



ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING  
GRADUATE STUDIES

THE EFFECT OF SMALL VEHICLES' MODAL SHIFTING TO BUS ON THE  
PERFORMANCE OF SOME SELECTED ROUNDABOUTS IN ADDIS ABABA

By

Rahel Birhanu

Thesis submitted to school of civil and environmental engineering of Addis Ababa institute of  
technology in partial fulfillment of the requirements for the degree of

Master of Science

In

Civil Engineering

(Road and Transport Engineering)

Advisor

Dr. Robam Solomon

2024

Addis Ababa, Ethiopia

Addis Ababa University  
Addis Ababa Institute of Technology  
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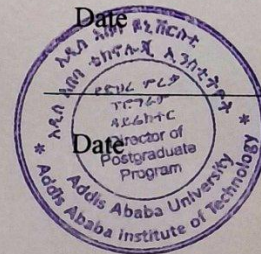
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## **Declaration**

I certify that research work titled “The Effect of Small Vehicles’ Modal Shifting to Bus on The Performance of Some Selected Roundabouts in Addis Ababa” is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged / referred.

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## **Abstract**

Roundabouts are the circular island for vehicles movement from different direction to change movement directions, paths and for crossing by counterclockwise movement around the circle. The imbalanced increase traffic volume will result traffic congestion. The main determinant for performance is traffic volume and the geometry of the roads. Many intersections and roundabouts in Addis Ababa city suffer from poor traffic management, leading to congestion and delays. To address this issue, the Addis Ababa Traffic Management Office has converted most roundabouts into signalized intersections. Additionally, the Ministry of Transport has developed a 10-year plan aimed at increasing the share of urban mass transport services from 34% in 2020 to 70% in 2030. This plan is expected to greatly improve the efficiency and quality of transportation in the city. On this study the performance analysis for the selected areas was performed using PTV Vissim 9 software program. To evaluate the performance of roundabouts, three different approaches were followed: PCU modal shift, unit change modal shift, and carpooling modal shift. The result of the analysis on the baseline scenario for Urael, Lamberet and Salitemeheret roundabout is LOS F, F and F respectively. Then the LOS for Urael and Lamberet roundabout upgraded to LOS B and E respectively and still LOS F for Salitemeheret roundabout with the PCU modal shift path and the LOS of those three roundabouts changed to LOS B, F and F respectively with unit change shift and carpooling modal shift paths. Based on the evaluation results of the Urael roundabout, the vehicular delay time in the baseline scenario was 51.73 seconds. However, in the modal shift scenario, the vehicular delay time ranged from the highest of 51.73 seconds to the lowest of 13.45 seconds and the upgrade was a result of 74% delay reduction from baseline scenario. Similarly, at the Lamberet roundabout, the vehicular delay time was 78.87 seconds in the baseline scenario while in the modal shift scenario; it varied from the highest of 88.90 seconds to the lowest of 42.39 seconds and the upgrade was a result of delay reduction with 46% from the baseline scenario. Lastly, at the Salitemeheret roundabout, the vehicular delay time in the baseline scenario was 92.54 seconds but in the modal shift scenario, it ranged from the highest of 92.54 seconds to the lowest of 27.80 seconds and the upgrade was a result of delay reduction with 70% from the baseline scenario. When the LOS upgrade the travel time was decreased, vehicular traveling speed, queue length, vehicles stop, fuel consumption and the emission was decreased. Finally, this research has significant to determine the preferable modal shift and it will provide information for Ministry of Transport, Traffic Management Office and other concerned group.

Key Words: Level of service (LOS), Congestion, Travel time, travel speed and Queue length

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## Abbreviations

**AACRA:** Addis Ababa City Roads Authority

**CO:** Carbon Monoxide

**ERA:** Ethiopian Roads Authority

**GEH:** Geoffrey E. Havers

**HCM:** Highway Capacity Manual

**LOS:** Level of Service

**ME:** Mean Error

**RMSE:** Root Mean Square Error

**RMSPE:** Root Mean Square Percent Error

**MPE:** Mean Percent Error

**NO<sub>x</sub>:** Nitrogen Oxide

**PCU:** Passenger Car Unit

**r:** The correlation coefficient

**U:** Thiel's Inequality Coefficient

**U<sup>c</sup>:** Variance Proportion

**U<sup>M</sup>:** Bias Proportion

**U<sup>s</sup>:** Covariance Proportions

**VOC:** Volatile Organic Compound

# **Chapter 1 INTRODUCTION**

## **1.1 Background of the Study**

Addis Ababa City Administration, the major economic center of Ethiopia, has a large concentration of motorized vehicles. The Ministry of Transport and Logistics recently reported that One Million Two Hundred Thousand One Hundred Ten (1,200,110) vehicles are available in Ethiopia. There are lots of motor vehicles in Addis Ababa compared to other cities in the nation, estimated to be Six Hundred Thirty Thousand Four Hundred Forty (630,440) vehicles with a total share of Fifty-Three (53) percent of the total motor vehicles in the country (Yonas Abiye (2020)).

According to the Ethiopian Roads Authority, geometric design manual description junctions are areas where two or more roads join and a place to change direction. Junctions are technically designed to move/return/directional change free from risk (ERA, 2013). In line with this thought, economic development and the transportation infrastructure are closely related. Road infrastructure is one of the implications of city development; it results from the economic development of the country (MOT, 2009). Due to the topography, Target access, and existing space; the roads connect using different types of junctions.

The designer is professionally expected to make a topography and location selection to design the layout of the intersection carefully (AACRA, 2003). The ERA manual also states that the junction needs attention and careful design for safe transportation (ERA, 2013). Good junctions transit the users from one route to another route with minimum delay and maximum safety. According to the HCM manual Layout of the junction should be visible for the drivers to reduce conflict movements (HCM, 2010).

According to Addis Ababa drivers and vehicles licensing and control authority the registered vehicles with different vehicle categories from the Ten years record data trend the number of vehicles increased from time to time. With this respect there was congestion occur on corridors and junctions of the road.

Public transportation has benefits in improving community health, and economic benefits to the community, improving fuel efficiency, reducing air pollution, improving road congestion, improving community mobility, providing an equitable transportation system, and improving community productivity.

In many road segments, congestion may occur due to the imbalance capacity of the road for the demand. Imbalanced traffic typically refers to a situation where there is a disproportionate flow of vehicles between different routes or areas. The performance of roads can increase by widening the width of existing roads, increasing the number of lanes, and changing the existing intersection to another type of intersection. The level of service and capacity of the road can also measure the performance of the road. One of the strategic plans of the country is to increase the capacity of infrastructure and management. Using public transport is one measure that can change the capacity of road management (FDRE Transport Sector Plan, 2020).

## 1.2 Statement of the Problem

The main issue in Addis Ababa city is traffic congestion caused by Imbalanced Traffic Flows, inadequate road infrastructure, rapid urbanization and so on. As urbanization continues to increase, the number of vehicles on the road tends to increase and leading to more traffic congestion. To reduce traffic congestion and improve transportation, investing in road infrastructure, increasing the capacity and demand for public transportation, introducing alternative modes of transportation, charging tolls at congested areas, improving traffic management, carpooling, and ridesharing as legislation will be solutions to alleviate congestion.

Many studies have been conducted to determine the performance of intersections, roundabouts, and roads in terms of capacity and level of service. Such studies were conducted by Temsegen, Nurhusan, and Theodore, who evaluated the level of service and capacity of roundabouts and junctions during peak hour traffic using the Sidra software. Their findings showed that many of the roundabouts they analyzed had poor service levels, indicating the need for improvements (Temesgen, 2015, Nurhussain, 2015 and Tewodros, 2007). Other studies have focused on modal shift, by Helen's analysis of mode share among major modes of public transportation. In her study, Helen confirmed that passengers prefer minibuses over Anbessa buses (Helen, 2018).

And also, Netanet's research focused on the impact of the Bus Rapid Transit Corridor on passenger modal shift from Wingate to Autobistera and aimed to assess whether the introduction of the Bus Rapid Transit (BRT) system has influenced commuters' choice of transport mode. The study identified various solutions and scenarios to increase the demand for bus transportation (Netanet, 2022). All the research efforts mentioned above were conducted to address the issue of traffic congestion in Addis Ababa by evaluating the performance of roads, understanding passenger preferences, and promoting more efficient public transportation options.

In general, these research works are aimed at evaluating road performance to solve the problem of traffic congestion in Addis Ababa city. This study uniquely from other studies by combining performance evaluation with modal shift and showing the impact on routing performance of performance metrics such as LOS, delay, travel time, travel speed, queue length, fuel consumption, and emissions. By analyzing modal shift in terms of PCU and passenger capacity, the research will determine the optimal percentage shift and determine the level of service and capacity of the

roundabout with the vehicle's passenger holding capacity (unit change shift and Carpooling Shift) to alleviate congestion. Finally, the findings will contribute to the city's ten-year plan to provide integrated and accessible transportation services.

### **1.3 Objectives of the Study**

This study will have one general objective and three specific objectives. This will be done carefully to achieve the intended purpose of the study.

#### **1.3.1 General Objective**

The general objective of this study will be to investigate the effect of the modal shift of small vehicles to buses (public transport) on the Roundabout performance.

#### **1.3.2 Specific Objectives**

The study will be directed to achieve the following specific objectives:

- ✓ To determine the existing actual level of service and capacity of the roundabout at the time of high traffic in the composition of the various vehicles.
- ✓ To determine optimal upgrading scenario (most favorable and Applicable) roundabout capacity by changing small vehicles to buses through PCU path (by incrementally shifting modal share), unit change path and carpooling path.
- ✓ To acquaint at which scenario of the modal shift from small vehicle to Bus the roundabout performs better in the existing condition?

### **1.4 Basic Research Questions**

- ✓ What is the current performance of the Roundabouts?
- ✓ What will the performance of the roundabouts be after the modal shifts?
- ✓ What will be the capacity of the roundabouts with the incremental present modal shift?
- ✓ How will be vehicles' passenger holding capacity (unit change shift and Carpooling Shift) impact the performance of the Roundabouts?

### **1.5 Scope of the Study**

To manage the study effectively, it is delimited from two perspectives. The first is from research title perspective, which focuses on the effect of small vehicles' modal shifting to bus on the performance of some selected Roundabouts in Addis Ababa City Administration. The second is from research setting perspective, which is purposely delimited to Addis Ababa City Administration focusing on sample selected roundabouts.

### **1.6 Significance of the Study**

It is politely assumed that the results of the study will help different stakeholders. In the first place, the results of the study will primarily help the Ministry of Transport and Logistics to realize the current performance of the selected Roundabouts in Addis Ababa City Administration. The Addis Ababa City Administration Road Authority will also learn something fundamental to revise the system. For example, it will give clues to professionals in the field to know how public transport (Bus) affects the performance of roundabouts relative to the small vehicles in Addis Ababa City Administration. The research will imply what will the future consistent plan be for and the management of the transport for the city public transport service providers. It will also be informative for the traffic management bureau as a reference to settle performance evaluation on public transport service and to change the infrastructure type to the better execution.

### **1.7 Limitation of the study**

The study will not cover all of the Roundabouts in the city due to the financial and time limitations to cover the performance analysis of all roundabouts in the city.

### **1.8 Challenges faced during the study**

- ✓ The licensed VISSIM software is not available as required; it is only available at the transport program management office.
- ✓ The data collection was difficult due to roundabouts geometry complexity.
- ✓ Moreover, the HCM manual in Chapter 21 only contains methodology for single and two-lane roundabouts.

## **1.9 Thesis Organization**

This research paper is organized into five chapters. Chapter one contains the general background of the study, statement of the problem, objectives, research questions, scope of the study, the significance of the study limitations of the study, and challenges faced during the study. In chapter two different kinds of literature are visited related to this research idea; Types of intersection/junction control, Roundabout Junction, Traffic Congestion, Traffic Conflict, Traffic queue, Traffic delay, Performance Evaluation of junctions, Capacity and Level of Service for Roundabout analysis, Comparison of Microscopic and Mesoscopic Traffic for Evaluation Analysis, An Overview of Public Transport in Developing the Country, The Role of Public Transport in the Developing Country, Strategies of the Federal Transport and Logistics Ministry, Transport Modal shift, Carpooling and its benefit, Calibration of PTV Vistro Software and incremental trained of traffic volume in Addis Ababa are contained. Chapter three describes the study area, Sample size determination, type of collected data, methods of data collection, Methods of Roundabout junction analysis, Research Approach and Default Values from the HCM manual for vissim analysis. Chapter four contains Analysis and Result of the research. Chapter five contains contain of Conclusion and Recommendations.

## **Chapter 2 LITERATURE REVIEW**

### **2.1 Types of intersection/junction control**

The different roads with different origins to the destination are joined and crossed through different types of junctions. For different types of intersections, the traffic flow on the intersection and approach road stretches are controlled to make safe transportation (Tom V & K V (2007)). Tom classifies junctions into three; Passive traffic control, semi-control traffic control, and Active Traffic control, accordingly roundabouts are passive traffic control types.

### **2.2 Roundabout Junction**

The highway capacity manual defines a Roundabout as a circular island intersection, at which all traffic moves anticlockwise around its central according to the Ethiopian driving Rule [HCM]. If a Roundabout is well-designed, it is the safest type of intersection control. Accidents that occur on roundabouts are fewer than accidents that occur on the other types of at-grade intersections. According to the Addis Ababa city roads authority manual, the reason that makes roundabout the safest intersection type relative to the other intersection types is because the relative speeds of vehicles are considerably lower. The lower potential relative speeds of vehicles reduce vehicle accident rates and severity. The circular entry curvature of the roundabout and circular carriageway of the roundabout compels the driver to slow down. The roundabout layout must be apparent to drivers and encourage drivers to enter the intersection slowly with adequate sight distance to enable drivers to observe the movements of other vehicles, cyclists, and pedestrians. Roundabouts operate with lower delays and better safety than other types of intersections and can operate efficiently with high volumes of left-turning vehicles (HCM, 2010).

Roundabouts are considered one of the safest forms of junctions. The Department of Transport has stated that the average accident cost at a roundabout is approximately 30 percent less than at all other junctions and about 60 percent less than on the approach carriageways (HCM, 2010).

## **2.3 Traffic Congestion**

Traffic congestion occurs through an insufficient number of traffic lanes, lack of exclusive lanes, inadequate length for right and left turning traffic, heavy traffic volumes turning movement's approaches to intersections, and heavy pedestrian and bicycle movements interrupt traffic flow causing conflicting movement. The stopped time on each approach is a cause of congestion during periods of heavy traffic volume (John & Herbert (2015)).

Congestion in transportation also occurs when the occupancy of (roadways, sidewalks, transit lines, and terminals) is realized by vehicles or people. When this happens, an unacceptable level of discomfort and delay is occurred. For vehicles, the concept is expressed as the number of vehicles per unit length of roadway. As the congested space increases, the speed of movement decreases. (John & Herbert (2015)).

## **2.4 Traffic Conflict**

Conflicts occur at the bottlenecks and in the Intersection. Intersections of major streets are often areas of traffic congestion during peak periods of travel. The many conflicts between pedestrians, cyclists, and motorized traffic occur between through and cross traffic, and between straight movement and turning movement vehicles are major sources of congestion (Nurhussain, 2015).

Conflicts will also observe at the bottlenecks and intersections of the city. Intersections of major streets are often taken as the focal areas of traffic congestion during peak periods of travel. Most of the conflicts have occurred among pedestrians, cyclists, and motorized traffic police when vehicles are turning to other sides. In general, these are often regarded as the major sources of congestion (Johnc. Falcocchio, 2015).

Conflicting traffic movements through street intersections are usually separated by a traffic signal that alternatively allocates a proportion/phase of the total time available cycle to move traffic and to stop traffic from moving. The stopped time on each approach caused by periods of heavy traffic volume will be higher (Johnc. Falcocchio, 2015).

## **2.5 Traffic queue**

A traffic queue is a line of vehicles, bicycles, or people waiting to be served by the system. The average speed of the vehicles, bicycles, or people in the queue is determined by the flow rate from the front of the queue. A queue occurs when the demand exceeds the available capacity. Queuing can happen at red lights, stop signs, bottlenecks, or any traffic-based or design-based flow constriction in transportation engineering. (John & Herbert (2015)).

## **2.6 Traffic delay**

Traffic delay is additional travel time experienced by a driver, passenger, or pedestrian due to circumstances that disrupt the desirable movement of traffic. Delay is measured as the time difference between actual travel time and free-flow travel time (AACRA, 2003).

Delay measures excess time consumed in traversing the intersection. The most common measures are average delay per vehicle, average queue length, and number of stops. Delay is the most frequently used measure of effectiveness for signalized intersections. It is directly perceived by a driver. The estimation of delay is complex due to the random arrival of vehicles, lost time due to stopping of vehicles, and over-saturated flow conditions. The level of service is directly related to the control delay value. (Cao NY. et al. (2010), John & Herbert (2015)).

## **2.7 Performance Evaluation of junctions**

In Addis Ababa City Administration, most of the intersections are functional beyond their capacity. This scenario results in congested and poor level of service intersections. It is common to see traffic congestion, queues, delays, and traffic jams at the junctions. In line with this, Temesgen Alemayehu conducted related research on the capacity evaluation of roundabouts and signalized intersections in 2015 taking some selected intersections as samples of the study. The researcher was able to measure the performance of the intersections in terms of volume capacity ratio, degree of saturation, average control delay per vehicle, and level of service (LOS) conducted using the Highway Capacity Manual (HCM, 2010) and using SIDRA INTERSECTION software for analyzing and results of the input data for performance measurement. In Temesgen's research, Two intersections and four roundabouts were selected and the result of the analysis for the sampled junctions indicated that the level of service of the

selected intersections are Los E and F and the delay time on the junctions was 80 seconds. He further stated that the major factors affecting the capacity of the intersection were inadequate geometric nature, high traffic volume, and driver's aggressive behavior. The researcher also concluded that most of the intersections in Addis Ababa have been found in the worst condition on their available capacity during peak hours. He recommended replacing roundabouts with another junction type through careful study, there is a need to separate the pedestrian's road from the main road to minimize vehicle traffic accidents. This will help the nation at large to improve the existing condition of roundabouts and signalized intersections to reduce delay time and increase the level of service (Temesgen, 2015).

Another study was also made on Performance evaluation considering some selected intersections in Bahir Dar City in 2015 by Nurhussain Hassen. The researcher computed the capacity and the level of service for selected intersections to know the performance of the intersections by making use of a parameter known as SIDRA INTERSECTION 5.1. Finally, he recommended that to increase public transportation, there is a need to improve the performance of the intersections (Nurhussain, 2015).

### **2.7.1 Capacity**

HCM Manual developed for U.S. conditions. The methodology applies up to two entry lanes per roundabout approach leg and one bypass lane per approach however it does not cover all situations that may be encountered in practice. In this study, the roundabouts encountered have multilane approaches however, which are in the HCM 2010 roundabout performance evaluation method multilane evaluation methodology dose not covered. Therefore, other methodologies for multilane analysis need to be assessed.

According to the Highway Capacity Manual, the capacity of a roundabout is affected by the flow pattern. The flow on a roundabout is inversely proportional to the conflicting flow. There are three types of flows in roundabouts: entering flow, exiting flow, and circulating flow. The circulating flow can conflict with the entering and exiting flow, and the exit flows also affect the decisions of drivers who enter the roundabout. The primary conflict occurs on roundabouts due to the circulatory flow with the entering, exiting, and circulating flow, as stated by HCM in 2010 (HCM, 2010).

The roundabout priority rule is applied at each of the conflict points. On roundabout Traffic merges with circulating the central circled island. About roundabouts, there are points taken into account to analyze the capacity and level of service considering three types of conflicts that occurred those are eight merging, four converging, and four driving conflict points (Tewodros, 2007). Moreover, to analyze the Hindawi mathematical problem in an engineering research article on mathematical analysis of the roundabout VISSIM simulation software it was used to handle the case effectively. There is a critical point to be considered at which the speed is controlled and the desired speed decision points for the roundabout. Generally, the researcher determined the capacity of the roundabout using VISSIM simulation software (Wonho Suh. et al (2018)).

The main objective of Hindawi's research was to accurately model the merging point at all legs of a roundabout using VISSIM simulation. As it is a roundabout and the researcher assumed that all legs have a similar volume, only one-leg data was taken into account. The simulation lasted for seventy minutes, including a ten-minute warm-up period, and three different scenarios were considered: priority rule and conflicting zones, priority rule only, and priority rules and adjusted input. Using some selected scenarios, the researcher estimated the capacity of the roundabout based on the impact of priority rules in microscopic traffic simulation. (Wonho Suh. et al, 2018).

In the Hindawi research article, the traffic from each leg of the roundabout was assumed to be equal, even though there could be differences in traffic volume and category. The study only focused on the effect of priority on the roundabout's capacity in terms of gap time. In this research, the traffic category was not described.

Capacity is subject to variation in both time and space. The volume capacity ratio is one of the most used indexes to assess traffic status by various researchers (AASHTO, 2004).

### **2.7.2 Level of service**

The service level of a road is a measure of its performance and operational quality. It is determined by various factors such as speed, travel time, traffic density, interruption, and comfort. The Ethiopian Road Authority manual and Highway Capacity Manual use a six-level classification system, ranging from LOS A to LOS F, to describe the level of service of a road.

The level of service of a roundabout, which is an un-signalized intersection, is determined by the control delay or the number of vehicles that have to stop. One of the indicators for the level of service is the ratio of vehicle volume to capacity and if the ratio is greater than one, the level of service will be categorized at LOS F.

The table below shows the level of service of the roundabout based on the delay time (in seconds) and the ratio of the traffic volume to the road capacity, as stated in the HCM 2010 manual. (HCM, 2010).

Volume capacity ratio (V/C) is also taken as one of the most utilized indexes to assess traffic status (C. V. Yeramwar. et al. (2016)).

**Table 2. 7. 2 Volume capacity ratio and LOS (HCM 2010)**

Control Delay (S/Veh)	LOS by volume-to-capacity ratio	
	V/C≤1	V/C>1
0-10	A	F
>10-15	B	F
>15-25	C	F
>25-35	D	F
>35-50	E	F
>50	F	F

The service level of the road is also used to measure the performance of the road. The level of service is professionally described as the quality of operation on the road. It measures the quality of the speed, travel time, freedom of traffic density, traffic interruption, and comfort. Both the Ethiopian Road Authority manual and highway capacity manual about the road level of service have six levels going from LOS A to LOS F ((AACRA, 2003), (ERA, 2013)).

## **2.8 Comparison of Microscopic and Mesoscopic Traffic for Evaluation Analysis**

Micro modeling details the cooperating network between vehicles and the model also simulates each vehicle's movement between vehicles. Micro modeling devices work with a variety of mechanisms, such as car models and lane-shift models. Vehicle movement to travel on a given route may follow other vehicles or change their route. The micro-simulation model has measures of effectiveness like delay, network travel time, fuel consumption, and emissions. The gap between microscopic and macroscopic models is filled by mesoscopic models. Mesoscopic models were developed for real traffic conditions to simulate in medium to large networks. Mesoscopic models cannot model the interaction between vehicles and their behaviors at a high level of detail (Mohammad, 2017).

## **2.9 An Overview of Public Transport in Developing the Country**

The road infrastructure is one of the most important infrastructures in any country. It is used for most of the activities that take place in the world, including the movement of passengers and goods from one place to another. In some countries, public transport has been given a lot of attention and as a result, those countries have reached a much more advanced level of development compared to others. With the world's population rapidly increasing, there is a need to balance the delivery of public transport services accordingly.

However, some developing countries, like Ethiopia, whose economic growth is low, may suffer a lot to maintain this project. According to reports, in 2021, the population of Addis Ababa City Administration is estimated to be 5,005,524 million. The growth rate in 2021 increased by 211,825 million (4.42%) from the previous year 2020 and it is expected to grow to 7,057,107 million in 2029 and 7,352,269 million in 2030 with a growth rate of 4.18%.

The operation of public transport depends on the income level of people, i.e., the users. Richard stated that car ownership is dependent on income. He also classifies public transport into two types, i.e., large buses and minibuses. If the income is less, people prefer large buses to minibuses. This implies that the demand for public transport directly depends on the income level and number of populations.

## **2.10 The Role of Public Transport in the Developing Country**

A good transport service can play an important role in the development of the country. People travel from one place to another for work, education, shopping, and leisure activities. People may also travel frequently/daily from origin to destination using public transportation or other alternatives (Richard. I, 2005). In most developing countries, public transport depends on population growth. If Journeys are greater than 8km, most people prefer to use public transport to go on walking. Sometimes, car owners prefer to use public transport to minimize difficulties related to parking, accessing certain streets, traffic congestion, and other conditions.

Public transport is more vital in terms of accommodating low-income level communities than using privately owned car mobility. One of the goals of the Ministry of Federal Transport and Logistics is to increase the large number of passengers (i.e. from the current 722 million to 1.5 billion) awareness to use public transport by 2030 over the country (Richard. I, 2005).

## **2.11 Strategies of the Federal Transport and Logistics Ministry**

The Federal Democratic Republic of Ethiopian Transport and Logistics Ministry has prepared a 10-year plan which is applicable from 2020/21 – 2029/30 (FDRE Transport Sector plan, 2020). The ministry also assessed the previous 10 years' plan status for all transport sectors. This plan is prepared for Road transport, Rail transport, Air transport, and water transport to abide with it. The previous plan was not properly applicable even though it had positive progress from the base plan year. The density of the road in km per area is also increased. Federal Democratic Republic of Ethiopian Transport and Logistics Ministry has prepared the Ten years plan which is applicable from 2020/21 – 2029/30 (FDRE Transport Sector plan, 2020). The ministry also assessed the previous 10 years plan status for all transport sectors. This plan is prepared for Road transport, Rail transport, Air transport and water transport to abide with it. The previous plan was not properly applicable even though it had a positive progress from the base plan year. Density of the road in km per area is also increased. One of the future strategies of the transport sector is:

Improve integration, equity and accessibility of public transport service use public transport (introduce public transport system)

- ✓ Bus rapid transport (BRT)
- ✓ Light Rail transport (LRT)

## 2.12 Transport Modal shift

In recent years various countries all over the world have patronized public transportation in their strategy. Ethiopia also recommends public transportation in the transport sector strategy. Previously researchers conducted studies on transport modal shift. Netanet Kassahun conducted a study on the impact of Bus Rapid Transit System on a modal shift to bus from Winget to Autobistera corridor. According to Netsanet's study travelers for specific trip purposes are interested in diverting their mode choice to Bus Rapid Transit. (Netanet, 2022).

Several determinants lead individuals to use personal cars for transportation. These determinants include socio-demographic factors, journey characteristics, and spatial patterns. Socio-demographic factors such as age, gender, education, occupation, household composition, income, and population density are some of the factors that influence the use of passenger cars. Journey characteristics also play a role in determining the mode of transportation, such as the reason for travel, distance, travel time and costs, departure time, trip chaining, weather, information, and interchange availability. Spatial patterns, including urban and rural density, diversity, proximity to infrastructure and services, frequency of public transport, and availability of parking in the city, are also factors that determine the mode of transportation. (Pastori et al., 2018) Various countries all over the world have implemented public transportation in their transportation strategies. Ethiopia also recommends the use of public transportation in its transport sector strategy. Researchers have conducted studies on transport modal shift, such as the Effect of the Bus Rapid Transit System on a Modal Shift to Bus, which was studied by Netsanet Kassahun for the Winget to Autobistera corridor. According to Netsanet's study, travelers who have specific trip purposes are interested in diverting their mode choice to Bus Rapid Transit (Netanet, 2022).

Researcher Helen also conducted a study to analyze mode share among major modes of public transport (i.e. Minibus, Higer bus, Anbessa bus, and LRT) giving transport service in Addis Ababa, from Megenagna to Ayat corridor. Helen's research result that passengers were not interested in using Anbessa buses but had a preference for minibuses (Helen, 2018)

## 2.13 Carpooling and benefits attended from carpooling

Carpooling means sharing vehicles commonly for similar origin-destination movements. Carpooling can be Causal carpooling, real-time carpooling, or Van Vanpooling. Causal carpooling there may be no money exchange or passengers may pay a normal amount to substitute the driver's actual cost also known as flexible car-pooling. On causal carpooling, the driver may pick up passengers from Witting for other shard transport modes.in real-time carpooling; the passengers use Applications using their smartphones to access the service. In van-pooling the number of passengers relatively increased from the other callings. In this carpooling, the passengers pay money to share the cost of the van, and also passengers share the driving responsibility. Carpooling has several benefits from different directions; social benefits, employer benefits and individual benefits.

✓ Social benefits: -

- ✚ Reduced vehicle traveled distance
- ✚ Reduce fuel consumption
- ✚ Reduce air pollution (reduce emission)
- ✚ Minimize cost

✓ Employer benefits: -

- ✚ Reduce need for parking area
- ✚ Increase employers' productivity and there moral
- ✚ Have financial and tax benefit

✓ Individual benefits: -

- ✚ Accessible and affordable for low-income societies
- ✚ Cost minimizing because of shared travel cost
- ✚ increased comfort and reduce stress
- ✚ Reduce travel time because of using HOV (heavy occupancy vehicle lane can use due to availability of multiple passengers)

## 2.14 Calibration of PTV Vistro Software

Calibration is configuring an instrument to provide sample results within an acceptable range. The PTV Vissim software analyzes traffic solutions for traffic engineering, transportation planning, and evaluations to solve problems. The software saves time during analysis and can be used to analyze and evaluate the development impacts, optimize and re-time the existing traffic signals, and evaluate the level of service at intersections and roundabouts. Finally, the software outputs and generates reports, whether in the form of tables or figures. The software uses the Highway Capacity Manual (HCM, 2010), Intersection Capacity Utilization (ICU), Canada Capacity Guide (CCG), and Kimber methods as guides for analyzing purposes. The overall performance of simulation model goodness is measured by several methods (Tomer & Harris, 2004). From them, for this research, the following are more related comparison tests.

### 2.14.1 Calibration Quality test

The comparison of observed and modeled values can be statistically measured using the GEH value. GEH value measures quality and the method introduced by Geoffrey E. Havers. Geoffrey E develops this method in the 1970s for traffic planning purposes.

Geoffrey E. Havers invited the GEH statistic formula to compare two sets of traffic volumes; observed and simulated volumes. Geoffrey Goodness of fit computing formula is similar to chi-squared statistic. This formula is designed to tolerate larger errors in low flows. (Dowling, et al., 2004, Traffic Modeling Guidelines, 2013).

🚦 Applications (The GEH formula is useful in)

- ✓ To compare a set of traffic volumes which attained from manual traffic counts with a set of volumes from simulation.
- ✓ To compare the traffic volumes obtained from this year's traffic counts with a group of counts done at the same locations in a previous year.
- ✓ To compare the traffic volumes obtained from a travel demand forecasting model (for the "base year" scenario) with the real-world traffic volumes (Shaw, et al (2014)).

### 2.14.2 Calibration Statistical test

The main purpose of calibration is it maintains accuracy, standardization and repeatability in measurements, assuring reliable and standard references and results. There are a large number of statistical tests for stability.

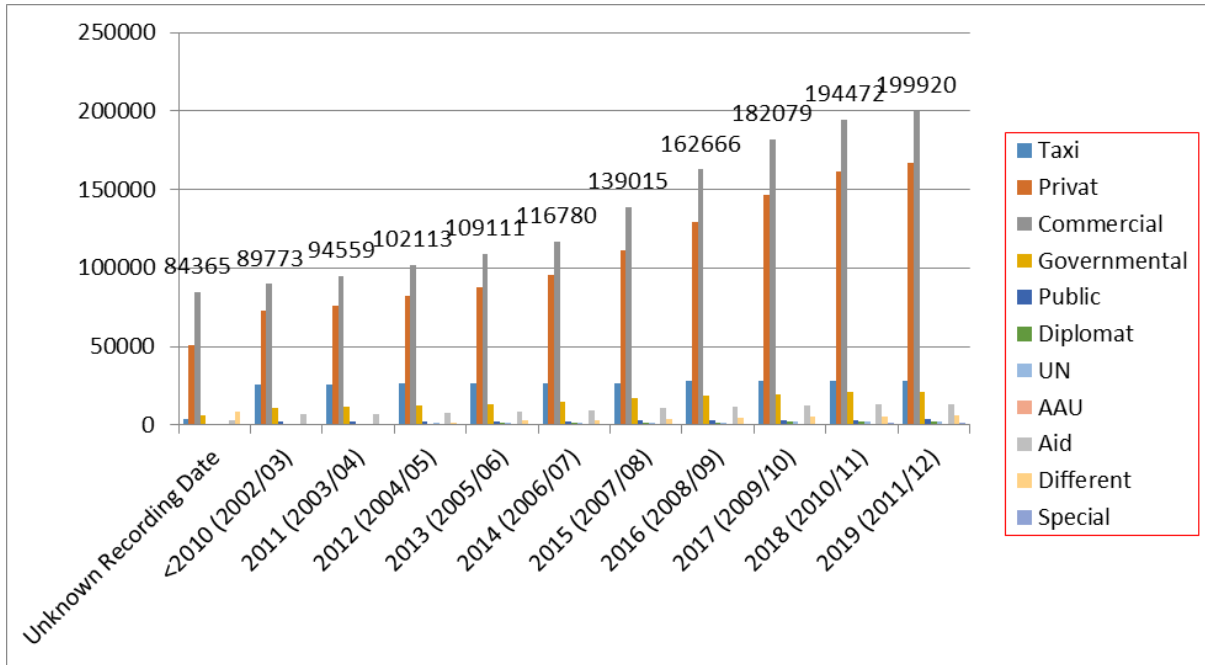
- ✓ Normality Test
- ✓ Root Mean Square Error (RMSE)
- ✓ Root Mean Square Percent Error (RMSPE)
- ✓ Mean Error (ME)
- ✓ Mean Percent Error (MPE): - Indicates the existence of systematic under or over predictions in the simulated measurements
- ✓ The correlation coefficient (r) it shows the linear associations between the simulated and observed traffic measurement (John, et al.2023)
- ✓ Theil's Inequality Coefficients (U): - A measure that provides information on the relative error bounded between 0 and 1 implying perfect and worst fit possibilities respectively. It is decomposed into three proportions of inequalities, Bias ( $U_m$ ), Variance ( $U_s$ ) and covariance ( $U_c$ ) proportions (Tomer &Harris,2024)

Theil's inequality coefficient values are computed to evaluate and compare the actual value and simulated values inequality.

GEH & RMSE are a useful measure of goodness of fit between modeled and observed (Traffic Modeling Guidelines). Simulation models provide a wealth of information with regards to performance measures, including delay, queue length, travel time and vehicular speed.

## 2.15 Incremental Trained of traffic volume in Addis Ababa

According to Addis Ababa city administration driver and vehicle, licensing & control authority ten years recorded data the number of vehicles increased from year to year. The data from the authority is organized and recorded as follows.



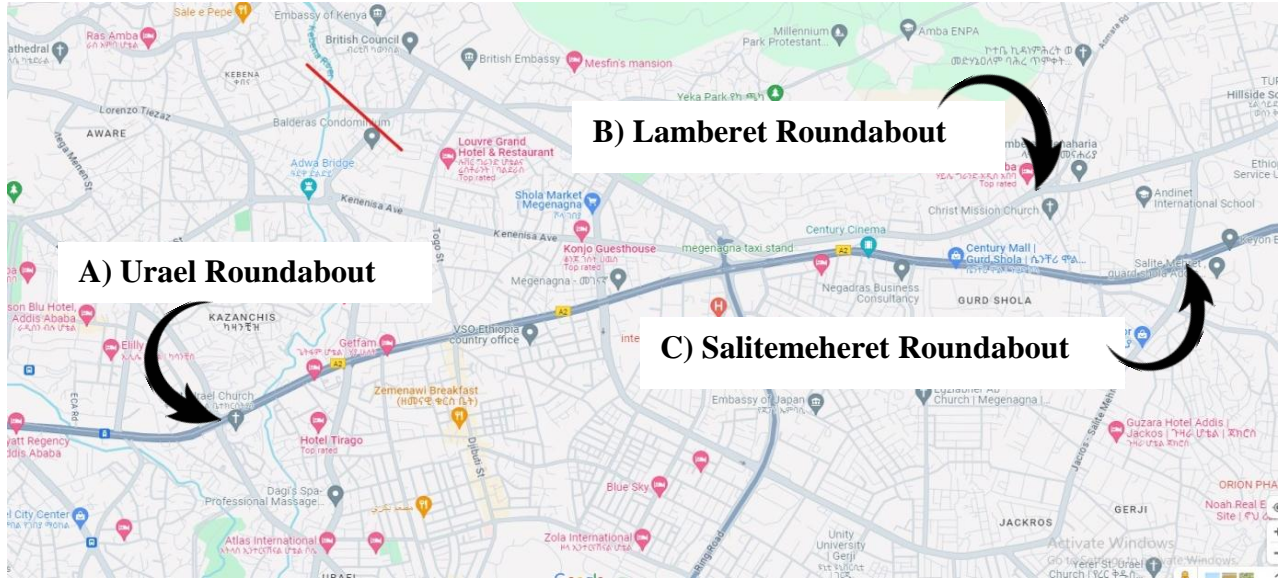
**Figure 2. 15 Increment on Traffic Volume (Addis Ababa Driver Vehicle Authority)**

## **Chapter 3 METHODOLOGY**

### **3.1 Study Area**

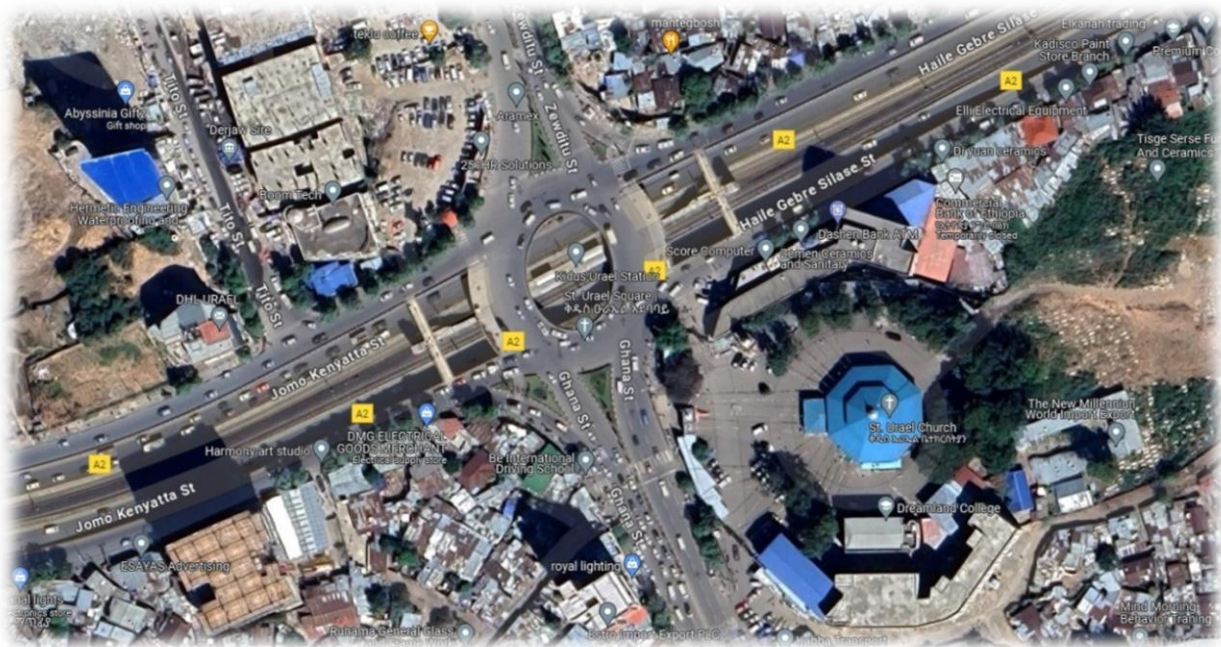
Addis Ababa is the capital, political, commercial, and industrial city of Ethiopia. It is where the African Union is based. It also hosts the headquarters of the United Nations Economic Commission for Africa (ECA) and numerous other continental and international organizations. The coordinate location with a rough center located at 9011'30"N and 38035'30"E, covering an area of 527 km<sup>2</sup>. In 2000 the population of Ethiopia was around 65 million people and it was grown to 115 million people in 2020, in the future expected and will be grow to 145 million in 2030, 205 million in 2050, and 294 million in 2100. (World counts, what is the population of Ethiopia).

Addis Ababa has several roads, Roundabouts and Intersections. The study mainly focuses on; Urael Roundabout, Lambert Roundabout and Salitemiheret Roundabout. The study roundabouts are selected with the merits of the town down, frequent congestion occurrences and the existence of light rail transit. Addis Ababa has many roads, roundabouts, and junctions. This study mainly focuses on Uriel, Lambert, and Salitemaheret squares. The study squares were selected according to different criteria - Urail Square is in the center of the city, Lambert Square is frequently busy with traffic, and Salitemhret Square is crossed by the light rail. These squares were chosen for the study. All the selected roundabouts use Megenaga approach communally as a travel route.



**Figure 3. 1. 1 Google Earth Map of the study Areas**

**A) Urael Roundabout**



**Figure 3. 1. 2 Google Earth Map of Urael Roundabout**



**Figure 3. 1. 3 Google Earth Map of Lamberet Roundabout**

**C) Salitemeheret Roundabout**



**Figure 3. 1. 4 Google Earth Map of Salitemeheret Roundabout**

### **3.2 Sample size determination**

In this research, the samples of the study area were determined in a non-probability sampling as convenience samples because of the time and money limitations. However, in this sample, the most congested, city center road and roundabout with light rail crossing are selected to make representation variants on the available roundabout representative of the city.

### **3.3 Methods of Data Collection**

The necessary data for the analysis was collected from reliable sources. The primary data for current traffic, the amount at the intersections, was collected using cameras. The approach roads and roundabout geometric data were taken from the sites by direct measurement to analyze the capacity and level of service of the road. The traffic count of motorized vehicles and measurements of geometric elements of the roundabout and approach roads were collected. The aforementioned data collection was used for the relevant data for analysis purposes.

Tools that were used for data collection; Meter, Video Camera, recording stationary, and other essential instruments were used.

### **3.4 Types of data collection**

#### **3.4.1 Geometric Data**

Junction's data was collected according to the AACRA manual by considering their importance for the simulation. The geometric data for the analysis of PTV VISSUM software, the geometric data collected includes; the number of entry lanes, and the average lane width at entry for roundabout the number of circulatory lanes, the number of circulatory lanes, and the width of circulatory lane.

Urael roundabout have four approach lages from Bole,Kazanchis, Megenaga, and Meskel squar. The approach entry lanes for Bole and Kazanchis approaches have three lanes with a width of 3.2 meter. The approach lane for Megenaga and Meskelsquar are two lanes with a width of 3.2 meter. The roundabout circulatory lanes are three with a width of 3.2 meter.

Lamberet roundabout similarly have four approaches from Gurd Shola, Koteba, Megenaga and Wosen. All the approaches have two lanes with a similar width of three meter. The circulatory lanes of the roundabout are three with a width of three meter.

Salitemeheret roundabout have also four approach legs. The approach legs from Megenaga and CMC have four lanes with a width of Three meter. Approach legs Jackros and wosen joine the roundabout with three land and Jackros approach lane have Three-meter width and Wosen approach lanes have Two-meter width. The circulatory lanes of Salitemeheret roundabout have four lanes with width of Three meter.

### **3.4.2 Traffic Data**

Traffic flow data entering the roundabout was collected using the AACRA Traffic Manual and Axle Load Survey Manual using a video recording camera. The traffic flow count data was collected in two shifts, morning and afternoon-evening shifts, for three consecutive working days at the entire roundabout. The morning census was conducted between 12:00 and 04:00 of morning and the afternoon-evening census was conducted between 09:30 and 01:30. A total of eight hours of traffic is accounted for and all three roundabouts have four-legged approaches.

The traffic count at Urail roundabout, peak traffic was observed between 02:15 and 03:15 on the third day morning of the count. At Lambret roundabout, the highest traffic volume was observed between 02:00 and 03:00 on the second day of the census. At the Salitemeheret roundabout, the highest traffic volume was observed on the first day of the census between 11:15 and 12:15.

The traffic is classified under passenger cars and heavy vehicles according to highway capacity guidelines. Small vehicles like Vitz, Corolla, Pickups, Land Cruiser, Mini Bus, Mid Bus, and other small vehicles are classified as passenger cars while cars and buses are classified as heavy vehicles as per HCM 2010 guidelines. The highest traffic volume recorded in each direction was analyzed on Vissim software for the research results.

The surveys were carried out during the month of April, 2023. Detailed information on the vehicles counts, please see Appendix A.

### 3.4.3 Critical gap and follow up Data

The Critical headway between two vehicles traveling in the same lane and the follow-up time between the departure of one vehicle from the minor street and the departure of the next vehicle from the major-street was taken from the recorded video.

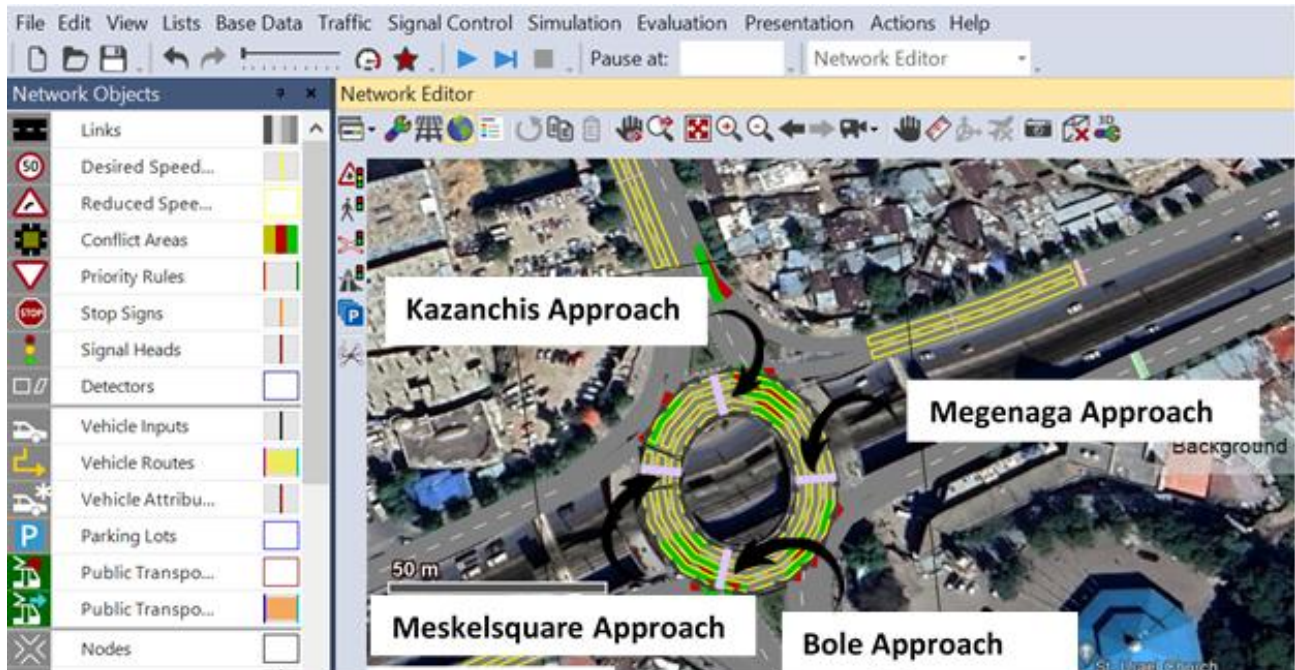
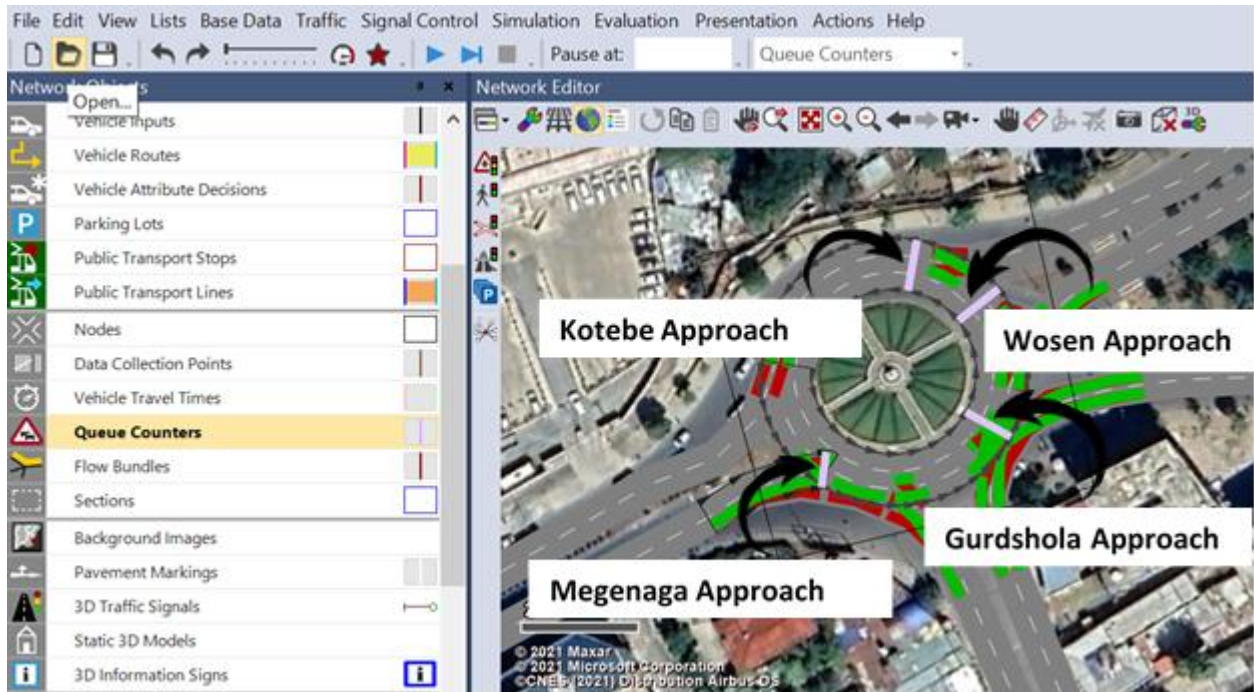
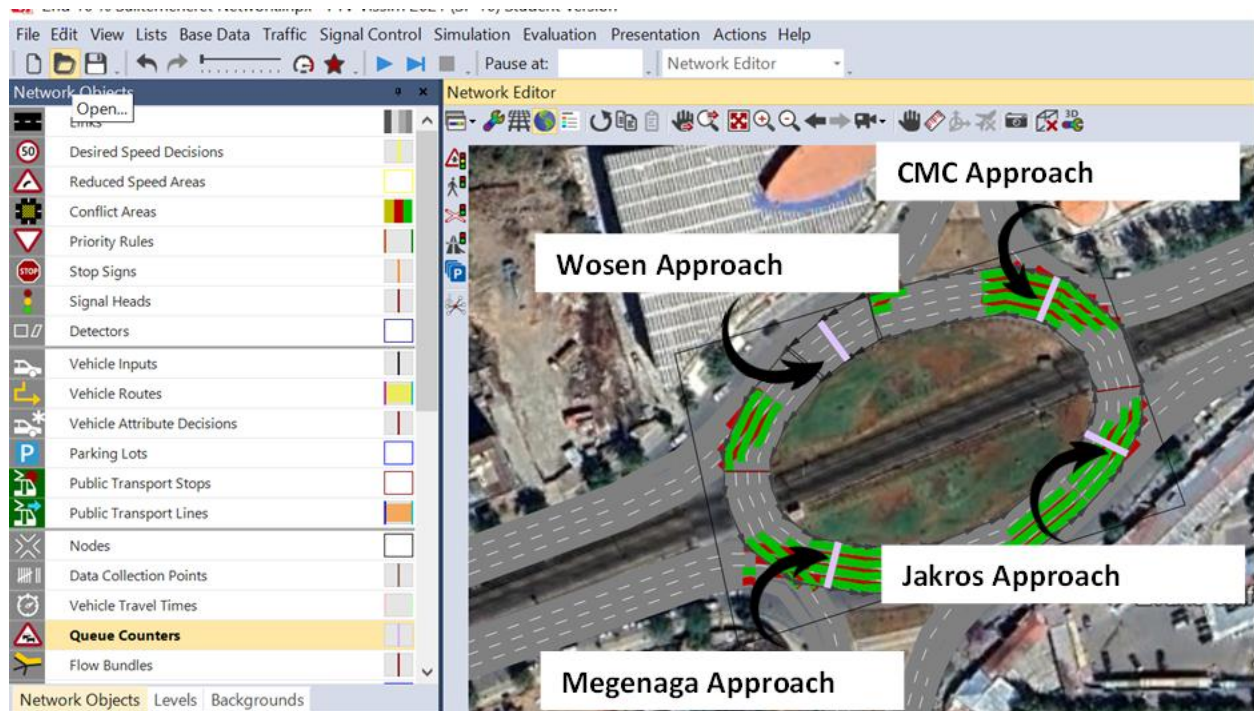


Figure 3. 4. 3. 1 Urael Roundabout Critical Gap (headway) and Follow up Gap Data Collection Point



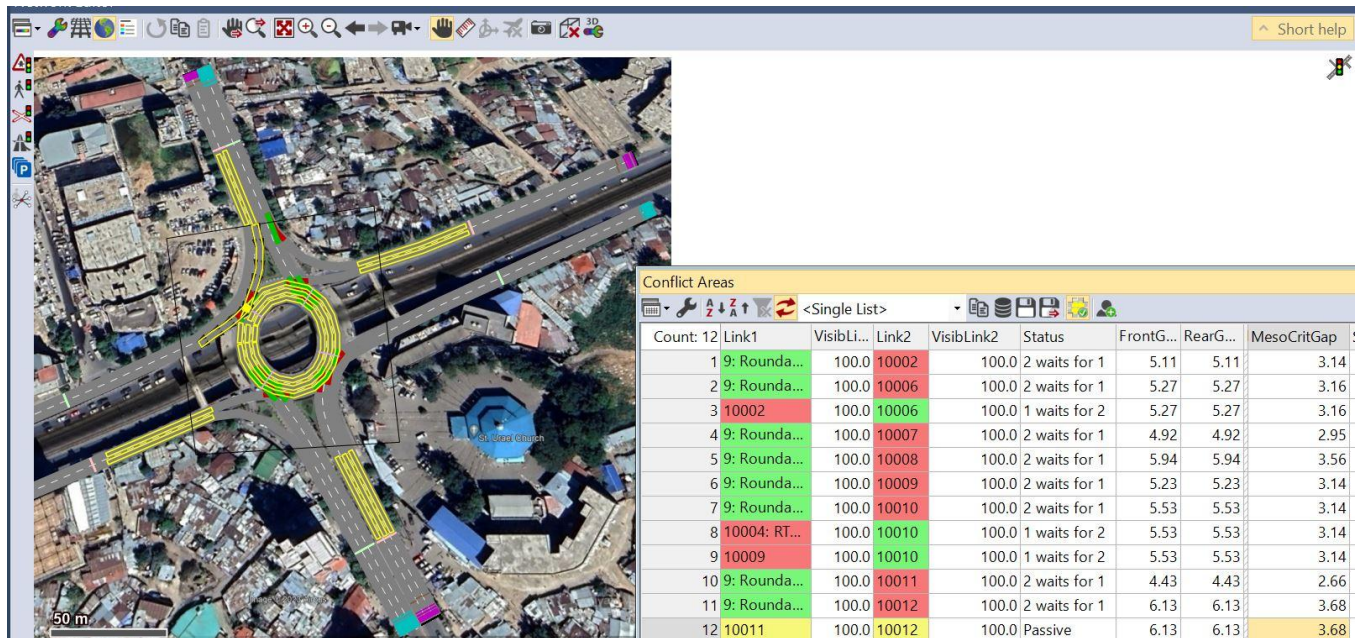
**Figure 3. 4. 3. 2 Lamberet Roundabout Critical Gap (headway) and Follow up Gap Data Collection Point**



**Figure 3. 4. 3. 3 Salitemheret Roundabout Critical Gap (headway) and Follow up Gap Data Collection Point**

**Table 3. 4. 3 Critical Gap (headway) and Follow up Gap of the roundabouts**

Sn.	Roundabout Name	Approach leg	Entrance Critical Headway	Entrance Follow Up Time	Exit Critical Headway	Exit Follow Up Time
1	Urael Roundabout	Bole Approach	4.92	2.95	5.27	3.16
		Meskel Squar Approach	5.11	3.07	6.13	3.68
		Megenaga Approach	5.23	3.14	5.94	3.56
		Kazanchis Approach	4.43	2.66	5.53	3.31
2	Lamberet Roundabout	Wosen Approach	5.41	3.24	5.71	3.42
		Kotebe Approach	5.28	3.17	5.52	3.31
		Megenaga Approach	5.17	3.1	5.24	3.15
		Gurd shola Approach	4.71	2.83	4.91	2.95
3	Salitemeheret Roundabout	Megenaga Approach	5.68	3.41	6.12	3.67
		CMC Approach	4.36	2.62	5.63	2.78
		Wosen Approach	4.22	2.53	4.41	2.64
		Jakros Approach	4.02	2.41	4.25	2.55



**Figure 3. 4. 3. 4 Critical gap (Headway) and follow up gap input to software**

### 3.4.4 Data Extraction

Vehicle volume and light rail traffic light timing and interval were recorded on site directly, and extracted by video playback technique. The traffic was categorized as passenger cars and heavy vehicles using the HCM 2010 manual classification.

### 3.4.5 Light Rail Signal Data

There is a light rail crossing available at Salitemeheret Roundabout. The light rail signal light automatically obligates vehicles to stop when the tram approaches and crosses the roundabout. On the path, trams cross the roundabout, and overall, the Salitemeheret roundabout trams five times cross the roundabout within an hour at peak traffic volume. The rail signal light stops vehicles for average of 30 seconds five times.

**Table 3. 4. 5. 1 Rail Signal Light**

SN.	Light Rail Number	Rail flow direction	Rail intry to Roundabout (Time)	Railexit from Roundabout (time)	Rail signal light (second)
1	1st Tram	Megenaga - CMC	11:21:16	11:21:48	32
2	2nd Tram	Megenaga - CMC	11:33:10	11:33:39	29
3	3rd Tram	CMC- Megenaga	11:38:42	11:39:16	26
4	4th Tram	Megenaga - CMC	11:53:24	11:53:51	27
5	5th Tram	CMC- Megenaga	12:13:53	12:14:29	36
Average					30

### 3.5 Methods of Roundabout Junction Analysis

The analysis method for intersection capacity and level of service can be in empirical and analytical models as Highway Capacity Manual 2000 stated by the Transportation Research Board. Empirical models use observations at many different intersections under all types of conditions to develop regression equations that match intersection characteristics with intersection capacity. Analytical models estimate capacity based on gap-acceptance relationships that do not require observations under congested conditions. Since the Empirical Method depends on the geometric elements of the roundabout, it is sometimes difficult to find the

necessary geometric features on Addis Ababa's roundabouts. In this regard, the Analytical Method is more realistic than the Empirical Method since it considers the traffic environment. The choice of an analysis approach depends on the available data. For this research, the method used the analytical model of Roundabout analysis.

The collected traffic count and geometric data were analyzed to attain the necessary results about the roundabout's performance. The data from the traffic count was analyzed using PTV VISSIM software to address the proposed research objectives. The necessary data was obtained from the site, adjusted, and it was fed to the software as input. The software analyzes the input data and verifies different results via the throughput process. Finally, the study results show the capacity and level of service of the roundabout using PTV software through collected quantitative data, and the modal shift was also conducted using incremental change.

The Highway Capacity Manual, Ethiopian Roads Authority Manual, and Addis Ababa City Roads Authority Annual were used as guidelines and references to analyze the data through the software. According to the collected data, the PTV Vissim software analyzed the input data and outputted the results including the capacity and level of service of the selected roundabout's analysis.

### 3.5.1 Path followed in Analysis

In this research, the analysis was performed by three methods to make the modal shifting and determine the performance of the roundabouts and approach roads.

- ✓ Passenger car unit (PCU) path - The modal shifting was performed based on the PCU of the vehicles on the HCM manual in chapter 21 of the roundabout analysis.

**Table 3. 5. 1. 1 Passenger Car Equivalency Value from HCM 2010**

Exhibit 21-10 Passanger Car Equivalencies	Vehicl Type	Passanger Car Equivalent,ET
	Passanger Car	1
	Heavy Vehicle	2

The modal shift was made following the HCM 2010 manual for passenger cars and was calculated by using PCU values of 1 for passenger cars and 2 for heavy vehicles respectively.

- ✓ Unit change path - the modal shift was performed based on the actual count of the passengers in small cars, minibuses, and bus modes of transport.
  - The average occupancy of the small vehicles (cars) is 1.68 from a sample of 50 cars
  - The average occupancy of the minibus is 13 from a sample of 50 minibuses
  - The average occupancy of the Buses is 73 from a sample of 50 buses

**Table 3. 5. 1. 2 Passenger per vehicle type on Unit change path**

Vehicle Type	Average Passanger
Car	1.68
Mini - Bus	13
Bus	73

It is difficult to make an acceptable and realistic modal shift of passengers change small car passengers to bus. Based on the recorded data on the number of passengers from direct recorded data in the above table Simultaneous equation was used for replacing the mods or for modal shifting.

- $(1.68 \text{Car passengers} * X) = 13 \text{minibus passengers}$   
 $X = 7.738 \sim 8$  on this substitution 1 minibus can substitute 8 cars and it can serve as 8 cares based on number of passengers.
- $(13 \text{minibus passengers} * Y) = 73 \text{ bus passenger}$   
 $Y = 5.615 \sim 6$  on this substitution 1 bus can substitute 6 minibus and it can serve as 6 minibus based on number of passengers.

$$1 \text{minibus} = 8 \text{ Car}$$

$$1 \text{bus} = 6 \text{ minibus}$$

- ✓ Carpooling path – the modal shift was performed by considering the vehicles serve with their full capacity of number of sets. Accordingly, the vehicles serve with full capacity by sharing the ride
  - Small vehicles serve with full capacity five persons can share including the driver.

**Table 3. 5. 1. 3 Passenger per vehicle type on Carpooling path**

Vehicle Type	Average Passanger
Car	5
Mini - Bus	13
Bus	73

✚ (5Car passengers \*X) =13minibus passengers

X=2.6~3 on this substitution 1 minibus can substitute 8 cars and it can serve as 3 cares based on number of passengers with full capacity.

✚ (13minibus passengers \*Y) = 73 bus passengers

Y=5.615~6 on this substitution 1 bus can substitute 6 minibus and it can serve as 6 minibus based on number of passengers.

1Minibus = 3 Car

1Bus= 6 Mini Bus

### 3.5.2 Base model Development

The base model was developed and calibrated to make a simulation with acceptable range of simulation outputs. The base model was calibrated on Urael roundabout for morning traffic flow and validated on night Urael traffic volume.

### 3.5.3 Calibration and Validation

In this research Calibration and validation was made on Urael roundabout simulation. On this roundabout the calibration was made on various parameters of the simulation model are adjusted until the model accurately represents field conditions by changing seed number and by changing the default gap as HCM 2010 manual. The parameters are adjusted during calibration so that the model replicates field observed conditions. During VISSIM calibration the model outputs were compared against observed data to determine if the output was within acceptable levels of the VISSIM outputted value not far from observed values. (VISSIM Calibration and Validation Technical Report, 2006).

### 3.6 Research Approach

The study used a mixed method for its research approach. Quantitative data were collected from primary and secondary sources, and the results obtained after analysis were qualitative and quantitative. The study determined the capacity and service level for selected roundabouts using the collected data. Primary and secondary data were used to assess the current traffic flow of the roundabout and the impact of modal shifts on-road performance. The study was conducted by simulating 12 basic scenarios for three different modal shift paths, such as:

- ✚ Baseline scenario (current traffic count simulation).
- ✚ Scenario - 1 Current traffic count with 10% modal shift from car to Bus (public transport)
- ✚ Scenario - 2 Current traffic count with 20% modal shift from car to Bus (public transport)
- ✚ Scenario - 3 Current traffic count with 30% modal shift from car to Bus (public transport)
- ✚ Scenario - 4 Current traffic count with 40% modal shift from car to Bus (public transport)
- ✚ Scenario - 5 Current traffic count with 50% modal shift from car to Bus (public transport)
- ✚ Scenario - 6 Current traffic count with 60% modal shift from car to Bus (public transport)
- ✚ Scenario - 7 Current traffic count with 70% modal shift from car to Bus (public transport)
- ✚ Scenario - 8 Current traffic count with 80% modal shift from car to Bus (public transport)
- ✚ Scenario - 9 Current traffic count with 90% modal shift from car to Bus (public transport)
- ✚ Scenario - 10 Current traffic count with 100% modal shift from car to Bus (public transport)
- ✚ Scenario - 11 unit change modal shift, shift by substituting one (1) minibus instead of eight (8) cars and one (1) bus instead of six (6) minibuses.

- ✚ Scenario - 12 carpooling modal shift, shift by substituting one (1) minibus instead of three (3) cars and one (1) bus instead of six (6) minibuses.

The approach in this thesis involves using PTV VISSIM 9 for all scenarios; base model development, model calibration, validation for base model, and the other scenarios of a roundabout to determine the roundabout and approach roads LOS (level of serves), Travel Time, delay, queue length, emission and Fuel Consumption was computed with Vissim. The base model represents the current field conditions with the actual count constructed and calibration was done on the base mode. Calibrated model stability was tested using Stata MP 13 with a different random number of seeds to account for the variability of vehicular inflow the model was validated on Night using night traffic count on the baseline scenario.

The description presented in this research contains the current service level and capacity for the selected roundabouts. According to the plan for the research, the transport sector's ten-year strategic plan for the country is to use public transport, and this research will provide information about the level of service at the selected roundabouts after the modal shift and it will indicate what percent is effective for the modal shift. PTV-Vissim analyzing software was used to analyze the results. Primary Data is straight from the site and other necessary data was collected from manuals in the form of secondary data. The analysis was performed based on the HCM-2010 PTV Vissim model for analysis.

## **Chapter 4 ANALYSIS AND RESULTS**

On this chapter the analysis was made using Stata 13 and Vissim 9 software's to archives the research objectives and for the attainment of finding is presented and discussed in graphical and in tabular forms.

### **4.1 Analysis**

The analysis in this study was conducted using PTV VISSIM Version 9 simulation software. The purpose of the analysis is to display the performance of the current roundabout, starting from the baseline scenario with the current traffic, up to the expected result from each incremental modal shift based on the baseline traffic. The baseline scenario was analyzed with different random seed numbers, and critical gap checking was performed to select the significant seed and critical gap. The different seeds and critical gaps produced different numbers of vehicles. In this study, the critical gaps in VISSIM software use 0.5 critical gaps and 3.5 as meso-critical gaps by default. However, for this study, the critical and meso-critical gaps were taken as 2.6 and 4.1, respectively, as per the manual restriction of HCM 2010.

Although the seed number can be changed unconditionally on the simulation parameter, for this study, seeds 35, 38, 42, 45, and 48 were tried to check the output and identify the seed number at which the actual and simulated vehicle numbers are approached and the small actual and simulated difference value seed was taken for the analysis.

The analysis of this study was conducted using two modal shifts: passenger car unit (PCU) and passengers on vehicles. The modal shift of the passenger car unit (PCU) is based on the Highway Capacity Manual (HCM) instructions. According to the HCM Manual Volume 3 Return Performance Evaluation Chapter 21, PCU for small cars like passenger cars is One (1), and PCU for heavy vehicles is Two (2). The other modal shift method used in this study is based on the passenger. Modal change using the passenger in the vehicle is based on observations and results obtained when drivers share their vehicles with other passengers.

## 4.2 Base Model Calibration and Validation Analysis

The base model was developed and calibrated on Urael roundabout for morning traffic flow and validated on night Urael traffic volume.

### 4.2.1 Calibration Tests

#### 4.2.1.1 Quality Measure Tests

**Table 4. 2. 1. 1. 1 Result table for quality and error tests outputted calibration tests value**

S. N	Performed Quality and Error Tests for Calibration	Seed No 35	Seed No 38	Seed No 42	Seed No 45	Seed No 48
1	Maximum GEH Value	0.544	<b>0.75</b>	3.804	3.901	3.707
2	RMSE	0.0107	<b>0.0101</b>	0.0571	0.0582	0.0556
3	RMSPE in %	0.009	<b>0.00881</b>	0.0481	0.049	0.0469
4	ME	-16	<b>-15</b>	-68	-69	-65
5	MPE in %	0.0085	<b>0.0075</b>	0.0359	0.0365	0.0344
6	MAPE in %	0.8582	<b>0.759</b>	3.8438	3.9084	3.6741
7	U	0.0046	<b>0.005</b>	0.0242	0.0247	0.0236
8	UM	0.8704	<b>0.70154</b>	0.5694	0.5639	0.5458
9	US	0.0971	<b>0.27636</b>	0.0547	0.0613	0.0059
10	UC	0.073	<b>0.0308</b>	0.5209	1.043	1.0956

**Table 4. 2. 1. 1. 2 Quality and error tests results review**

S.N	Performed Quality and error tests for calibration	Seed No 35	Seed No 38	Seed No 42	Seed No 45	Seed No 48
1	GEH Value	pass	<b>pass</b>	pass	pass	pass
2	RMSE	0.0107	<b>0.0101(small)</b>	0.0571	0.0582	0.0556
3	RMSPE in %	0.009	<b>0.00881 (small)</b>	0.0481	0.049	0.0469
4	ME	-16	<b>-15</b>	-68	-69	-65
5	MPE in %	0.0085	<b>0.0075</b>	0.0359	0.0365	0.0344
6	MAPE in %	0.8582	<b>0.759</b>	3.8438	3.9084	3.6741
7	U	0.0046	<b>0.005</b>	0.0242	0.0247	0.0236
8	UM	0.8704	<b>0.70154</b>	0.5694	0.5639	0.5458
9	US	0.0971	<b>0.27636</b>	0.0547	0.0613	0.0059
10	UC	0.073	<b>0.0308</b>	0.5209	1.043	1.0956

#### 4.2.1.2 Stability tests

**Table 4. 2. 1. 2. 1 Stability test values**

S.N	Stability Test	Seed 35	Seed 38	Seed 42	Seed 45	Seed 48
1	<b>Normality Test</b>	Normal Distribution	Normal Distribution	Normal Distribution	Normal Distribution	Normal Distribution
2	<b>Correlation(r)</b>	<b>0.9948</b> the is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.9993</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.7699</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.7642</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.77</b> there is very strong correlation and positive Association b/n Actual and simulated Value
3	<b>Student T-test P-value</b>	<b>0.020</b> For P-value < 0.05 Significant	<b>0.064</b> For P-value > 0.05 not Significant	<b>0.143</b> For P-value >0.05 not Significant	<b>0.146</b> For P-value >0.05 not Significant	<b>0.016</b> For P-value >0.05 not Significant

**Table 4. 2. 1. 2. 2 Acceptable and passed level**

S.N	Stability Test	Seed 35	Seed 38	Seed 42	Seed 45	Seed 48
1	<b>Normality Test</b>	Normal Distribution	<b>Normal Distribution</b>	Normal Distribution	Normal Distribution	Normal Distribution
2	<b>Correlation(r)</b>	0.9948	<b>0.9993</b>	0.7699	0.7642	0.77
3	<b>Student T-test P-value</b>	0.02	<b>0.064</b>	0.143	0.146	0.016

#### 4.2.1.3 Vehicular Speed Calibration

The software outputted speed was approached to the actual speed from site observation this implies that the calibration result was closer to the real speed on each seed number with an adjusted critical gap based on HCM 2010 Manual

However, the simulated traffic volume for each seed number and critical gap have difference, due to this reason seed no 38 was have relatively closer simulated value than the other seed numbers simulation output.

**Table 4. 2. 1. 3 Actual Speed comparison with simulation outputted speed**

SN.	Approach Roads	Actual Average Speed (Morning)	Seed 35 Speed	Seed 38 Speed	Seed 42 Speed	Seed 45 Speed	Seed 48 Speed
1	M/Square Approach	32.13	31.21	<b>31.13</b>	31.24	31.24	31.33
2	Bole Approach	33.7	29.82	<b>30.18</b>	30.03	30.09	30.26
3	Megenaga Approach	21.13	24.98	<b>19.54</b>	25.5	25.23	24.94
4	Kazanchis Approach	32.54	29.62	<b>30.18</b>	29.82	30.07	29.89

#### 4.2.1.4 Vehicle number Calibration

**Table 4. 2. 1. 4 Number of Vehicle Calibration**

SN	Actual Value	Simulated Value Seed No 35	Simulated Value Seed No 38	Simulated Value Seed No 42	Simulated Value Seed No 45	Simulated Value Seed No 48
1	1808	1796	1801	1796	1796	1796
2	1932	1904	1922	1912	1912	1920
3	2005	1980	1974	1924	1924	1924
4	1856	1828	1846	1696	1692	1700
<b>Total</b>	<b>7601</b>	<b>7508</b>	<b>7543</b>	<b>7328</b>	<b>7324</b>	<b>7340</b>

Finally Due to the above all tests and calibration values seed no 38 was selected and validation was made on night traffic data for the same parameter of simulation.

## 4.2.2 Validation on night traffic

### 4.2.2.1 Quality Measure test for Validation

**Table 4. 2. 2. 1. 1 Result table for quality and error tests outputted for Validation tests value**

S. N	Performed Quality and error tests for calibration	Seed No 35	Seed No 38	Seed No 42	Seed No 45	Seed No 48
1	GEH Value	3.79	2.787	4.141	3.79	3.834
2	RMSE	0.0522	0.0496	0.0571	0.0522	0.0521
3	RMSPE in %	0.0428	0.0072	0.0087	0.0073	0.0073
4	ME	-87	-36	-95	-87	-88
5	MPE in %	0.0399	0.016	0.0436	0.0399	0.0404
6	MAPE in %	4.184	3.789	4.589	4.184	4.232
7	U	0.0221	0.0212	0.0242	0.0221	0.0221
8	UM	0.861	0.1575	0.8617	0.861	0.8828
9	US	0.1149	0.00067	0.8617	0.861	0.8828
10	UC	0.0696	0.0914	0.0951	0.0696	0.5301

**Table 4. 2. 2. 1. 2 Quality and error tests results review**

S. N	Performed Quality and error tests for calibration	Seed No 35	Seed No 38	Seed No 42	Seed No 45	Seed No 48
1	GEH Value	pass	<b>pass</b>	pass	pass	pass
2	RMSE	0.0522	<b>0.0496</b>	0.0571	0.0522	0.0521
3	RMSPE in %	0.0428	<b>0.0072</b>	0.0087	0.0073	0.0073
4	ME	-87	<b>-36</b>	-95	-87	-88
5	MPE in %	0.0399	<b>0.016</b>	0.0436	0.0399	0.0404
6	MAPE in %	4.184	<b>3.789</b>	4.589	4.184	4.232
7	U	0.0221	<b>0.0212</b>	0.0242	0.0221	0.0221
8	UM	0.861	<b>0.1575</b>	0.8617	0.861	0.8828
9	US	0.1149	<b>0.00067</b>	0.8617	0.861	0.8828
10	UC	0.0696	<b>0.0914</b>	0.0951	0.0696	0.5301

#### 4.2.2.2 Stability tests for validation

The night traffic simulation values stability also checked as follow

**Table 4. 2. 2. 2. 1 Stability test values**

S. N	Stability Test	Seed 35	Seed 38	Seed 42	Seed 45	Seed 48
1	<b>Normality Test</b>	Normal Distribution	Normal Distribution	Normal Distribution	Normal Distribution	Normal Distribution
2	<b>Correlation(r)</b>	<b>0.8586</b> the is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.9132</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.7792</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>0.8586</b> there is very strong correlation and positive Association b/n Actual and simulated Value	<b>-0.0609</b> there is very strong correlation and positive Association b/n Actual and simulated Value
3	<b>Student T-test P-value</b>	<b>0.0226</b> For P-value < 0.05 Significant	<b>0.5054</b> For P-value > 0.05 not Significant	<b>0.0224</b> For P-value >0.05 not Significant	<b>0.0226</b> For P-value >0.05 not Significant	<b>0.0173</b> For P-value >0.05 not Significant

**Table 4. 2. 2. 2. 2 Acceptable and passed level**

S. N	Stability Test	Seed 35	Seed 38	Seed 42	Seed 45	Seed 48
1	<b>Normality Test</b>	Normal Distribution	<b>Normal Distribution</b>	Normal Distribution	Normal Distribution	Normal Distribution
2	<b>Correlation(r)</b>	0.8586	<b>0.9132</b>	0.7792	0.8586	-0.0609
3	<b>Student T-test P-value</b>	0.0226	<b>0.5054</b>	0.0224	0.0226	0.0173

### 4.2.2.3 Night traffic Vehicular Speed Calibration

**Table 4. 2. 2. 3 Actual Speed comparison with simulation outputted speed for Night Traffic**

SN.	Approch Roads	Actual Average Speed (Moorning)	Seed 35 Speed	Seed 38 Speed	Seed 42 Speed	Seed 45 Speed	Seed 48 Speed
1	M/Square Approach	24.13	17.74	<b>17.99</b>	17.93	18.91	19.94
2	Bole Approach	35.83	30.41	<b>30.42</b>	30.56	30.31	30.38
3	Megenaga Approach	32.6	30.85	<b>30.84</b>	30.84	30.83	30.94
4	Kasanchis Approach	21.42	14.22	<b>13.91</b>	14.54	13.4	13.3

The software outputted speed was approached to the actual speed from site observation this implies that the calibration result was closer to the real speed on each seed number with an adjusted critical gap based on HCM 2010 Manual refer table 3.4.

However, the simulated traffic volume for each seed number and critical gap have difference, due to this reason seed no 38 was have relatively closer simulated value than the other seed numbers simulation output.

- ✓ Finally Due to the above all tests and calibration values seed no 38 was selected and the simulation was made on that calibrated and validated seed number with the.

### 4.3 Results

According to the HCM description, the operational performance is determined by traffic flow data and geometric configuration as input data for the analysis. The analysis was made in Vissim simulation software using the input data. The analysis results for the roundabout performance evaluation are level of service from LOS A to LOS F, vehicular delay in second, vehicular stop in second, vehicular stop in number of stoppings, Queue length and queue stop results are obtained from the analysis of the roundabouts.

The approach roads of the roundabout also have a level of service, vehicular delay, stop delay, vehicular stop, queue length, and queue stop results similar to the roundabout, and for approach roads, the travel time in second and travel speed in Km/h results was obtained from the analysis.

✚ Each roundabouts results are illustrated as follow in the form of tables and Figures.

### 4.3.1 Result for Urael Roundabout

According to ERA 2013 Geometric Design Manual modern roundabouts minimize conflict area to eight (8) in roundabouts rather than the other junctions. Numbers of conflict area on Urael roundabout, there were 17 conflicts occurred. Those conflicts were occurred between vehicles for the movement across the roundabout. The conflicts removed by giving priority to left-hand and circulatory movements.



Figure 4. 3. 1. 1 Conflict areas at Urael roundabout

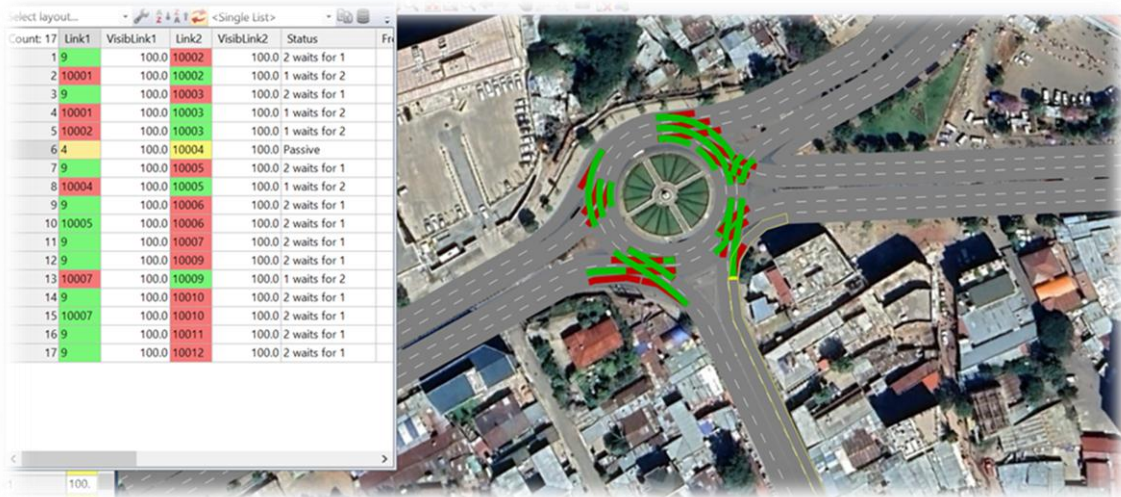


Figure 4. 3. 1. 2 Conflict areas solved at Urael roundabout

### 4.3.1.1 Roundabout Evaluation Result

Roundabout results include; vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay and stop frequency as the figures below and tabulated in table 4.12

#### 4.3.1.1.1 Roundabout Level of Service, Volume – Capacity ratio, Vehicular Delay, Stop Delay and Vehicles Stop Frequency Results

The results include vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay, Vehicles stop frequency results on the roundabout.

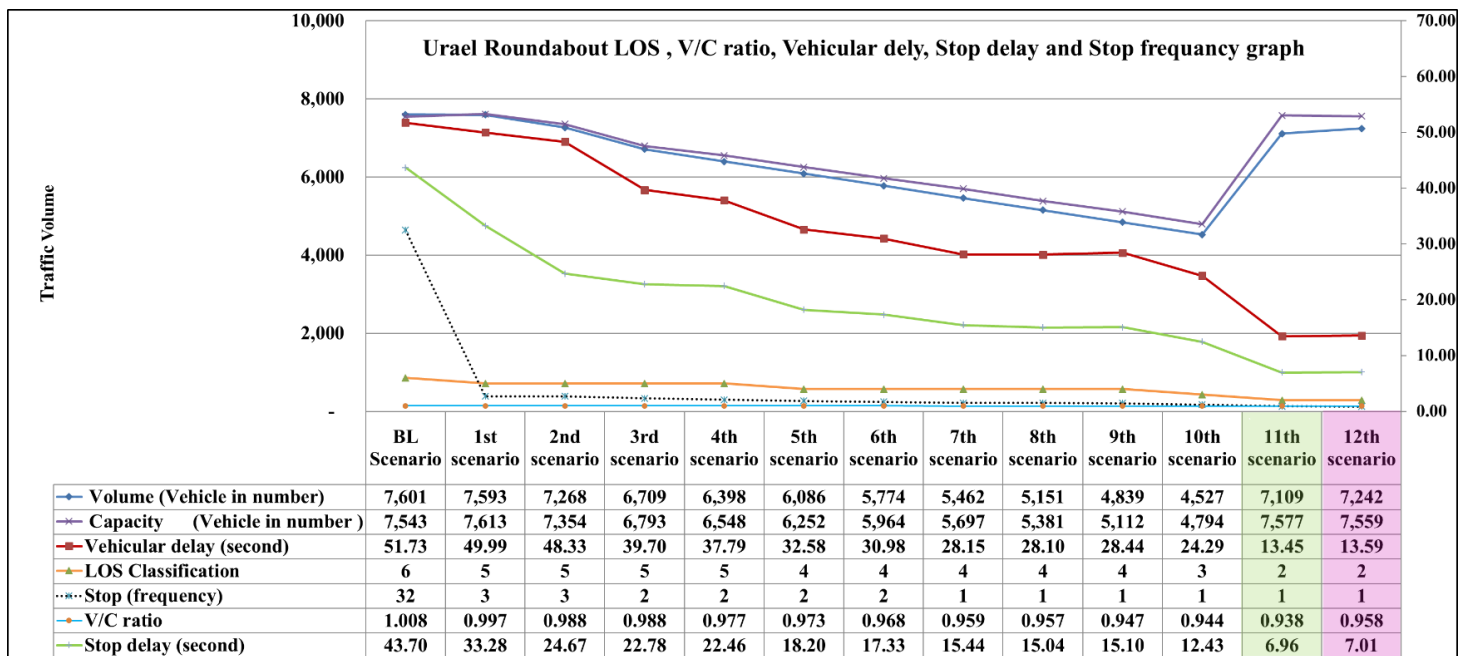


Figure 4. 3. 1. 1. 1 Urael roundabout LOS, Volume- Capacity ratio, Vehicular delay, stop delay, and Vehicular Stop Frequency results graphical interpretation

**Table 4. 3. 1. 1. 1 Urael roundabout LOS, Volume- Capacity ratio, Vehicular delay, stop delay, and Vehicular Stop Frequency Evaluation Results**

Scenarios	Volume (Vehicle in number)	Capacity (Vehicle in number )	V/c Ratio	Vehicular delay (second)	LOS Classification	Stop delay (second)	Stop (frequency)
<b>BL Scenario</b>	7,601	7,543	1.008	51.73	LOS F	43.70	32
<b>1st Scenario</b>	7,593	7,613	0.997	49.99	LOS E	33.28	3
<b>2nd Scenario</b>	7,268	7,354	0.988	48.33	LOS E	24.67	3
<b>3rd Scenario</b>	6,709	6,793	0.988	39.70	LOS E	22.78	2
<b>4th Scenario</b>	6,398	6,548	0.977	37.79	LOS E	22.46	2
<b>5th Scenario</b>	6,086	6,252	0.973	32.58	LOS D	18.20	2
<b>6th Scenario</b>	5,774	5,964	0.968	30.98	LOS D	17.33	2
<b>7th Scenario</b>	5,462	5,697	0.959	28.15	LOS D	15.44	1
<b>8th Scenario</b>	5,151	5,381	0.957	28.10	LOS D	15.04	1
<b>9th Scenario</b>	4,839	5,112	0.947	28.44	LOS D	15.10	1
<b>10th Scenario</b>	4,527	4,794	0.944	24.29	LOS C	12.43	1
<b>11th Scenario</b>	7,109	7,577	0.938	13.45	LOS B	6.96	1
<b>12th Scenario</b>	7,242	7,559	0.958	13.59	LOS B	7.01	1

⊗ Volume denotes the input vehicle

⊗ Capacity denotes output vehicle

The Urael roundabout experienced a notable improvement in its Level of Service (LOS), transitioning from Level of Service F to Level of Service B. This research discussion focuses on the positive outcomes associated with this upgrade and its implications for traffic congestion reduction and overall traffic performance.

The main solution for congestion reduction is balance the traffic demand with the road capacity and optimize traffic patterns. The roundabout performance upgrading alleviates delays and congestion, which tend to worsen when traffic demand surpasses the road capacity. By implementing various scenarios and encouraging a modal shift towards more efficient paths, resulting in a significant improvement in the roundabout's level of service.

The transition from Level of Service F to Level of Service B indicates a substantial enhancement in traffic conditions. Level of Service B suggests that the roundabout now operates under reasonably uncongested conditions, providing road users with enhanced comfort and convenience. The reduced delays and improved traffic flow enhance the overall efficiency of the roundabout, allowing vehicles to move more smoothly through the intersection.

One of the key observations made during this study was the decrease in the number of vehicles stopped at the roundabout following the upgrade. This reduction indicates an improvement in the flow of traffic, facilitating a more efficient movement of vehicles. It is reasonable to assume that the upgraded level of service has increased the capacity and efficiency of the roundabout, contributing to a reduction in congestion.

The positive outcomes observed at the Urael roundabout serve as a promising model for future transportation planning and infrastructure development efforts. This research demonstrates that by effectively managing traffic demand and optimizing traffic patterns, significant improvements in level of service can be achieved, leading to a decrease in congestion and enhanced traffic flow.

The findings of this study have several implications for transportation planning and policy decisions. The research highlights the importance of balancing efficient traffic operations with environmental stewardship, emphasizing the need to consider congestion reduction as a key objective in transportation planning efforts. By striving for improved levels of service, transportation planners can enhance the overall quality of transportation systems, benefiting both road users and the environment.

It is worth noting that further research can explore additional factors that may have contributed to the observed improvements, such as changes in travel patterns or the promotion of alternative transportation modes. Understanding these factors in more detail can provide valuable insights into achieving sustainable and efficient transportation systems.

In conclusion, the research findings confirm that the upgraded level of service at the Urael roundabout is in line with the HCM 2010 manual's guidelines and demonstrates a significant reduction in congestion. These results highlight the potential benefits of implementing similar enhancements in other roundabouts and emphasize the importance of considering the relationship between level of service, delay, and congestion in transportation planning efforts.

#### 4.3.1.1.2 Roundabout Queue Length and Vehicular Stop Result

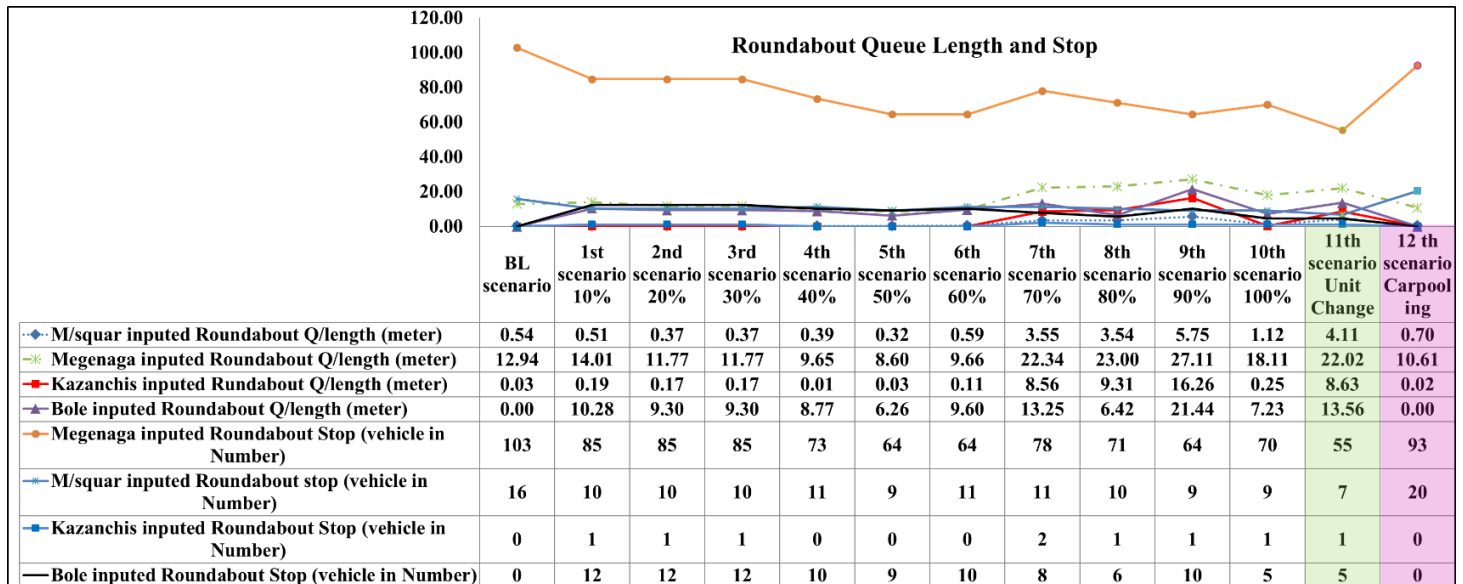


Figure 4. 3. 1. 1. 2. 1 Urael Roundabout Queue length and Number of Stop Vehicles result graphical interpretation

**Table 4. 3. 1. 1. 2. 1 Urael Roundabout Queue Length Result**

Queue Length (in meter)													
	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
<b>On Roundabout After M/sqar Traffic Inputed</b>	0.54	0.51	0.37	0.37	0.39	0.32	0.59	3.55	3.54	5.75	1.12	4.11	0.70
<b>On Roundabout After Bole Traffic Inputed</b>	12.94	14.01	11.77	11.77	9.65	8.60	9.66	22.34	23.00	27.11	18.11	22.02	10.61
<b>On Roundabout After Kazanchis Traffic Inputed</b>	0.03	0.19	0.17	0.17	0.01	0.03	0.11	8.56	9.31	16.26	0.25	8.63	0.02
<b>On Roundabout After Megenaga Traffic inputed</b>	0.00	10.28	9.30	9.30	8.77	6.26	9.60	13.25	6.42	21.44	7.23	13.56	0.00

**Table 4. 3. 1. 1. 2. 2 Urael Roundabout Number of Stop Vehicles Result**

Stop (vehicle in number)													
	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
<b>On Roundabout After M/sqar Traffic Inputed</b>	16	10	10	10	11	9	11	11	10	9	9	7	20
<b>On Roundabout After Bole Traffic Inputed</b>	103	85	85	85	73	64	64	78	71	64	70	55	93
<b>On Roundabout After Kazanchis Traffic Inputed</b>	0	1	1	1	0	0	0	2	1	1	1	1	0
<b>On Roundabout After Megenaga Traffic inputed</b>	0	12	12	12	10	9	10	8	6	10	5	5	0

In this roundabout result the stop vehicles number varies in each scenario and as queue length decrease the number of stop vehicles decreased however, it's important to note that the relationship between queue length and stoppages is not always linear or consistent. As reduce

vehicular delays and subsequently possible to decrease the vehicles queue length. The findings indicate that these shift scenarios were effective in reducing congestion, as evidenced by the decreased number of stop vehicles and decrease the queue length.

Roundabouts, including the Urael roundabout, are designed to facilitate a continuous flow of vehicles. However, when traffic volume exceeds the roundabout's capacity, congestion can occur, leading to queues and delays. The study recognizes the impact of traffic volume variability from each approach leg on the roundabout's level of service. Overall, the study suggests that implementing strategies to balance traffic demand and road capacity can lead to positive outcomes, such as reduced queue length and vehicle stops, thereby improving the overall performance of the Urael roundabout. According to the Highway Capacity Manual (HCM, 2010) level of service category, the level of service (LOS) of Urael roundabout was upgraded with vehicular delay reduction refer to Table 2.7.1 and Table 4.3.1.1.1 to assure. Overall, the findings of this roundabout emphasize the positive result on reduction of queue length and vehicle stop.

### 4.3.1.2 Approach Road Evaluation Results

The evaluation result for the approach roads was tabulated as follow in the table below



**Figure 4. 3. 1. 2 Urael Roundabout Approach Roads speed reduction point for result output**

**Table 4. 3. 1. 2 Urael Roundabout Speed Data**

SN	Approach Leg	Sample Number	Travel Speed (Km/h)	Travel Length in (Meter)				Average Speed (km/h)
				RT	TM	LT	UT	
1	Meskelsquar	1	40.45	247.16	294.55	316.32	359.8	32.13
		2	36	222.16	269.55	291.32	334.8	
		3	34.8	197.16	244.55	266.32	309.8	
		4	28.4	172.16	219.55	241.32	284.8	
		5	21	147.16	194.55	216.32	259.8	
2	Bole	1	38.18	260.16	288.1	330.66	357.17	33.70
		2	35.21	235.16	263.1	305.66	332.17	
		3	34.07	210.16	238.1	280.66	307.17	
		4	32.82	185.16	213.1	255.66	282.17	
		5	28.22	160.16	188.1	230.66	257.17	
3	Megenaga	1	27.91	234.57	290.82	318.98	349.74	21.124
		2	23.32	209.57	265.82	293.98	324.74	
		3	22.55	184.57	240.82	268.98	299.74	
		4	16.31	159.57	215.82	243.98	274.74	
		5	15.53	134.57	190.82	218.98	249.74	
4	Kazanchis	1	39.47	255.79	290.94	323.89	344.09	32.54
		2	37.11	230.79	265.94	298.89	319.09	
		3	33.56	205.79	240.94	273.89	294.09	
		4	27.18	180.79	215.94	248.89	269.09	
		5	25.38	155.79	190.94	223.89	244.09	

#### 4.3.1.2.1 Approach Road Level of service, Stop delay, stop frequency and Vehicular Delay results

**Table 4. 3. 1. 2. 1. 1 Urael Roundabout Approach Roads LOS, Stop Delay, Stop Frequency and Vehicular Delay (a)**

Movement	Distance (meter)	BL scenario				10 % ( scenario 1)				20 % (scenario 2)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: Bole RT	160.16	0.06	0.06	0.39	LOS A	0.00	0.00	0.12	LOS A	0.00	0	0.12	LOS A
2: Bole Tm	188.10	3.98	0.74	8.91	LOS A	4.53	0.76	9.36	LOS A	4.53	1	9.36	LOS A
3: Bole LT	230.66	3.35	0.75	10.72	LOS B	3.38	0.66	9.98	LOS A	3.38	1	9.98	LOS A
4: Bole UT	257.17	2.88	0.59	7.91	LOS A	2.96	0.63	7.85	LOS A	2.96	1	7.85	LOS A
5: Megenaga RT	134.57	34.72	2.09	48.10	LOS E	35.34	2.00	49.04	LOS D	35.34	2	49.04	LOS E
6: Megenaga TM	190.82	91.11	7.50	142.03	LOS F	90.38	6.85	136.96	LOS F	90.38	7	136.96	LOS F
7: Megenaga LT	218.98	95.52	7.72	145.58	LOS F	90.02	7.15	137.81	LOS F	90.02	7	137.81	LOS F
8: Megenaga UT	249.74	85.07	7.47	134.80	LOS F	92.59	7.24	140.16	LOS F	92.59	7	140.16	LOS F
9: Kasanchis RT	155.79	0.00	0.00	0.04	LOS A	0.00	0.00	0.12	LOS A	0.00	0	0.12	LOS A
10: Kazanchis TM	190.94	8.78	1.26	16.01	LOS C	5.95	0.92	12.44	LOS B	5.95	1	12.44	LOS B
11: Kazanchis LT	223.89	10.15	1.44	18.17	LOS C	7.14	1.02	14.18	LOS B	7.14	1	14.18	LOS B
12: Kazanchis UT	244.09	6.01	1.01	11.61	LOS C	4.58	0.73	9.86	LOS A	4.58	1	9.86	LOS A
13: M/Squar RT	147.16	0.00	0.00	0.06	LOS A	0.00	0.00	0.10	LOS A	0.00	0	0.10	LOS A
14: M/Squar TM	194.55	4.61	0.95	11.30	LOS B	6.07	1.01	13.99	LOS B	6.07	1	13.99	LOS B
15: M/Squar LT	216.32	4.81	0.92	11.65	LOS B	6.89	1.18	16.01	LOS C	6.89	1	16.01	LOS C
16: M/Squar UT	259.80	4.50	0.91	11.48	LOS B	6.61	1.14	15.66	LOS C	6.61	1	15.66	LOS C

**Table 4. 3. 1. 2. 1. 2 Urael Roundabout Approach Roads LOS, Stop Delay, Stop Frequency and Vehicular Delay (b)**

Movement	Distance (meter)	30 % (scenario 3)				40 % (scenario 4)				50 % (scenario 5)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: Bole RT	160.16	0.00	0	0.08	LOS A	0.00	0	0.03	LOS A	0.00	0	0.05	LOS A
2: Bole Tm	188.10	3.16	1	7.24	LOS A	4.14	1	8.75	LOS A	3.70	1	8.05	LOS A
3: Bole LT	230.66	2.77	1	8.45	LOS A	1.80	0	6.67	LOS A	1.86	0	6.76	LOS A
4: Bole UT	257.17	3.08	0	6.48	LOS A	1.73	0	6.01	LOS A	1.16	0	5.45	LOS A
5: Megenaga RT	134.57	14.69	1	23.04	LOS D	19.53	1	28.39	LOS D	10.49	1	17.65	LOSC
6: Megenaga TM	190.82	63.45	6	106.47	LOS F	56.14	5	92.02	LOS F	47.28	5	80.91	LOS F
7: Megenaga LT	218.98	60.86	6	103.39	LOS F	57.26	5	92.46	LOS F	49.11	5	83.38	LOS F
8: Megenaga UT	249.74	67.02	7	110.87	LOS F	58.01	5	93.02	LOS F	45.04	5	77.52	LOS F
9: Kasanchis RT	155.79	0.01	0	0.11	LOS A	0.01	0	0.11	LOS A	0.00	0	0.07	LOS A
10: Kazanchis TM	190.94	7.71	1	16.17	LOS C	6.72	1	13.49	LOS B	6.92	1	14.55	LOS B
11: Kazanchis LT	223.89	7.63	1	15.58	LOS C	8.45	1	16.81	LOS C	6.19	1	13.04	LOS C
12: Kazanchis UT	244.09	5.65	1	14.09	LOS B	7.98	1	16.05	LOS C	6.71	1	12.10	LOS C
13: M/Squar RT	147.16	0.06	0	0.24	LOS A	0.00	0	0.13	LOS A	0.04	0	0.18	LOS A
14: M/Squar TM	194.55	5.41	1	13.33	LOS B	4.43	1	12.10	LOS A	6.65	1	14.40	LOSB
15: M/Squar LT	216.32	6.58	1	14.69	LOS B	4.28	1	11.91	LOS B	9.36	1	20.53	LOS C
16: M/Squar UT	259.80	5.89	1	14.95	LOS B	6.04	1	16.16	LOSC	7.47	1	17.44	LOS C

**Table 4. 3. 1. 2. 1. 3 Urael Roundabout Approach Roads LOS, Stop Delay, Stop Frequency and Vehicular Delay (c)**

Movement	Distance (meter)	60 % (scenario 6)				70 % (scenario 7)				80 % (scenario 8)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: Bole RT	160.16	0.87	0	1.34	LOS A	0.00	0	0.16	LOS A	0.13	0	0.66	LOS A
2: Bole Tm	188.10	5.47	1	12.63	LOS B	5.32	1	12.36	LOS B	4.59	1	11.64	LOS B
3: Bole LT	230.66	4.02	1	12.60	LOS B	3.77	1	11.99	LOS B	3.57	1	12.40	LOS B
4: Bole UT	257.17	1.33	1	8.09	LOS A	3.22	1	9.34	LOS A	3.25	1	8.76	LOS A
5: Megenaga RT	134.57	10.04	1	16.08	LOS C	10.08	1	15.58	LOS C	8.90	1	14.59	LOS B
6: Megenaga TM	190.82	68.10	6	107.60	LOS F	50.34	4	79.17	LOS F	47.69	4	76.88	LOS F
7: Megenaga LT	218.98	66.42	5	105.14	LOS F	47.15	4	76.02	LOS F	44.13	4	74.75	LOS F
8: Megenaga UT	249.74	68.61	6	108.10	LOS F	48.87	4	77.32	LOS F	46.26	4	77.97	LOS F
9: Kasanchis RT	155.79	0.00	0	0.06	LOS A	0.00	0	0.06	LOS A	0.00	0	0.03	LOS A
10: Kazanchis TM	190.94	4.64	1	9.77	LOS A	4.68	1	11.03	LOS B	5.92	1	12.58	LOS B
11: Kazanchis LT	223.89	3.82	1	10.34	LOS B	4.87	1	12.26	LOS B	7.13	1	15.30	LOS C
12: Kazanchis UT	244.09	7.99	1	15.59	LOS C	2.59	0	7.82	LOS A	2.16	1	9.61	LOS A
13: M/Squar RT	147.16	0.34	0	0.87	LOS A	0.48	0	1.02	LOS A	2.85	0	4.41	LOS A
14: M/Squar TM	194.55	8.94	1	19.30	LOS C	10.24	1	23.15	LOS C	7.01	1	17.88	LOS C
15: M/Squar LT	216.32	7.17	1	16.80	LOS C	9.43	2	22.88	LOS C	6.09	1	14.78	LOS C
16: M/Squar UT	259.80	8.50	1	20.72	LOS C	10.40	2	24.83	LOS C	7.51	1	20.18	LOS C

**Table 4.3.1.2.1. 4 Urael Roundabout Approach Roads LOS, Stop Delay, Stop Frequency and Vehicular Delay (d)**

Movement	Distance (meter)	90 % ( scenario 9)				100 % ( scenario 10)				Unit Change (scenario 11)				Carpooling (scenario 12)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: Bole RT	160.16	0.56	0	1.27	LOS A	1.00	0	2.10	LOS A	0.00	0	0.12	LOS A	0.00	0	0.016	LOS A
2: Bole Tm	188.10	6.40	1	14.25	LOS B	5.42	1	14.01	LOS B	2.84	1	7.34	LOS A	3.39	1	8.095	LOS A
3: Bole LT	230.66	4.62	1	14.61	LOS B	4.08	1	13.45	LOS B	1.99	1	8.22	LOS A	1.87	1	8.051	LOS A
4: Bole UT	257.17	9.90	0	15.80	LOS C	2.36	0	10.36	LOS B	1.56	1	5.64	LOS A	1.24	0	5.428	LOS A
5: Megenaga RT	134.57	5.26	1	10.38	LOS B	5.69	0	9.46	LOS A	0.75	0	2.71	LOS A	0.72	0	2.788	LOS A
6: Megenaga TM	190.82	44.11	4	73.56	LOS F	35.29	3	60.44	LOS F	40.30	3	62.62	LOS F	38.43	4	61.207	LOS F
7: Megenaga LT	218.98	47.04	4	78.71	LOS F	35.52	3	62.98	LOS F	33.46	3	53.87	LOS F	33.78	3	54.059	LOS F
8: Megenaga UT	249.74	47.10	4	78.22	LOS F	36.16	3	62.81	LOS F	38.97	4	61.88	LOS F	37.74	4	59.974	LOS F
9: Kasanchis RT	155.79	0.02	0	0.10	LOS A	0.00	0	0.11	LOS A	0.00	0	0.02	LOS A	0.00	0	0.036	LOS A
10: Kazanchis TM	190.94	4.33	1	10.70	LOS B	5.11	1	11.52	LOS B	6.83	1	12.22	LOS B	8.08	1	14.699	LOS B
11: Kazanchis LT	223.89	7.52	1	17.16	LOS C	5.67	1	14.64	LOS B	7.07	1	13.34	LOS B	8.07	1	15.113	LOS C
12: Kazanchis UT	244.09	7.44	1	12.10	LOS B	11.41	1	21.09	LOS C	4.59	1	12.30	LOS B	7.54	1	15.202	LOS C
13: M/Squar RT	147.16	0.55	0	1.20	LOS A	0.54	0	0.98	LOS A	0.20	0	0.73	LOS A	0.04	0	0.400	LOS A
14: M/Squar TM	194.55	9.60	1	20.14	LOS C	5.93	1	14.69	LOS B	1.99	1	6.27	LOS A	2.06	1	6.417	LOS A
15: M/Squar LT	216.32	11.24	1	22.39	LOS C	10.77	1	22.83	LOS C	2.49	1	6.12	LOS A	2.32	1	5.712	LOS A
16: M/Squar UT	259.80	10.02	1	22.20	LOS C	6.99	1	17.77	LOS C	1.60	0	5.97	LOS A	1.32	0	5.683	LOS A

Based on the result, it appears that the Urael roundabout experiences congestion and delays primarily in the initial scenarios due to the traffic demand and road capacity imbalance. The level of service (LOS) for the approach roads is determined by the delay experienced by vehicles, with a higher delay indicating a poorer level of service. The Megenaga approach was identified as having a poor level of service compared with other legs due to imbalanced number of vehicles with the capacity and it was resulting in increased delays and congestion. According to the Highway Capacity Manual (HCM, 2010) level of service category, the level of service (LOS) of Urael roundabout approach roads was upgraded with vehicular delay range on HCM manual refer to Table 2.7.2 and Table 4.3.1.2.1-4.3.1.2.4 to assure.

### 4.3.1.2.2 Approach Roads Travel Time Result

The software calculated travel times for different shifts and types of turns based on diverse traffic flows.

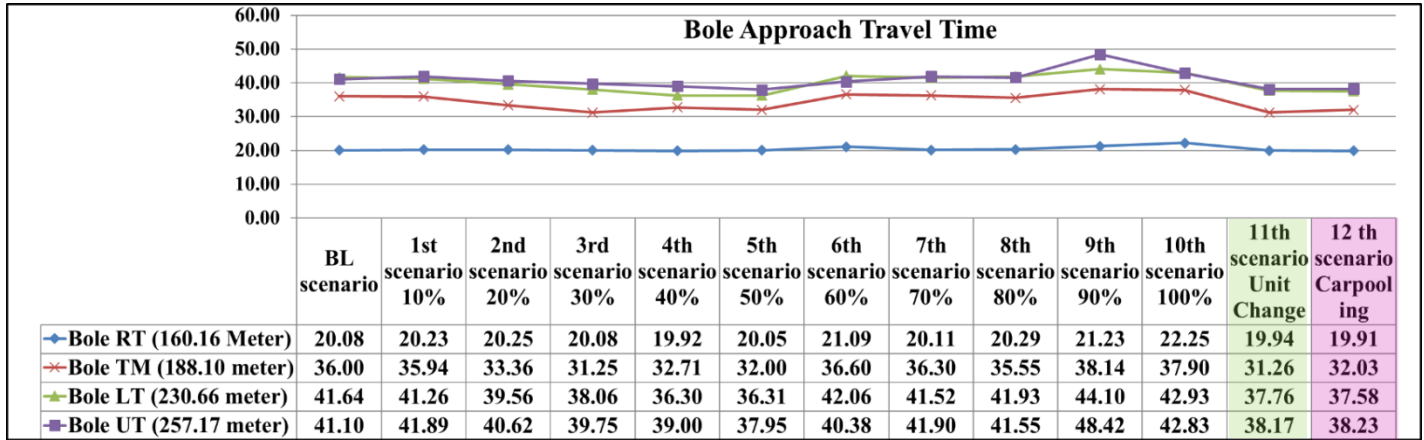


Figure 4. 3. 1. 2. 2. 1 Urael Roundabout Bole Approach Vehicles Travel Time Result Graphical Interpretations

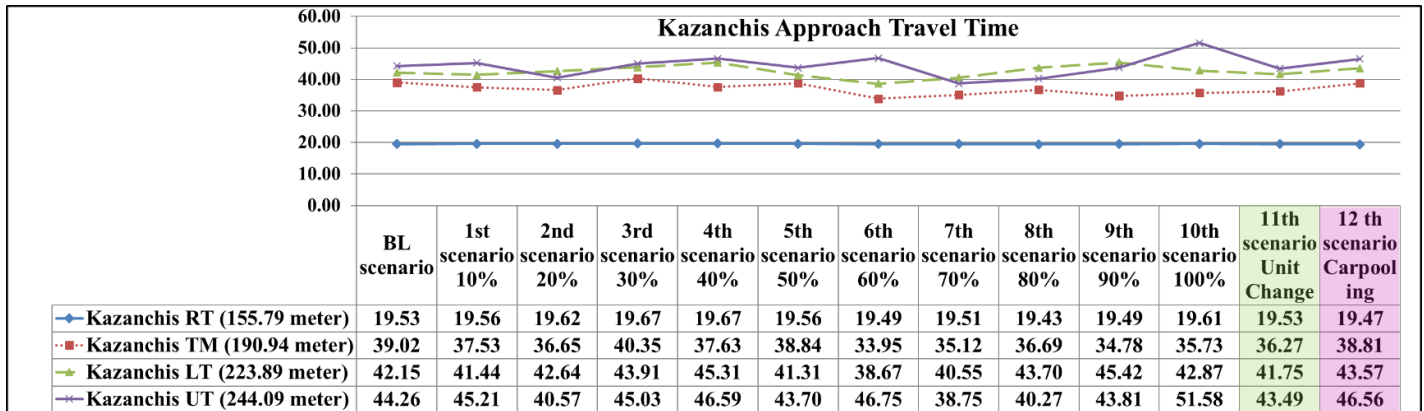


Figure 4. 3. 1. 2. 2. 2 Urael Roundabout Kazanchis Approach Vehicles Travel Time Result Graphical Interpretations

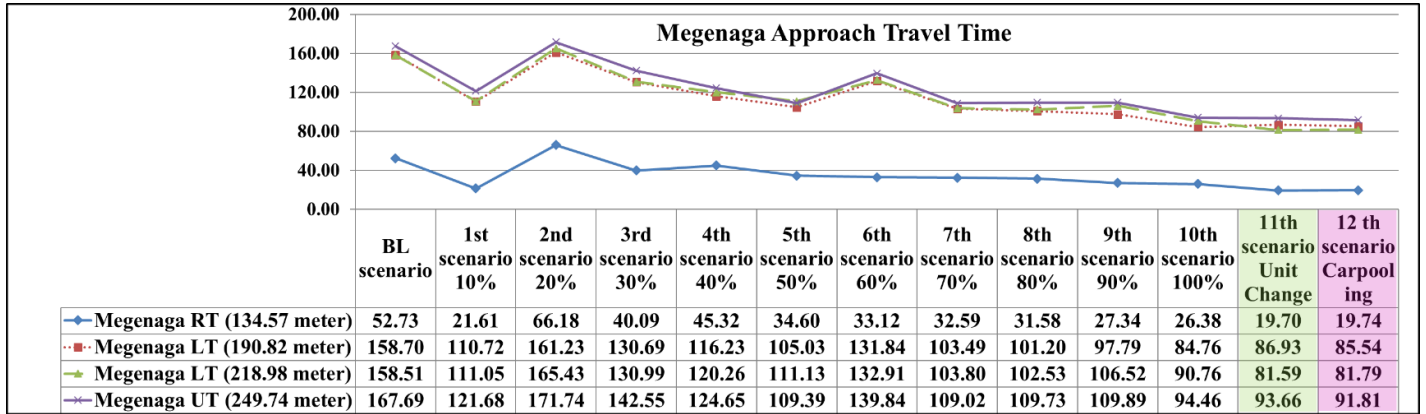


Figure 4. 3. 1. 2. 2. 3 Urael Roundabout Megenaga Approach Vehicles Travel Time Result Graphical Interpretations

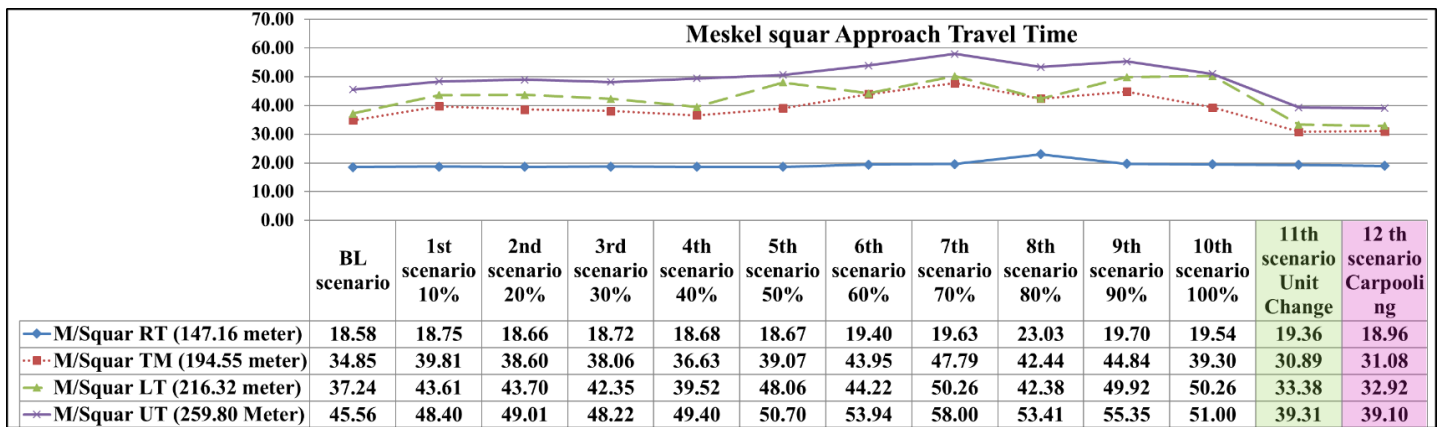


Figure 4. 3. 1. 2. 2. 4 Urael Roundabout Meskel Square Approach Vehicles Travel Time Result Graphical Interpretations

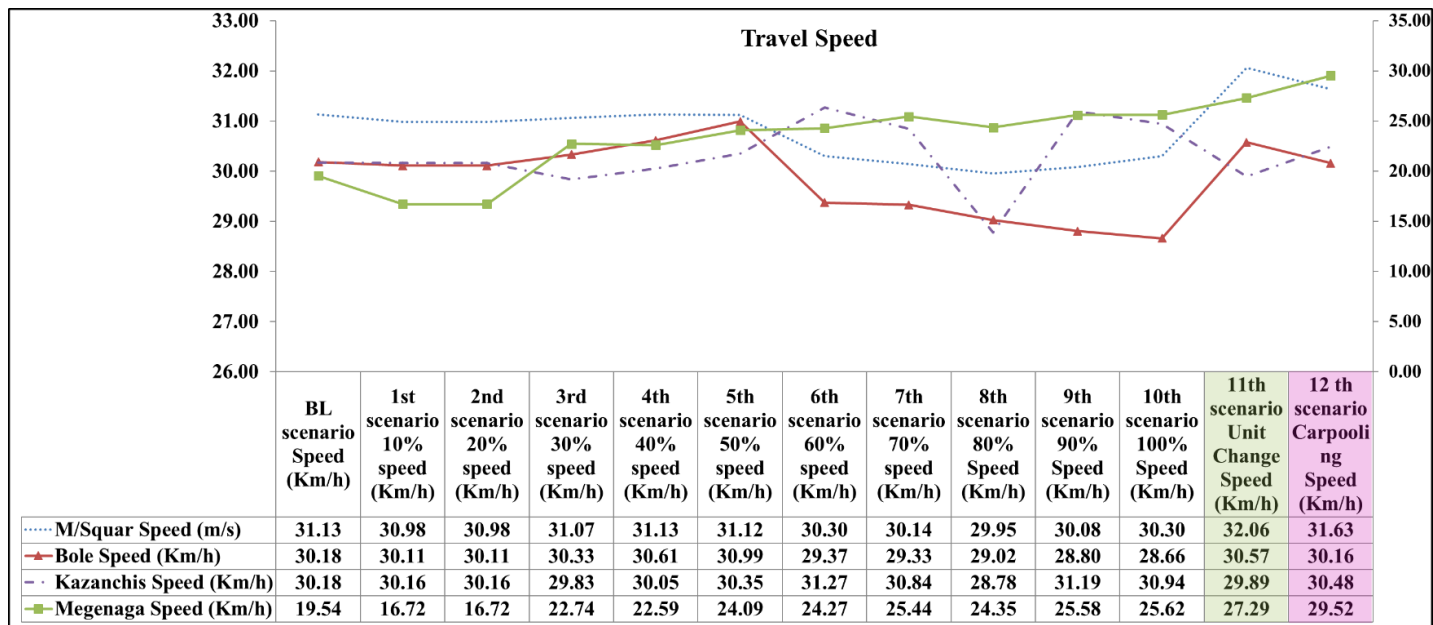
**Table 4. 3. 1. 2. 2 Urael Roundabout Approach Legs Vehicles Travel Time for each Origin Destination Movements result**

Movement	Distance (meter)	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
		Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)
<b>1: Bole RT</b>	160.16	20.08	20.23	20.25	20.08	19.92	20.05	21.09	20.11	20.29	21.23	22.25	19.94	19.91
<b>2: Bole Tm</b>	188.10	36.00	35.94	33.36	31.25	32.71	32.00	36.60	36.30	35.55	38.14	37.90	31.26	32.03
<b>3: Bole LT</b>	230.66	41.64	41.26	39.56	38.06	36.30	36.31	42.06	41.52	41.93	44.10	42.93	37.76	37.58
<b>4: Bole UT</b>	257.17	41.10	41.89	40.62	39.75	39.00	37.95	40.38	41.90	41.55	48.42	42.83	38.17	38.23
<b>5: Megenaga RT</b>	134.57	52.73	21.61	66.18	40.09	45.32	34.60	33.12	32.59	31.58	27.34	26.38	19.70	19.74
<b>6: Megenaga TM</b>	190.82	158.70	110.72	161.23	130.69	116.23	105.03	131.84	103.49	101.20	97.79	84.76	86.93	85.54
<b>7: Megenaga LT</b>	218.98	158.51	111.05	165.43	130.99	120.26	111.13	132.91	103.80	102.53	106.52	90.76	81.59	81.79
<b>8: Megenaga UT</b>	249.74	167.69	121.68	171.74	142.55	124.65	109.39	139.84	109.02	109.73	109.89	94.46	93.66	91.81
<b>9: Kazanchis RT</b>	155.79	19.53	19.56	19.62	19.67	19.67	19.56	19.49	19.51	19.43	19.49	19.61	19.53	19.47
<b>10: Kazanchis TM</b>	190.94	39.02	37.53	36.65	40.35	37.63	38.84	33.95	35.12	36.69	34.78	35.73	36.27	38.81
<b>11: Kazanchis LT</b>	223.89	42.15	41.44	42.64	43.91	45.31	41.31	38.67	40.55	43.70	45.42	42.87	41.75	43.57
<b>12: Kazanchis UT</b>	244.09	44.26	45.21	40.57	45.03	46.59	43.70	46.75	38.75	40.27	43.81	51.58	43.49	46.56
<b>13: M/Squar RT</b>	147.16	18.58	18.75	18.66	18.72	18.68	18.67	19.40	19.63	23.03	19.70	19.54	19.36	18.96
<b>14: M/Squar TM</b>	194.55	34.85	39.81	38.60	38.06	36.63	39.07	43.95	47.79	42.44	44.84	39.30	30.89	31.08
<b>15: M/Squar LT</b>	216.32	37.24	43.61	43.70	42.35	39.52	48.06	44.22	50.26	42.38	49.92	50.26	33.38	32.92
<b>16: M/Squar UT</b>	259.80	45.56	48.40	49.01	48.22	49.40	50.70	53.94	58.00	53.41	55.35	51.00	39.31	39.10

A study conducted on the Urael roundabout analyzed the travel time of vehicles. A shorter travel time is considered favorable, while congestion leads to increased travel time. The result found upgraded roundabout performance and this was resulting reduction in congestion and a minimum travel time, which benefits road users by saving them time and helping them arrive at their destinations punctually. The study highlights that changing the scenario positively impacts reducing travel time. As shown the trained on the above graphs the maximum travel time experienced on the Megenaga approach is attributed to the imbalanced traffic volume of vehicles from the Megenaga approach.

#### 4.3.1.2.3 . Travel Speed Results

The travel speed of the vehicles from each road approach of the Urael roundabout resulted in the following table and graph from the result the minimum speed was recorded on the Megenaga approach. The speeds of the vehicles were relatively increased on unit-change shift on the three approaches except on the Kazanchis approach. As travel speed increased it resulted in minimized travel time.



**Figure 4. 3. 1. 2. 3 Urael Roundabout Approach Legs Vehicles Travel Speed Graphical Interpretation**

**Table 4. 3. 1. 2. 3 Urael approach roads travel speed results**

Approach Leg	BL scenario Speed (Km/h)	1st scenario 10% speed (Km/h)	2nd scenario 20% speed (Km/h)	3rd scenario 30% speed (Km/h)	4th scenario 40% speed (Km/h)	5th scenario 50% speed (Km/h)	6th scenario 60% speed (Km/h)	7th scenario 70% speed (Km/h)	8th scenario 80% Speed (Km/h)	9th scenario 90% Speed (Km/h)	10th scenario 100% Speed (Km/h)	11th scenario Unit Change Speed (Km/h)	12 th scenario Carpooling Speed (Km/h)
M/Squar Speed (Km/h)	31.13	30.98	30.98	31.07	31.13	31.12	30.30	30.14	29.95	30.08	30.30	32.06	31.63
Bole Speed (Km/h)	30.18	30.11	30.11	30.33	30.61	30.99	29.37	29.33	29.02	28.80	28.66	30.57	30.16
Megenaga Speed (Km/h)	19.54	16.72	16.72	22.74	22.59	24.09	24.27	25.44	24.35	25.58	25.62	27.29	29.52
Kasanchis Speed (Km/h)	30.18	30.16	30.16	29.83	30.05	30.35	31.27	30.84	28.78	31.19	30.94	29.89	30.48

The travel speed simulation results output that the travel speed of vehicles not further far from the posted speed and AACRA speed on the roundabouts 30 km/h. The speed increased due to the balance of traffic demand with road capacity and vehicles composition pattern, reduced congestion of the road. However, in the free condition, the vehicles can travel above the limit speed, and if there is congestion the vehicles may travel at a small speed even if they may stop.

#### 4.3.1.2.4 Approach Road Queue Length and vehicular stop Result

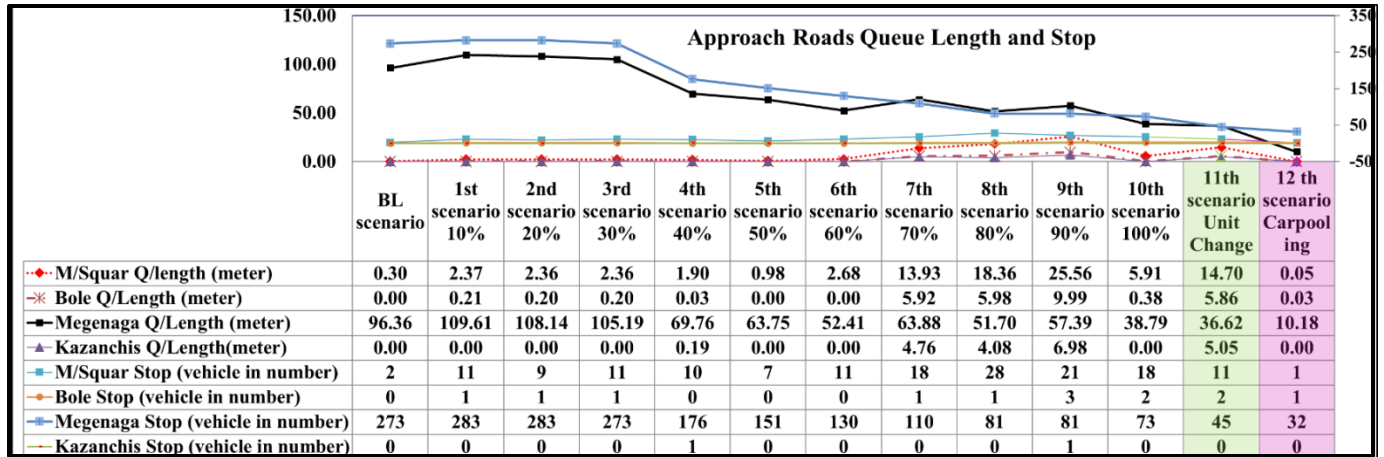


Figure 4. 3. 1. 2. 4 Urael roundabout approach legs queue length and vehicular stop graphical interpretation

Table 4. 3. 1. 2. 4. 1 Urael roundabout approach legs queue length

Approach	Queue Length (in meter)												
	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
From M/Squar Leg	0.30	2.37	2.36	2.36	1.90	0.98	2.68	13.93	18.36	25.56	5.91	14.70	0.05
From Bole Leg	0.00	0.21	0.20	0.20	0.03	0.00	0.00	5.92	5.98	9.99	0.38	5.86	0.03
From Megenaga Leg	96.36	109.61	108.14	105.19	69.76	63.75	52.41	63.88	51.70	57.39	38.79	36.62	10.18
From Kazanchis Leg	0.00	0.00	0.00	0.00	0.19	0.00	0.00	4.76	4.08	6.98	0.00	5.05	0.00

**Table 4. 3. 1. 2. 4. 2 Urael roundabout approach legs number of stop vehicles result**

Approach	Stop (vehicle in number)												
	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
From M/Squar Leg	2	11	9	11	10	7	11	18	28	21	18	11	1
From Bole Leg	0	1	1	1	0	0	0	1	1	3	2	2	1
From Megenaga Leg	273	283	283	273	176	151	130	110	81	81	73	45	32
From Kazanchis Leg	0	0	0	0	1	0	0	0	0	1	0	0	0

As the queue length increased the number of stop vehicles also increased. On this roundabout, the approach roads queue length decreased relatively from the baseline scenario to the other scenarios the fluctuation is caused by the vehicle’s composition patterns. From the study result the queue length was decreased stop was also decreased this implies both queue length and stop are linearly related. Maximum queue length and vehicle stop have occurred at the Megenega approach. The stop vehicle and the queue length fluctuation in scenarios occurred because of the change of relative flow.

**4.3.1.3 Summary of Urael Roundabout Result**

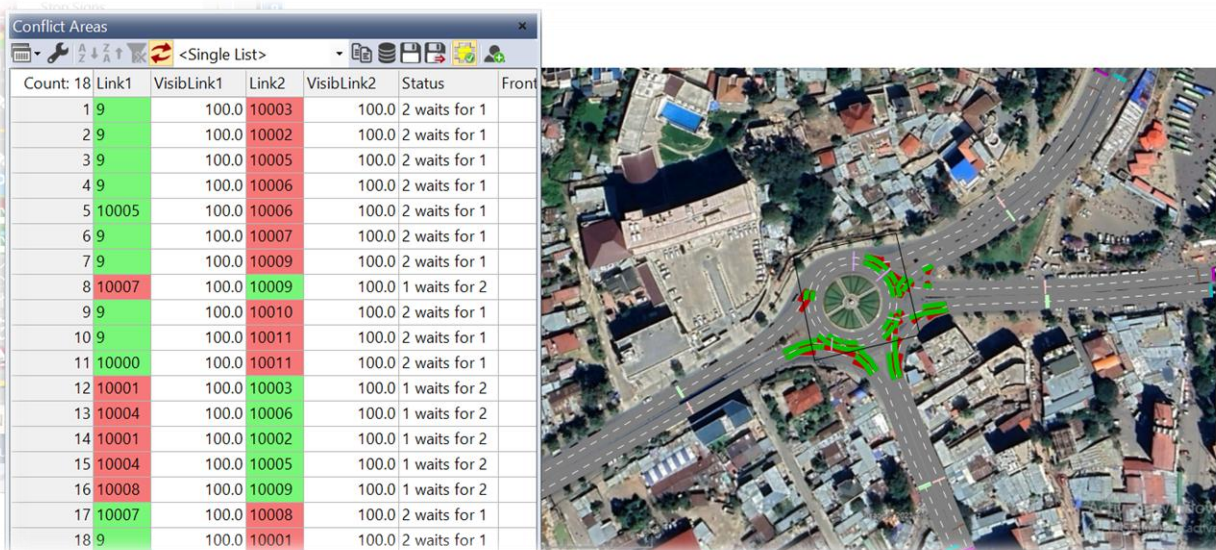
Urael roundabout analyzed in multiple scenarios to assess the performance and to confirm whether the performance of the roundabout upgrade or downgrade its performance with the various scenarios. The first optimal scenario involves a ten percent modal shift relative to the baseline scenario, resulting in upgraded level of service (LOS) and improvements across various metrics. These include a reduction in the volume to capacity ratio, decreased vehicular and stop delays, a lower number of stop frequencies, and reduced travel time compared to the baseline. The second optimal scenario is the fifth scenario. Lastly, the eleventh scenario entails a unit changing shift with minimum volume to capacity ratio, vehicular and stop delays, stop frequency, and an upgraded level of service category is the best and the better scenario of modal shifting. These scenarios have been identified based on their positive impacts on key performance indicators.

### 4.3.2 Result for Lamberet Roundabout

Numbers of conflict area on Lamberet roundabout, there were 18 conflicts occurred. Those conflicts were occurred between vehicles for the movement across the roundabout. The conflicts removed by giving priority to left-hand and circulatory movements.



**Figure 4.3.2. 1 Conflict areas at lamberet roundabout**



**Figure 4.3.2. 2 Conflict areas solved at lamberet roundabout**

### 4.3.2.1 Roundabout Evaluation Result

Roundabout results include; vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay, and stop frequency as figures below and tabulated in table 4.23

#### 4.3.2.1.1 Roundabout Level of Service, Volume – Capacity ratio Result, Vehicular Delay, Stop Delay and Vehicles Stop frequency Results

The results include vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay, stop results on the roundabout.

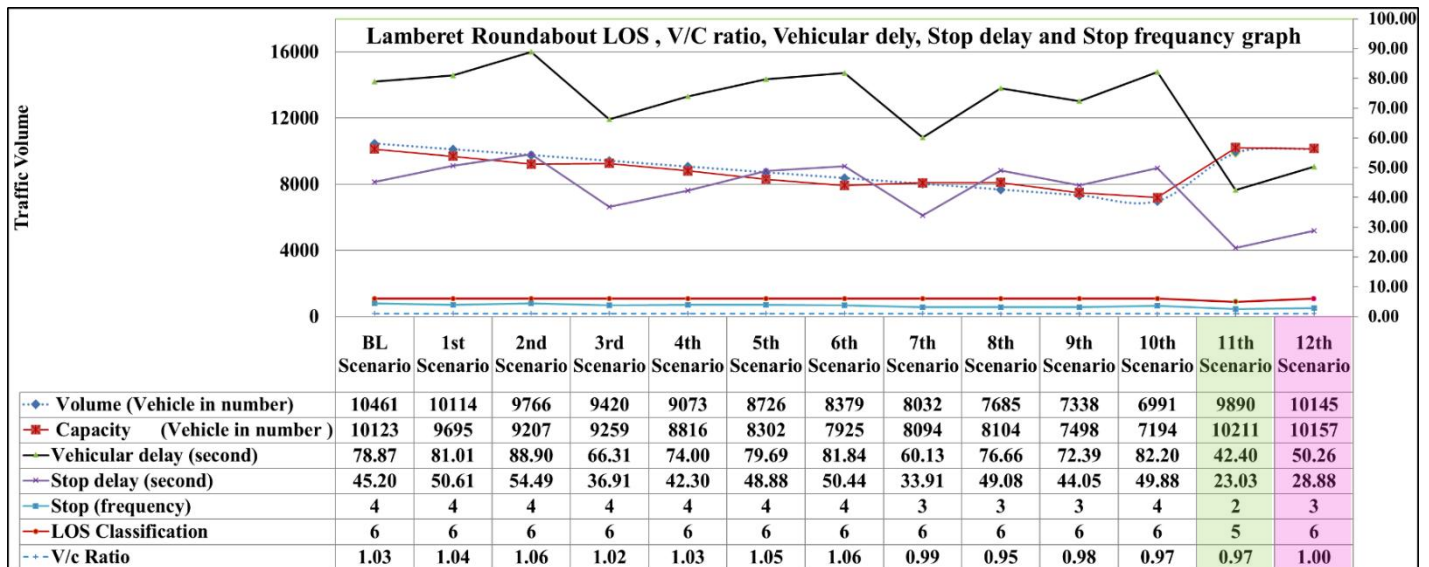


Figure 4. 3. 2. 1. 1 Lamberet roundabout LOS Volume- Capacity ratio, Vehicular delay, stop delay and vehicular stop frequency results graphical interpretation

**Table 4. 3. 2. 1. 1 Lamberet roundabout LOS, Volume- Capacity ratio, Vehicular delay, stop delay, and Vehicular Stop Frequency Evaluation Results**

Scenarios	Volume (Vehicle in number)	Capacity (Vehicle in number )	V/c Ratio	Vehicular delay (second)	LOS Classification	Stop delay (second)	Stop (frequency)
<b>BL Scenario</b>	10461	10123	1.03	78.87	LOS F	45.20	4
<b>1st Scenario</b>	10114	9695	1.04	81.01	LOS F	50.61	4
<b>2nd Scenario</b>	9766	9207	1.06	88.90	LOS F	54.49	4
<b>3rd Scenario</b>	9420	9259	1.02	66.31	LOS F	36.91	4
<b>4th Scenario</b>	9073	8816	1.03	74.00	LOS F	42.30	4
<b>5th Scenario</b>	8726	8302	1.05	79.69	LOS F	48.88	4
<b>6th Scenario</b>	8379	7925	1.06	81.84	LOS F	50.44	4
<b>7th Scenario</b>	8032	8094	0.99	60.13	LOS F	33.91	3
<b>8th Scenario</b>	7685	8104	0.95	76.66	LOS F	49.08	3
<b>9th Scenario</b>	7338	7498	0.98	72.39	LOS F	44.05	3
<b>10th Scenario</b>	6991	7194	0.97	82.20	LOS F	49.88	4
<b>11th Scenario</b>	9890	10211	0.97	42.40	LOS E	23.03	2
<b>12th Scenario</b>	10145	10157	1.00	50.26	LOS F	28.88	3

⊗ Volume denotes the input vehicle

⊗ Capacity denotes output vehicle

Based on the study results, it was found that the performance of the road did not experience a significant upgrade as a result of the adjustments made to scenarios 11 and 12. These adjustments only resulted in minor improvements, specifically in terms of reducing vehicular delays, which led to a slight improvement from Level of Service (LOS) F to LOS E. However, despite the spare capacity of the road, queue conditions and congestion were still observed.

In conclusion, the study suggests that the roundabout did not have a significant positive impact on the road's LOS and congestion. It indicates that additional measures and adjustments may be necessary to effectively address these issues and enhance the overall performance of the

roundabout. By implementing further modifications or considering alternative strategies, it might be possible to achieve more substantial improvements in terms of reducing delays and congestion on the road.

#### 4.3.2.1.2 Roundabout Queue length and vehicular Stop result

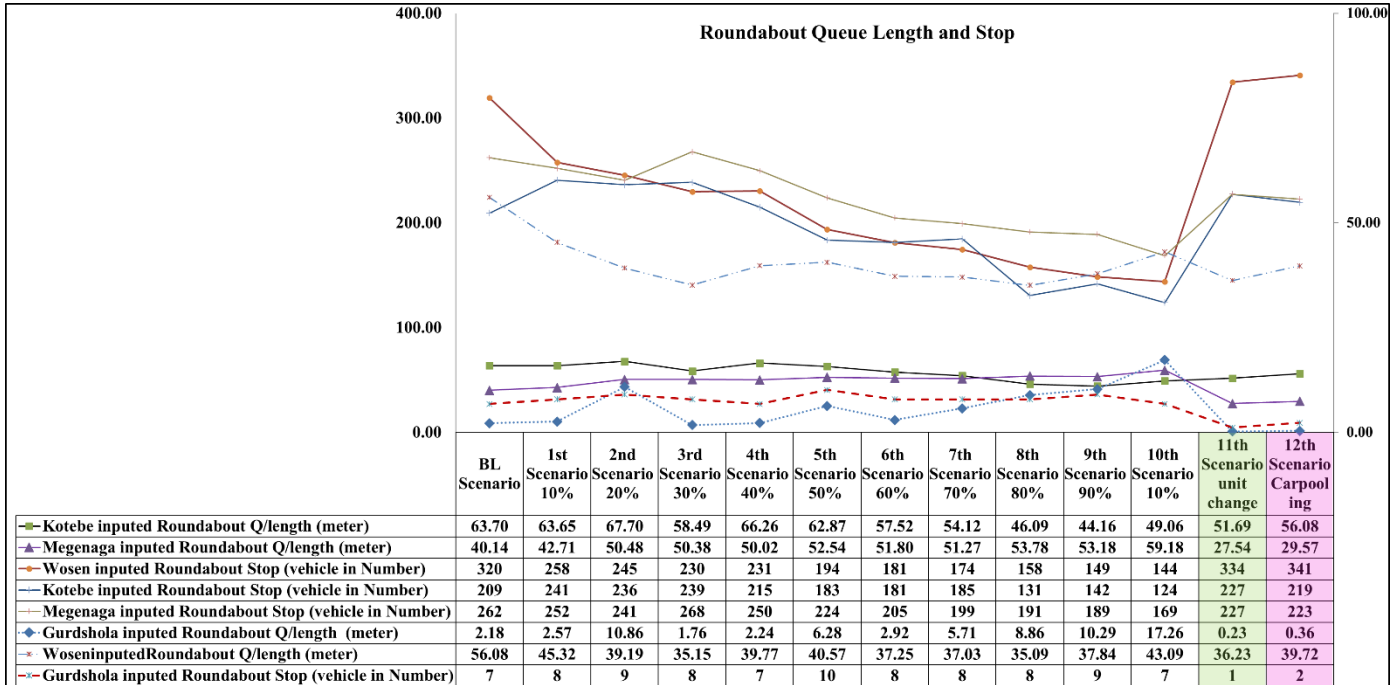


Figure 4. 3. 2. 1. 2 Lamberet roundabout Queue length and number of stop vehicles result graphical interpretation

Table 4. 3. 2. 1. 2. 1 Lamberet roundabout queue length result

Approach	Queue Length (in meter)												
	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
On Roundabout After G/Shola Traffic inputed	2.18	2.57	10.86	1.76	2.24	6.28	2.92	5.71	8.86	10.29	17.26	0.23	0.36
On Roundabout After Wosen Traffic inputed	56.08	45.32	39.19	35.15	39.77	40.57	37.25	37.03	35.09	37.84	43.09	36.23	39.72
On Roundabout After Koteba Traffic inputed	63.70	63.65	67.70	58.49	66.26	62.87	57.52	54.12	46.09	44.16	49.06	51.69	56.08
On Roundabout After Megenaga Traffic inputed	40.14	42.71	50.48	50.38	50.02	52.54	51.80	51.27	53.78	53.18	59.18	27.54	29.57

**Table 4. 3. 2. 1. 2. 2 Lamberet roundabout number of Stop vehicles result**

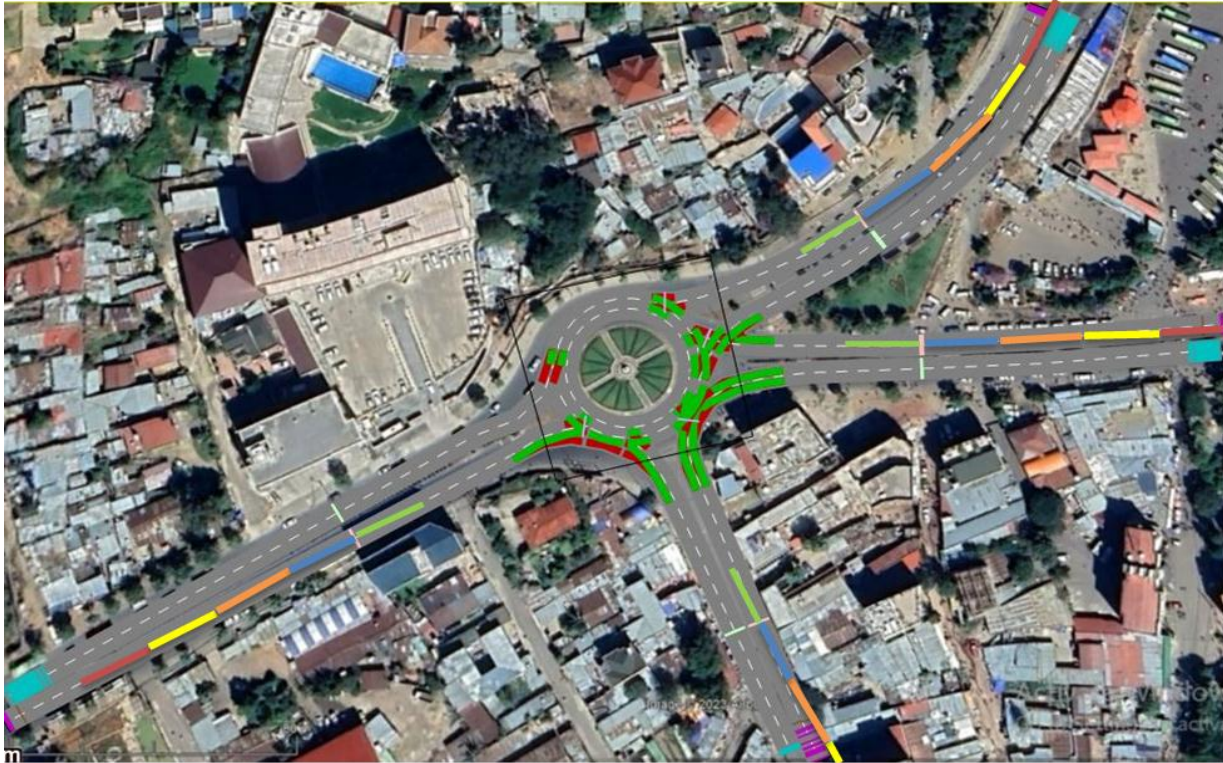
Stop (vehicle in number)													
Approach	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
On Roundabout After G/Shola Traffic inputed	7	8	9	8	7	10	8	8	8	9	7	1	2
On Roundabout After Wosen Traffic inputed	320	258	245	230	231	194	181	174	158	149	144	334	341
On Roundabout After Koteba Traffic inputed	209	241	236	239	215	183	181	185	131	142	124	227	219
On Roundabout After Megenaga Traffic inputed	262	252	241	268	250	224	205	199	191	189	169	227	223

Based on the guidelines provided in the Highway Capacity Manual (HCM 2010), as the level of service of the road upgraded the average spacing between vehicles is increased, which in turn resulted in a decrease in the queue length.

The imbalanced number of vehicles with road capacity on the road leads to congestion, resulting in more vehicles stopping and causing queues. The queue length is a measure of the length of the formed queue. Conversely, when the number of vehicles decreases, they are able to move freely without stopping and eliminating the formation of queues.

In this roundabout, various shift scenarios were implemented to balance the traffic demand with the available road capacity. As a result of these scenarios, the stop frequency and queue length were not decreased. This indicates that the implemented shift scenarios were not effective in reducing the queue and stop there was no any significant queue length and stop reduction, it is better to make other means to decrease the queue length.

### 4.3.2.2 Approach Roads Evaluation Results



**Figure 4. 3. 2. 2. 1 Lamberet Roundabout Approach Roads speed reduction point for result output**

**Table 4. 3. 2. 2 Lamberet Roundabout Speed Data**

SN	Approach Leg	Sample Number	Travel Speed (Km/h)	Travel Length				Average Speed (km/h)
				RT	TM	LT	UT	
1	Gurdshola	1	43.11	230.795	240.404	311.7	No Movement	33.19
		2	37.15	205.795	215.404	286.7	No Movement	
		3	34.13	180.795	190.404	261.7	No Movement	
		4	28.31	155.795	165.404	236.7	No Movement	
		5	23.25	130.795	140.404	211.7	No Movement	
2	Kotebe	1	30.04	275.92	294.25	314.514	322.139	23.50
		2	25.12	250.92	269.25	289.514	297.139	
		3	23.247	225.92	244.25	264.514	272.139	
		4	20.15	200.92	219.25	239.514	247.139	
		5	18.94	175.92	194.25	214.514	222.139	
3	Megenaga	1	31.17	244.759	268.629	276.398	346.006	24.15
		2	26.16	219.759	243.629	251.398	321.006	
		3	24.13	194.759	218.629	226.398	296.006	
		4	21.15	169.759	193.629	201.398	271.006	
		5	18.14	144.759	168.629	176.398	246.006	
4	Wosen	1	32.45	336.222	290.767	307.628	329.271	26.45
		2	28.6	311.222	265.767	282.628	304.271	
		3	25.29	286.222	240.767	257.628	279.271	
		4	24.15	261.222	215.767	232.628	254.271	
		5	21.76	236.222	190.767	207.628	229.271	

#### 4.3.2.2.1 Approach Roads Level of Service, stop delay, stop frequency and vehicular delay Result

**Table 4. 3. 2. 2. 1. 1 Lamberet roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (a)**

Movement	Distance (meter)	BL scenario				10 % ( scenario 1)				20 % (scenario 2)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: G/shola RT	130.795	8.18	0.77	12.08	B	17.97	0.88	22.52	C	64.56	1.23	70.18	F
2: G/shola TM	140.404	14.41	0.92	19.16	C	20.26	1.51	25.85	D	15.04	2.15	21.32	C
3: G/shola LT	211.700	37.17	3.26	48.45	E	24.51	1.37	32.67	D	11.57	1.91	20.80	C
4: G/shola UT	-	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
5: Koteba RT	175.924	52.96	3.74	80.46	F	43.63	2.33	63.51	F	35.19	2.92	57.26	F
6: Koteba TM	194.251	31.56	3.62	59.21	F	30.86	2.76	52.45	E	22.99	2.50	42.79	E
7: Koteba LT	214.514	19.92	3.13	46.27	E	13.22	1.47	27.66	D	14.90	2.03	30.44	D
8: Koteba UT	222.139	26.48	3.74	55.59	F	28.97	2.64	49.94	E	23.59	2.64	44.93	E
9: Megenaga RT	144.759	59.38	3.09	85.10	F	25.76	3.13	54.51	F	33.42	4.35	67.74	F
10: Megenaga TM	168.629	85.41	4.58	117.64	F	245.11	4.47	277.45	F	112.33	4.60	145.24	F
11: Megenaga LT	176.398	73.15	4.74	104.18	F	58.29	4.60	90.96	F	198.39	4.01	228.45	F
12: Megenaga UT	246.006	124.47	5.25	162.82	F	53.54	4.31	91.43	F	80.62	5.75	122.14	F
13: Wosen RT	236.222	26.00	2.25	32.13	D	13.67	1.45	29.13	D	20.71	1.89	35.84	E
14: Wosen TM	190.767	13.54	2.23	30.53	D	20.88	2.25	37.35	E	21.52	2.66	41.52	E
15: Wosen LT	207.628	19.27	3.38	24.87	C	0.17	1.13	12.31	B	17.87	2.08	36.20	E
16: Wosen UT	229.271	118.25	3.38	141.23	F	100.39	4.50	131.20	F	27.76	5.63	47.62	E

**Table 4. 3. 2. 2. 1. 2 Lamberet roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (b)**

Movement	Distance (meter)	30 % (scenario 3)				40 % ( scenario 4)				50 % ( scenario 5)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: G/shola RT	130.795	9.40	0.85	13.85	B	9.37	0.86	14.04	B	23.35	1.07	29.27	D
2: G/shola TM	140.404	11.15	2.10	17.69	C	12.19	1.67	19.33	C	9.71	1.93	17.75	C
3: G/shola LT	211.700	10.89	2.16	22.38	C	17.63	2.71	30.55	D	28.38	2.32	41.85	E
4: G/shola UT	-	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
5: Koteba RT	175.924	11.99	1.51	26.66	D	15.24	2.16	33.01	D	27.74	2.08	45.12	E
6: Koteba TM	194.251	13.84	1.80	28.76	D	15.67	2.09	33.36	D	20.56	2.00	37.63	E
7: Koteba LT	214.514	15.55	1.87	28.21	D	14.20	2.06	31.88	D	8.68	1.50	20.89	C
8: Koteba UT	222.139	11.70	1.80	25.70	D	15.41	2.22	34.09	D	19.02	2.07	37.00	E
9: Megenaga RT	144.759	18.90	3.07	43.49	E	44.87	2.83	70.11	F	25.44	2.74	51.75	F
10: Megenaga TM	168.629	58.94	3.95	88.32	F	74.29	4.33	105.87	F	93.26	4.10	123.12	F
11: Megenaga LT	176.398	54.95	4.10	84.21	F	76.98	4.22	109.29	F	70.62	3.77	99.03	F
12: Megenaga UT	246.006	49.49	3.71	82.25	F	101.24	4.92	140.04	F	67.96	3.88	98.92	F
13: Wosen RT	236.222	14.50	2.06	30.62	D	17.97	2.32	34.60	D	16.39	1.71	31.23	D
14: Wosen TM	190.767	23.43	3.06	45.58	E	23.52	2.80	44.53	E	21.78	2.56	41.75	E
15: Wosen LT	207.628	19.62	3.32	42.59	E	37.91	2.98	63.97	F	25.94	3.43	53.35	F
16: Wosen UT	229.271	24.55	2.94	46.54	E	22.65	2.87	44.36	E	29.33	2.61	50.60	F

**Table 4. 3. 2. 2. 1. 3 Lamberet roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (c)**

Movement	Distance (meter)	60 % ( scenario 6)				70 % ( scenario 7)				80 % ( scenario 8)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: G/shola RT	130.795	11.90	0.97	16.92	C	8.89	0.84	14.01	B	46.25	1.11	53.26	F
2: G/shola TM	140.404	9.53	1.67	17.58	C	9.39	2.61	17.59	C	41.99	1.94	50.74	F
3: G/shola LT	211.700	15.07	1.88	25.32	D	18.11	2.53	32.13	D	48.19	3.74	65.66	F
4: G/shola UT	-	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
5: Koteba RT	175.924	18.57	2.68	36.18	E	14.34	1.55	28.87	D	21.68	2.13	39.09	E
6: Koteba TM	194.251	27.95	2.34	47.24	E	17.18	1.77	33.20	D	20.61	2.01	39.12	E
7: Koteba LT	214.514	8.40	1.57	22.83	C	4.76	0.94	16.54	C	12.26	1.87	30.08	D
8: Koteba UT	222.139	28.14	2.28	46.73	E	12.87	1.75	27.53	D	31.85	2.34	51.12	F
9: Megenaga RT	144.759	19.50	2.40	45.09	E	34.72	3.03	58.76	F	26.01	3.10	48.84	E
10: Megenaga TM	168.629	107.46	4.39	139.70	F	50.14	3.37	75.28	F	172.95	2.79	193.97	F
11: Megenaga LT	176.398	93.25	4.31	126.19	F	58.73	3.60	88.40	F	173.16	2.84	196.97	F
12: Megenaga UT	246.006	125.82	4.19	158.68	F	34.20	2.69	59.70	F	44.15	3.60	72.03	F
13: Wosen RT	236.222	24.41	1.93	42.44	E	25.06	2.23	43.66	E	82.44	2.51	103.57	F
14: Wosen TM	190.767	27.75	2.53	47.86	E	24.38	2.55	44.51	E	24.76	2.47	45.27	E
15: Wosen LT	207.628	28.63	2.81	50.89	F	16.76	2.68	38.19	D	31.39	3.14	60.19	F
16: Wosen UT	229.271	22.93	2.45	43.00	E	20.08	2.70	39.10	D	30.24	2.72	52.07	F

**Table 4. 3. 2. 2. 1. 4 Lamberet roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (D)**

Movement	Distance (meter)	90 % ( scenario 9)				100 % ( scenario 10)				Unit Change (scenario 11)				Carpooling (scenario 12)			
		Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)	Stop Delay (second)	Stop (frequency)	Vehicular Delay (second)	Approach LOS (category)
1: G/shola RT	130.795	60.68	1.08	67.76	F	76.29	1.41	84.91	F	3.52	0.28	3.89	A	8.84	0.86	12.63	B
2: G/shola TM	140.404	7.56	2.72	18.10	C	106.44	4.94	119.79	F	2.11	0.92	4.27	A	5.70	0.71	9.02	A
3: G/shola LT	211.700	60.51	3.69	76.37	F	166.61	3.34	185.76	F	22.65	1.13	28.87	D	17.20	1.41	23.54	C
4: G/shola UT	-	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
5: Koteba RT	175.924	18.45	1.79	36.05	E	30.54	2.65	53.25	F	5.60	0.91	11.21	B	17.86	1.94	34.11	D
6: Koteba TM	194.251	17.11	1.79	34.58	D	28.38	2.57	52.43	F	4.07	0.55	8.11	A	15.77	1.99	31.63	D
7: Koteba LT	214.514	19.25	1.82	33.98	D	15.03	2.74	38.12	E	8.99	1.48	15.60	C	13.39	2.16	28.64	D
8: Koteba UT	222.139	20.04	1.76	37.38	E	25.73	2.86	51.53	F	5.08	0.56	8.07	A	15.56	2.12	31.84	D
9: Megenaga RT	144.759	16.77	1.70	36.36	E	73.78	3.08	98.85	F	42.38	1.71	52.19	F	15.96	2.78	40.35	E
10: Megenaga TM	168.629	64.57	2.87	87.08	F	77.97	3.28	102.27	F	26.11	1.28	35.68	E	69.77	3.48	95.73	F
11: Megenaga LT	176.398	40.31	2.99	64.58	F	43.07	3.01	68.01	F	38.56	1.75	48.21	E	87.73	3.28	113.20	F
12: Megenaga UT	246.006	53.51	3.43	84.58	F	178.19	6.19	220.14	F	70.50	1.53	73.33	F	58.40	3.20	85.83	F
13: Wosen RT	236.222	103.77	2.45	125.27	F	85.16	2.21	104.89	F	12.62	1.38	13.65	B	0.20	1.13	15.95	C
14: Wosen TM	190.767	24.42	2.67	45.84	E	22.35	2.32	42.65	E	2.81	0.44	5.59	A	11.76	1.59	23.47	C
15: Wosen LT	207.628	27.34	2.12	57.26	F	22.16	4.07	43.59	E	17.85	0.63	39.85	E	35.15	1.37	48.68	E
16: Wosen UT	229.271	22.02	2.52	42.48	E	20.68	2.25	39.54	E	48.54	4.50	61.01	F	58.87	6.75	90.73	F

There was no significant upgrade made to the level of service (LOS) of the Lambert roundabout's approach roads/legs. Specifically, the LOS of the Gurd shola, Koteba, and Megenaga legs of the roundabout were upgraded, but the wosen approach was not upgraded.

The upgrade resulted from the implementation of the 9th scenario of a 90% shift, as well as other unit changes and carpooling shifts. These changes improved the level of service of the roundabout from LOS F to LOS E.

In the context of the Lambert roundabout, the level of service is determined by the delay experienced by vehicles approaching the roundabout. As the number of vehicles from the approach leg increases, the road becomes congested, leading to delays for vehicles. The delay is then compared to the ranges specified in the HCM 2010 manual, specifically table 2.1, to determine the level of service for each approach leg.

The primary reason for the poor level of service at the roundabout is heavy traffic. Although there were no significant upgrades in the shift on the approach legs, they continue to serve with a poor level of service.

#### 4.3.2.2.2 Approach Roads Travel Time Result

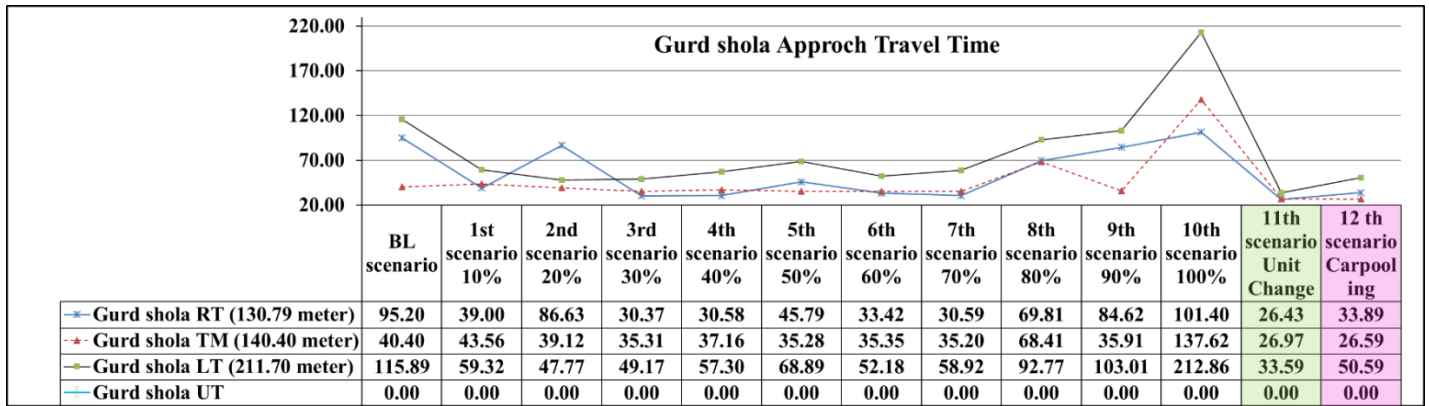


Figure 4. 3. 2. 2. 1 Lamberet Roundabout Gurdshola Approach Vehicles Travel Time Result Graphical Interpretations

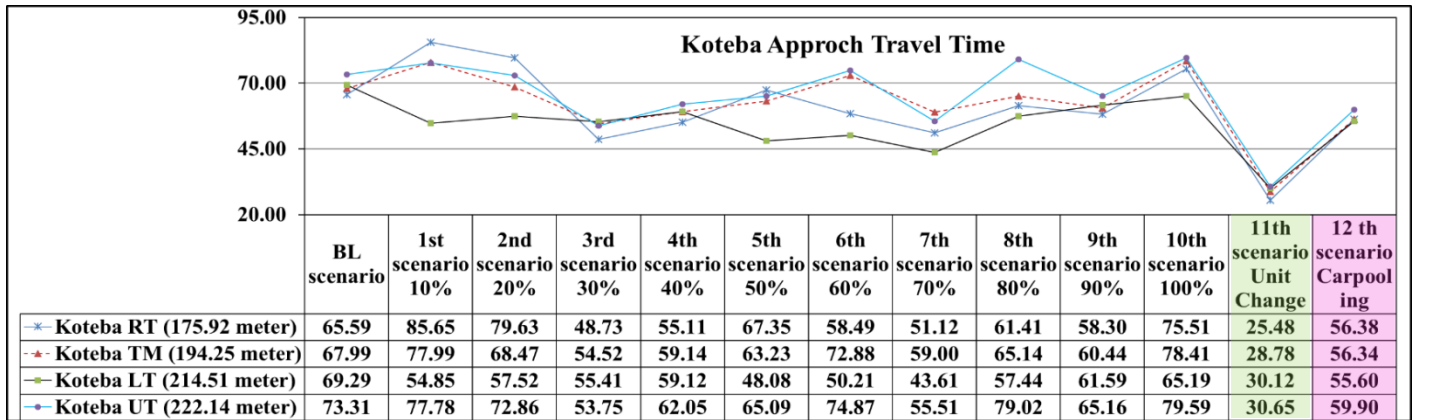


Figure 4. 3. 2. 2. 2 Lamberet Roundabout Koteba Approach Vehicles Travel Time Result Graphical Interpretations

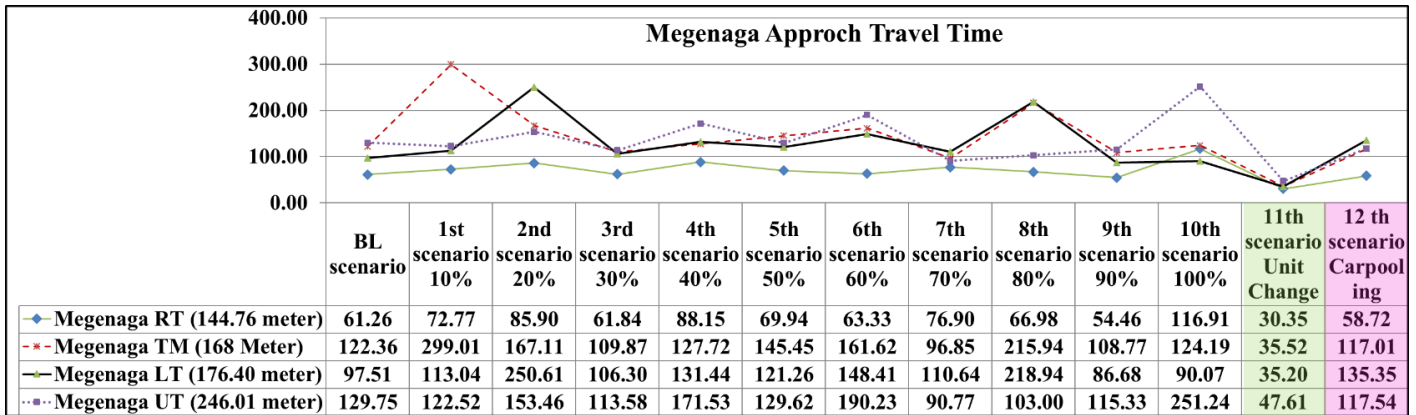


Figure 4. 3. 2. 2. 3 Lamberet Roundabout Megenaga Approach Vehicles Travel Time Result Graphical Interpretations

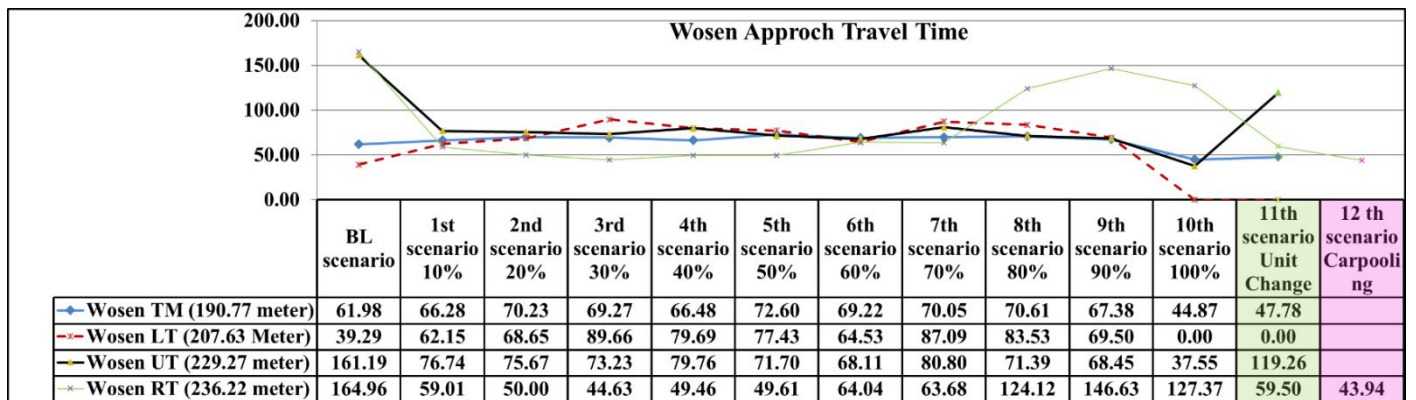


Figure 4. 3. 2. 2. 4 Lamberet roundabout Wosen Approach legs vehicles Travel time result graphical interpretation

**Table 4. 3. 2. 2 Lamberet roundabout Approach legs vehicles Travel time for each origin Destination Movements result**

Movement	Distance (meter)	BL scenario	1st scenario 10%	2nd scenario 20%	3rd scenario 30%	4th scenario 40%	5th scenario 50%	6th scenario 60%	7th scenario 70%	8th scenario 80%	9th scenario 90%	10th scenario 100%	11th scenario Unit Change	12 th scenario Carpooling
		Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)	Travel time (second)
1: G/shola RT	130.79	95.20	39.00	86.63	30.37	30.58	45.79	33.42	30.59	69.81	84.62	101.40	26.43	33.89
2: G/shola TM	140.40	40.40	43.56	39.12	35.31	37.16	35.28	35.35	35.20	68.41	35.91	137.62	26.97	26.59
3: G/shola LT	211.70	115.89	59.32	47.77	49.17	57.30	68.89	52.18	58.92	92.77	103.01	212.86	33.59	50.59
4: G/shola UT	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5: Koteba RT	175.92	65.59	85.65	79.63	48.73	55.11	67.35	58.49	51.12	61.41	58.30	75.51	25.48	56.38
6: Koteba TM	194.25	67.99	77.99	68.47	54.52	59.14	63.23	72.88	59.00	65.14	60.44	78.41	28.78	56.34
7: Koteba LT	214.51	69.29	54.85	57.52	55.41	59.12	48.08	50.21	43.61	57.44	61.59	65.19	30.12	55.60
8: Koteba UT	222.14	73.31	77.78	72.86	53.75	62.05	65.09	74.87	55.51	79.02	65.16	79.59	30.65	59.90
9: Megenaga RT	144.76	61.26	72.77	85.90	61.84	88.15	69.94	63.33	76.90	66.98	54.46	116.91	30.35	58.72
10: Megenaga TM	168.63	122.36	299.01	167.11	109.87	127.72	145.45	161.62	96.85	215.94	108.77	124.19	35.52	117.01
11: Megenaga LT	176.40	97.51	113.04	250.61	106.30	131.44	121.26	148.41	110.64	218.94	86.68	90.07	35.20	135.35
12: Megenaga UT	246.01	129.75	122.52	153.46	113.58	171.53	129.62	190.23	90.77	103.00	115.33	251.24	47.61	117.54
13: Wosen RT	236.22	164.96	59.01	50.00	44.63	49.46	49.61	64.04	63.68	124.12	146.63	127.37	59.50	43.94
14: Wosen TM	190.77	79.44	61.98	66.28	70.23	69.27	66.48	72.60	69.22	70.05	70.61	67.38	44.87	47.78
15: Wosen LT	207.63	93.97	39.29	62.15	68.65	89.66	79.69	77.43	64.53	87.09	83.53	69.50	0.00	0.00
16: Wosen UT	229.27	80.32	161.19	76.74	75.67	73.23	79.76	71.70	68.11	80.80	71.39	68.45	37.55	119.26

A study conducted on the Lambert roundabout analyzed the travel time of vehicles. A shorter travel time is considered favorable, while congestion leads to increased travel time. The result found upgraded roundabout performance and this was resulting reduction in congestion and a minimum travel time, which benefits road users by saving them time and helping them arrive at their destinations punctually. The study highlights that changing the scenario change the travel time. As shown the trained on the above figure the maximum travel time experienced on the Megenaga approach is attributed to the imbalanced traffic volume of vehicles from the Megenaga approach. The travel time change was not continuous due to the various relative flows of the vehicles category (passenger and heavy vehicles) traffics.

### 4.3.2.2.3 Approach Roads Travel Speed Result

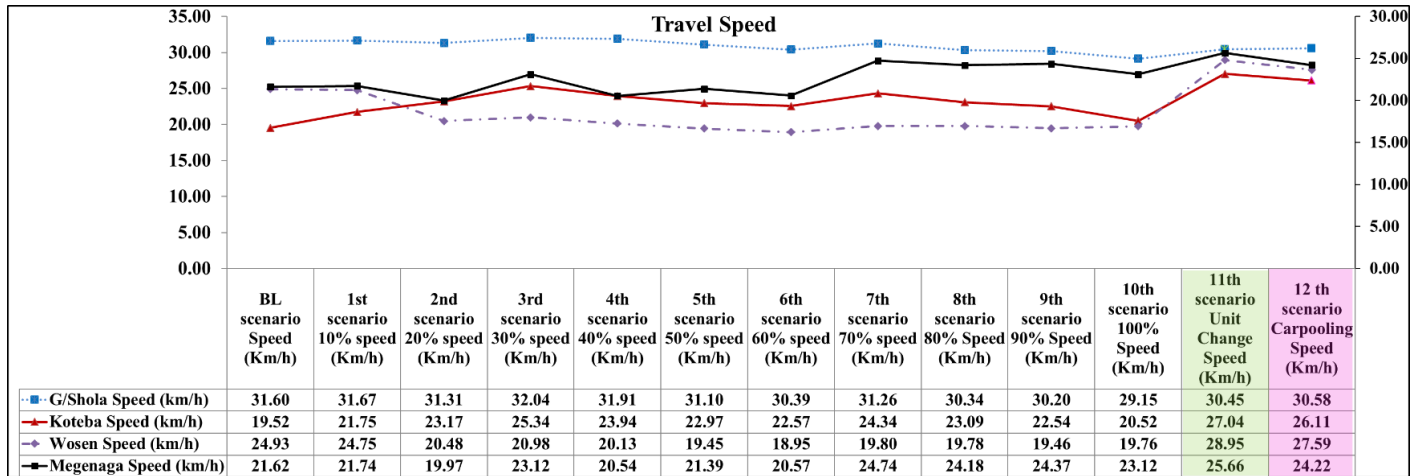


Figure 4. 3. 2. 2. 3 Lamberet Roundabout Approach legs vehicle Travel Speed graphical interpretation

Table 4. 3. 2. 2. 3 Lamberet Roundabout Approach legs vehicle Travel Speed result

Approach Leg	BL scenario Speed (Km/h)	1st scenario 10% speed (Km/h)	2nd scenario 20% speed (Km/h)	3rd scenario 30% speed (Km/h)	4th scenario 40% speed (Km/h)	5th scenario 50% speed (Km/h)	6th scenario 60% speed (Km/h)	7th scenario 70% speed (Km/h)	8th scenario 80% Speed (Km/h)	9th scenario 90% Speed (Km/h)	10th scenario 100% Speed (Km/h)	11th scenario Unit Change Speed (Km/h)	12 th scenario Carpooling Speed (Km/h)
G/Shola Speed (Km/h)	31.60	31.67	31.31	32.04	31.91	31.10	30.39	31.26	30.34	30.20	29.15	30.45	30.58
Koteba Speed (Km/h)	19.52	21.75	23.17	25.34	23.94	22.97	22.57	24.34	23.09	22.54	20.52	27.04	26.11
Megenaga Speed (Km/h)	21.62	21.74	19.97	23.12	20.54	21.39	20.57	24.74	24.18	24.37	23.12	25.66	24.22
Wosen ISpeed (Km/h)	24.93	24.75	20.48	20.98	20.13	19.45	18.95	19.80	19.78	19.46	19.76	28.95	27.59

The travel speed of the vehicles for koteba, wosen, and Megenaga -originated vehicles was increased through all of the modal shift scenarios. But, for the Gurd shola leg, the travel speed was not visibly changed /increased. However, for overall approaches, the travel speed was increased on the 11th scenario of the unit change modal shift path. The vehicle's travel speed for the carpooling shift path was smaller than on the unit change shift path speed from the speed graph trend the speed was greater in scenario 11th scenario than in other scenarios.

The travel speed simulation results output that the travel speed of vehicles not further far from the posted speed and AACRA speed on the roundabouts 30 km/h and the speed increased due to the vehicular number decrease and reduced congestion of the road. However, in free conditions, the vehicles can travel above the limit speed, and if there is congestion the vehicles may travel at a small speed even and they may stop. On the Lambert roundabout, the travel speed is not much greater than the AACRA restriction.

#### 4.3.2.2.4 Approach Road Queue length and vehicular stop Result

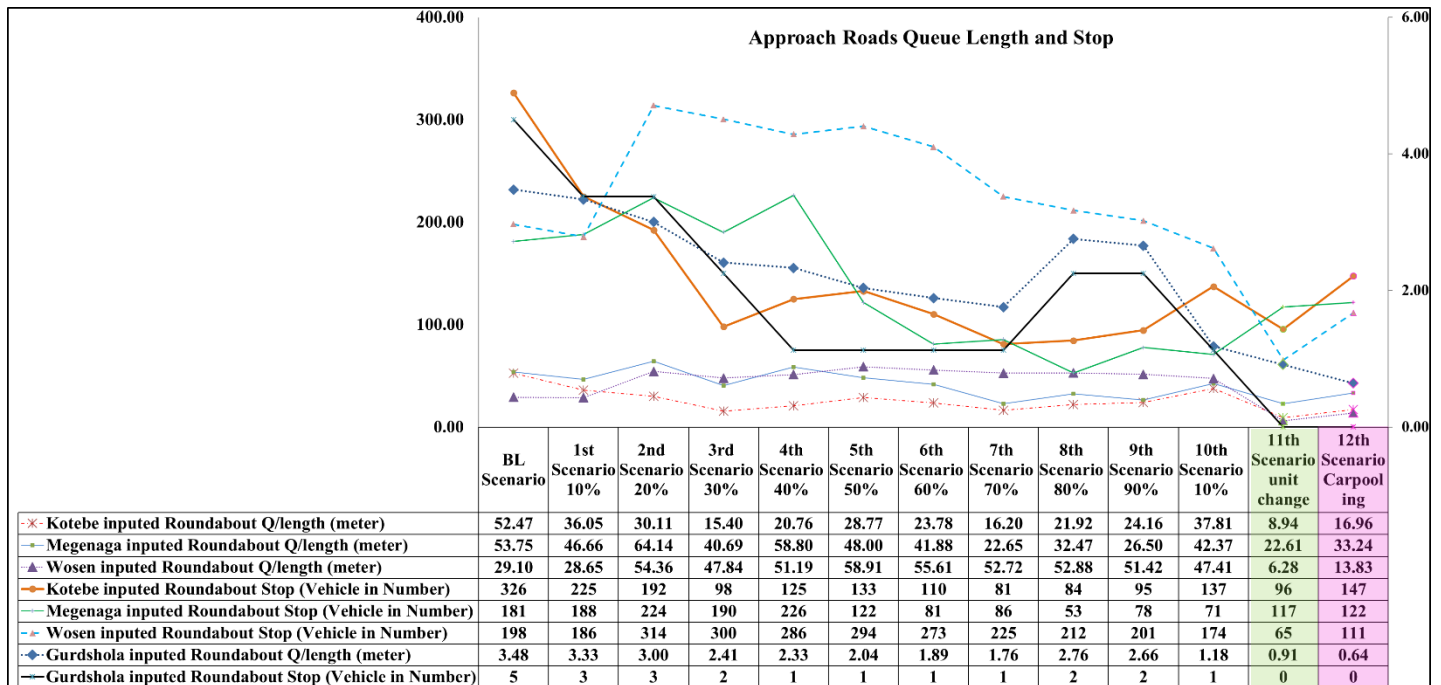


Figure 4. 3. 2. 2. 4 Lamberet roundabout approach legs queue length and vehicular stop graphical interpretation

**Table 4.3.2.2.4.1 Lamberet approach legs queue length result**

Queue Length (in meter)													
Approach	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
From G/Shola Leg	3.48	3.33	3.00	2.41	2.33	2.04	1.89	1.76	2.76	2.66	1.18	0.91	0.64
From Koteba Leg	52.47	36.05	30.11	15.40	20.76	28.77	23.78	16.20	21.92	24.16	37.81	8.94	16.96
From Megenaga Leg	53.75	46.66	64.14	40.69	58.80	48.00	41.88	22.65	32.47	26.50	42.37	22.61	33.24
From Wosen Leg	29.10	28.65	54.36	47.84	51.19	58.91	55.61	52.72	52.88	51.42	47.41	6.28	13.83

**Table 4.3.2.2.4.2 Lamberet approach legs number of stop Vehicles result**

Stop (vehicle in number)													
Approach	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
From G/Shola Leg	5	3	3	2	1	1	1	1	2	2	1	0	0
From Koteba Leg	326	225	192	98	125	133	110	81	84	95	137	96	147
From Megenaga Leg	181	188	224	190	226	122	81	86	53	78	71	117	122
From Wosen Leg	198	186	314	300	286	294	273	225	212	201	174	65	111

The level of service and delay of the roundabout have no significant upgrade performance until the 11th scenario. The queue length and the number of stops of the vehicles decreased until the 10th scenario. As the number of vehicles increases roads will be congested, and it causes more vehicles to stop and form queues. The occurred queue was measured by queue length. As the number of vehicles decreases, they can move freely without stopping so there is no queue occurrence. As the HCM 2010 manual illustration as the level of service of the road was

upgraded the average spacing between the vehicles increased and the queue length decreased. So, in this study the stop and queue length were not significantly decreased with the tried shift scenarios so, it is better to make other means to decrease the queue length.

#### **4.3.2.3 Summary of Lamberet Roundabout Result**

Lamberet roundabout also analyzed in multiple scenarios to assess the performance and to confirm whether the performance of the roundabout upgrade or downgrade its performance with the various scenarios. However, the performance of this roundabout is unexpected, both optimal and the better scenario of modal shifting at the eleventh scenario entails a unit changing shift with minimum volume to capacity ratio, vehicular and stop delays and stop frequency relatively with the other scenarios.

### 4.3.3 Result for Salitemeheret Roundabout

On this roundabout, there were 21 conflicts occurred. The conflict areas for the movement across the roundabout were solved by providing priority for the circulatory and the left entry movements.



Figure 4. 3. 3. 1 Conflict areas at Salitemeheret roundabout

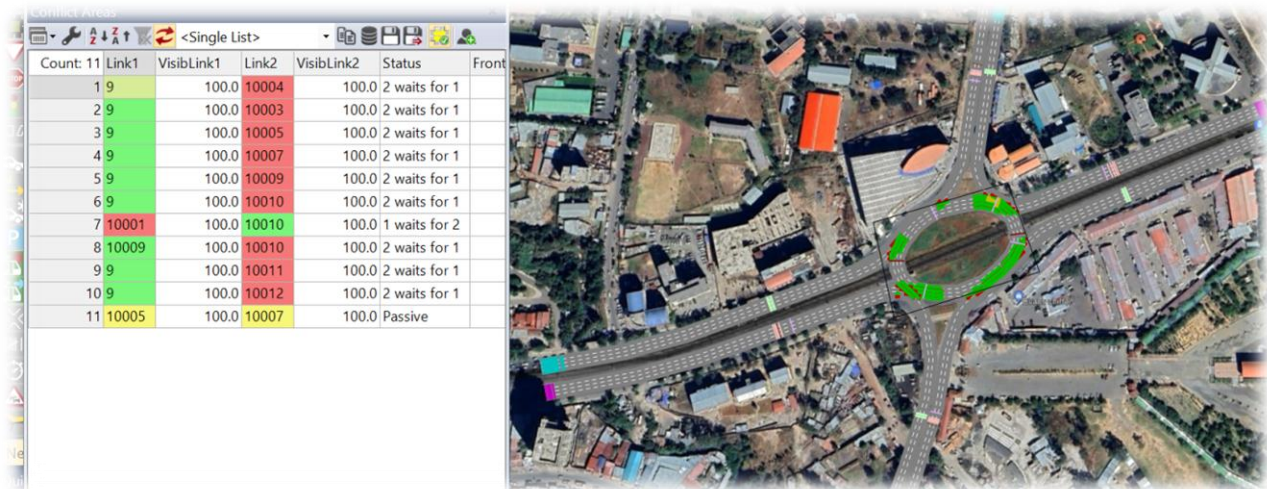


Figure 4. 3. 3. 2 Conflict areas solved at Salitemeheret roundabout

### 4.3.3.1 Roundabout Evaluation Results

Roundabout results include; vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay, and stop frequency as figures below and tabulated in table 4.34

#### 4.3.3.1.1 Roundabout Level of Service, Volume – Capacity ratio, Vehicular Delay, Stop Delay and Vehicles Stop Frequency Result

The results include vehicle input volume, vehicle output volume, volume-to-capacity ratio, Vehicular delay, Level of service, stop delay, stop results on the roundabout.

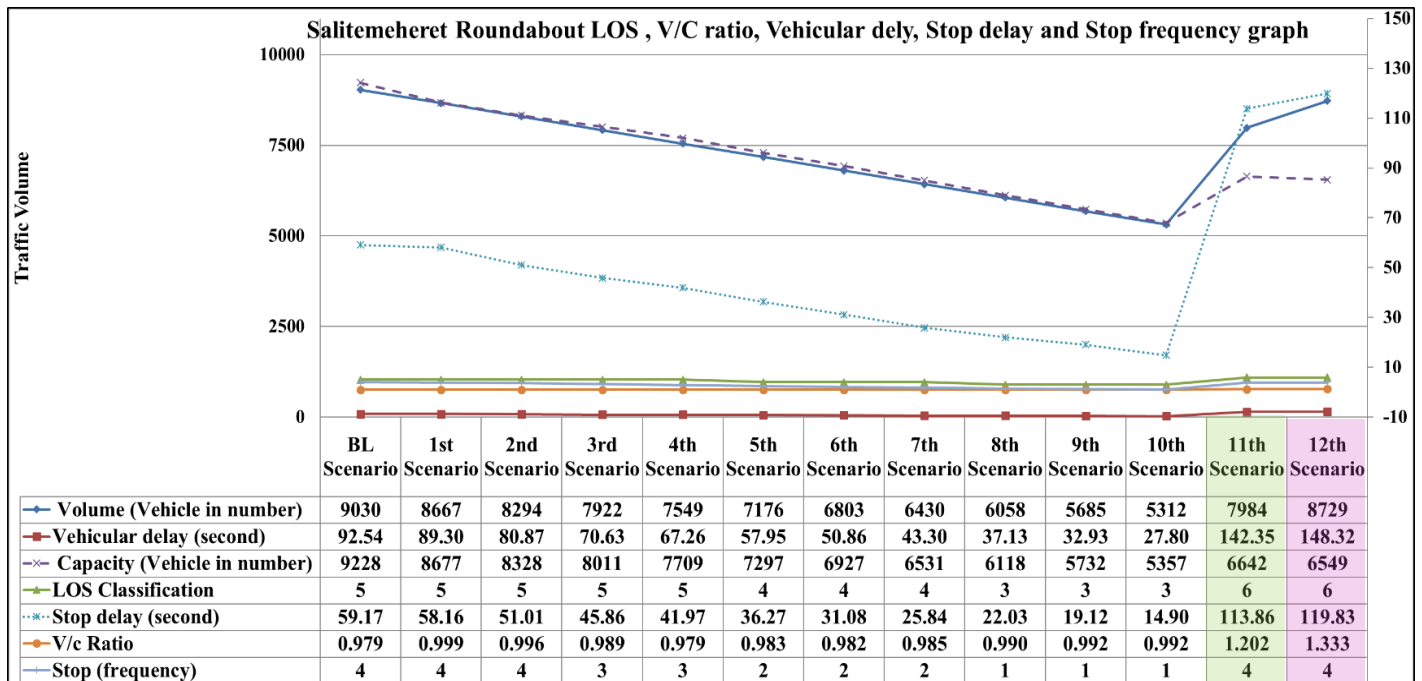


Figure 4. 3. 3. 1. 1 Salitemeheret roundabout LOS, Volume – Capacity ratio, Vehicular Delay, Stop Delay and Vehicles Stop Frequency graphical interpretation

**Table 4. 3. 3. 1. 1 Salitemeheret roundabout LOS, Volume- Capacity ratio, Vehicular delay, stop delay, and Vehicular Stop Frequency Evaluation Results**

Scenarios	Volume (Vehicle in number)	Capacity (Vehicle in number)	V/c Ratio	Vehicular delay (second)	LOS Classification	Stop delay (second)	Stop (frequency)
<b>BL Scenario</b>	9030	9228	0.979	92.54	LOS F	59.17	4
<b>1st Scenario</b>	8667	8677	0.999	89.30	LOS F	58.16	4
<b>2nd Scenario</b>	8294	8328	0.996	80.87	LOS F	51.01	4
<b>3rd Scenario</b>	7922	8011	0.989	70.63	LOS F	45.86	3
<b>4th Scenario</b>	7549	7709	0.979	67.26	LOS F	41.97	3
<b>5th Scenario</b>	7176	7297	0.983	57.95	LOS F	36.27	2
<b>6th Scenario</b>	6803	6927	0.982	50.86	LOS F	31.08	2
<b>7th Scenario</b>	6430	6531	0.985	43.30	LOS E	25.84	2
<b>8th Scenario</b>	6058	6118	0.990	37.13	LOS E	22.03	1
<b>9th Scenario</b>	5685	5732	0.992	32.93	LOS E	19.12	1
<b>10th Scenario</b>	5312	5357	0.992	27.80	LOS D	14.90	1
<b>11th Scenario</b>	7984	6642	1.202	142.35	LOS F	113.86	4
<b>12th Scenario</b>	8729	6549	1.333	148.32	LOS F	119.83	4

⊗ Volume denotes the input vehicle

⊗ Capacity denotes output vehicle

When there are more vehicles on the road and roundabouts, they stop more times and cannot flow freely due to congestion. As the number of vehicles on the road increases, there will be congestion because more vehicles stop many times due to congestion. Thus, the result indicates that the decreased stopping of vehicles depended on the minimized queue length and minimized congestion.

According to the study results, referring to the HCM and ERA manual, the road's level of service in the baseline scenario was LOS E, which means that the road was under a queue condition, even if the ratio of volume to capacity was less than one. The road was at poor level of service,

and the LOS was not significantly upgraded in the other scenarios. Since the shift was made using the changed traffic volume and relative flow, it resulted in poor road level of service. As illustrated in the HCM 2010 manual, roads with poor level of service are congested, and the traffic demand exceeds the capacity.

From the study result the emissions were reduced and the Level of service of the road was upgraded. The increase in traffic volume and the flow imbalance with the capacity of the road will cause congestion, and through that congestion, more vehicles stop and consume more fuel which results in more emissions in the waiting area and it was causes climatic change and air pollution. On this roundabout emission was determined and the emission amount was reduced smaller amount than the other roundabouts. From the result, there was an emission reduction and the Los upgraded.

#### 4.3.3.1.2 Roundabout Queue length and vehicular Stop result

The Queue length and the stop vehicles of this roundabout have fluctuated over all scenarios of the modal shifts. The queue length and the stop vehicles do not upgrade with the shifts like the other two analyzed roundabouts. However, on the 10th scenario of 100% PCU modal shift both the queue length and stop vehicles were reduced after CMC, Megenaga and Jackros traffic joined the roundabout. The queue length and the stop vehicles were increased only at the wosen originated traffic joined the roundabout.

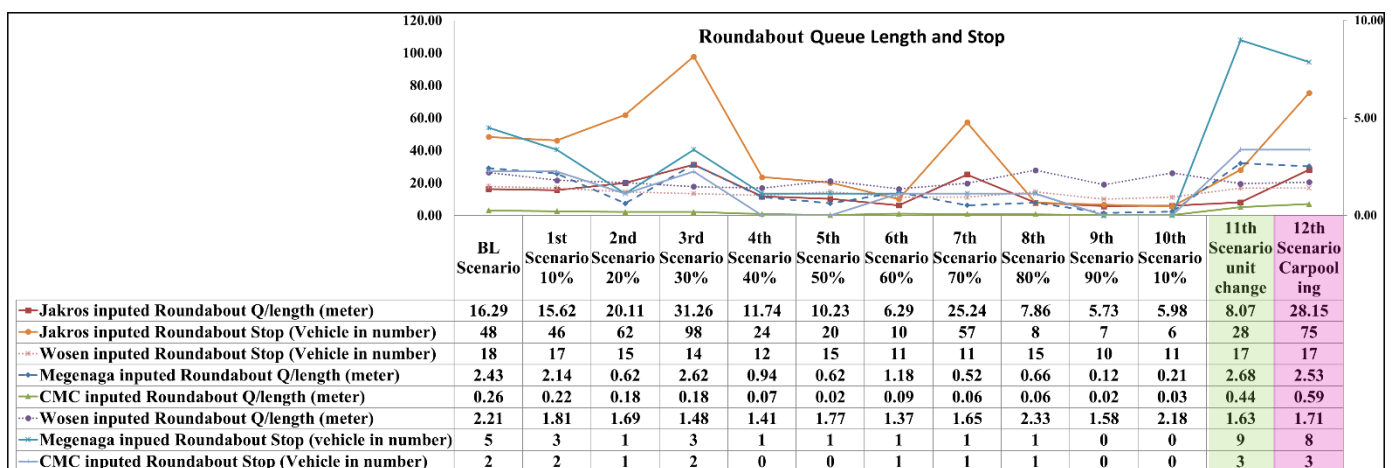


Figure 4. 3. 3. 1. 2 Salitemeheret Roundabout Queue length and number of stop vehicles result graphical interpretation

**Table 4. 3. 3. 1. 2. 1 Salitemeheret roundabout queue length**

	Queue Length (in meter)												
	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
On Roundabout After Megenaga Traffic inputed	2.43	2.14	0.62	2.62	0.94	0.62	1.18	0.52	0.66	0.12	0.21	2.68	2.53
On Roundabout After Jakros Traffic inputed	16.29	15.62	20.11	31.26	11.74	10.23	6.29	25.24	7.86	5.73	5.98	8.07	28.15
On Roundabout After CMC Traffic inputed	0.26	0.22	0.18	0.18	0.07	0.02	0.09	0.06	0.06	0.02	0.03	0.44	0.59
On Roundabout After Wosen Traffic inputed	2.21	1.81	1.69	1.48	1.41	1.77	1.37	1.65	2.33	1.58	2.18	1.63	1.71

**Table 4. 3. 3. 1. 2. 2 Salitemeheret roundabout stop**

	Stop (Vehicle in number)												
	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
On Roundabout After Megenaga Traffic inputed	5	3	1	3	1	1	1	1	1	0	0	9	8
On Roundabout After Jakros Traffic inputed	48	46	62	98	24	20	10	57	8	7	6	28	75
On Roundabout After CMC Traffic inputed	2	2	1	2	0	0	1	1	1	0	0	3	3
On Roundabout After Wosen Traffic inputed	18	17	15	14	12	15	11	11	15	10	11	17	17

### 4.3.3.2 Approach Roads Evaluation Results



Figure 4. 3. 3. 2 Salitemeheret Roundabout Approach Roads speed reduction point for result output

Table 4. 3. 3. 2 Salitemeheret Roundabout Speed Data

SN	Approach Leg	Sample Number	Travel Speed (Km/h)	Travel Length in (Meter)				Average Speed (km/h)
				RT	TM	LT	UT	
1	Megenaga	1	20.12	260.43	358.51	410.23	502.37	16.798
		2	19.23	250.43	348.51	400.23	492.37	
		3	17.15	240.43	338.51	390.23	482.37	
		4	15.22	230.43	328.51	380.23	472.37	
		5	12.27	205.43	303.51	355.23	447.37	
2	Jakros	1	42.18	345.72	403.65	498.54	524.84	34.39
		2	38.27	320.72	378.65	473.54	499.84	
		3	34.15	295.72	353.65	448.54	474.84	
		4	31.22	270.72	328.65	423.54	449.84	
		5	26.13	245.72	303.65	398.54	424.84	
3	CMC	1	45.72	296.04	397.61	428.19	510.1	37.094
		2	41.26	271.04	372.61	403.19	485.1	
		3	37.25	246.04	347.61	378.19	460.1	
		4	33.12	221.04	322.61	353.19	435.1	
		5	28.12	196.04	297.61	328.19	410.1	
4	Wosen	1	45.22	360.28	393.21	481.57	535.51	35.794
		2	38.27	335.28	368.21	456.57	510.51	
		3	35.13	310.28	343.21	431.57	485.51	
		4	31.22	285.28	318.21	406.57	460.51	
		5	29.13	260.28	293.21	381.57	435.51	

#### 4.3.3.2.1 Approach Roads Level of Service, stop delay, stop frequency and Vehicular Delay Result

**Table 4. 3. 3. 2. 1. 1 Salitemeheret roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (a)**

Movement	Distance (meter)	BL Scenario				10 % ( Scenario 1)				20 % ( Scenario 2)			
		Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)
1: Megenaga RT	205.43	80.83	4.88	114.38	F	76.88	4.65	108.78	F	69.74	4.31	98.43	F
2: Megenaga Tm	303.51	100.28	7.53	152.87	F	95.38	7.16	145.40	F	84.59	6.93	133.66	F
3: Megenaga LT	355.23	97.24	7.97	153.61	F	92.49	7.58	146.10	F	93.45	7.66	147.35	F
4: Megenaga UT	447.37	19.26	2.76	27.18	D	17.84	2.50	25.44	D	17.70	2.43	25.23	D
5: Jakros RT	245.72	0.00	0.00	0.05	A	0.00	0.00	0.05	A	0.00	0.00	0.05	A
6: Jakros TM	303.65	15.77	1.46	23.09	C	15.00	1.39	21.96	C	14.91	1.61	22.77	C
7: Jakros LT	398.54	16.85	1.73	25.44	D	16.03	1.65	24.20	C	20.10	1.95	29.09	D
8: Jakros UT	424.84	13.68	1.38	20.11	C	13.01	1.32	19.12	C	19.69	1.50	27.77	D
9: CMC RT	196.04	0.00	0.00	0.00	A	0.00	0.00	0.00	A	0.01	0.03	0.29	A
10: CMC TM	297.61	1.35	0.29	3.94	A	1.29	0.28	3.75	A	1.26	0.24	4.02	A
11: CMC LT	328.19	1.72	0.28	4.80	A	1.64	0.27	4.57	A	2.35	0.28	5.41	A
12: CMC UT	410.10	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
13: Wosen RT	260.28	0.00	0.00	0.09	A	0.00	0.00	0.09	A	0.00	0.00	0.10	A
14: Wosen TM	293.21	2.60	0.30	5.48	A	2.48	0.28	5.21	A	1.61	0.25	4.22	A
15: Wosen LT	381.57	6.41	0.52	11.22	B	6.09	0.49	10.67	B	5.10	0.48	9.49	A
16: Wosen UT	435.51	4.34	0.50	10.35	B	4.13	0.47	9.85	A	4.42	0.60	10.44	B

**Table 4. 3. 3. 2. 1. 2 Salitemeheret roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (b)**

Movement	Distance (meter)	30 % ( Scenario 3)				40 % ( Scenario 4)				50 % ( Scenario 5)			
		Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)
1: Megenaga RT	205.43	57.51	3.57	82.15	F	44.26	2.03	59.55	F	41.36	2.17	59.04	F
2: Megenaga Tm	303.51	75.46	6.03	118.98	F	69.74	5.43	111.28	F	62.66	4.61	98.30	F
3: Megenaga LT	355.23	80.84	6.87	129.73	F	71.65	5.90	117.52	F	63.06	5.24	104.54	F
4: Megenaga UT	447.37	17.03	2.30	24.66	C	16.56	2.18	23.70	C	15.85	2.07	23.54	C
5: Jakros RT	245.72	0.01	0.00	0.08	A	0.00	0.00	0.03	A	0.00	0.00	0.02	A
6: Jakros TM	303.65	17.03	1.48	24.71	C	17.02	1.58	25.17	D	12.96	1.49	20.35	C
7: Jakros LT	398.54	19.37	1.53	28.50	D	20.22	1.54	29.62	D	13.94	1.50	22.16	C
8: Jakros UT	424.84	18.49	1.73	27.21	D	13.85	1.09	21.01	C	13.39	1.52	21.75	C
9: CMC RT	196.04	0.00	0.00	0.00	A	0.00	0.00	0.00	A	0.26	0.04	0.63	A
10: CMC TM	297.61	1.70	0.31	4.69	A	1.19	0.24	4.00	A	0.98	0.21	3.86	A
11: CMC LT	328.19	3.50	0.32	6.89	A	2.37	0.26	5.43	A	1.95	0.32	5.69	A
12: CMC UT	410.10	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
13: Wosen RT	260.28	0.00	0.00	0.03	A	0.00	0.00	0.11	A	0.00	0.00	0.09	A
14: Wosen TM	293.21	1.55	0.23	4.24	A	1.98	0.20	4.68	A	1.17	0.19	3.79	A
15: Wosen LT	381.57	7.68	0.51	12.75	B	6.51	0.45	11.21	B	4.06	0.44	8.90	A
16: Wosen UT	435.51	3.77	0.60	10.77	B	3.47	0.40	8.18	A	12.49	0.59	21.07	C

**Table 4. 3. 3. 2. 1. 3 Salitemeheret roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (c)**

Movement	Distance (meter)	60 % ( Scenario 6)				70 % ( Scenario 7)				80 % ( Scenario 8)			
		Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)
1: Megenaga RT	205.43	26.79	1.58	39.81	E	18.41	1.22	29.51	D	11.54	0.94	20.00	C
2: Megenaga Tm	303.51	51.84	3.88	83.40	F	42.96	3.20	70.53	F	41.41	2.93	67.59	F
3: Megenaga LT	355.23	56.50	4.45	92.80	F	48.79	3.66	81.88	F	43.06	3.28	72.29	F
4: Megenaga UT	447.37	15.65	2.01	22.55	C	14.81	1.99	22.41	C	14.88	1.92	21.53	C
5: Jakros RT	245.72	0.00	0.00	0.06	A	0.00	0.00	0.05	A	0.00	0.00	0.07	A
6: Jakros TM	303.65	12.21	1.31	19.33	C	11.75	1.06	18.80	C	12.74	1.32	21.10	C
7: Jakros LT	398.54	10.79	1.44	19.85	C	15.57	1.67	24.33	C	10.56	1.21	19.13	C



**Table 4. 3. 3. 2. 1. 4 Salitemeheret roundabout approach roads LOS, stop delay, stop frequency and Vehicular Delay result (d)**

Movement	Distance (meter)	90 % ( Scenario 9)				100 % ( Scenario 10)				Unit Change (Scenario 11)				Carpooling (Scenario 12)			
		Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)	Stop Delay (Second)	Stop (frequency)	Vehicular Delay (second)	Approch LOS (category)
1: Megenaga RT	205.43	13.47	1.05	21.66	C	6.14	0.73	13.41	B	230.94	7.65	279.87	F	257.11	7.40	304.00	F
2: Megenaga Tm	303.51	36.39	2.59	59.87	F	27.29	2.16	48.61	E	250.06	8.91	307.73	F	283.79	9.66	345.36	F
3: Megenaga LT	355.23	37.03	2.81	64.10	F	28.23	2.39	52.42	F	252.17	9.56	314.21	F	272.25	10.32	338.06	F
4: Megenaga UT	447.37	14.59	1.89	21.08	C	13.56	1.81	19.26	C	14.76	1.83	20.76	C	15.93	2.26	21.83	C
5: Jakros RT	245.72	0.00	0.00	0.03	A	0.00	0.00	0.06	A	0.00	0.00	0.00	A	0.00	0.00	0.00	A
6: Jakros TM	303.65	6.17	0.72	13.21	B	8.99	1.03	17.23	C	13.29	1.28	19.70	C	12.67	1.42	20.40	C
7: Jakros LT	398.54	9.91	0.96	18.57	C	7.31	1.03	15.05	C	15.57	1.51	26.01	D	16.26	1.65	27.63	D
8: Jakros UT	424.84	4.43	0.42	9.92	A	12.63	2.10	24.39	C	13.62	1.44	21.03	C	14.98	1.76	23.86	C
9: CMC RT	196.04	0.00	0.00	0.19	A	0.00	0.00	0.00	A	0.00	0.00	0.00	A	0.00	0.00	0.00	A
10: CMC TM	297.61	0.82	0.20	3.94	A	0.69	0.19	3.85	A	0.00	0.00	0.00	A	0.00	0.00	0.00	A
11: CMC LT	328.19	1.04	0.23	4.66	A	1.46	0.26	5.18	A	1.62	0.34	4.70	A	0.00	0.00	0.00	A
12: CMC UT	410.10	0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00	
13: Wosen RT	260.28	0.00	0.00	0.09	A	0.01	0.01	0.16	A	0.01	0.00	0.12	A	0.00	0.00	0.14	A
14: Wosen TM	293.21	0.81	0.15	3.59	A	1.59	0.22	5.13	A	2.45	0.27	5.56	A	2.22	0.31	4.94	A
15: Wosen LT	381.57	2.37	0.35	7.09	A	3.74	0.31	8.66	A	2.21	0.45	6.72	A	3.41	0.48	7.98	A
16: Wosen UT	435.51	1.61	0.27	6.01	A	0.00	0.00	0.00	A	8.31	0.61	13.87	B	7.28	1.34	17.82	C

From the analysis result on this roundabout, the main reason for poor level of service on this roundabout is imbalanced traffic demand with the road capacity. To reduce congestion and upgrade the level of service of the approaches, a shift was made. However, most approach legs of the Salitemeheret roundabout have higher traffic and have delay, so the level of service of the Megenaga and Jackros approaches are poor, while the CMC and Wosen approaches have good level of service because of the flow volume.

### 4.3.3.2.2 Approach roads Travel Time Result

The travel time of vehicles on the Salitemeheret roundabout resulted from an analysis that measures the length of time vehicles take for the movement. The vehicles' travel time is better to be small. The travel time will be max if there a congestion. As shown the trained on the above graphs a shifting percentage increases, vehicle numbers decrease on the road network which will reduce congestion. Minimum travel time will satisfy the road users by saving their time and arriving on the required time. This research indicates that the scenario change has a positive impact on travel time reduction. The maximum vehicle travel time at the Megenaga approach is because of the maximum input volume.

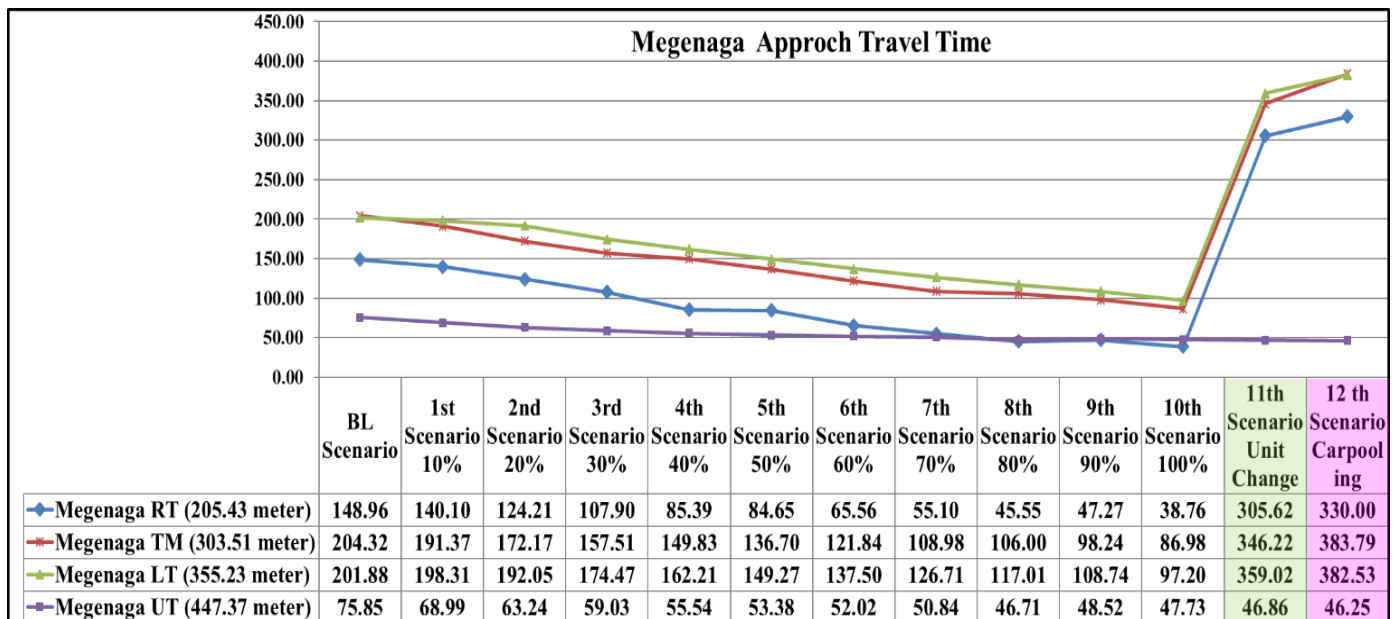


Figure 4. 3. 3. 2. 2. 1 Salitemeheret Roundabout Megenaga Approach Vehicles Travel Time Result Graphical Interpretations

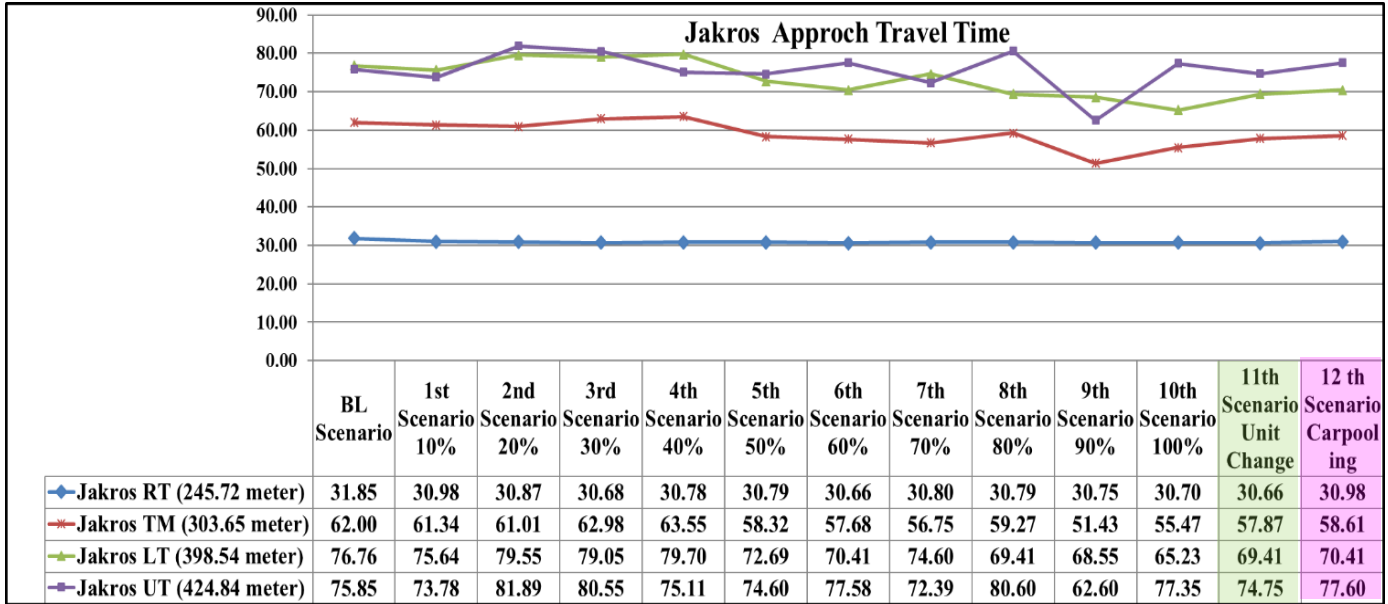


Figure 4. 3. 3. 2. 2 Salitemeheret Roundabout Jackros Approach Vehicles Travel Time Result Graphical Interpretations

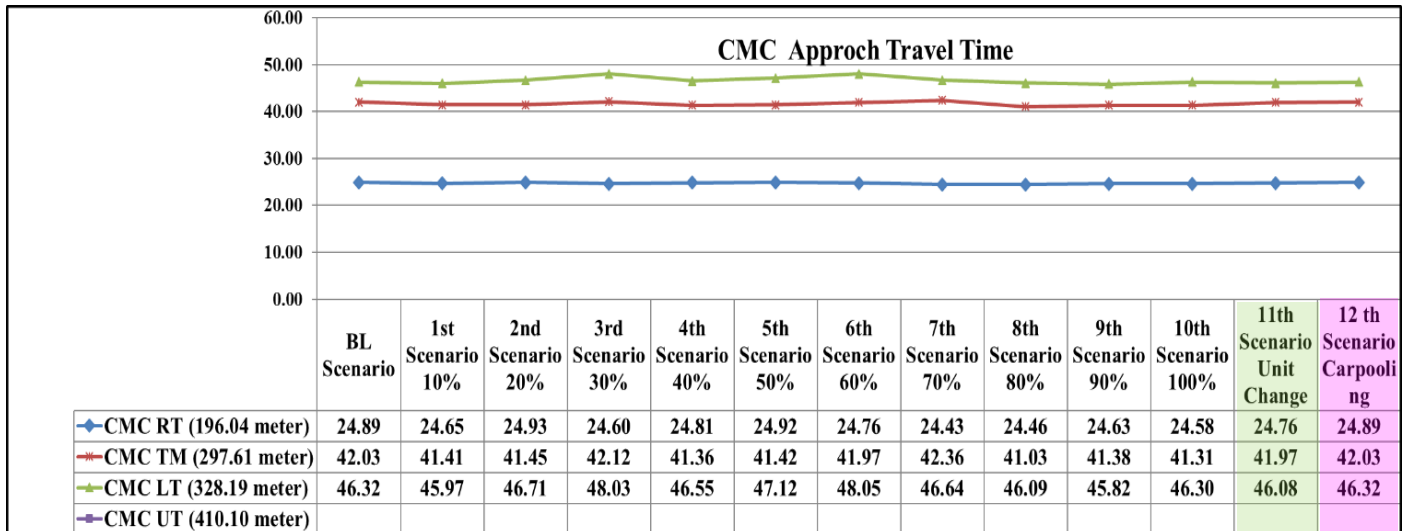


Figure 4. 3. 3. 2. 3 Salitemeheret Roundabout CMC Approach Vehicles Travel Time Result Graphical Interpretations

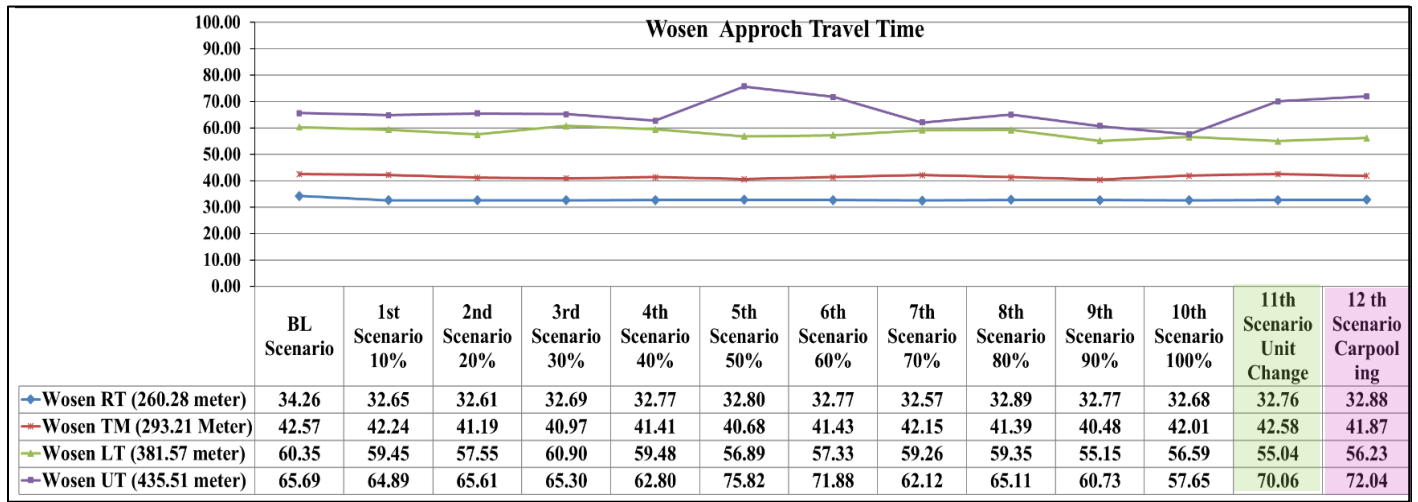


Figure 4. 3. 3. 2. 2. 4 Salitemeheret roundabout Wosen Approach legs vehicles travel time result graphical interpretation

Table 4. 3. 3. 2. 2 Salitemeheret roundabout approach vehicles travel time for each origin Destination Movement result

Movement	Distance (meter)	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 100%	11th Scenario Unit Change	12th Scenario Carpooling
		Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)	Travel time (Second)
1: Megenaga RT	205.43	148.96	140.10	124.21	107.90	85.39	84.65	65.56	55.10	45.55	47.27	38.76	305.62	330.00
2: Megenaga TM	303.51	204.32	191.37	172.17	157.51	149.83	136.70	121.84	108.98	106.00	98.24	86.98	346.22	383.79
3: Megenaga LT	355.23	201.88	198.31	192.05	174.47	162.21	149.27	137.50	126.71	117.01	108.74	97.20	359.02	382.53
4: Megenaga UT	447.37	75.85	68.99	63.24	59.03	55.54	53.38	52.02	50.84	46.71	48.52	47.73	46.86	46.25
5: Jakros RT	245.72	31.85	30.98	30.87	30.68	30.78	30.79	30.66	30.80	30.79	30.75	30.70	30.66	30.98
6: Jakros TM	303.65	62.00	61.34	61.01	62.98	63.55	58.32	57.68	56.75	59.27	51.43	55.47	57.87	58.61
7: Jakros LT	398.54	76.76	75.64	79.55	79.05	79.70	72.69	70.41	74.60	69.41	68.55	65.23	69.41	70.41
8: Jakros UT	424.84	75.85	73.78	81.89	80.55	75.11	74.60	77.58	72.39	80.60	62.60	77.35	74.75	77.60
9: CMC RT	196.04	24.89	24.65	24.93	24.60	24.81	24.92	24.76	24.43	24.46	24.63	24.58	24.76	24.89
10: CMC TM	297.61	42.03	41.41	41.45	42.12	41.36	41.42	41.97	42.36	41.03	41.38	41.31	41.97	42.03
11: CMC LT	328.19	46.32	45.97	46.71	48.03	46.55	47.12	48.05	46.64	46.09	45.82	46.30	46.08	46.32
12: CMC UT	410.10													
13: Wosen RT	260.28	34.26	32.65	32.61	32.69	32.77	32.80	32.77	32.57	32.89	32.77	32.68	32.76	32.88
14: Wosen TM	293.21	42.57	42.24	41.19	40.97	41.41	40.68	41.43	42.15	41.39	40.48	42.01	42.58	41.87
15: Wosen LT	381.57	60.35	59.45	57.55	60.90	59.48	56.89	57.33	59.26	59.35	55.15	56.59	55.04	56.23
16: Wosen UT	435.51	65.69	64.89	65.61	65.30	62.80	75.82	71.88	62.12	65.11	60.73	57.65	70.06	72.04

### 4.3.3.2.3 Approach Roads Travel Speed results

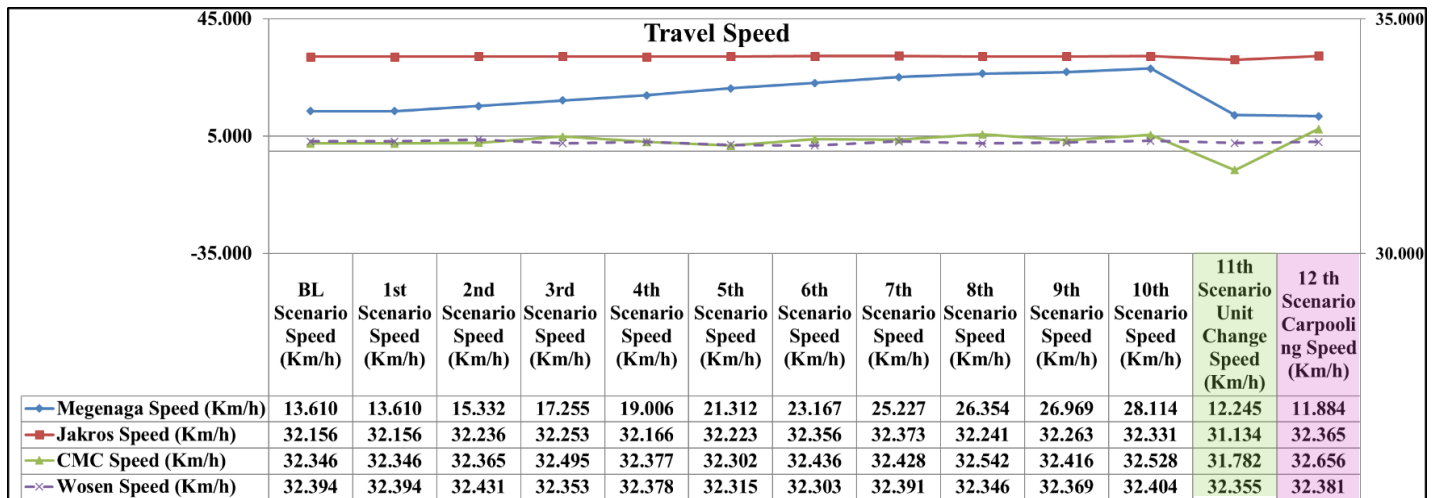


Figure 4. 3. 3. 2. 3 Salitemeheret roundabout approach legs vehicle travel travel speed graphical interpretation

Table 4. 3. 3. 2. 3 Salitemeheret roundabout Approach legs Vehicles travel speed

Approach Leg	BL Scenario Speed (Km/h)	1st Scenario Speed (Km/h)	2nd Scenario Speed (Km/h)	3rd Scenario Speed (Km/h)	4th Scenario Speed (Km/h)	5th Scenario Speed (Km/h)	6th Scenario Speed (Km/h)	7th Scenario Speed (Km/h)	8th Scenario Speed (Km/h)	9th Scenario Speed (Km/h)	10th Scenario Speed (Km/h)	11th Scenario Unit Change Speed (Km/h)	12 th Scenario Carpooling Speed (Km/h)
Megenaga Speed (Km/h)	13.610	13.610	15.332	17.255	19.006	21.312	23.167	25.227	26.354	26.969	28.114	12.245	11.884
Jakros Speed (Km/h)	32.156	32.156	32.236	32.253	32.166	32.223	32.356	32.373	32.241	32.263	32.331	31.134	32.365
CMC Speed (Km/h)	32.346	32.346	32.365	32.495	32.377	32.302	32.436	32.428	32.542	32.416	32.528	31.782	32.656
Wosen Speed (Km/h)	32.394	32.394	32.431	32.353	32.378	32.315	32.303	32.391	32.346	32.369	32.404	32.355	32.381

The travel speed of the vehicles on each leg of the roundabout was nested for Jackros, CMC, and Wosen legs however vehicles from the Megenaga approach were relatively smaller than the other approaches. The minimum speed was attended at the 11th scenario of the unit change modal shift path. Speed on the carpooling modal shift path is relatively higher than in the 11th scenario.

The travel speed simulation results output that the travel speed of vehicles not further far from the posted speed and AACRA speed on the roundabouts 30 km/h and the speed increased due to the vehicular number decrease and reduced congestion of the road. However, in the free condition, the vehicles can travel above the limit speed, and if there is congestion the vehicles may travel at a small speed even if they may stop. On the Salitemeheret roundabout, the travel speed is not much greater than the AACRA restriction.

#### 4.3.3.2.4 Approach Roads Queue length and vehicular stop Result

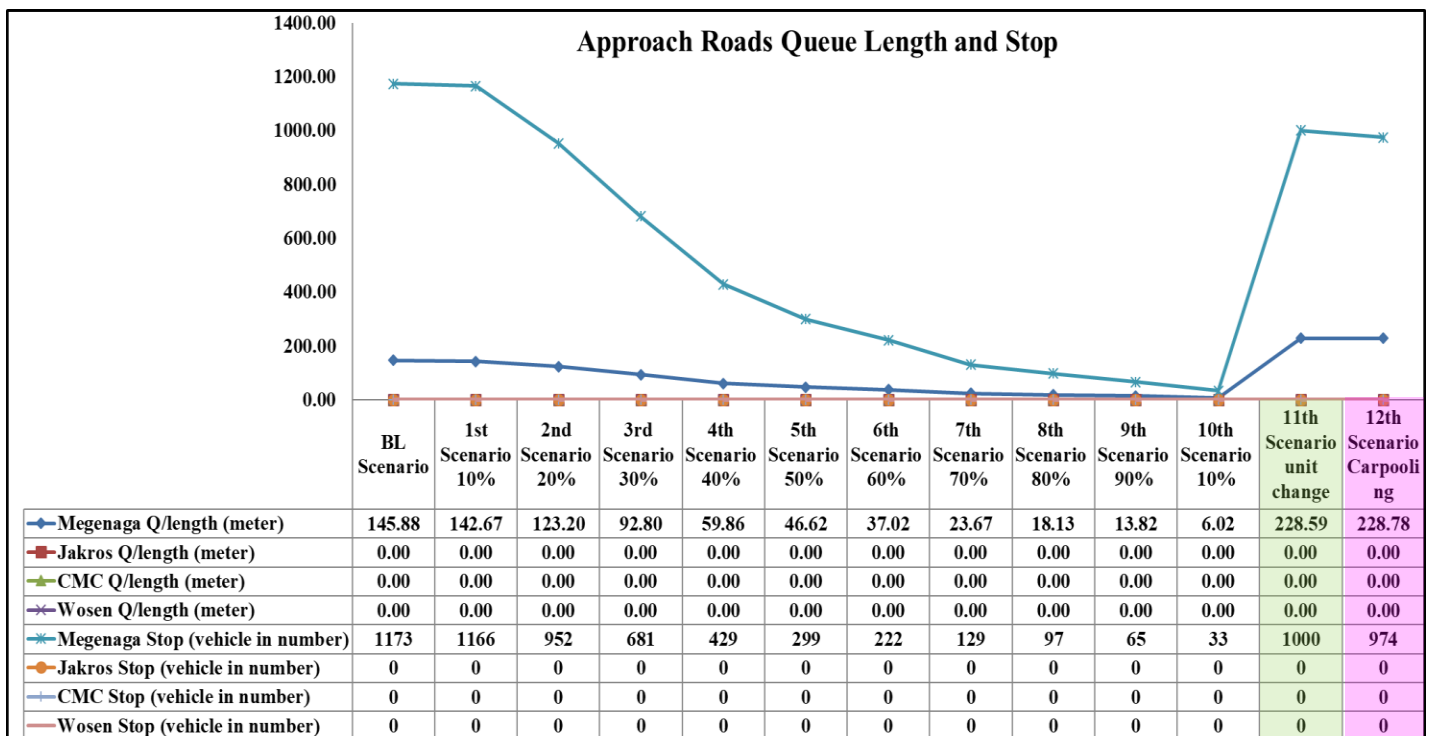


Figure 4. 3. 3. 2. 4 Salitemeheret roundabout approach legs queue length and vehicular stop graphical interpretation

**Table 4. 3. 3. 2. 4. 1 Salitemeheret roundabout approach legs queue length result**

Queue Length (in meter)													
Approch	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
From Megenaga Leg	145.88	142.67	123.20	92.80	59.86	46.62	37.02	23.67	18.13	13.82	6.02	228.59	228.78
From Jakros Leg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From CMC Leg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From Wosen Leg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

**Table 4. 3. 3. 2. 4. 2 Salitemeheret roundabout approach legs number of stop vehicles result**

Stop (Vehicle in number)													
Approch	BL Scenario	1st Scenario 10%	2nd Scenario 20%	3rd Scenario 30%	4th Scenario 40%	5th Scenario 50%	6th Scenario 60%	7th Scenario 70%	8th Scenario 80%	9th Scenario 90%	10th Scenario 10%	11th Scenario unit change	12th Scenario Carpooling
From Megenaga Leg	1173	1166	952	681	429	299	222	129	97	65	33	1000	974
From Jakros Leg	0	0	0	0	0	0	0	0	0	0	0	0	0
From CMC Leg	0	0	0	0	0	0	0	0	0	0	0	0	0
From Wosen Leg	0	0	0	0	0	0	0	0	0	0	0	0	0

According to the HCM 2010 manual illustration the result the level of service of the road upgraded, the average spacing between the vehicles increased and the queue length decreased. So, on this roundabout, the stop and queue lengths were not visible on the Jackros, CMC, and Wosen approaches. The queue length and vehicles stopped significantly decreased with the tried shift scenarios only on the Megenaga approach but, there was an overblown queue and stop vehicles on the Megenaga approach because of maximum traffic. For the congested approach, it is better to make other means to decrease the queue length and stop.

#### **4.3.3.3 Summary of Salitemeheret Roundabout Result**

Salitemeheret roundabout also analyzed in multiple scenarios to assess the performance and to confirm whether the performance of the roundabout upgrade or downgrade its performance with the various scenarios. However, the performance of this roundabout is not significant, both optimal and the better scenario of modal shifting at the seventh scenario of seventy (70) percent modal shifting with minimum volume to capacity ratio, vehicular and stop delays and stop frequency relatively with the other scenarios.

## Chapter 5 Conclusion and Recommendations

### 5.1 Conclusion

The research assesses the impact of small vehicles on the performance of selected roundabouts under various scenarios using PTV Vissim 9 software. The analysis considered modal shift through PCU, unit change, and carpooling paths, and evaluated performance measures such as LOS, delay, travel time, travel speed and queue length.

The results of the analysis show that:

- ✓ Urail and Salitmeheret roundabouts exhibited significant improvements in LOS when modal shift was implemented using PCU.
- ✓ Lambrete roundabout remained at low LOS in all cases, indicating the need for further improvements.
- ✓ Uriel Roundabout showed a strong performance improvement, when analyzing the unit change modal conversion path and Surprisingly, Salitemeheret roundabout experienced a decline in performance with this modal shift. But Lambret roundabout showed a slight improvement in unit change modal shift path rather than the PCU path.

The evaluations achieved the specific objectives of the study:

- ✓ The study's overall objective was achieved by evaluating and presenting the results of each scenario for all roundabouts.
- ✓ Evaluating service level and capacity of roundabouts using current traffic as the baseline scenario.
- ✓ Assessing the impact of PCU modal shift at different percentages, identifying optimal scenarios for Urail, Lamberet and Salitmhret roundabouts, while the Lambert roundabout performed best under the baseline scenario.
- ✓ Evaluating the performance of roundabouts using unit shift and carpooling scenarios, resulting in LOS B for Urail roundabout, LOS E for Lambert roundabout, and LOS F for Salitmhret roundabout.

In summary, the research study demonstrated that:

- ✓ Modal shift strategies can lead to performance improvements in roundabouts, such as reduced delays, travel time, and fuel consumption, increased travel speed, shorter queues, and lower emissions.
- ✓ The findings provide valuable insights into the effects of different modal shift methods on roundabout performance.
- ✓ It is important to note that the conclusions may not directly apply to other locations, and further research is recommended to validate and extend these findings to a broader context.

## 5.2 Recommendations

- In order to convert passenger/small vehicle users to other public transports it recommended.
  - ✓ Change the congested and town down roads to toll roads.
  - ✓ Increase parking charge for passenger/small vehicles.
  - ✓ Subsidy the fuel cost for public transport vehicles (minibus and buses).
  - ✓ Increase the tax for individual vehicles.
  - ✓ Increase the public transport comfort.
  - ✓ Compel small vehicle owners' to share their vehicle
- After additional seek for unit change and carpooling modal shift path if there is no upgrading change the geometry to other junction type.
- Over all from this research the existing operational performance of Addis Ababa roundabouts are poor LOS with unbalanced capacity and demand volume so, it is better to improve their performance with able means.
- Restrict the traveling time for private vehicles.

### Recommendations for future study

- I recommend that researchers do research on how to bring people who drive private cars to use public transportation.
- Instead of changing the geometry of squares, if researchers pay attention to what method we can use to improve the performance of congested squares, a different way can be found from this study.

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**Appendix A**  
**Traffic input values and relative flows**

**Table A - 1 Urael approach input traffic**

Vehicle Type with Specific Time	Baseline Senario	1st Senario 10%	2nd Senario 20%	3rd Senario 30%	4th Senario 40%	5th Senario 50%	6th Senario 60%	7th Senario 70%	8th Senario 80%	9th Senario 90%	10th Senario 100%	11th Senario unit change	12th Senario Carpooling
Car Bole 1st 15	596	545	493	442	390	339	288	236	185	133	82	562	576
Car Bole 2nd 15	647	592	537	482	427	372	317	262	207	152	97	613	627
Car Bole 3rd 15	658	602	547	491	436	380	324	269	213	158	102	630	638
Car Bole 4th 15	603	551	500	448	397	346	294	243	191	140	89	568	583
Bus Bole 1st 15	4	26	51	77	103	128	154	180	206	231	257	1	0
Bus Bole 2nd 15	4	27	55	82	110	137	165	192	220	247	275	2	0
Bus Bole 3rd 15	0	30	58	86	113	141	169	197	225	252	280	0	2
Bus Bole 4th 15	0	28	54	79	105	131	156	182	208	233	259	2	2
HV Bole 1st 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Bole 2nd 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Bole 3rd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Bole 4th 15	0	0	0	0	0	0	0	0	0	0	0	0	0
Car Kashanchis 1st 15	269	245	220	196	171	147	122	98	73	49	24	241	249
Car Kasanchis 2nd 15	300	274	247	221	194	168	141	115	88	62	35	269	280
Car Kashanchis 3rd 15	257	235	212	190	168	146	123	101	79	56	34	229	237
Car Kashanchis 4th 15	310	282	254	226	198	170	142	114	86	58	30	283	290
Bus kashanchis 1st 15	0	12	25	37	49	61	74	86	98	110	123	2	0
Bus kashanchis 2nd 15	0	13	27	40	53	66	80	93	106	119	133	2	0
Bus Kashanchis 3rd 15	2	13	25	36	47	58	69	80	91	103	114	1	2
Bus Kashanchis 4th 15	0	18	32	46	60	74	88	102	116	130	144	3	4
HV Kashanchis 1st 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Kashanchis 2nd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Kashanchis 3rd 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Kashanchis 4th 15	0	0	0	0	0	0	0	0	0	0	0	0	0
Car Megenaga 1st 15	383	375	346	316	287	257	228	198	169	139	110	359	363
Car Megenaga 2nd 15	388	359	330	300	270	240	210	180	150	120	90	367	368
Car Megenaga 3rd 15	472	446	409	371	333	296	258	220	183	145	107	453	452
Car Megenaga 4th 15	412	392	361	330	298	267	236	205	173	142	111	387	392
Bus Megenaga 1st 15	18	18	47	62	77	91	106	121	136	150	165	22	18
Bus Megenaga 2nd 15	7	7	37	52	66	81	96	111	126	141	156	8	7
Bus Megenaga 3rd 15	8	9	47	65	84	103	122	141	160	178	197	5	9
Bus Megenaga 4th 15	17	18	49	65	80	96	111	127	143	158	174	15	18
HV Megenaga 1st 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Megenaga 2nd 15	6	7	7	7	7	7	7	7	7	7	7	7	7
HV Megenaga 3rd 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Megenaga 4th 15	0	0	0	0	0	0	0	0	0	0	0	0	0
Car M/Squar 1st 15	518	478	466	397	356	316	275	235	194	154	113	480	498
Car M/Squar 2nd 15	567	517	517	416	366	316	265	215	165	115	64	528	547
Car M/Squar 3rd 15	587	539	539	442	393	344	296	247	199	150	102	547	567
Car M/Squar 4th 15	501	459	459	377	336	295	253	212	171	130	89	452	481
Bus M/squar 1st 15	16	36	56	76	97	117	137	157	178	198	218	19	16
Bus M/squar 2nd 15	6	32	57	82	107	132	158	183	208	233	258	10	7
Bus M/squar 3rd 15	11	35	60	84	108	132	157	181	205	229	254	12	11
Bus M/Squar 4th 15	6	27	48	68	89	110	130	151	171	192	213	10	7
HV M/Squar 1st 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV M/Squar 2nd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV M/Squar 3rd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV M/Squar 4th 15	2	2	2	2	2	2	2	2	2	2	2	2	2
<b>TOTAL</b>	<b>7593</b>	<b>7268</b>	<b>7190</b>	<b>6709</b>	<b>6398</b>	<b>6086</b>	<b>5774</b>	<b>5462</b>	<b>5151</b>	<b>4839</b>	<b>4527</b>	<b>7109</b>	<b>7278</b>

**Table A - 2 Lamberet approach input traffic**

Vehicle Type with Spesific Time	Baseline Senario	1st Senario 10%	2nd Senario 20%	3rd Senario 30%	4th Senario 40%	5th Senario 50%	6th Senario 60%	7th Senario 70%	8th Senario 80%	9th Senario 90%	10th Senario 100%	11th Senario unit change	12th Senario Carpooling
Car G/shola 1st 15	51	47	42	38	33	29	24	20	16	11	7	31	38
Car G/shola 2nd 15	80	72	65	58	51	43	36	29	21	14	7	59	74
Car G/shola 3rd 15	113	103	93	82	72	62	52	42	31	21	11	86	101
Car G/shola 4th 15	126	116	106	96	86	76	66	56	47	37	27	93	108
Bus G/shola 1st 15	0	2	4	7	9	11	13	16	18	20	22	1	1
Bus G/shola 2nd 15	2	6	10	13	17	20	24	28	31	35	39	2	2
Bus G/shola 3rd 15	0	5	10	15	20	25	31	36	41	46	51	1	1
Bus G/shola 4th 15	0	5	10	15	20	25	30	35	40	45	50	2	2
HV G/shola 1st 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV G/shola 2nd 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV G/shola 3rd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV G/shola 4th 15	2	2	2	2	2	2	2	2	2	2	2	2	2
Car Koteba 1st 15	937	872	808	743	678	614	549	484	420	355	290	891	911
Car Koteba 2nd 15	1001	924	847	770	693	616	539	462	385	307	230	955	975
Car Koteba 3rd 15	911	847	783	720	656	593	529	465	402	338	275	859	879
Car Koteba 4th 15	924	856	788	720	653	585	517	449	381	314	246	879	898
Bus Kotebas 1st 15	40	72	105	137	169	202	234	266	299	331	363	43	43
Bus Koteba 2nd 15	26	65	103	142	181	219	258	296	335	373	412	29	29
Bus Koteba 3rd 15	40	72	104	136	168	199	231	263	295	327	358	43	43
Bus Koteba 4th 15	24	58	92	126	160	194	228	261	295	329	363	27	27
HV Koteba 1st 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Koteba 2nd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Koteba 3rd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Kotebas 4th 15	11	11	11	11	11	11	11	11	11	11	11	11	11
Car Megenaga 1st 15	474	450	427	403	379	356	332	308	284	261	237	441	454
Car Megenaga 2nd 15	521	494	467	440	412	385	358	331	304	277	250	488	500
Car Megenaga 3rd 15	591	558	525	491	458	424	391	357	324	290	257	558	572
Car Megenaga 4th 15	521	491	462	432	403	373	344	314	285	255	226	488	501
Bus Megenaga 1st 15	44	56	68	80	92	104	115	127	139	151	163	47	47
Bus Megenaga 2nd 15	27	40	54	67	81	94	108	121	135	148	162	29	29
Bus Megenaga 3rd 15	9	26	42	59	76	92	109	126	143	159	176	11	11
Bus Megenaga 4th 15	31	46	60	75	90	105	119	134	149	164	178	33	33
HV Megenaga 1st 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Megenaga 2nd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Megenaga 3rd 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV Megenaga 4th 15	0	0	0	0	0	0	0	0	0	0	0	0	0
Car Wosen 1st 15	959	892	825	759	692	625	558	491	424	357	290	913	933
Car Wosen 2nd 15	1001	924	847	770	693	616	539	462	385	307	230	955	975
Car Wosen 3rd 15	911	847	783	720	656	593	529	465	402	338	275	859	879
Car Wosen 4th 15	924	856	788	720	653	585	517	449	381	314	246	885	897
Bus Wosen 1st 15	40	73	107	140	174	207	241	274	307	341	374	43	43
Bus Wosen 2nd 15	27	65	104	142	181	219	258	296	335	374	412	30	30
Bus Wosen 3rd 15	40	72	103	135	167	199	231	262	294	326	358	43	43
Bus Wosen 4th 15	24	58	92	126	160	194	228	262	296	329	363	27	27
HV Wosen1st 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Wosen 2nd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Wosen 3rd 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Wosen 4th 15	4	4	4	4	4	4	4	4	4	4	4	4	4
<b>TOTAL</b>	<b>10461</b>	<b>10114</b>	<b>9767</b>	<b>9420</b>	<b>9073</b>	<b>8726</b>	<b>8379</b>	<b>8032</b>	<b>7685</b>	<b>7338</b>	<b>6991</b>	<b>9890</b>	<b>10145</b>

**Table A - 3 Salitemeheret approach input traffic**

Vehicle Type with Specific Time	Baseline Senario	1st Senario 10%	2nd Senario 20%	3rd Senario 30%	4th Senario 40%	5th Senario 50%	6th Senario 60%	7th Senario 70%	8th Senario 80%	9th Senario 90%	10th Senario 100%	11th Senario unit change	12th Senario Carpooling
Car Bole 1st 15	877	806	735	663	592	521	449	378	307	235	164	844	859
Car Bole 2nd 15	1296	1184	1072	960	848	737	625	513	401	289	177	1263	1278
Car Bole 3rd 15	1261	1151	1041	931	821	711	601	491	381	272	162	1227	1239
Car Bole 4th 15	1272	1165	1058	951	844	737	630	523	416	309	202	1238	1253
Bus Bole 1st 15	11	47	82	118	154	189	225	261	296	332	368	13	13
Bus Bole 2nd 15	11	67	123	179	235	291	347	403	459	515	570	13	13
Bus Bole 3rd 15	16	70	125	180	235	290	345	400	455	510	565	17	17
Bus Bole 4th 15	20	73	127	180	234	287	341	394	448	501	555	22	22
HV Bole 1st 15	13	13	13	13	13	13	13	13	13	13	13	13	13
HV Bole 2nd 15	16	16	16	16	16	16	16	16	16	16	16	16	16
HV Bole 3rd 15	7	7	7	7	7	7	7	7	7	7	7	7	7
HV Bole 4th 15	7	7	7	7	7	7	7	7	7	7	7	7	7
Car Kashanchis 1st 15	269	245	220	196	171	147	122	98	73	49	24	223	243
Car Kasanchis 2nd 15	300	274	247	221	194	168	141	115	88	62	35	246	266
Car Kashanchis 3rd 15	257	235	212	190	168	146	123	101	79	56	34	219	239
Car Kashanchis 4th 15	310	282	254	226	198	170	142	114	86	58	30	280	292
Bus kashanchis 1st 15	0	12	25	37	49	61	74	86	98	110	123	1	1
Bus kashanchis 2nd 15	7	20	34	47	60	73	87	100	113	126	140	9	8
Bus Kashanchis 3rd 15	1	12	23	34	46	57	68	79	90	101	113	3	3
Bus Kashanchis 4th 15	1	15	29	43	57	71	85	99	113	127	141	3	3
HV Kashanchis 1st 15	1	1	1	1	1	1	1	1	1	1	1	1	1
HV Kashanchis 2nd 15	6	6	6	6	6	6	6	6	6	6	6	6	6
HV Kashanchis 3rd 15	6	6	6	6	6	6	6	6	6	6	6	6	6
HV Kashanchis 4th 15	6	6	6	6	6	6	6	6	6	6	6	6	6
Car Megenaga 1st 15	332	305	278	251	224	197	170	143	116	89	62	305	320
Car Megenaga 2nd 15	376	347	319	290	262	233	204	176	147	119	90	349	364
Car Megenaga 3rd 15	382	350	318	287	255	223	191	159	128	96	64	355	370
Car Megenaga 4th 15	372	342	312	283	253	223	193	163	134	104	74	339	354
Bus Megenaga 1st 15	2	16	29	43	56	70	83	97	110	124	137	4	3
Bus Megenaga 2nd 15	5	19	34	48	62	77	91	105	119	134	148	7	6
Bus Megenaga 3rd 15	10	26	42	58	74	90	105	121	137	153	169	12	11
Bus Megenaga 4th 15	8	23	38	53	68	83	97	112	127	142	157	11	10
HV Megenaga 1st 15	0	0	0	0	0	0	0	0	0	0	0	0	0
HV Megenaga 2nd 15	1	1	1	1	1	1	1	1	1	1	1	1	1
HV Megenaga 3rd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV Megenaga 4th 15	5	5	5	5	5	5	5	5	5	5	5	5	5
Car M/Squar 1st 15	354	325	295	265	236	206	176	147	117	87	58	308	328
Car M/Squar 2nd 15	476	437	397	358	319	279	240	200	161	121	82	430	450
Car M/Squar 3rd 15	374	343	312	281	250	219	188	157	126	95	64	328	348
Car M/Squar 4th 15	328	301	274	247	221	194	167	140	113	87	60	281	301
Bus M/squar 1st 15	2	17	32	47	61	76	91	106	121	136	150	5	5
Bus M/squar 2nd 15	4	25	44	64	84	104	123	143	163	182	202	7	7
Bus M/squar 3rd 15	4	26	41	57	72	88	103	119	134	150	165	7	7
Bus M/Squar 4th 15	4	21	35	48	62	75	88	102	115	129	142	7	7
HV M/Squar 1st 15	4	4	4	4	4	4	4	4	4	4	4	4	4
HV M/Squar 2nd 15	7	7	7	7	7	7	7	7	7	7	7	7	7
HV M/Squar 3rd 15	2	2	2	2	2	2	2	2	2	2	2	2	2
HV M/Squar 4th 15	4	4	4	4	4	4	4	4	4	4	4	4	4
<b>TOTAL</b>	<b>9030</b>	<b>8667</b>	<b>8294</b>	<b>7922</b>	<b>7549</b>	<b>7176</b>	<b>6803</b>	<b>6430</b>	<b>6058</b>	<b>5685</b>	<b>5312</b>	<b>8465</b>	<b>8729</b>



Table A - 4 Relative Flow

SN	Vehicle Type	Movement	Length in Meter	BL Relative Flow	10 % shift Relative flow	20 % shift Relative flow	30 % shift Relative flow	40 % shift Relative flow	50 % shift Relative flow	60 % shift Relative flow	70 % shift Relative flow	80 % shift Relative flow	90 % shift Relative flow	100 % shift Relative flow	unit change shift Relative flow	Carpooling shift Relative flow	Sum
1	1: Car G/Shola 1st 15	RT	132.01	0.739	0.743	0.747	0.753	0.760	0.769	0.782	0.800	0.829	0.880	1.000	0.808	0.760	
2	1: Car G/Shola 1st 15	TM	65.76	0.174	0.171	0.168	0.165	0.160	0.154	0.145	0.133	0.114	0.080	0.000	0.061	0.160	
3	1: Car G/Shola 1st 15	LT	134.40	0.087	0.086	0.084	0.082	0.080	0.077	0.073	0.067	0.057	0.040	0.000	0.131	0.080	
4	1: Car G/Shola 1st 15	UT	83.30	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	1.000
5	2: Car G/Shola 2nd 15	RT	133.36	0.389	0.394	0.401	0.410	0.421	0.436	0.457	0.488	0.542	0.651	1.000	0.407	0.422	
6	2: Car G/Shola 2nd 15	TM	69.10	0.361	0.358	0.354	0.349	0.342	0.333	0.321	0.302	0.271	0.206	0.000	0.372	0.342	
7	2: Car G/Shola 2nd 15	LT	133.65	0.250	0.248	0.245	0.241	0.237	0.231	0.222	0.209	0.188	0.143	0.000	0.221	0.237	
8	2: Car G/Shola 2nd 15	UT	83.67	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	1.000
9	3: Car G/Shola 3rd 15	RT	132.21	0.373	0.375	0.378	0.382	0.387	0.393	0.402	0.415	0.437	0.479	0.600	0.340	0.387	
10	3: Car G/Shola 3rd 15	TM	66.74	0.235	0.235	0.234	0.234	0.233	0.232	0.231	0.229	0.225	0.219	0.200	0.226	0.233	
11	3: Car G/Shola 3rd 15	LT	135.15	0.392	0.390	0.388	0.384	0.380	0.375	0.368	0.356	0.338	0.302	0.200	0.434	0.380	
12	3: Car G/Shola 3rd 15	UT	82.01	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	1.000
13	4: Car G/Shola 4rd 15	RT	133.03	0.439	0.442	0.446	0.451	0.456	0.464	0.473	0.486	0.505	0.533	0.583	0.457	0.457	
14	4: Car G/Shola 4rd 15	TM	66.27	0.263	0.261	0.258	0.255	0.251	0.246	0.240	0.231	0.219	0.200	0.167	0.278	0.251	
15	4: Car G/Shola 4rd 15	LT	134.50	0.298	0.297	0.296	0.294	0.292	0.290	0.287	0.282	0.276	0.267	0.250	0.266	0.292	
16	4: Car G/Shola 4rd 15	UT	81.72	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	1.000
17	5: Bus G/Shola 1st 15	RT	131.72	0.000	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	1.000	0.000	
18	5: Bus G/Shola 1st 15	TM	64.04	0.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.000	0.000	
19	5: Bus G/Shola 1st 15	LT	132.61	0.000	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.000	0.000	
20	5: Bus G/Shola 1st 15	UT	84.73	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
21	6: Bus G/Shola 2nd 15	RT	132.03	0.000	0.208	0.256	0.277	0.289	0.297	0.303	0.307	0.310	0.312	0.314	0.000	0.000	
22	6: Bus G/Shola 2nd 15	TM	64.44	1.000	0.623	0.535	0.496	0.474	0.459	0.450	0.442	0.437	0.432	0.429	1.000	1.000	
23	6: Bus G/Shola 2nd 15	LT	134.94	0.000	0.170	0.209	0.227	0.237	0.243	0.248	0.251	0.254	0.256	0.257	0.000	0.000	
24	6: Bus G/Shola 2nd 15	UT	80.34	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
25	7: Bus G/Shola 3rd 15	RT	132.28	0.000	0.348	0.348	0.348	0.348	0.348	0.348	0.348	0.348	0.348	0.348	1.000	0.000	
26	7: Bus G/Shola 3rd 15	TM	67.85	0.000	0.239	0.239	0.239	0.239	0.239	0.239	0.239	0.239	0.239	0.239	0.000	0.000	
27	7: Bus G/Shola 3rd 15	LT	134.70	0.000	0.413	0.413	0.413	0.413	0.413	0.413	0.413	0.413	0.413	0.413	0.000	0.000	
28	7: Bus G/Shola 3rd 15	UT	83.49	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
29	8: Bus G/Shola 4rd 15	RT	132.21	0.000	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.500	0.000	
30	8: Bus G/Shola 4rd 15	TM	67.45	0.000	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.289	0.000	0.000	
31	8: Bus G/Shola 4rd 15	LT	134.08	0.000	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.500	0.000	
32	8: Bus G/Shola 4rd 15	UT	81.42	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
33	9: HV G/Shola 1st 15	RT	134.05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
34	9: HV G/Shola 1st 15	TM	67.44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
35	9: HV G/Shola 1st 15	LT	135.55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
36	9: HV G/Shola 1st 15	UT	81.74	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	10: HV G/Shola 2nd 15	RT	131.60	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	10: HV G/Shola 2nd 15	TM	68.46	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
39	10: HV G/Shola 2nd 15	LT	133.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
40	10: HV G/Shola 2nd 15	UT	85.18	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
41	11: HV G/Shola 3rd 15	RT	132.11	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	11: HV G/Shola 3rd 15	TM	65.77	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
43	11: HV G/Shola 3rd 15	LT	134.65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
44	11: HV G/Shola 3rd 15	UT	82.43	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
45	12: HV G/Shola 4th 15	RT	133.91	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	12: HV G/Shola 4th 15	TM	66.89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
47	12: HV G/Shola 4th 15	LT	133.64	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
48	12: HV G/Shola 4th 15	UT	84.71	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000

## Shifting representation

### Baseline Scenario

**Table A - 5 Baseline scenario Traffic**

Hour	Minute	Car				Minibus				Mid Bus				Passanger Vehicles				Bus				Truck				Truck Trailer				Heavy Vehicles				Three Wheelers				Motor Cycle				Bicycel			
		RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT				
2:00-3:00	02:15 - 02:30	31	4	9	0	7	0	0	0	0	0	0	0	38	4	9	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:30 - 02:45	24	20	29	0	2	0	0	0	4	0	0	0	31	20	29	0	1	1	4	0	4	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:45 - 03:00	35	42	24	0	7	2	2	0	0	0	0	0	42	44	27	0	2	2	1	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00 - 03:15	40	31	29	0	13	7	4	0	2	0	0	0	55	38	33	0	2	2	1	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
The total one hour flow	02:15-03:15	131	97	91	0	29	9	7	0	7	0	0	0	166	106	97	0	7	5	7	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

### 1st Scenario of 10 % shift

10 % of cars shift to Bus

Baseline Car RT=31 (for all scenarios)

PCU for Bus=2 (for all scenarios) , Using PCU of HCM 2010 Manual.

$$\text{Car} = 31 - (31 * 0.1) = 28$$

$$\text{Bus} = 0 + ((31 * 0.1) / 2) = 2$$

**Table A - 6 PCU Shifting (Car- Bus) with 10 % shift**

Hour	Minute	Car				Minibus				Mid Bus				Passanger Vehicles				Bus				Truck				Truck Trailer				Heavy Vehicles				Three Wheelers				Motor Cycle				Bicycel			
		RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT				
2:00-3:00	02:15 - 02:30	28	4	8	0	7	0	0	0	0	0	0	0	35	4	8	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:30 - 02:45	22	18	26	0	2	0	0	0	4	0	0	0	29	18	26	0	1	1	4	0	4	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:45 - 03:00	32	38	22	0	7	2	2	0	0	0	0	0	39	40	24	0	2	2	1	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	03:00 - 03:15	36	28	26	0	13	7	4	0	2	0	0	0	51	35	30	0	2	2	1	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
the total one hour flow	02:15-03:15	118	88	82	0	29	9	7	0	7	0	0	0	153	97	88	0	7	5	7	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



**Table A - 9 Unit Change traffic Shift**

Hour	Minute	Car				Minibus				Mid Bus				Passanger Vehicles				Bus				Truck				Truck Trailer				Heavy Vehicles				Three Wheelers				Motor Cycle				Bicycel			
		RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT				
2:00-3:00	02:15 - 02:30	23	4	1	0	2	0	1	0	0	0	0	0	25	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:30 - 02:45	16	12	21	0	3	1	1	0	4	0	0	0	24	13	22	0	0	0	2	0	4	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0				
	02:45 - 03:00	27	34	16	0	2	3	3	0	0	0	0	0	29	37	19	0	1	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0				
	03:00 - 03:15	32	23	21	0	8	2	5	0	2	0	0	0	42	25	26	0	1	1	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0				
the total one hour flow	02:15-03:15	99	73	59	0	15	6	10	0	7	0	0	0	120	79	69	0	3	1	2	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0				

**12th scenario of Carpooling shift**

Car = (31-3) =28

Minibus= (7+1-6) =2

Bus = (0+1) =1

✚ Note

- ✓ 3 Car = 1 Mini Bus based on passengers' occupancy, carpooling mandatory.
- ✓ 6 Minibus = 1Bus based on passengers' occupancy

**Table A - 10 Carpooling Traffic Shift**

Hour	Minute	Car				Minibus				Mid Bus				Passanger Vehicles				Bus				Truck				Truck Trailer				Heavy Vehicles				Three Wheelers				Motor Cycle				Bicycel			
		RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT	RT	LT	TM	UT				
2:00-3:00	02:15 - 02:30	28	1	6	0	2	0	1	0	0	0	0	0	30	1	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	02:30 - 02:45	21	17	26	0	3	1	1	0	4	0	0	0	29	18	27	0	0	0	0	2	4	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0				
	02:45 - 03:00	32	39	21	0	2	3	3	0	0	0	0	0	34	42	24	0	1	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0				
	03:00 - 03:15	37	28	26	0	8	2	5	0	2	0	0	0	47	30	31	0	1	1	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0				
the total one hour flow	02:15-03:15	119	85	79	0	15	6	10	0	7	0	0	0	140	91	89	0	3	1	2	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0				



**Table A - 11 Actual passenger occupancy with in small Vehicles**

observations	Small Car				
	Passangeres with in the vehicle				
1	<del>1</del>	2	3	4	5
2	<del>1</del>	2	3	4	5
3	1	<del>2</del>	3	4	5
4	<del>1</del>	2	3	4	5
5	1	<del>2</del>	3	4	5
6	1	2	3	4	<del>5</del>
7	<del>1</del>	2	3	4	5
8	1	<del>2</del>	3	4	5
9	1	<del>2</del>	3	4	5
10	1	2	<del>3</del>	4	5
11	<del>1</del>	2	3	4	5
12	1	2	3	<del>4</del>	5
13	1	2	3	4	<del>5</del>
14	1	<del>2</del>	3	4	5
15	1	<del>2</del>	3	4	5
16	<del>1</del>	2	3	4	5
17	<del>1</del>	2	3	4	5
18	<del>1</del>	2	3	4	5
19	1	2	<del>3</del>	4	5
20	<del>1</del>	2	3	4	5
21	<del>1</del>	2	3	4	5
22	<del>1</del>	2	3	4	5
23	<del>1</del>	2	3	4	5
24	1	2	<del>3</del>	4	5
25	1	<del>2</del>	3	4	5
26	<del>1</del>	2	3	4	5
27	<del>1</del>	2	3	4	5
28	1	<del>2</del>	3	4	5
29	<del>1</del>	2	3	4	5
30	<del>1</del>	2	3	4	5
31	<del>1</del>	2	3	4	5
32	<del>1</del>	2	3	4	5
33	<del>1</del>	2	3	4	5
34	<del>1</del>	2	3	4	5
35	<del>1</del>	2	3	4	5
36	1	<del>2</del>	3	4	5
37	1	2	<del>3</del>	4	5
38	<del>1</del>	2	3	4	5
39	<del>1</del>	2	3	4	5
40	<del>1</del>	2	3	4	5
41	<del>1</del>	2	3	4	5
42	1	2	3	<del>4</del>	5
43	<del>1</del>	2	3	4	5
44	<del>1</del>	2	3	4	5
45	1	<del>2</del>	3	4	5
46	1	2	<del>3</del>	4	5
47	<del>1</del>	2	3	4	5
48	<del>1</del>	2	3	4	5
49	<del>1</del>	2	3	4	5
50	<del>1</del>	2	3	4	5

Average of small cars  
passengers (occupancy) =1.68

**Table A - 12 Actual passenger occupancy with in Mini- bus Vehicles**

observations	Mini-Bus			
	Passangeres with in the vehicle			
1	<del>12</del>	13	14	15
2	<del>12</del>	13	14	15
3	12	<del>13</del>	14	15
4	<del>12</del>	13	14	15
5	12	13	<del>14</del>	15
6	12	13	14	<del>15</del>
7	<del>12</del>	13	14	15
8	12	13	<del>14</del>	15
9	12	13	14	<del>15</del>
10	<del>12</del>	13	14	15
11	12	13	<del>14</del>	15
12	<del>12</del>	13	14	15
13	<del>12</del>	13	14	15
14	12	13	14	<del>15</del>
15	<del>12</del>	13	14	15
16	12	13	<del>14</del>	15
17	<del>12</del>	13	14	15
18	<del>12</del>	13	14	15
19	12	<del>13</del>	14	15
20	12	13	14	<del>15</del>
21	<del>12</del>	13	14	15
22	12	<del>13</del>	14	15
23	12	13	<del>14</del>	15
24	12	<del>13</del>	14	15
25	12	13	14	<del>15</del>
26	<del>12</del>	13	14	15
27	<del>12</del>	13	14	15
28	<del>12</del>	13	14	15
29	12	<del>13</del>	14	15
30	<del>12</del>	13	14	15
31	<del>12</del>	13	14	15
32	12	13	14	<del>15</del>
33	12	<del>13</del>	14	15
34	<del>12</del>	13	14	15
35	<del>12</del>	13	14	15
36	12	13	<del>14</del>	15
37	<del>12</del>	13	14	15
38	12	<del>13</del>	14	15
39	12	13	14	<del>15</del>
40	<del>12</del>	13	14	15
41	12	<del>13</del>	14	15
42	<del>12</del>	13	14	15
43	12	<del>13</del>	14	15
44	12	13	14	<del>15</del>
45	<del>12</del>	13	14	15
46	<del>12</del>	13	14	15
47	12	13	<del>14</del>	15
48	12	13	14	<del>15</del>
49	<del>12</del>	13	14	15
50	<del>12</del>	13	14	15

Average of Mini Bus  
passengers (occupancy) =13



**Appendix B**  
**Quality Measures for calibrated model**

**🚩 Geoffrey E. Heavers (GEH)**

$$\mathbf{GEH} = \sqrt{\left(\frac{(X_i - Y_i)^2}{\frac{(X_i - Y_i)}{2}}\right)} \dots\dots\dots \text{Equation 1}$$

Where  $Y_i$  is simulated value,  $X_i$  is observed value and  $n$  is the number of intervals.

- Acceptable Values for GEH
  - ✓ GEH values less than 5 indicate a good fit
  - ✓ Values between 5 and 10 require further investigation
  - ✓ Values above 10 indicate a poor fit (I. Hoque & A. Naz ICPACE 2023)

**🚩 Root Mean Square Error (RMSE)**

$$\mathbf{RMSE} = \sqrt{\left(\sum_{i=1}^N \left(\frac{(X_i - Y_i)^2}{n}\right)\right)} \dots\dots\dots \text{Equation 2}$$

Where  $Y_i$  is simulated value,  $X_i$  is observed value and  $n$  is the number of intervals.

- Acceptable Values for RMSE
  - ✓ A lower value is advisable

**🚩 Root Mean Square Percent Error (RMSPE)**

$$\mathbf{RMSPE} = \sqrt{\sum_{i=1}^n \left(\frac{\left(\frac{X_i - Y_i}{X_i}\right)^2}{n}\right)} \dots\dots\dots \text{Equation 3}$$

**🚩 Mean Error (ME)**

$$\mathbf{ME} = \frac{1}{n} * \sum_{i=1}^N (X_i - Y_i) \dots\dots\dots \text{Equation 4}$$

Where  $Y_i$  is simulated value,  $X_i$  is observed value and  $n$  is the number of intervals.

- Acceptable Values for ME
  - ✓ A lower value is advisable

**✚ Mean Percent Error (MPE)**

$$\text{MPE} = \frac{1}{n} * \sum_{i=1}^n \left( \frac{(X_i - Y_i)}{X_i} \right) \dots \dots \dots \text{Equation 5}$$

Where  $Y_i$  is simulated value,  $X_i$  is observed value and  $n$  is the number of intervals.

- Acceptable Values for MPE
  - ✓ A lower value is advisable

**✚ Mean Absolute Percent Error (MAPE)**

$$\text{MAPE} = \frac{100\%}{n} \sum_{i=1}^n \left| \left( \frac{X_i - Y_i}{Y_i} \right) \right| \dots \dots \dots \text{Equation 6}$$

Where  $Y_i$  is simulated value,  $X_i$  is observed value and  $n$  is the number of intervals.

- Acceptable Values for MAPE
  - ✓ Cannot be used if there are zero values
  - ✓ Cannot exceed 100 %

**✚ Theil's Inequality Coefficients (U)**

$$U = \frac{\sqrt{\frac{1}{N} \sum_{n=1}^N (Y_n^{\text{sim}} - Y_n^{\text{obs}})^2}}{\sqrt{\left( \frac{1}{N} \sum_{n=1}^N (Y_n^{\text{sim}})^2 \right) + \left( \frac{1}{N} \sum_{n=1}^N (Y_n^{\text{obs}})^2 \right)}} \dots \dots \dots \text{Equation 7}$$

Where  $Y_n^{\text{sim}}$  is simulated value,  $Y_n^{\text{obs}}$  observed value and  $n$  is the number of intervals.

- Acceptable Values for U
  - ✓ U is bounded,  $0 \leq U \leq 1$ .
  - ✓  $U=0$  implies perfect fit between the observed and simulated measurements.
  - ✓  $U=1$  implies the worst possible fit.

❖ **Bias proportion between the actual and modeled value (Um)**

$$U^M = \frac{(Y^{sim} - Y^{obs})^2}{\frac{1}{N} \sum (Y_n^{sim} - Y_n^{obs})^2} \dots \dots \dots \text{Equation 8}$$

Where Ysim is simulated value, Yobs is observed value and n is the number of intervals

- Acceptable Values for Um
  - ✓ It should be small as possible

❖ **Variance proportion between the actual and modeled value (Us).**

$$U^S = \frac{(s^{sim} - s^{obs})^2}{\frac{1}{N} \sum_{n=1}^N (Y_n^{sim} - Y_n^{obs})^2} \dots \dots \dots \text{Equation 9}$$

Where Ssim and Sobs are standard deviations of simulated and observed

- Acceptable Values for Us
  - ✓ It should be small as possible

❖ **Convenience proportion between the actual and modeled value (Uc).**

$$U^C = \frac{2(1-\rho)s^{sim}s^{obs}}{\frac{1}{N} \sum_{n=1}^N (Y_n^{sim} - Y_n^{obs})^2} \dots \dots \dots \text{Equation 10}$$

- Acceptable Values for Uc
  - ✓ It should be small Close to 1

- Geoffrey E. Havers (GEH) Quality Measure test for comparison of observed and modeled values.

**Table B - 1 Quality Measure test (GEH For seed number 38)**

GEH Seed Number 38									
Simulated value -A	Actual value-B	Minit of observation-C	D=B-A	E=D <sup>2</sup>	F=A+B	G=F/2	H=E/G	GEH	Criteria
1801	1808	0-15	-7	52	3609	1805	0	0.170	GEH<5, 85% of all flow
1922	1932	15-30	-10	97	3854	1927	0	0.224	
1974	2005	30-45	-31	955	3979	1989	0	0.750	
1846	1856	45-60	-10	106	3702	1851	0	0.239	
7543	7601		-58	3395	15144	7572			

- Root Mean Square Error (RMSE)

**Table B - 2 Root mean square error for seed number 38**

RMSE				
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E=D <sup>2</sup>
1801	1808	0-15	-7	52
1922	1932	15-30	-10	97
1974	2005	30-45	-31	955
1846	1856	45-60	-10	106
			Total	1210
			A	Total E/(4-1) 403.3221
			B	Average A 1885.75
			C	SQRT(A) 20.1
			B/C	RMSE= 0.0101

- Root Mean Square Percent Error (RMSPE)

**Table B - 3 Mean Square Percent Error for seed number 38**

RMSPE					
Simulated value -A	Actual value-B	Number of observation-C	D=A-B	E=D/B	F=E <sup>2</sup>
1801	1808	0-15	7	0.00	0.0000
1922	1932	15-30	10	0.01	0.0000
1974	2005	30-45	31	0.02	0.0002
1846	1856	45-60	10	0.01	0.0000
			A	total	0.00031
			B	n	4
			SQRT(A/B)	SQRT	0.00881

- Mean Error (ME)

**Table B - 4 Mean Error for seed number 38**

ME			
Simulated value -A	Actual value-B	Number of observation-C	D=B-A
1801	1808	0-15	-7
1922	1932	15-30	-10
1974	2005	30-45	-31
1846	1856	45-60	-10
		<b>ME</b>	<b>-15</b>

- Mean Percent Error (MPE)

**Table B - 5 Mean Percent Error for seed number 38**

MPE				
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E= D/B
1801	1808	0-15	7	0.004
1922	1932	15-30	10	0.005
1974	2005	30-45	31	0.015
1846	1856	45-60	10	0.006
			<b>MPE</b>	<b>0.0075</b>

MPE= Average of E

- MAPE

**Table B - 6 Average Percent Error for seed number 38**

MAPE					
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E= B-A	F=E/A
1801	1808	0-15	-7	7	0.0040
1922	1932	15-30	-10	10	0.0051
1974	2005	30-45	-31	31	0.0157
1846	1856	45-60	-10	10	0.0056

**MAPE 0.759%**

MAPE=Average of F

➤ Theil's Inequality Coefficients

**Table B - 7 Theil's Inequality Coefficients for seed number 38**

U							
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E=D <sup>2</sup>	F=B <sup>2</sup>	G=A <sup>2</sup>	Criteria met if [0,1]
1801	1808	0-15	-7	52	3269684	3243601	Pass
1922	1932	15-30	-10	97	3732007	3694084	
1974	2005	30-45	-31	955	4019620	3896676	
1846	1856	45-60	-10	106	3445863	3407716	
				302	3616793	3560519	

U 0.005

**Table B - 8 Inequalities (Bias) proportion**

Um					
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E=D <sup>2</sup>	Criteria met if <0.1
1801	1808	0-15	-7.22685008	52	pass
1922	1932	15-30	-9.84023248	97	
1974	2005	30-45	-30.89896784	955	
1846	1856	45-60	-10.30352288	106	
1885.75	1900			1210	

Um 0.70154

**Table B - 9 Variance proportion**

Us					
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E=D <sup>2</sup>	Criteria met if <0.1
1801	1808	0-15	-7	52	Pass
1922	1932	15-30	-10	97	
1974	2005	30-45	-31	955	
1846	1856	45-60	-10	106	
77.17	86.31			1210	

Us 0.27636

**Table B - 10 Covariance proportion**

Uc					
Simulated value -A	Actual value-B	Number of observation-C	D=B-A	E=D <sup>2</sup>	Criteria met if >0.9
1801	1808	0-15	-7	52	Pass
1922	1932	15-30	-10	97	
1974	2005	30-45	-31	955	
1846	1856	45-60	-10	106	
77.17	86.31			1210	

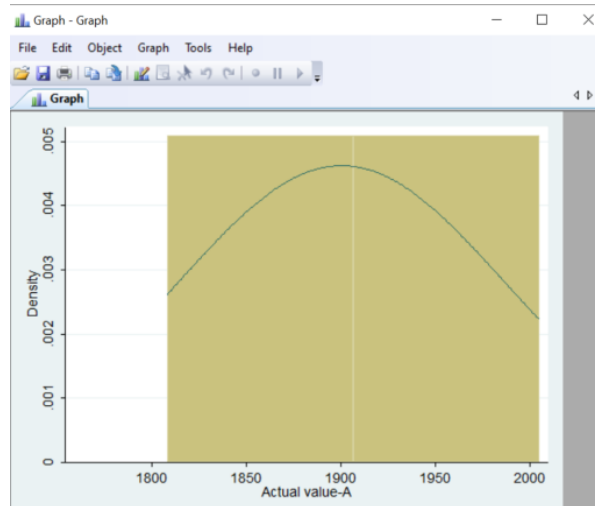
r 0.9993  
Uc 0.0308

## Stata Normality Tests

Normality Test

Actual Value

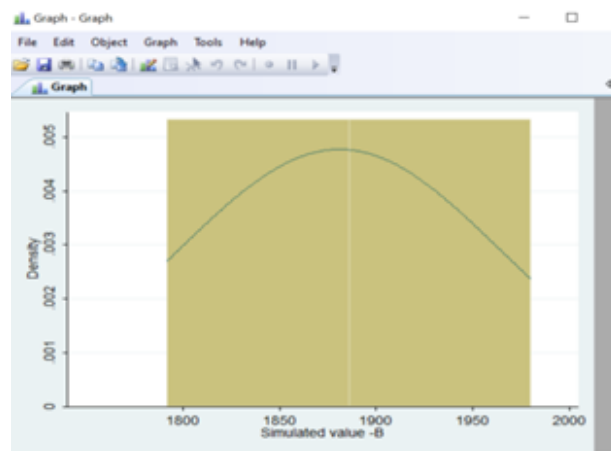
Normality of the actual Value using Stata MP Version 13 using the histogram graph of actual inputted data



**Figure B - 1 Actual Value Normality Test**

Simulated Value

Normality of the value using Stata MP Version 13 the histogram of outputted simulated value



**Figure B - 2 Normality test for Seed Number 38**

## Stata Correlation Value (r - Value)

```

Stata/MP 13.0 - C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\seed 38.dta - [Results]
File Edit Data Graphics Statistics User Window Help
Review
# Command _rc
1 use "C:\Users\pc\D...
2 save "C:\Users\pc\...
3 sktest Timeinterval ...
4 sktest Simulatedval...
5 pwcorr Timeinterva...

. pwcorr Timeinterval ActualvalueA SimulatedvalueB
(Timeinterval ignored because string variable)

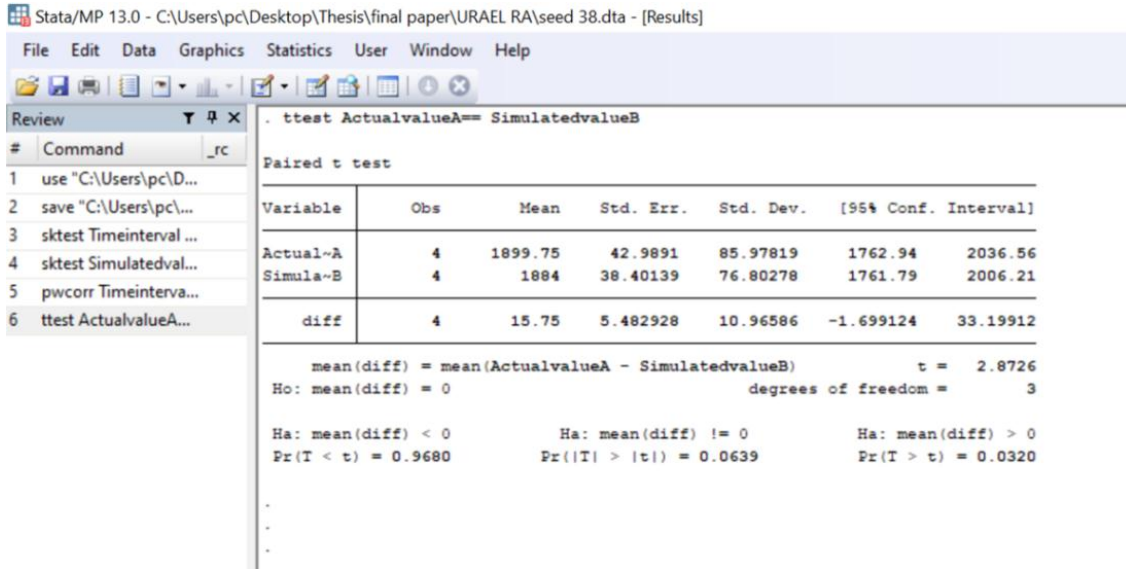
              | Actual~A Simula~B
-----|-----
ActualvalueA | 1.0000
Simulatedv~B | 0.9973 1.0000
    
```

**Figure B - 3 Correlation value for Seed Number 38**

**Table B - 11 Status for r- values**

Seed Number	r value	Status
seed 35	r =0.9984	the is very strong corrilation and posetive Association b/n Actual and simulated Value
seed 38	r =0.9993	ther is very strong corrilation and posetive Association b/n Actual and simulated Value
seed 42	r =0.7699	ther is very strong corrilation and posetive Association b/n Actual and simulated Value
seed 45	r =0.7642	ther is very strong corrilation and posetive Association b/n Actual and simulated Value
seed 48	r =0.7700	ther is very strong corrilation and posetive Association b/n Actual and simulated Value

## Stata Student T-test (P- Value)



**Figure B - 4 P – Value for seed Number 38**

**Table B - 12 Status for P-value**

Seed Number	P value	Status
seed 35	P-Value =0.0201	For P-value < 0.05 Significant
seed 38	P-Value =0.0639	For P-value > 0.05 not Significant
seed 42	P-Value =0.1430	For P-value >0.05 not Significant
seed 45	P-Value =0.1461	For P-value >0.05 not Significant
seed 48	P-Value =0.01567	For P-value >0.05 not Significant

**Appendix C**  
**Vissim Output Evaluation Configurations**

**Table C - 1 Result description and unit**

SN.	Result	Description	Unit
<b>Roundabout Results</b>			
1	Input Vehicles	The actual traffic count on site	Vehicle Number
2	Output Vehicles	the output vehicle (vehicle after simulation)	Vehicle Number
3	Vehicle Delay	Ideal travel time with actual Travel time (reduce speed area considered)	Second
4	Stopped Delay	delay per vehicle	Second
5	Stop	vehicles stop frequency	Stop Frequency
6	Level of Service	Operational condition Quality Measure	LOS A to LOS F
7	Volume- Capacity Ratio	The ratio of input vehicle/output vehicle	-
8	Co Emission	Carbon mono oxide emission	per gram
9	Nox Emission	Nitrogen oxide Emission	per gram
10	Voc Emission	Volatile organic compound emission	per gram
11	Fuel Consumption	amount of fule consumption	per US liquid gallon
12	Queue Length	The distance from the first stop vehicle to the end vehicle	length
13	Queue Stop	Number of stop vehicle	vehicle Number under Queue
<b>Approach Roads Result</b>			
1	Vehicle Delay	Ideal travel time with actual Travel time (reduce speed area considered)	Second
2	Stopped Delay	delay per vehicle	Second
3	Stop	vehicles stop frequency	Stop Frequency
4	Level of Service	Operational condition Quality Measure	LOS A to LOS F
5	Distance	vehicles path length on the simulation network	Meter
6	Travel Time	The travel time taken for the distance	Second
7	Travel Speed	vehicles speed on the network	m/s
8	Queue Length	The distance from the first stop vehicle to the end vehicle	length
9	Queue Stop	Number of stop vehicle	vehicles Number under Queue

## Seed number and parameters

Simulation parameters

General Meso

Comment:

Period: 3600 Simulation seconds

Start time: 00:00:00 [hh:mm:ss]

Start date: [DD.MM.YYYY]

Simulation resolution: 10 Time step(s) / Sim. sec.

Random Seed: 38

Number of runs: 13

Random seed increment: 1

Dynamic assignment volume increment: 0.00 %

Simulation speed:  10.0 Sim. sec. / s  
 Maximum

retrospective synchronization

Break at: 0 Simulation seconds

Number of cores: use all cores

OK Cancel

Figure C - 1 Seed Number 38 Parameters

## Data Collection Result- Result management

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA

Result Management Result Attributes Direct Output

Keep result attributes of previous simulation runs

None  
 of current (multi-)run only  
 of all simulation runs

Automatically add new columns in lists

Automatic list export destination

File  
 Database

Available aggregation percentiles

Count: 0	Value
----------	-------

OK Cancel

Figure C - 2 Result Management configurations

## ✓ Result Attributes

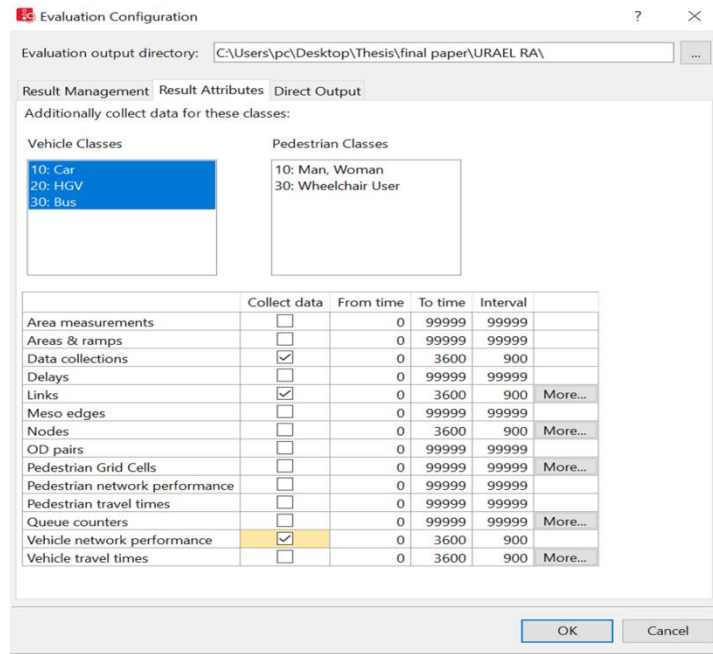


Figure C - 3 Result Attribute for data collection result

## ✓ Direct Output

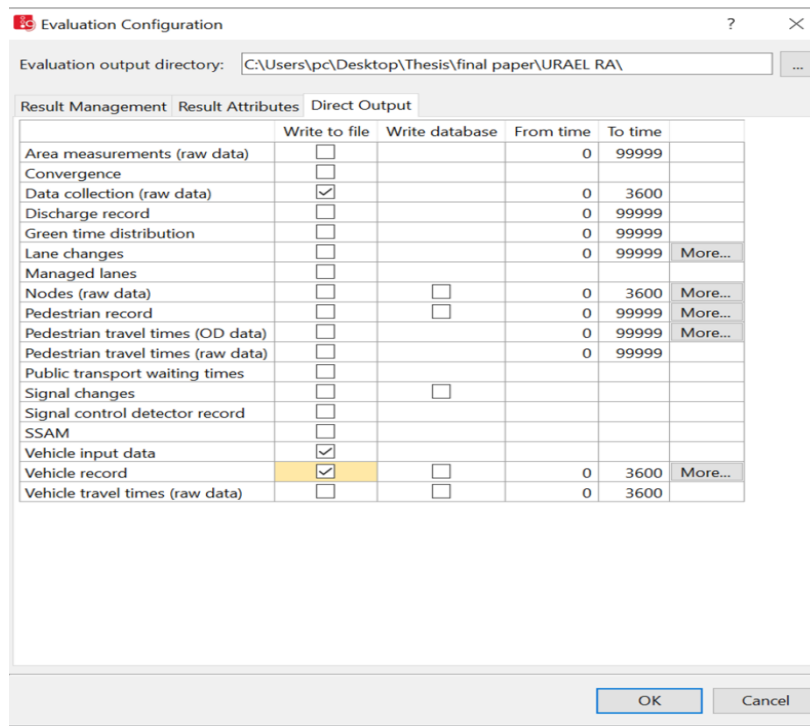


Figure C - 4 Direct Output for data collection result

## Nodes Result

### ✓ Result Attribute

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

Additionally collect data for these classes:

Vehicle Classes

- 10: Car
- 20: HGV
- 30: Bus

Pedestrian Classes

- 10: Man, Woman
- 30: Wheelchair User

	Collect data	From time	To time	Interval	
Area measurements	<input type="checkbox"/>	0	99999	99999	
Areas & ramps	<input type="checkbox"/>	0	99999	99999	
Data collections	<input type="checkbox"/>	0	3600	900	
Delays	<input type="checkbox"/>	0	99999	99999	
Links	<input type="checkbox"/>	0	3600	900	More...
Meso edges	<input type="checkbox"/>	0	99999	99999	
Nodes	<input checked="" type="checkbox"/>	0	3600	900	More...
OD pairs	<input type="checkbox"/>	0	99999	99999	
Pedestrian Grid Cells	<input type="checkbox"/>	0	99999	99999	More...
Pedestrian network performance	<input type="checkbox"/>	0	99999	99999	
Pedestrian travel times	<input type="checkbox"/>	0	99999	99999	
Queue counters	<input type="checkbox"/>	0	99999	99999	More...
Vehicle network performance	<input type="checkbox"/>	0	3600	900	
Vehicle travel times	<input type="checkbox"/>	0	3600	900	More...

OK Cancel

Figure C - 5 Result Attribute for Node result

### ✓ Direct Output

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

	Write to file	Write database	From time	To time	
Area measurements (raw data)	<input type="checkbox"/>		0	99999	
Convergence	<input type="checkbox"/>				
Data collection (raw data)	<input type="checkbox"/>		0	3600	
Discharge record	<input type="checkbox"/>		0	99999	
Green time distribution	<input type="checkbox"/>		0	99999	
Lane changes	<input type="checkbox"/>		0	99999	More...
Managed lanes	<input type="checkbox"/>				
Nodes (raw data)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Pedestrian record	<input type="checkbox"/>	<input type="checkbox"/>	0	99999	More...
Pedestrian travel times (OD data)	<input type="checkbox"/>		0	99999	More...
Pedestrian travel times (raw data)	<input type="checkbox"/>		0	99999	
Public transport waiting times	<input type="checkbox"/>				
Signal changes	<input type="checkbox"/>	<input type="checkbox"/>			
Signal control detector record	<input type="checkbox"/>				
SSAM	<input type="checkbox"/>				
Vehicle input data	<input type="checkbox"/>				
Vehicle record	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Vehicle travel times (raw data)	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	

OK Cancel

Figure C - 6 Direct output for Node result

## ✚ Travel Time Result

### ✓ Result Attribute

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

Additionally collect data for these classes:

Vehicle Classes

- 10: Car
- 20: HGV
- 30: Bus

Pedestrian Classes

- 10: Man, Woman
- 30: Wheelchair User

	Collect data	From time	To time	Interval	
Area measurements	<input type="checkbox"/>	0	99999	99999	
Areas & ramps	<input type="checkbox"/>	0	99999	99999	
Data collections	<input type="checkbox"/>	0	3600	900	
Delays	<input type="checkbox"/>	0	99999	99999	
Links	<input type="checkbox"/>	0	3600	900	More...
Meso edges	<input type="checkbox"/>	0	99999	99999	
Nodes	<input type="checkbox"/>	0	3600	900	More...
OD pairs	<input type="checkbox"/>	0	99999	99999	
Pedestrian Grid Cells	<input type="checkbox"/>	0	99999	99999	More...
Pedestrian network performance	<input type="checkbox"/>	0	99999	99999	
Pedestrian travel times	<input type="checkbox"/>	0	99999	99999	
Queue counters	<input type="checkbox"/>	0	3600	900	More...
Vehicle network performance	<input type="checkbox"/>	0	3600	900	
Vehicle travel times	<input checked="" type="checkbox"/>	0	3600	900	More...

OK Cancel

Figure C - 7 Result Attribute for Travel Time result

### ✓ Direct Output

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

	Write to file	Write database	From time	To time	
Area measurements (raw data)	<input type="checkbox"/>		0	99999	
Convergence	<input type="checkbox"/>				
Data collection (raw data)	<input type="checkbox"/>		0	3600	
Discharge record	<input type="checkbox"/>		0	99999	
Green time distribution	<input type="checkbox"/>		0	99999	
Lane changes	<input type="checkbox"/>		0	99999	More...
Managed lanes	<input type="checkbox"/>				
Nodes (raw data)	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Pedestrian record	<input type="checkbox"/>	<input type="checkbox"/>	0	99999	More...
Pedestrian travel times (OD data)	<input type="checkbox"/>		0	99999	More...
Pedestrian travel times (raw data)	<input type="checkbox"/>		0	99999	
Public transport waiting times	<input type="checkbox"/>				
Signal changes	<input type="checkbox"/>	<input type="checkbox"/>			
Signal control detector record	<input type="checkbox"/>				
SSAM	<input type="checkbox"/>				
Vehicle input data	<input type="checkbox"/>				
Vehicle record	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Vehicle travel times (raw data)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	0	3600	

OK Cancel

Figure C - 8 Direct output for Travel time

## Delay Result

### ✓ Result Attribute)

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

Additionally collect data for these classes:

Vehicle Classes

- 10: Car
- 20: HGV
- 30: Bus

Pedestrian Classes

- 10: Man, Woman
- 30: Wheelchair User

	Collect data	From time	To time	Interval	
Area measurements	<input type="checkbox"/>	0	99999	99999	
Areas & ramps	<input type="checkbox"/>	0	99999	99999	
Data collections	<input type="checkbox"/>	0	3600	900	
Delays	<input checked="" type="checkbox"/>	0	3600	900	
Links	<input type="checkbox"/>	0	3600	900	More...
Meso edges	<input type="checkbox"/>	0	99999	99999	
Nodes	<input type="checkbox"/>	0	3600	900	More...
OD pairs	<input type="checkbox"/>	0	99999	99999	
Pedestrian Grid Cells	<input type="checkbox"/>	0	99999	99999	More...
Pedestrian network performance	<input type="checkbox"/>	0	99999	99999	
Pedestrian travel times	<input type="checkbox"/>	0	99999	99999	
Queue counters	<input checked="" type="checkbox"/>	0	3600	900	More...
Vehicle network performance	<input type="checkbox"/>	0	3600	900	
Vehicle travel times	<input type="checkbox"/>	0	3600	900	More...

OK Cancel

Figure C - 9 Direct Results Attribute for Delay

### ✓ Direct Output

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

	Write to file	Write database	From time	To time	
Area measurements (raw data)	<input type="checkbox"/>		0	99999	
Convergence	<input type="checkbox"/>				
Data collection (raw data)	<input checked="" type="checkbox"/>		0	3600	
Discharge record	<input type="checkbox"/>		0	99999	
Green time distribution	<input type="checkbox"/>		0	99999	
Lane changes	<input type="checkbox"/>		0	99999	More...
Managed lanes	<input type="checkbox"/>				
Nodes (raw data)	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Pedestrian record	<input type="checkbox"/>	<input type="checkbox"/>	0	99999	More...
Pedestrian travel times (OD data)	<input type="checkbox"/>		0	99999	More...
Pedestrian travel times (raw data)	<input type="checkbox"/>		0	99999	
Public transport waiting times	<input type="checkbox"/>				
Signal changes	<input type="checkbox"/>	<input type="checkbox"/>			
Signal control detector record	<input type="checkbox"/>				
SSAM	<input type="checkbox"/>				
Vehicle input data	<input type="checkbox"/>				
Vehicle record	<input checked="" type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Vehicle travel times (raw data)	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	

OK Cancel

Figure C - 10 Direct output for Delay

## Queue Counter Result

### ✓ Result Attribute

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

Additionally collect data for these classes:

Vehicle Classes

- 10: Car
- 20: HGV
- 30: Bus

Pedestrian Classes

- 10: Man, Woman
- 30: Wheelchair User

	Collect data	From time	To time	Interval	
Area measurements	<input type="checkbox"/>	0	99999	99999	
Areas & ramps	<input type="checkbox"/>	0	99999	99999	
Data collections	<input type="checkbox"/>	0	3600	900	
Delays	<input type="checkbox"/>	0	3600	900	
Links	<input type="checkbox"/>	0	3600	900	More...
Meso edges	<input type="checkbox"/>	0	99999	99999	
Nodes	<input type="checkbox"/>	0	3600	900	More...
OD pairs	<input type="checkbox"/>	0	99999	99999	
Pedestrian Grid Cells	<input type="checkbox"/>	0	99999	99999	More...
Pedestrian network performance	<input type="checkbox"/>	0	99999	99999	
Pedestrian travel times	<input type="checkbox"/>	0	99999	99999	
Queue counters	<input checked="" type="checkbox"/>	0	3600	900	More...
Vehicle network performance	<input type="checkbox"/>	0	3600	900	
Vehicle travel times	<input type="checkbox"/>	0	3600	900	More...

OK Cancel

Figure C - 11 Results Attribute for Queue Counter

### ✓ Direct Output

Evaluation Configuration

Evaluation output directory: C:\Users\pc\Desktop\Thesis\final paper\URAEI RA\

Result Management Result Attributes Direct Output

	Write to file	Write database	From time	To time	
Area measurements (raw data)	<input type="checkbox"/>		0	99999	
Convergence	<input type="checkbox"/>				
Data collection (raw data)	<input checked="" type="checkbox"/>		0	3600	
Discharge record	<input type="checkbox"/>		0	99999	
Green time distribution	<input type="checkbox"/>		0	99999	
Lane changes	<input type="checkbox"/>		0	99999	More...
Managed lanes	<input type="checkbox"/>				
Nodes (raw data)	<input type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Pedestrian record	<input type="checkbox"/>	<input type="checkbox"/>	0	99999	More...
Pedestrian travel times (OD data)	<input type="checkbox"/>		0	99999	More...
Pedestrian travel times (raw data)	<input type="checkbox"/>		0	99999	
Public transport waiting times	<input type="checkbox"/>				
Signal changes	<input type="checkbox"/>	<input type="checkbox"/>			
Signal control detector record	<input type="checkbox"/>				
SSAM	<input type="checkbox"/>				
Vehicle input data	<input type="checkbox"/>				
Vehicle record	<input checked="" type="checkbox"/>	<input type="checkbox"/>	0	3600	More...
Vehicle travel times (raw data)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	0	3600	

OK Cancel

Figure C - 12 Direct Results Attribute for Queue Counter