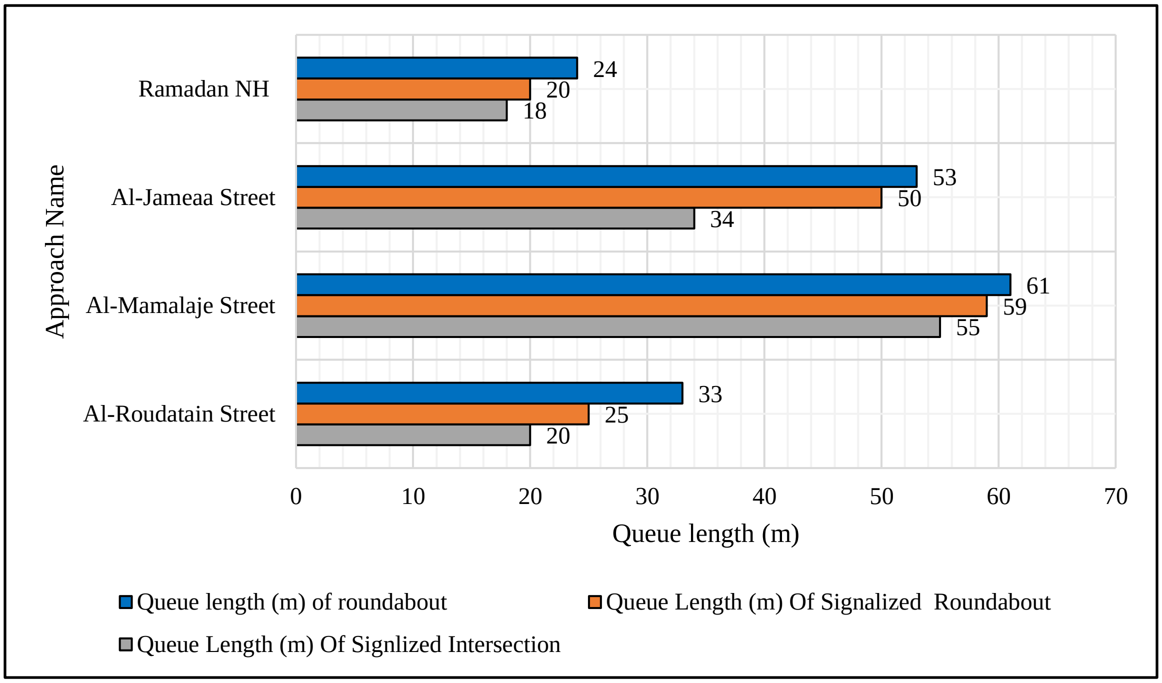


Figure 4-9 Comparison Chart between Queue Length in Said Al-Assar Roundabout, Signalized Roundabout and Signalized Intersection

4.12.2 Queue Length at Al-Mohafada Roundabout before and after Changing

Figure 4-10 shows the queue length values differ between Said Al-Assar Roundabout and Said Al-Assar signalized Roundabout, Where it displays all approaches of the roundabout separately as follows:

•Al-Abass Street shows a decrease in the queue length from 41m to 39m, which has increased by 5%. While it decreased by 10% when converting it to a signalized intersection

•Al-Jayer Street shows a decrease in the queue length values from 66m to 50m, which has decreased by 24%, while it decreased by 33% when converting it to a signalized intersection

•Al-Mohafada Street shows a decrease in the queue length values from 53m to 50m, which decreases by about 14%. While it decreased by 20% when converting it to a signalized intersection

The improvement had a favorable effect when the queue length values were contrasted before and after the roundabout was converted into a signalized roundabout and a signalized intersection. After the roundabout was changed to a signalized roundabout, the average queue length was dropped by about 14%, and when the roundabout was changed to a signalized intersection, it decreased by about 21%.

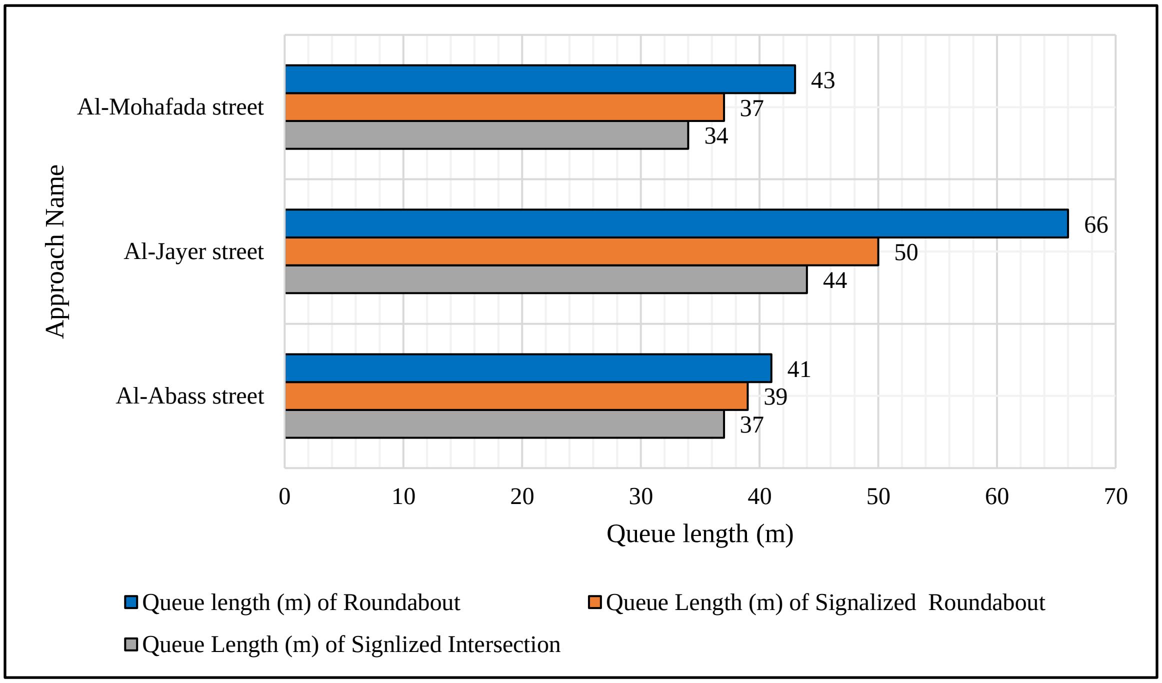


Figure 4-10 Comparison Chart between Queue Length in Al-Mohafada Roundabout, Signalized Roundabout and Signalized Intersection

The effect of changing the roundabouts from one case to another can be summarized in Table 4-28, which shows the increase and decrease in each approach of the roundabouts for all causes.

Table 4-28 Summaries of Effect Change between Three Cases

Roundabouts Name	Approach Name	% Delay Affected In Signalized Roundabout	% Delay Affected In Signalized Intersection	% Qlen Affected In Signalized Roundabout	% Qlen Affected In Signalized Intersection
AL-Tarbia	Imam Hussein	- 40%	- 77%	- 16%	- 36%
	Al-Mohafada	- 35%	- 68%	- 30%	- 45%
	Al-Dareba	- 31%	- 67%	- 14%	- 18%
	Al-Tarbia	- 20%	- 60%	- 31%	- 36%.
Said AL-Assar	Al-Roudatain	- 54%	- 68%	- 24%	- 39%
	Al-Mamalaje	- 46%	- 67%	- 3%	- 10%
	Al-Jameaa	- 37%	- 64%	- 6%	- 35%
	Ramadan NH	- 63%	- 77%	- 16%	- 25%
AL-Mohafada	Al-Abass	- 42%	- 62%	- 5%	- 10%
	Al-Jayer	- 53%	- 73%	- 24%	- 33%
	Al-Mohafada	- 5%	- 42%	- 14%	- 20%
Average Effect in Al-Tarbia Roundabout		- 30%	- 67%	- 22%	- 33%
Average Effect in Said Al-Assar Roundabout		- 53%	- 71%	- 13%	- 27%
Average Effect in Al-Mohafada Roundabout		- 38%	- 61%	- 14%	- 21%

4.13 Signalized Intersection in The Next 5 Years

After specifying and evaluating the Signalized intersection performance, this part will discuss the performance of the signalized intersection over five years, with a growth rate of traffic volumes of 3%, based on the Statistics Division of the Ministry of Planning.

A simulation was made for each intersection with a growth rate f 3% of the traffic volumes entering the intersection. The performance of the intersection was evaluated over the years shown in Figure 4-11

After checking Figure 4-11, the percentage of delay rate increased in Al-Tarbia Roundabout, where the delay increased by 154% in five years from its initial value in 2022 until 2027, and an annual increase of 10.8 Sec/year. and when comparing the delay values with the HCM2010 requirements, it is noted that the LOS has returned to Level E within three years and returned to LOS F after five years,

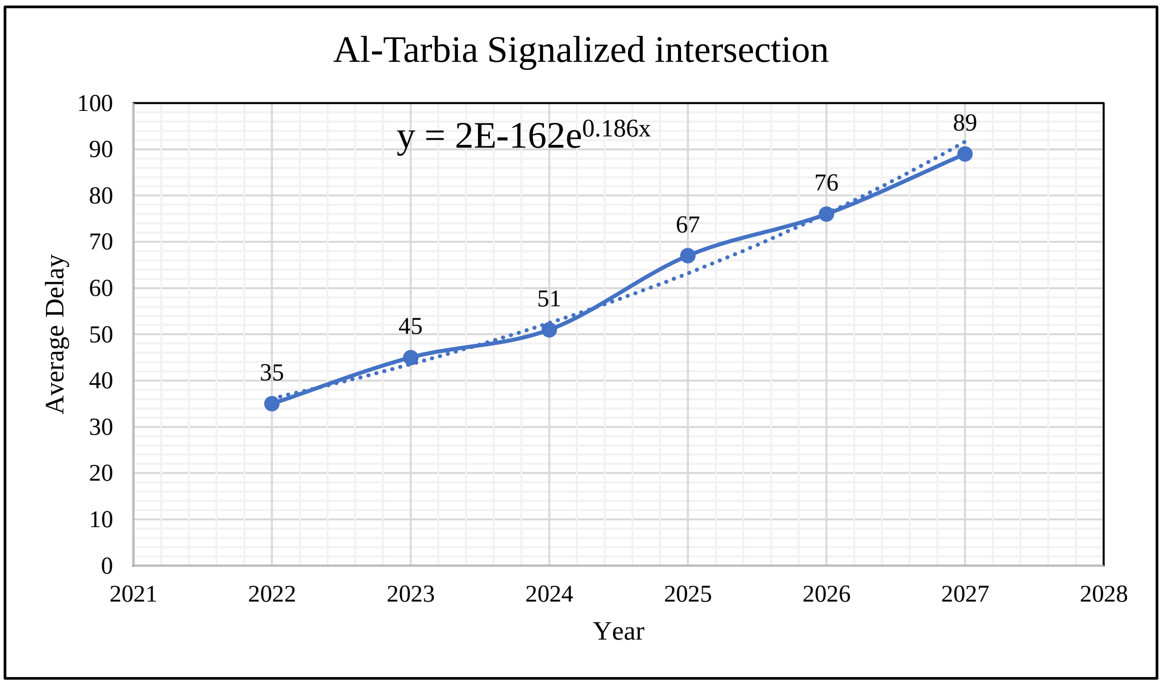


Figure 4-11 Curve of The Average Delay in the Next 5 Years In Al-Tarbia Signalized Intersection

When checking Figure 4-12, it is noted that the delay increased by 107% in five years from its initial value in 2022 until 2027, and an annual increase of 8.2 Sec/year. And when comparing the delay values with the HCM2010 requirements, it is noted that the LOS has returned to Level E within three years and returned to LOS F after six to seven years

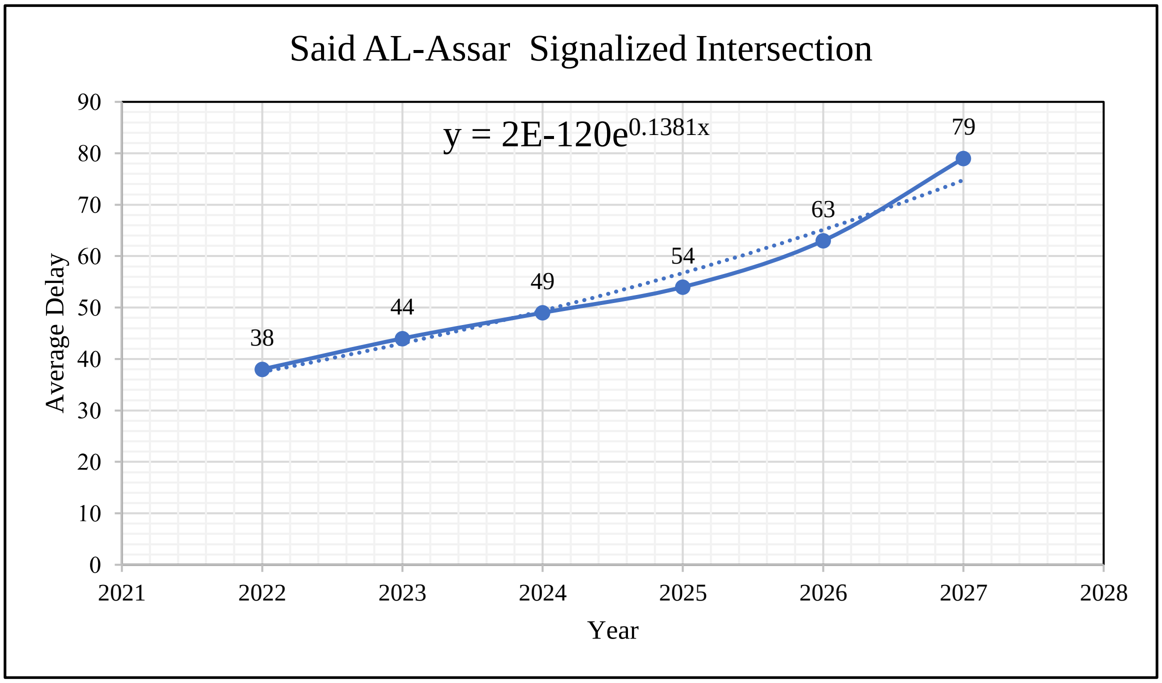


Figure 4-12 Curve of The Average Delay in The Next 5 Years in Said AL-Assar Signalized Intersection

Figure 4-13 The delay increased by 130% in five years from its initial value in 2022 until 2027, and an annual increase of 7.6 Sec/year. Moreover, When comparing the delay values with the HCM2010 requirements, it is noted that the LOS has returned to Level D within one year, to LOS E after five years, and to LOS F after six to seven years.

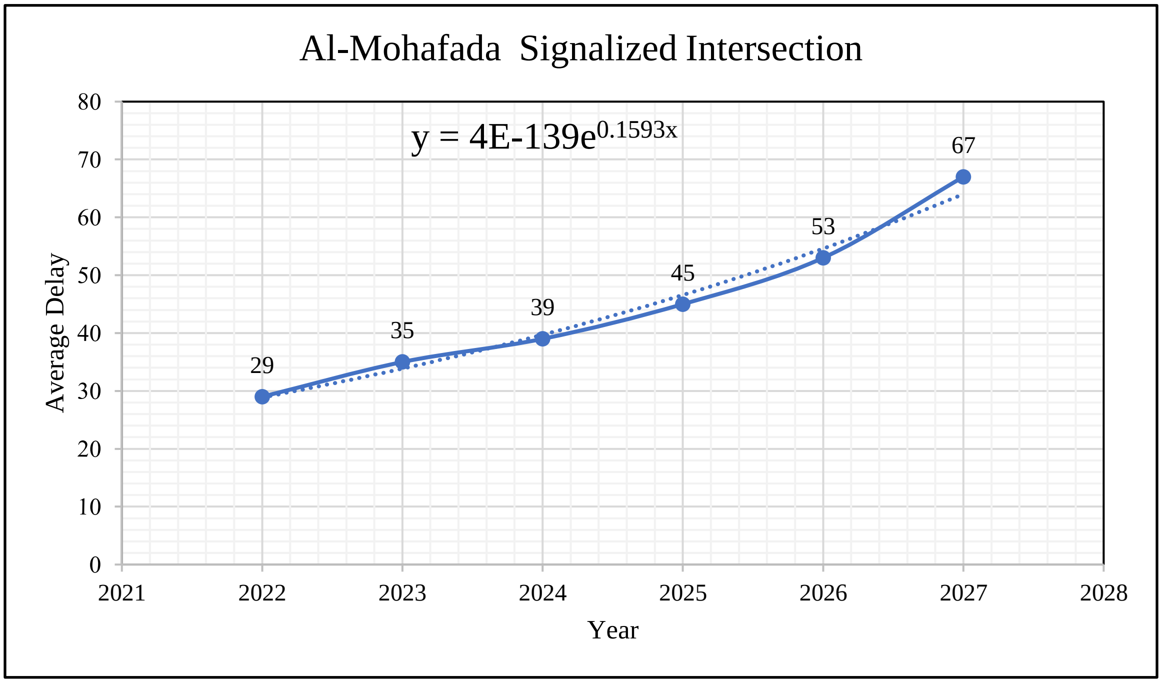


Figure 4-13 Curve of The Average Delay in The Next 5 Years in Al-Mohafada Signalized Intersection

The summary of all these Figures 4-11, Figures 4-12, Figures 4-13 is that the procedure of converting the roundabout to signalized intersection is also temporary, and work must be done on other additions to reduce the delay.

4.14 Affected Delay Values with an Increase in Traffic Volumes

This part discussed the relationship between the delay and the traffic volumes entering the roundabout. The values were calculated by providing the PTV Vissim with incremental values of traffic volumes (Arrival Rate V/S/L) and recording the delay values, so that Figure 4-14, Figure 4-15 and Figure 4-16 shows the increased delay with the increasing traffic volumes (Arrival Rate V/S/L), as shown

4.14.1 The General Behavior of Delay Values with an Increase in Traffic Volumes of Al-Tarbia Roundabout

Figure 4-14 shows a clear preference for the signalized intersection compared with the other types, as it provides the lowest value of delay compared to the highest value of arrival rate (v/s/l), but it starts with delay values higher than the roundabout and still higher until arrival rate 0.185 v/s/l. It is the arrival rate that the signalized intersection begins to have an advantage over the roundabout.

After this point, the delay in the signalized intersection will be less than it is at the roundabout. and it is preferable to change the roundabout into a signalized intersection

The roundabout's curve intersects with the signalized roundabout curve at the arrival rate of 0.315 v/s/l and a delay value of 63 seconds, which is the value that is preferable to put a light signal on the roundabout to control it in case of not wanting to convert it into a signalized roundabout.

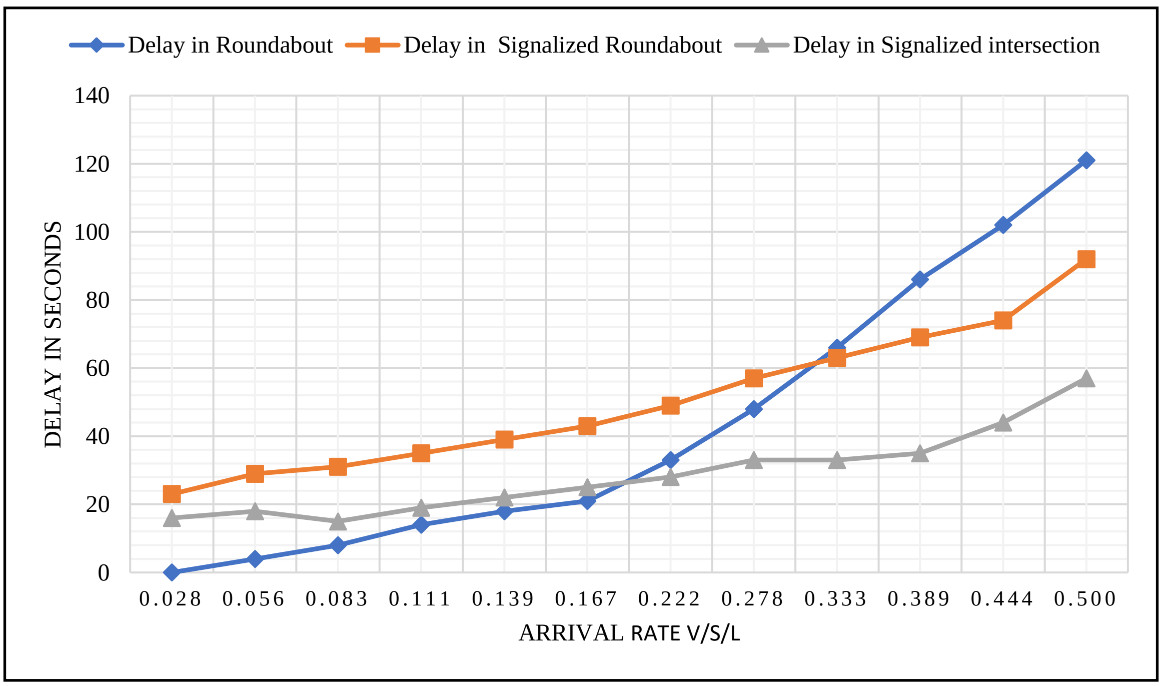


Figure 4-14 General Behaviour of Delay Values with Increase of Arrival Rate for Al-Tarbia Roundabout

4.14.2 The General Behavior of Delay Values with an Increase in Traffic Volumes of Said Al-Assar Roundabout

The signalized intersection is preferred over the other types, as shown in Figure 4-15, as it offers the lowest delay value relative to the highest arrival rate value (v/s/l). However, it initially experiences higher delay values than the roundabout and continues to show higher delay values until an arrival rate of 0.25 v/s/l, when the roundabout curve intersects signalized intersection curve and the delay in the signalized intersection is shorter than it is at the roundabout after this point.

Additionally, it is preferable to convert the roundabout to a signalized roundabout at an arrival rate of 0.3 v/s/l and a delay value of 55 seconds, where the roundabout's curve crosses with the signalized roundabout curve, it is ideal for installing a light signal to control it if the designer does not want to convert it into a signalized intersection.

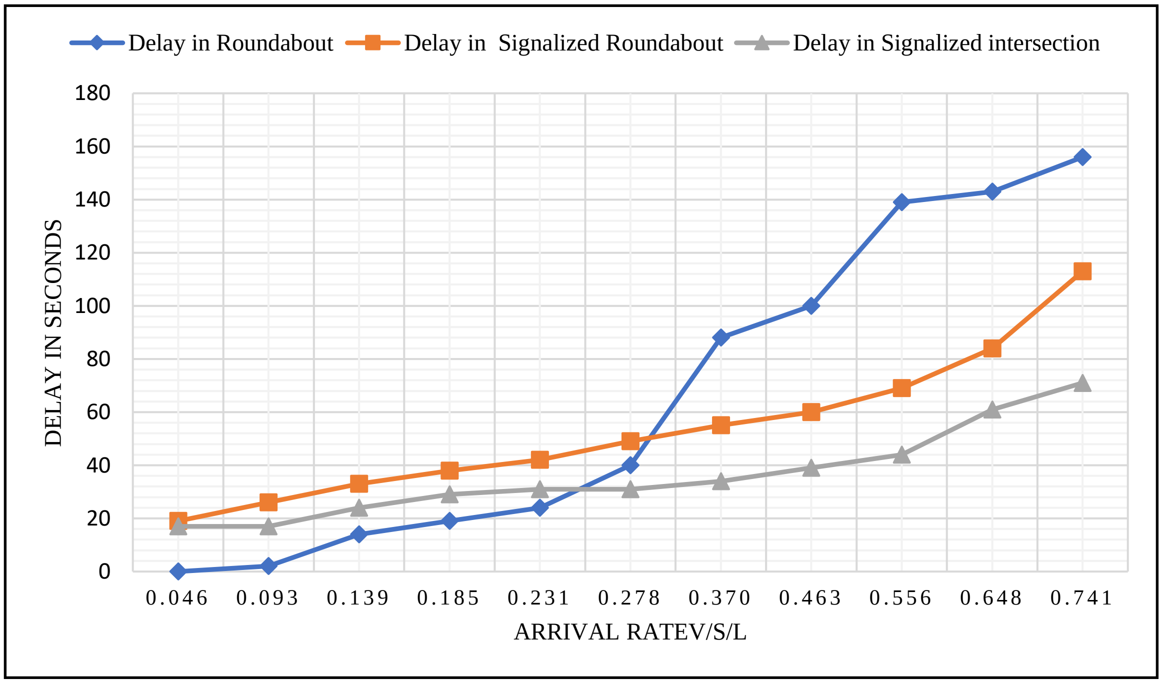


Figure 4-15 General Behaviour of Delay Values with Increase of Arrival Rate for Said Al-Assar Roundabout

4.14.3 The General Behavior of Delay Values with an Increase in Traffic Volumes of Al-Mohafada Roundabout

Figure 4-16 shows a better preference for the signalized intersection when compared with the signalized roundabout and roundabouts, especially at high traffic volumes, because it provides the lowest value of delay compared to the highest value of traffic volumes. signalized intersection starts with delay values higher than the roundabout and is still higher until the arrival rate is 0.188v/s/l. It is the arrival rate that the signalized intersection begins to have an advantage over the roundabout. After this point, the delay in the signalized intersection will be less than it is at the roundabout. Furthermore, it is preferable to change the roundabout into a signalized intersection. The signalized roundabout curve intersects with the roundabout's curve at the arrival rate of 0.25 v/s/l and delays value of 48 seconds. Therefore, it is preferable to put a light signal on the roundabout to control it if the responsible authorities do not wish to change it to a signalized intersection.

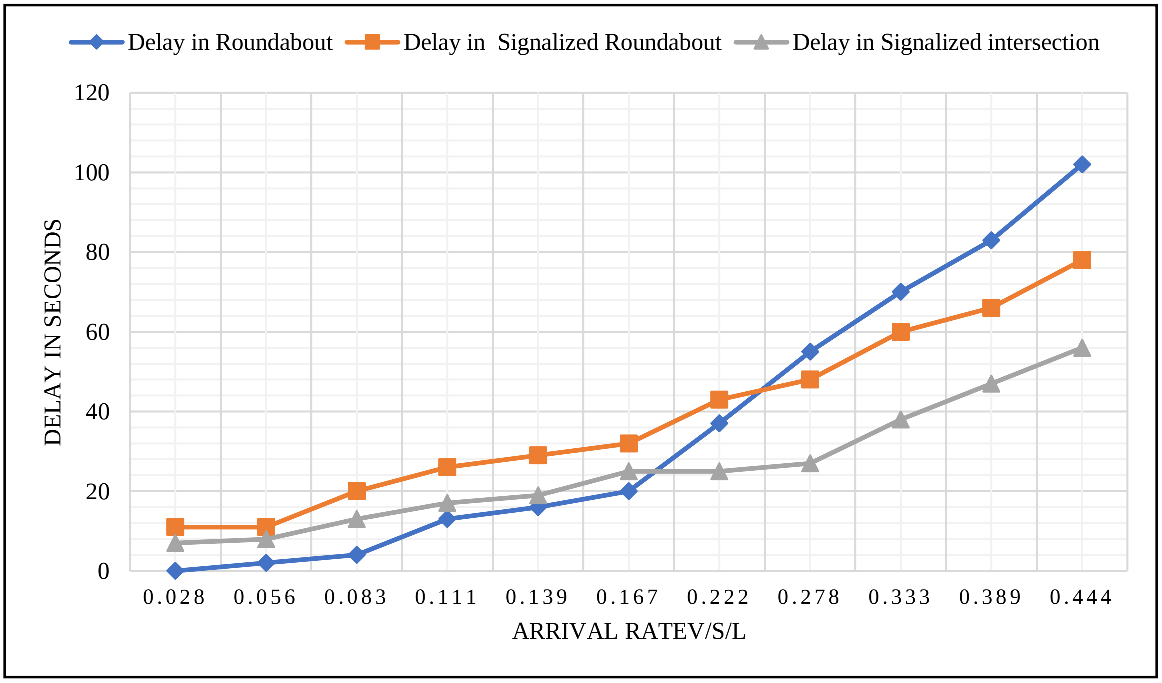
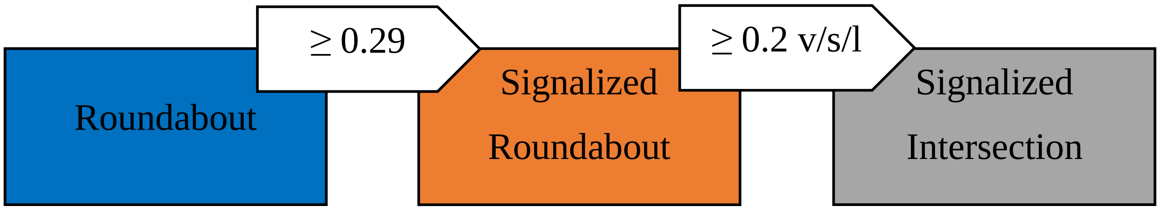


Figure 4-16 General Behaviour of Delay Values with Increase of Arrival Rate for AL-Mohafada Roundabout

4.15 Analyzing Results with Previous Research

From the values that were displayed in the previous figures, it can be concluded that the average critical arrival rate to separate between the three modes is 0.2 v/s/l and 0.29 v/s/l



When comparing the results with the researcher Yadeta, a discrepancy is noticed. The researcher determined the arrival rate of 0.1v/s/l that separates the use of the roundabout and signalized roundabout. While the results of this research were relatively more than this number, the arrival rate is 0.29. It is the separating boundary,

The arrival rate between the signalized intersection and roundabout was less than the values set by the researcher Yadeta to use the traffic intersection. The researcher specified the value of 0.64 v/s/l as a limit that must be reached, and then it is preferable to convert the roundabout to a signalized intersection, and this is more than the results obtained in this research, where it was the result of this search for reach rate is 0.2 v/s/l.

These differences may be due to many different points, essential methodologies, and research steps for each researcher. Although some points have a significant relationship in the results obtained, and some have a secondary relationship, all of these impacts lead to some differences between the results obtained from the two research.

4.15.1 The Main Differences in the Research Methodology

- Yadeta used a typical roundabout with two lines of four approaches, with a circumference of 100 meters for the outer lane, and each approach had two lines. It accommodates a maximum of 28 vehicles according to the CA system, which gives 28 cells per 100 meters, and each cell is a vehicle. The roundabouts that have been studied here are real roundabouts with four and three approaches and with a different number of lanes for each approach according to the situation and with different diameters. Their circumference average is 223 meters, i.e. according to the CA system, they accommodate approximately 63 vehicles for the outer lane in the roundabout. This difference explains the possibility of the large roundabout receiving vehicles with a higher arrival rate than the small roundabout that the researcher Yadeta studied, as the arrival rate is affected by the size of the roundabout. Logically, the large roundabout can accommodate traffic volumes more significantly than the small one. If we assume that the number of lanes will remain constant, will the arrival rate be affected if the roundabout has a circumference of 100 or 223 meters? Mostly it will be affected, and this topic can be studied in future research. Since the size of the roundabout studied is almost twice (2.23 times) the size of the roundabout studied by Yadeta. The arrival rate of the roundabout is affected by the size of the roundabout, which increased by nearly double. and increase size of the roundabout affects the time vehicle pass the roundabout, in addition to the time the vehicle stops at a traffic signal
- The other difference that significantly affects is the driving behavior in Iraq, which is calibrated as a heterogeneous behavior, where the researcher Yadeta relied on the behavior of the default program to

represent the traffic movement. This difference may lead to an apparent decrease in the possibility of using the signalized roundabout in developing countries, which consider this type of control method to be new and difficult to adhere to.

4.15.2 Minor Differences in Research Methodology

- The researcher distributed traffic volumes equally on all arms, with a percentage of 25% for each arm. this led to the availability of the best roundabout performance, while this part differed in this research. The different proportions depend on the reality of the situation, which reduces the performance of the roundabout .
- Three roundabouts of different shapes and dimensions were relied upon in the work of this research, while Yadeta relied on one typical roundabout.
- The researcher relied on a relatively old model, version 2007, compared to the program used in the research, version 2022, which provides the possibility of modification to most traffic characteristics and a behavioral approach between reality and the system built in the program.

4.16 Environmental Parameters

Many side factors are affected by changing the roundabout into a signalized roundabout and signalized Intersection like the quantity of carbon monoxide CO (gram), the quantity of nitrogen oxides NOx (gram), the quantity of volatile organic compounds VOC (gram), and fuel consumption (US liquid gallon). These parameters are studied, and the results show an apparent decrease in all criteria. Figure 4-17, Figure 4-18 and Figure 4-19 show a general decrease in the CO value; it decreased in the Al-Tarbia roundabout when it was transferred to the signalized roundabout by about 12%, while it decreased in the Said Al-Assar roundabout by about 19%, as well as in Al-Mohafada roundabout, where it decreased when it was transferred to the signalized roundabout by about 23%. The decrease appears more clearly when it is converted to a signalized intersection, where the decrease was about 44%, 33%, and 48% for the Al-Tarbia, Said Al-Assar, and Al-Mohafada Roundabout respectively

The value of NOx dropped in the Al-Tarbia roundabout when it converted to the signalized roundabout by about 10%. At the same time, it dropped in Said Al-Assar and Al-Mohafada roundabouts by about 17% and 25%, respectively. Furthermore, when it is converted to a signalized intersection, the decrease appears more clearly, where the decrease was about 21%, 42%, and 46% for the Al-Tarbia, Said Al-Assar, and Al-Mohafada Roundabout, respectively.

The figures show how much the VOC value is affected by the change in the roundabouts. The VOC dropped by about 19%, 16%, and 45% when Al-Tarbia, Said Al-Assar, and Al-Mohafada roundabouts, converted to a signalized roundabout. And when it is converted to a signalized intersection, the decrease appears more clearly, where the decrease was about 34%, 41%, and 70%, respectively.

Likewise, fuel consumption decreased by 16%, 24%, and 22% when converted to a signalized roundabout and decreased by 35%, 65%, and 44% when converted to a signalized intersection

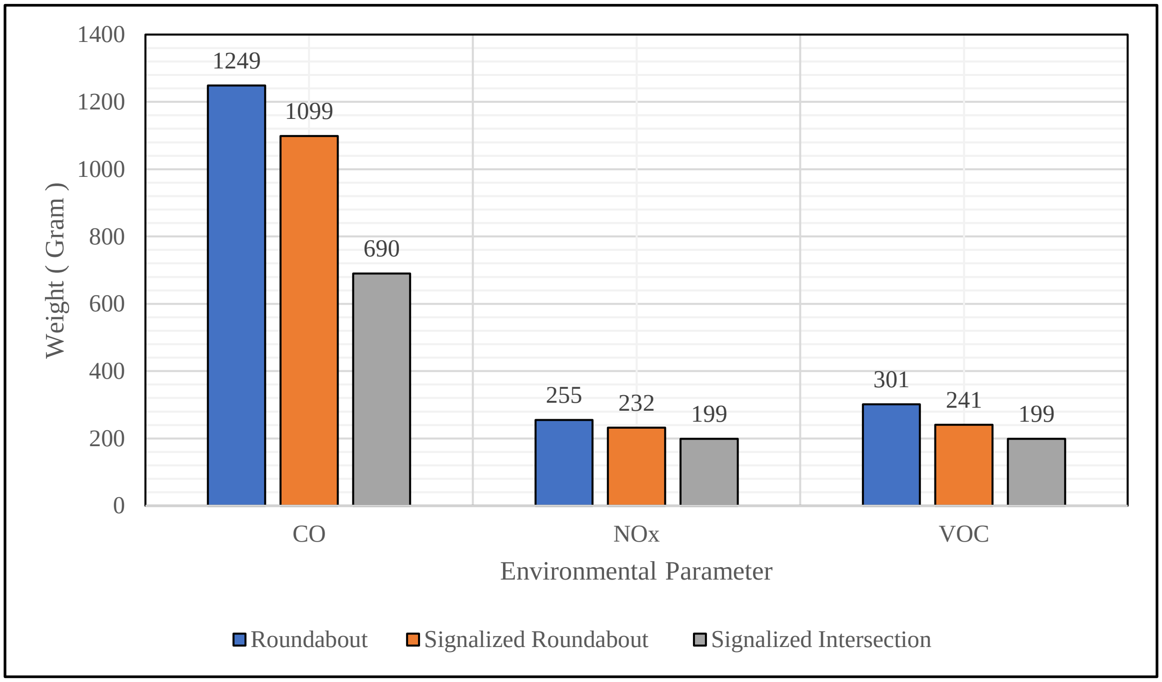


Figure 4-17 Affected of Environmental Parameters In Al-Tarbia Roundabout

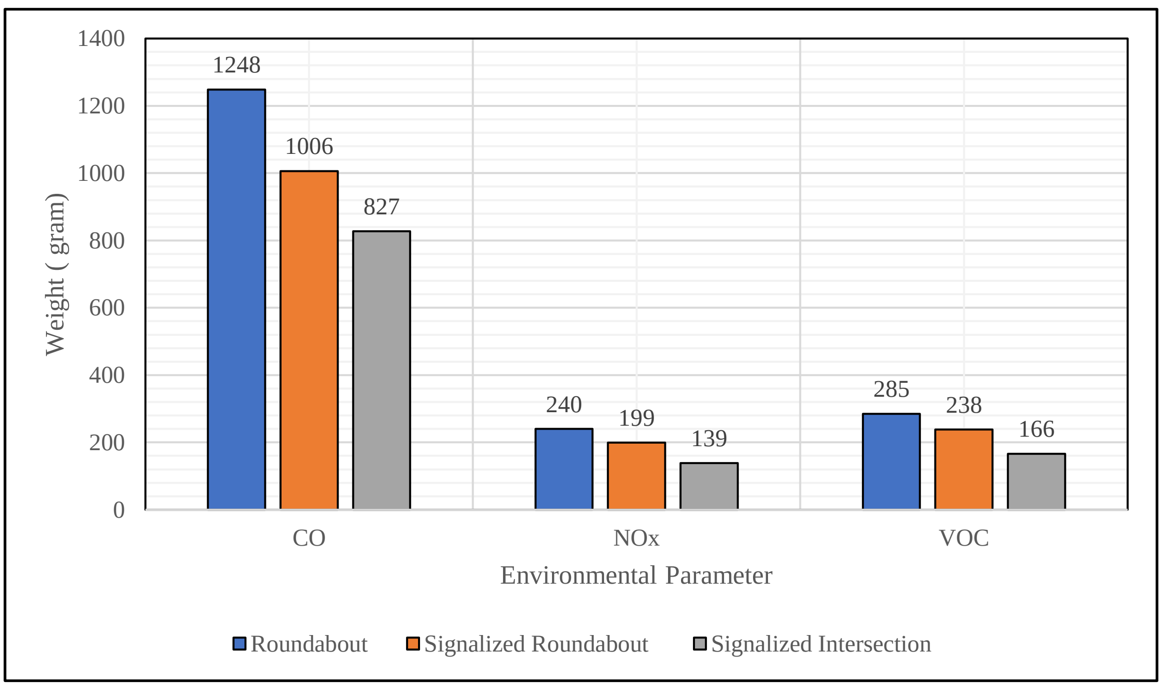


Figure 4-18 Affected of Environmental Parameters in Said AL-Assar Roundabout

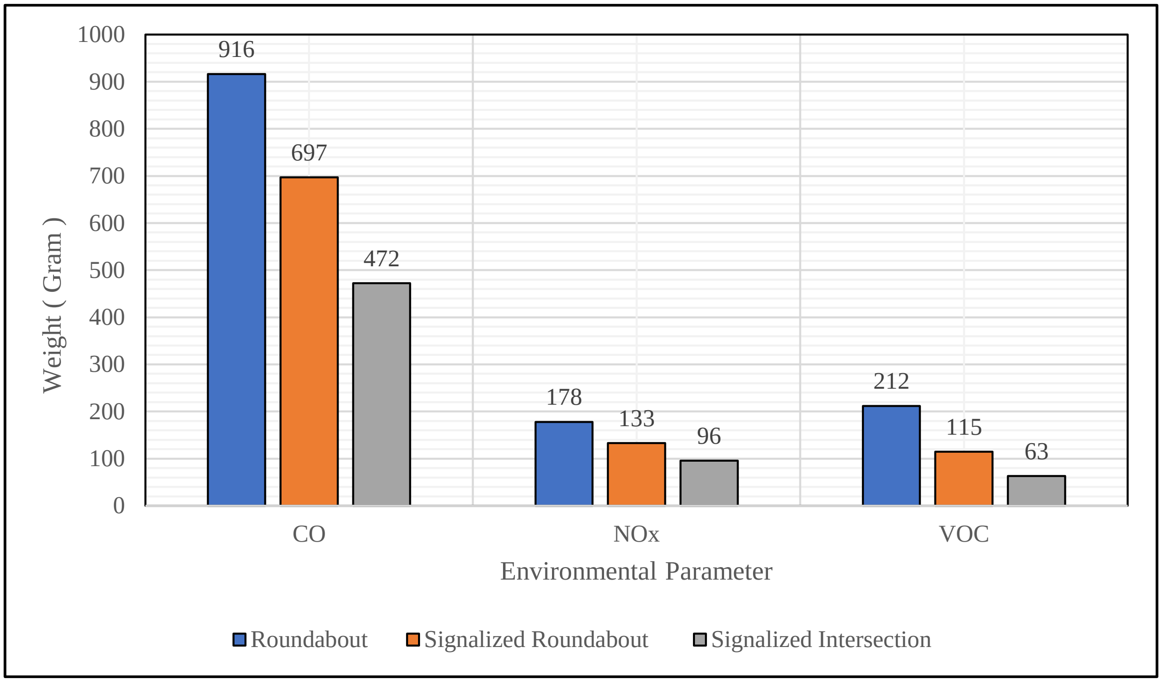


Figure 4-19 Affected of Environmental Parameters in Al-Mohafada Roundabout

Chapter Five:

Conclusions & Recommendations

Chapter Five

Conclusions & Recommendations

5.1 Conclusions

The significant results obtained in this research can be summarized as follows:

1- All roundabouts that have been studied contain at least three warrants to convert them into signalized intersections.

2- The optimal time for the traffic light at the AL-Tarbia, Al-Assar, and Al-Mohafada signalized intersections is 107, 100, and 50 seconds.

3- After comparing the value of the delay between reality and the model shown in PTV Vissim, it was found that the percentage of verification between the model built in the PTV Vissim program and reality is 87%, which is an acceptable percentage.

4- The level of service in all roundabouts currently is F, with a delay value exceeding the HCM requirements limit.

5- After converting the roundabout to a signalized roundabout, the delay values are reduced, but the level of service decreases slightly due to the large delay that the roundabouts face before converting them to signalized roundabouts. Delay at Al-Tarbia and Said Al-Assar roundabouts reduced by about 30% and 53%, and the LOS shifted from F to E. Al-Mohafada roundabout reduced by about 38%, and the LOS shifted from F to D with an average reduction of delay for all roundabouts 40% and average queue length reduce by about 16%.

6- When converting the roundabout to signalized intersections, a significant decrease in the delay time and an enhancement in the level of service were observed in all roundabouts. The delay was reduced by about 67% and

71%, And the LOS shifted from F to D at Al-Tarbia and Said Al-Assar Roundabout and was reduced by about 61%, and the LOS shifted from F to C at Al-Mohafada Roundabout with an average reduced delay for all roundabouts about 66 %, and average queue length decreased by about 27%.

7- When studying the effect of traffic volumes on the performance of the roundabout and comparing the three cases that have been studied (roundabout, signalized roundabout, and signalized intersections), the following point appears.

- In the AL-Tarbia, Said AL-Assar, and Al-Mohafada roundabouts, at an arrival rate of 0.185, 0.25, and 0.188 v/s/l, respectively, after which it is preferable to convert the roundabouts to signalized intersections. After this arrival rate, the delay time becomes less at signalized intersections than at the roundabout.
- In the AL-Tarbia, Said AL-Assar, and Al-Mohafada Roundabouts, with arrival rates 0.315, 0.3, and 0.25 v/s/l, respectively, it is preferable to convert the roundabout into a signalized roundabout, as the delay time becomes less than it is in a regular roundabout. This case is helpful if the official is unwilling to change the roundabout into a traffic light or to use it at certain times of the day.

8- When studying the effect of the growth rate of traffic volumes on the level of service at the studied intersections, it was found that most of the traffic lights will return to the level of service F in a few years that do not exceed five years. It indicates that the problem is more significant than a specific intersection or roundabout, so radical solutions must be developed for the problem.

9- The change in the roundabout to a signalized roundabout and signalized intersections shows an apparent effect on the environmental Parameters CO, NOx, VOC, and Fuel consumption, as all factors decreased in different proportions.

5.2 Recommendations

1- Converting the (AL-Tarbia, Said AL-Assar, and AL-Mohafada) roundabouts to signalized intersections, as it greatly enhances the level of service.
2- Considering the growth of transportation, constructively interchange infrastructure is appreciable to solve the congestion problem after five years.
3- Simulation of the change is promising to evaluate any alternative transportation system to solve the congestion problem.
4- Installing a traffic light on previously working roundabouts is advantageous because it reduces roundabout delay time and can be used partially during peak times.
5- Making a comprehensive plan to develop the traffic system in Karbala, as converting a specific roundabout into signalized roundabouts or a signalized intersection, is a temporary solution that disappears over time.
6- Transferring of governmental and service departments from the city center to prevent the merging between tourist and administrative centers in the city center.
7- Supporting public transportation and implement new transportation methods to reduce the traffic volumes that increase dramatically due to clear impact in the coming years.

5.3 Recommendations for Future Research

1- To start finding values for the parameters needed by the simulation programs to help calibrate the programs and obtain values that provide higher accuracy for traffic modeling in Iraq.

2- To conduct a simulation study to convert the roundabout site into an interchange.

3- A study of the effect of the size roundabout on the arrival rate of vehicles reaching it.

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Appendix-A

Cycle Length Design

Cycle Length Design

If tLi is the start-up lost time for a phase $\boldsymbol{i}$, then the total start-up lost time per cycle

$\boldsymbol{L = \sum_{i=1}^{N} t_{li}}$ where N is the number of phases. If start-up lost time is same for all phases, then the total start-up lost time is $\boldsymbol{L = N\,t_l}$.

If C is the cycle length in seconds, then the

$$\boldsymbol{number\ of\ cycles\ per\ hour = 3600/c}$$

The total lost time per hour is the number of cycles per hour times the

$$\boldsymbol{lost\ time\ per\ cycle\ and\ is = 3600 * L/c}$$

Substituting as $\boldsymbol{L = Nt_l}$

$$\boldsymbol{total\ lost\ time\ per\ hour\ can\ be\ written\ as = \frac{3600\,N\,t}{C}}$$

The total effective green time $\boldsymbol{T_g}$ available for the movement in

a hour will be one hour minus the total lost time in an hour. Therefore,

$$\boldsymbol{T_g = 3600 - \frac{3600 * N * t_L}{C}}$$

$$\boldsymbol{T_g = 3600\left[1 - \frac{N * t_L}{C}\right]}$$

Let the total number of critical lane volume that can be accommodated per hour is given by Vc,

$$\boldsymbol{Vc = \frac{T_g}{h}}$$

$\boldsymbol{h}$ is the saturation headway in seconds.

the expression for $\boldsymbol{C}$ can be obtained as follows:

$$\boldsymbol{VC = \frac{3600}{h}\left[1 - \frac{N * t_L}{C}\right]}$$

$$\therefore Si = \frac{3600}{h}$$

$\boldsymbol{Si}$ is the saturation flow rate in vehicles per hour of green time per lane,

$$\therefore C = \frac{N\,t_L}{1 - \frac{V_c}{S_i}}$$

Or follow Webster equations

$$C_o = \frac{1.5 * L + 5}{1 - \sum \frac{V}{S}}$$

C_o is optimal cycle length in seconds, generally the following 5 sec

L The total amount of time lost is made up of two parts:

the time lost at the start (When a traffic light passes from red (stop) to green (go)) and the time lost at the end to clearance the intersections.

When a traffic light passes from red (stop) to green (go), this is called "start-up lost time" (go).

V/s is Design flow rate to saturation flow rate for each phase's critical approach or channel

Cycle Length Design for Altarbia Roundabout

The cycle time was calculated based on the Webster equation

$\therefore C_o = \frac{1.5*L+5}{1-\sum\frac{V}{S}}$

$L =$ 16 second from (Table 10-17) in HCM2000

$\therefore NO.phases = 4$

$V = 1641$ veh/hour for 5 lanes (from peak hour without right turn)

$V = 329$ veh/hour/lane phase 1

$V = 474$ veh/hour/lane phase 2

$V = 483$ veh/hour/lane phase 3

$V = 465$ veh/hour/lane phase 4

$\therefore\ Si = \frac{3600}{h}\ \therefore h = 1.5\ \therefore Si = \frac{3600}{1.5} = 2400$

$$\therefore C_o = \frac{1.5 * 16 + 5}{1 - \sum \frac{329 + 474 + 483 + 465}{2400}} = 107\ sec$$

$t_g = C_O - L_t$

$t_g = 107 - (16)$

$t_g = 91\ sec$

$$\therefore gi = \left[\frac{V_C}{\sum_{i=1}^{N} VC}\right] * t_g$$

For Al-Tarbia street approach

$$\therefore gi = \left[\frac{1641}{5905}\right] * 91$$

$\therefore gi = 26\ sec$

For Imam Hussein street approach

$$\therefore gi = \left[\frac{1420}{5905}\right] * 91$$

$\therefore gi = 22\ sec$

For AL-dareba street approach

$$\therefore gi = \left[\frac{1449}{5905}\right] * 91$$

$\therefore gi = 22\ sec$

For Al-Al-Mohafada street approach

$$\therefore gi = \left[\frac{1395}{5905}\right] * 91$$

$\therefore gi = 21\ sec$

Cycle Length Design for Said Alassar Roundabout

The cycle time was calculated based on the Webster equation

$\therefore C_o = \frac{1.5*L+5}{1-\sum\frac{V}{S}}$

$L =$ 16 second from (Table 10-17) in HCM2000

$\therefore NO.phases = 4$

$V = 2667$ veh/hour for 3 lanes

$V = 889$ veh/hour/lane phase 1

$V = 136$veh/hour/lane phase 2

$V = 355$veh/hour/lane phase 3

$V = 355$veh/hour/lane phase 4

$\therefore\ Si = \frac{3600}{h}\ \therefore h = 1.5 \quad \therefore Si = \frac{3600}{1.5} = 2400$

$$\therefore C_o = \frac{1.5 * 12 + 5}{1 - \sum\frac{889 + 136 + 355 + 327}{2400}} = 100\ sec$$

$t_g = C_O - L_t$

$t_g = 100 - (16)$

$t_g = 84$ sec

$$\therefore gi = \left[\frac{V_C}{\sum_{i=1}^{N} VC}\right] * t_g$$

For Al-Mamalaje street approach

$$\therefore gi = \left[\frac{2667}{4983}\right] * 84$$

$\therefore gi = 42\ sec$

For Ramadan neighborhood approach

$$\therefore gi = \left[\frac{272}{4983}\right] * 84$$

$\therefore gi = 6\ sec$

For AL-Roudatain street approach

$$\therefore gi = \left\lceil \frac{1064}{4983} \right\rceil * 84$$

$$\therefore gi = 19\ sec$$

For Al-Jameaa street approach

$$\therefore gi = \left\lceil \frac{980}{4983} \right\rceil * 84$$

$$\therefore gi = 17\ sec$$

Cycle Length Design for Al-Mohafada Roundabout

The cycle time was calculated based on the Webster equation

$$\therefore C_o = \frac{1.5 * L + 5}{1 - \sum \frac{V}{S}}$$

$L =$ 12 second from (Table 10-17) in HCM2000

$$\therefore NO.phases = 3$$

$V = 326$ veh/hour/lane phase 1

$V = 347$veh/hour/lane phase 2

$V = 320$veh/hour/lane phase 3

$$\therefore\ Si = \frac{3600}{h} \ \therefore h = 1.5 \quad \therefore Si = \frac{3600}{1.5} = 2400$$

$$\therefore C_o = \frac{1.5 * 12 + 5}{1 - \sum \frac{326 + 347 + 320}{2400}} = 50\ sec$$

$$t_g = C_O - L_t$$

$$t_g = 50 - (12)$$

$t_g = 38$ sec

$$\therefore gi = \left\lceil \frac{V_C}{\sum_{i=1}^{N} VC} \right\rceil * t_g$$

For Al-Jaer street approach

$$\therefore gi = \left\lceil \frac{1304}{3997} \right\rceil * 38$$

$\therefore gi = 12\ sec$

For Al-Tarbia street approach

$$\therefore gi = \left[\frac{1735}{3997}\right] * 38$$

$\therefore gi = 16sec$

For Imam Abass street approach

$$\therefore gi = \left[\frac{960}{3997}\right] * 38$$

$\therefore gi = 10\ sec$

Appendix-B

Sample of Traffic Volume

in The Peak Hour

Table B-1 Traffic Volume of Al-Tarbia Roundabout 1/10/2022 (Saturday)

Vedio Record Time	Almohafada Street	Al-Dareba Street	Al-Tarbia Street	Imam Hussein Street	Total 15 min
07:30-07:45	360	160	462	238	1220
07:45-08:00	431	288	465	272	1456
08:00-08:15	300	335	445	341	1421
08:15-08:30	348	259	450	283	1340
Total	1439	1042	1822	1134	5437
12:30-12:45	348	288	407	254	1297
12:45-13:00	320	370	400	278	1368
13:00-13:15	389	419	465	283	1556
13:15-13:30	317	346	393	280	1336
Total	1374	1423	1665	1095	5557
19:30-19:45	433	438	508	447	1826
19:45-20:00	413	450	520	436	1819
20:00-20:15	435	453	516	451	1855
20:15-20:30	428	418	521	426	1793
Total	1709	1759	2065	1760	7293

Table B-2 Traffic Volume of Al-Tarbia Roundabout 2/10/2022 (Sunday)

Video Record Time	Al-Mohafada Street	Al-Dareba Street	Al-Tarbia Street	Imam Hussein Street	Total 15 min
07:30-07:45	392	368	489	296	1545
07:45-08:00	379	402	493	310	1584
08:00-08:15	404	421	514	365	1704
08:15-08:30	470	400	508	394	1772
Total	1645	1591	2004	1365	6605
12:30-12:45	353	382	465	423	1623
12:45-13:00	451	383	472	408	1714
13:00-13:15	432	360	487	421	1700
13:15-13:30	426	367	501	423	1717
Total	1662	1492	1925	1675	6754
19:30-19:45	423	469	531	420	1843

19:45-20:00	414	502	568	426	1910
20:00-20:15	431	521	545	432	1929
20:15-20:30	437	526	564	415	1942
Total	1705	2018	2208	1693	7624

Table B-3 Traffic Volume of Al-Tarbia Roundabout 4/10/2022 (Tuesday)

Video Record Time	Al-Mohafada Street	Al-Dareba Street	Al-Tarbia Street	Imam Hussein Street	Total 15 min
07:30-07:45	397	389	477	402	1665
07:45-08:00	400	381	504	393	1678
08:00-08:15	409	381	502	386	1678
08:15-08:30	388	375	472	381	1616
Total	1594	1526	1955	1562	6637
12:30-12:45	422	399	496	407	1724
12:45-13:00	432	399	533	454	1818
13:00-13:15	432	394	541	432	1799
13:15-13:30	433	380	523	393	1729
Total	1719	1572	2093	1686	7070
Video Record Time	Al-Mohafada Street	Al-Dareba Street	Al-Tarbia Street	Imam Hussein Street	Total 15 min
19:30-19:45	442	498	530	453	1923
19:45-20:00	449	463	541	463	1916
20:00-20:15	439	462	558	483	1942
20:15-20:30	413	504	545	480	1942
Total	1743	1927	2174	1879	7723

Table B-4 Traffic Volume of Al-Tarbia Roundabout 6/10/2022 (Thursday)

Video Record Time	Al-Mohafada Street	Al-Dareba Street	Al-Tarbia Street	Imam Hussein Street	Total 15 min
07:30-07:45	401	397	503	427	1728
07:45-08:00	407	407	532	436	1782
08:00-08:15	409	411	506	427	1753
08:15-08:30	401	406	519	453	1779
Total	1618	1621	2060	1743	7042
12:30-12:45	414	413	477	404	1708
12:45-13:00	404	410	497	453	1764
13:00-13:15	417	396	486	414	1713
13:15-13:30	426	398	511	418	1753
Total	1661	1617	1971	1689	6938
19:30-19:45	462	479	494	463	1898
19:45-20:00	499	506	502	474	1981
20:00-20:15	467	469	599	485	2020
20:15-20:30	498	483	586	473	2040
Total	1926	1937	2181	1895	7939

Table B-5 Said Al-Assar Roundabout 1/10/2022 (Saturday)

Video Record Time	Al-Jameaa Street	Al-Roudatain Street	Al-Mamalaje Street	Ramadan Neighborhood	Total 15 min
07:30-07:45	179	252	400	59	890
07:45-08:00	231	265	495	52	1043
08:00-08:15	230	285	445	50	1010
08:15-08:30	188	218	425	65	896
Total	828	1020	1765	226	3839
12:30-12:45	187	213	371	51	822
12:45-13:00	236	238	458	59	991
13:00-13:15	232	274	473	77	1056
13:15-13:30	170	216	378	46	810
Total	825	941	1680	233	3679
19:30-19:45	213	244		53	934

19:45-20:00	224	267	437	71	999
20:00-20:15	257	257	494	72	1080
20:15-20:30	214	220	453	57	944
Total	908	988	1808	253	3957

Table B-6 Traffic Volume of Said Al-Assar Roundabout 2/10/2022 (Sunday)

Vedio Record Time	Al-Jameaa Street	Al-Roudatain Street	Al-Mamalaje Street	Ramadan Neighborhood	Total 15 min
07:30-07:45	217	313	565	78	1173
07:45-08:00	291	398	628	64	1381
08:00-08:15	310	355	651	69	1385
08:15-08:30	202	259	581	94	1136
Total	1020	1325	2425	305	5075
12:30-12:45	260	320	614	81	1275
12:45-13:00	338	380	681	95	1494
13:00-13:15	379	404	722	93	1598
13:15-13:30	275	308	613	79	1275
Total	1252	1412	2630	348	5642
19:30-19:45	362	399	713	85	1559
19:45-20:00	327	380	889	97	1693
20:00-20:15	304	346	756	87	1493
20:15-20:30	298	305	636	75	1314
Total	1291	1430	2994	344	6059

Table B-7 Traffic Volume of Said Al-Assar Roundabout 4/10/2022 (Tuesday)

Video Record Time	Al-Jameaa Street	Al-Roudatain Street	Al-Mamalaje Street	Ramadan Neighborhood	Total 15 min
07:30-07:45	237	345	644	66	1292
07:45-08:00	426	350	757	105	1638
08:00-08:15	308	359	662	88	1417
08:15-08:30	274	319	588	63	1244
Total	1245	1373	2651	322	5591
12:30-12:45	380	412	710	103	1605

12:45-13:00	269	340	788	99	1496
13:00-13:15	295	340	636	83	1354
13:15-13:30	267	371	543	82	1263
Total	1211	1463	2677	367	5718
19:30-19:45	393	406	644	103	1546
19:45-20:00	326	404	623	97	1450
20:00-20:15	327	380	685	91	1483
20:15-20:30	240	338	686	76	1340
Total	1286	1528	2638	367	5819

Table B-8 Traffic volume of Said Al-Assar Roundabout 6/10/2022 (Thursday)

Vedio Record Time	Al-Jameaa Street	Al-Roudatain Street	Al-Mamalaje Street	Ramadan Neighborhood	Total 15 min
07:30-07:45	247	367	608	77	1299
07:45-08:00	399	302	763	104	1568
08:00-08:15	321	370	675	85	1451
08:15-08:30	260	295	592	80	1227
Total	1227	1334	2638	346	5545
12:30-12:45	289	359	637	90	1375
12:45-13:00	340	414	776	95	1625
13:00-13:15	328	398	722	104	1552
13:15-13:30	271	352	495	90	1208
Total	1228	1523	2630	379	5760
19:30-19:45	377	356	606	90	1429
19:45-20:00	326	397	679	102	1504
20:00-20:15	341	394	724	92	1551
20:15-20:30	280	348	737	102	1467
Total	1324	1495	2746	386	5951

Appendix-C

The Layout of Signalized Intersection in PTV Vissim 2022

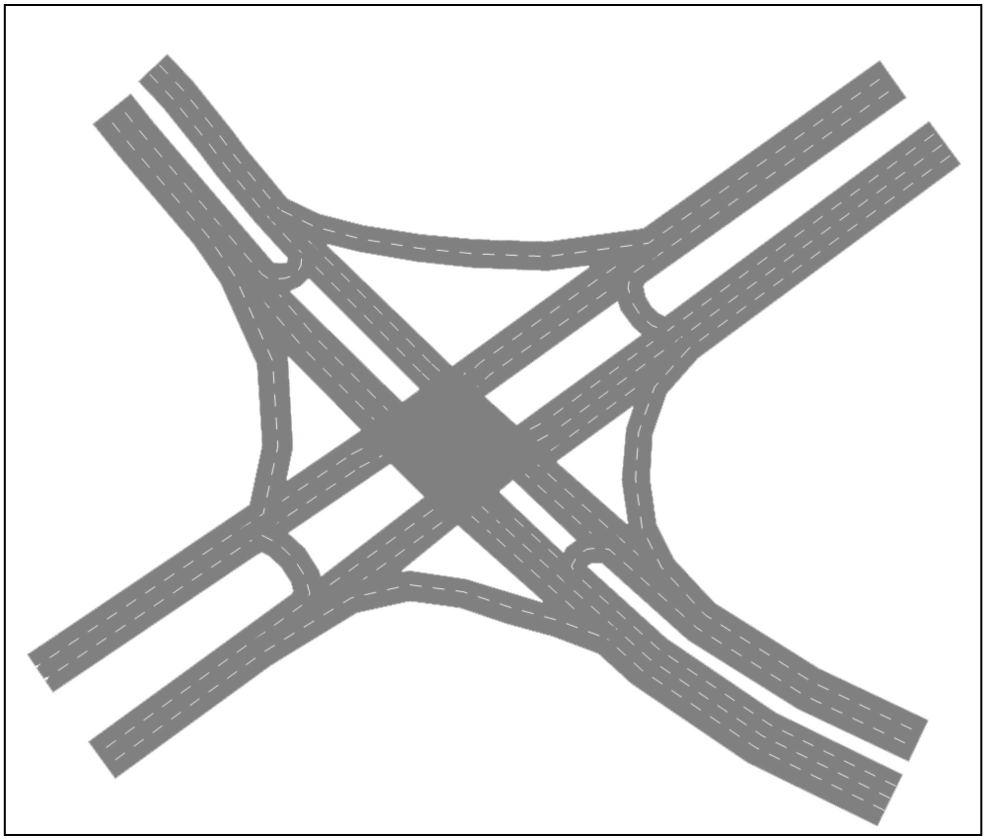

Figure C-1 Model of Signalized Intersection of AL-Tarbia Roundabout In PTV Vissim

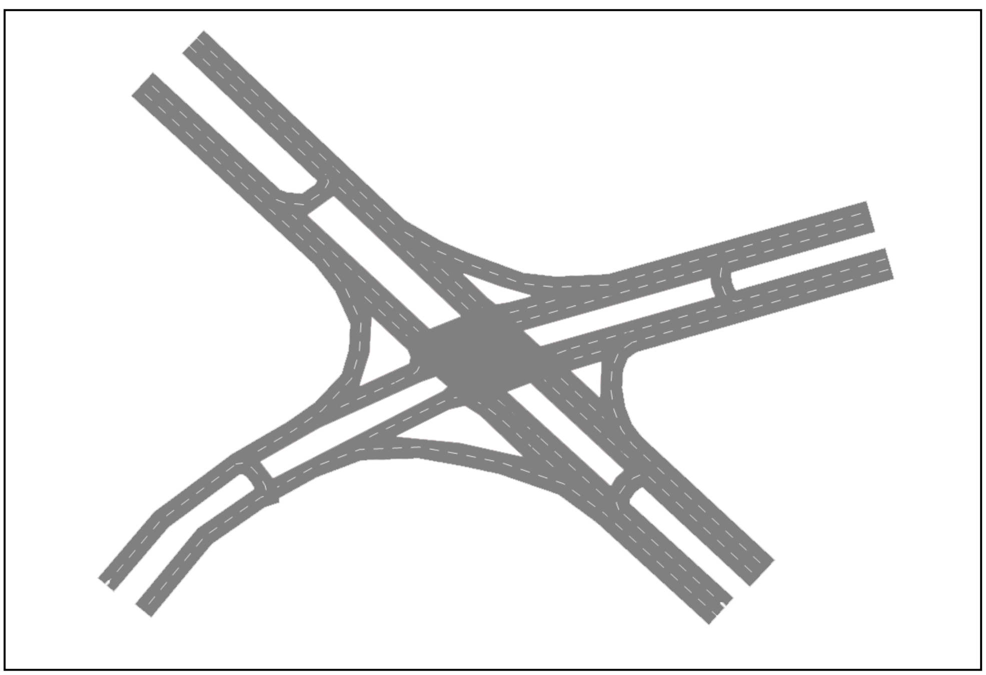

Figure C-2 Model of Signalized Intersection of Said AL-Assar Roundabout in PTV Vissim

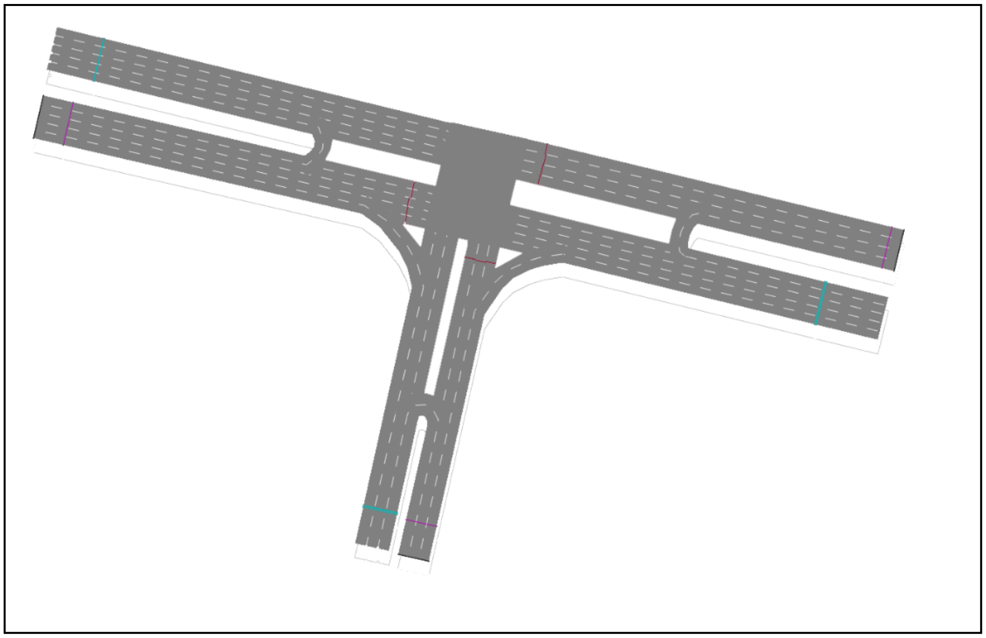

Figure C-3 Model of Signalized Intersection of AL-Mohafada Roundabout In PTV Vissim

Appendix-D

Sample of Free Flow Speed

Table D-1 Free-Flow Speed Data For Al-Tarbia Roundabout

Vehicle Sequence	FFS For Al-Tarbia (Km/h)
1	25
2	32
3	29
4	33
5	34
6	35
7	26
8	34
9	40
10	39
11	33
12	34
13	29
14	43
15	35
16	29
17	44
18	35
19	40
20	39

الخلاصة

تعتبر محافظة كربلاء من أكثر المحافظات شهرة في العراق بسبب معالمها الدينية والسياحية ، والتي استقطبت الكثير من الزوار ، مما أدى إلى تزايد الحاجة إلى خدمات نظام النقل. نتيجة لذلك ، يكون الازدحام شائعًا في العديد من الشوارع والتقاطعات. على وجه الخصوص ، في الدوارات التي تعاني من ازدحام كبيرة. يهدف هذا البحث إلى دراسة الحركة المرورية نتيجة مقاييس الأداء المختلفة في الدوار. علاوة على ذلك ، دراسة الدوار بعد تغييره إلى دوارات ذات إشارات ضوئية وتقاطعات بإشارات ضوئية. وكذلك دراسة تأثير نمو حركة المرور بعد خمس سنوات على الحركة المرورية بعد اجراء التحسينات المقترحة.

يركز البحث على ثلاثة دوارات شديدة الازدحام في مركز محافظة كربلاء (التربية ، سيد الاسعار و المحافظة). وتم الحصول على تسجيلات الفيديو من قسم شرطة كربلاء تم من خلاله حساب الاحجام المرورية المطلوبة في الدراسة خلال (7:30 صباحا - 8:30 صباحا) ، (12:30 - 13:30) ، (19:30 - 20) خلال ساعات الذروة. وتم الاعتماد على برنامج Planung Transport Verkehr Vissim 2022 لإنشاء نموذج يحاكي الواقع.

أظهرت النتائج تأخيراً كبيرا في الدوارات المدروسة مع مستوى خدمة F لجميع الدوارات. نظرًا لتحويل التقاطع الدائري إلى دوار بإشارات ضوئية وتقاطع بإشارات ضوئية ، فقد تحول مستوى الخدمة من F إلى D و C عند التقاطعات ذات الإشارات الضوئية و من F إلى E و D عند الدوارات ذات الإشارات الضوئية حيث كان متوسط انخفاض التأخير بنسبة 66٪ و 40٪ على التوالي ، وانخفض متوسط طول قائمة الانتظار بنسبة 27٪ و 16٪ على التوالي.

تشير نتائج تأثير أحجام المرور على أداء الدوار ومقارنة الحالات الثلاث التي تم دراستها (دوار، دوار بإشارات ضوئية، وتقاطعات ذات إشارات) إلى تحقيق معدلات وصول حركة مرور قدرها 0.2 مركبة / ثانية / مسلك، وبعد ذلك يفضل تحويل الدوارات إلى دوار بإشارات ضوئية. علاوة على ذلك، يفضل تحويل الدوار إلى دوارات ذات الإشارات عند 0.29 مركبة / ثانية / مسلك.

أظهرت دراسة تأثير معدل نمو أحجام المرور أن معظم التقاطعات ذات الإشارات الضوئية ستعود إلى مستوى الخدمة F في غضون سنوات قليلة لا تتجاوز خمس سنوات. واظهر تغيير الدوار إلى دوار بإشارات ضوئية وتقاطع بإشارات ضوئية تأثيرًا واضحًا على العناصر البيئية ثاني أكسيد الكربون وأكاسيد النيتروجين والمركبات العضوية المتطايرة واستهلاك الوقود ، حيث انخفضت جميع العوامل بنسب مختلفة

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة المدنية

دراسة محاكاة حركة المرور لتغيير دوار إلى تقاطع ذو إشارة ضوئية

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في هندسة البنى التحتية

من قبل:

علي فضـــــل الله حـــــسين

بكالوريوس في الهندسة المدنية /جامعة كربلاء (2018-2019)

بإشراف :

أ.د. حسين علي عوض

أ.م.د. رائد رحمن المحنه

ذو الحجة - 1444هـ

يونيو - 2023 م