Jimma University

Jimma Institute of Technology

School of Post Graduate Studies

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Evaluation of the Effectiveness of Road Underpass on the Traffic Flow: A Case Study at Wellosefer Intersection in Addis Ababa City

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Highway Engineering)

By:

Sentayehu Leleisa

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Main advisor: Prof. Emer Tucay Quezon

Co-advisor: Engr. Teyba Wedajo, (PhD Candidate)

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Declaration

I, the undersigned, declare that this thesis entitled: "Evaluation of the Effectiveness of Road Underpass on the Traffic Flow: A Case Study at Wellosefer Intersection in Addis Ababa City." is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for theses have been duly acknowledged.

Candidate:

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As Master's Research Advisors, we hereby certify that we have read and evaluated this MSc Thesis prepared under our guidance, by **Sentayehu Leleisa** entitled: "Evaluation of the Effectiveness of Road Underpass on the Traffic Flow: A Case Study at Wellosefer Intersection in Addis Ababa City."

We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

Prof. Emer T. Quezon	_____________	23/11/2017
Advisor	Signature	Date
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Co- Advisor	Signature	Date

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ABSTRACT

Urban cities introduced several remedies to decongest traffic and to reduce the severity of accidents, such as providing traffic signals at the intersecting roads at different levels, or grade separating the traffic movement towards different directions. One type of grade separation is Road Underpass. Construction of Road Underpass poses some doubts whether it is effective or not effective on the point of views of the addis ababa traffic management bure. It is for this reason that this study sought to evaluate the effectiveness of Road Underpass structure on traffic flow at the major intersection in the case of Wellosefer intersection in Addis Ababa. The data needed in this study are primary and secondary data. The primary data are the existing traffic volume recorded between 7:00 AM – 6:00 PM from Monday to Friday. While the secondary data obtained from the Consulting Office of the Project "before" the improvement of Wellosefer intersection and the previous study. From these data, the analysis provided results on vehicle travel time and delay for a case "before" and "after" improvement of a Road Underpass structure to serve as the measure for evaluation. The analysis was supplemented by SIDRA Software. Based on the findings of the study, a case "Before" Improvement of Wellosefer Un-Signalized T-Intersection indicated with an average delay of vehicles of about 535.7 seconds, while the travel time of vehicles of about 574.7 seconds. On the other hand, a case "After" Improvement of Wellosefer intersection considering Signalized T-Intersection, Roundabout only, and Road Underpass with Roundabout at the upper level, the Signalized T-intersection showed an average delay and travel time of 344.3 seconds and 365.0 seconds, respectively. From this result, there was a 15.4% reduction in average delay when signalized intersection had been implemented . Likewise, for Road Underpass with Roundabout at the upper level, the results revealed that there was a significant reduction in average delay of vehicles of about 42 % from Un-Signalized T-Intersection. Comparing this result with the Signalized intersection using the same traffic data, it indicated that there was a significant decrease in average delay. Extending the analysis for the case of Roundabout only considering the same traffic data at present condition. The results showed motorists and commuters could be experiencing an average delay of about 355.8 seconds and avergae travel time of 390.0 seconds. Therefore, the results of these findings of the study by comparing the different intersection design alternatives, a combination of Road Underpass and Roundabout at the upper level as in the case of Wellosefer intersection, is the most effective alternative. In addition, the results clarified some doubts of whether effective or not effective. However, to eliminate future traffic malady at the major intersections in Addis Ababa, a long-term solution is recommended such as construction of Road Underpass structure or flyover structure with Roundabout or Traffic signal lights at ground level, but subject to some constraints which requires proper integration of other factors affecting traffic flow within the entire road network.

Keywords: Design alternatives, "Before" and "After" Improvement, Road underpass, Travel Time & Delay, Traffic Volume, Traffic Conflict, Traffic congestion.

Table of Contents

List of tables

List of Figures

List of Acronyms

AACRA	Addis Ababa City Road Authority
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AATMA	Addis Ababa Traffic Management Agency
ECMT	European Conference of Ministers of Transport
ERA	Ethiopia Road Authority
FHWA	Federal Highway Administration
GDP	Gross Domestic Product
HCM	Highway Capacity Manual
LT	Left Turn
LOS	Level of Service
MUTCD	Manual of Uniform Traffic Control Design
PCE	Passenger Car Equivalent
PCU	Passenger Car Unit
RT	Right Turn
RV	Recreational Vehicles
SIDRA	Signalized and Un -Signalized Intersection Design and Research Aid
TH	Through Movement
WSDOT	Washington State Department of Transportation

CHAPTER ONE

INTRODUCTION

1.1 Background

In general, a capacity of the entire road network is dominated by capacity at intersections. Thus, there is a possibility to enhance the performance of the whole network in the urban area, if a capacity of a serious bottleneck of an intersection can be increased. Therefore, an implementation of an over/underpass for an intersection has been one of the most desirable measures to alleviate traffic congestion. However, because of the requirements of huge construction costs and wide spaces, this measure becomes impractical. To overcome these obstacles, the exclusive or simple over/underpass road is proposed with less construction cost and minimum environmental degradation. Although, the resource consumptions of this new facility are not as much of the ordinary over/underpass, there is still a question on its effectiveness in improving congestion condition. This point should be evaluated in this study. Because most existing evaluation approaches to evaluate a capacity of an intersection seems inapplicable to the situation under oversaturated flow and a wide range of heavy vehicle mixing rate, the study also needs to develop a specific evaluation methodology for this particular facility. Eventually, it intends to investigate the feasibility to implement the exclusive over/underpass for smaller vehicles as a countermeasure for alleviating traffic congestion at a saturated intersection (Toshiaki Muroi, 2005).

Safety, pollution and traffic congestion are in numerous cases interrelated. For example, long queues at signals cause pollution, and unexpected upcoming congestion can decrease the safety level due to potential head-tail collisions. This research focuses exclusively on the reduction of traffic congestion. However, an optimization towards traffic congestion reduction is likely to positively influence both safety and pollution-related challenges. Congestion can be measured in the average delay experienced per vehicle. On the other hand, to be able to measure the delay, individual vehicle tracking is needed. Since the available data does not support this method, this research focuses on maximizing the throughput at intersections. Assuming a demand larger than the supply, an increase of vehicle throughput at the intersection causes a decrease in (local) congestion.

The ability to accommodate high volumes of traffic safely and efficiently through intersections is mainly based on the arrangement that provided for handling intersecting traffic. The greatest efficiency, safety, and capacity attained when the crossing through traffic lanes are grade separated, which is constructed in the form of the overpass (flyover) or underpass structure. An interchange is a system of interconnecting roadways in conjunction with one or more grade separations that provide for the movement of traffic between two or more roadways or highways on different levels (Toshiaki Muroi, 2005).

Delay of vehicles at major Un-signalized intersections on urban roads around the cities worldwide is reached at an intolerable level, which significantly affects the movement of vehicles during peak hour (J.W.Zwarteveen, 2011). Most often the congested junction is selected for grade separation in isolation or combination with adjacent signalized intersections.

One type of grade separation is the underpass, of which this research study would be proposed to evaluate its effectiveness. The decision to opt for road overpass for particular intersection or with adjacent intersections is considered, based on the financial constraints, In Addis Ababa City, the effect of a road under/overpass on the traffic flow along the trunk roads do not often analyze in details. As a consequence, after the completion of the road under/overpass structure, congestion issue would have shifted to another location or the treatment would not have yielded the anticipated results.

In Addis Ababa city, nowadays congestion is increasing day today because of many cases likely rising in the number of a vehicle, less improvement of old roads and due to the types of vehicles which are contributing conflict along the road most of the time such as long and old vehicles. All major intersections in Addis Ababa were initially observed to pick one intersection which represents the study. Based on observation and data from AACRA, Wellosefer was the most problematic intersection “before” improvement of underpass due to high traffic volume of vehicles passing through it.

This study presented the analysis based on the data gathered such as field survey for traffic volume data. It will help the researcher to know the effect of road underpass on the traffic flow by considering the case "before" and "after" the structure was constructed at

Wellosefer intersection. This approach of the analysis would show how much travel time and delay will be reduced as a consequence of traffic congestion in the study area.

1.2 Statement of the Problem

Increasing individual ownership of vehicles in the metropolis is a major concern around the world. Traffic congestion poses a significant threat to the production of output and affects the economic activities.

The issue or problem is due to the reduction of travel time from one point to the other places or from their home to their workplaces. Some countries utilized different traffic controls in the intersections trying to decongest and to alleviate road crashes due to conflicting traffic flows. Traffic signal control under oversaturated condition was a long-lasting challenge, but the traffic malady persists. To address the problem, a grade separation structure introduced at the intersection.

Addis Ababa City is known in Ethiopia, which performs the fastest growing city due to its surprising initiatives for reconstruction and improvement of the road network towards north to south, and east-west to west directions. These improvements comprise widening of road segments, improvement of major intersections either by constructiong roundabout, provision of traffic signal control, and construction of road under/overpass structure. But the challenges still undoubtedly remain; commuters and motorists are experiencing the effect of traffic congestion during peak hour, specifically at major intersections. The roundabout intersection controls traffic movement, while the road under/overpass structure separates the traffic flow of incoming vehicles at the intersection. However, there are still ambiguities, how the road underpass works effectively or not, once an improvement had been implemented. To do this, it is important to evaluate its effectiveness in meeting its objectives as delivering the promised benefits.

Therefore, in order to fill the gap, the study conducted in this thematic area of research concerning a combination of road underpass construction with roundabout at the upper level relating with the traffic behavior at Wellosefer intersection.

1.3 Research Questions

1. What are the types of vehicles, mostly contributing the conflict of the traffic flow within the intersection before improvement?
2. How much travel time and delay incurred by the motorists for the case "before" and "after" improvement of Wellosefer intersection?
3. What are the occurring problems at-already completed road underpass structure? And, what are the suggested countermeasures on how to alleviate the problem?

1.4 Objectives of the Research Study

1.4.1 General Objective

The general objective of this research study is to evaluate the effectiveness of road underpass structure on traffic flow in order to clarify some doubts of the motorists and commuters.

1.4.2 Specific Objectives

The specific objectives of this study are:

- To identify the types of vehicles contributory to conflicting traffic flow at the intersection
- To analyze the travel time and delay as a measure of performance evaluation.
- To clarify the occurring problems at-already completed road underpass structure and to suggest countermeasures on how to alleviate the problem.

1.5 Significance of the Study

This study will help the agency to understand the effectiveness of the components of its program and to come up with a better design of new programs in the future.

The results of the study may provide additional helpful information to various stakeholders on the effect of a road under/overpass structure of the traffic flow. The City Administration of Addis Ababa would be benefitted from the study as a source of information and factual basis for the other projects to be constructed at the major intersections that may ease the traffic malady.

The rationale for conducting this study provided as the benchmarks under which the improvement of the intersection is very essential. Preliminary field observations on the traffic movement showed that there was a severe traffic problem in the Addis Ababa city around major intersections.

The study of a "before" and “after” case of a road underpass structure will prove situations that the planners would help to decide for a new design or to redesign the subject area based on the current traffic problems.
Also, it may serve as a lesson learned for the concerned body to adequately consider interrelated factors with appropriate measures to address the traffic problems which may be based on the results of this research study.

Lastly, the other researchers who are interested in similar studies may be found useful to them about the findings and to be used as a reference material.

1.6 Scope of the Study

The scope of the study limited to evaluate the effectiveness of the road underpass structure on travel time and delay at Wellosefer major intersection. And, in this study the types of vehicle which are contributory to the traffic flow, travel time and delay incurred by the motorist for the un-signalized, signalized, roundabout only and underpass with roundabout at the top level are analyzed. While, it may appear that the number of sampled intersection is not sufficient to give an overview of the effectiveness of the road overpass on the traffic flow, but because of the broadness of the study, in which only one intersection was selected.

1.7 Organization of the research

This report is organized into five chapters. Chapter one at the beginning of the paper gave a clue of the volume capacity of an intersection and congestion. It also described delay and cause of congestion at the intersections. The chapter also included the statement of the problem, objectives and research questions, the scope of the study, significance, and limitations of the study.

The second chapter discussed the review of related literature. The discussion of this chapter mainly focused on the overview of the effect of a road under/overpass structure of the traffic flow, General characteristics of vehicle contribute conflict on the traffic flow**,** concepts of delay and travel time at the intersection and occurring problem in current intersection condition. The analysis resorted different research methodologies utilized from various countries and selecting the most appropriate approach to delay and travel time computation.

The third chapter of this study discussed the methodology of the study. It included the study area, sampling methods and population, data collection, and analysis used in the study. Additionally, it contained variables of the study to relate from specific objectives.

Chapter four comprised the results and discussion of the collected data as analyzed and interpreted in details. In this chapter presented the analysis of delay and travel time for the study area and sample population. It included the comparison of delay and travel time "before" and "after" improvement of Wellosefer intersection.

The last part is Chapter five' It covered the conclusion and recommendation of the study. It embraced the results of the study, interpreted orderly and discussed the effectiveness of road underpass structure of the traffic flow. In addition, it contained the proposed countermeasures to minimize traffic congestion at different major intersections.

1.8 Limitation and challenge of the study

The analysis of this study is limited of the analyses of travel time and average delay not considering other parameters which describe the performance of the intersection.

During the preparation of this document the main problem faced was the lack of well-organized data and there was no data related to road underpass. Only the available data were the recent AutoCAD road network drawings, due to the recent establishment of different transportation and road related agencies such as AACRA and AATMA.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 A Theoretical Review

Grade separation intersection is a bridge that eliminates crossing conflicts and congestion at intersections by vertical separation of roadways in space. Grade separated intersection is otherwise known as Interchanges (AASHTO, 2001). Grade-separated crossings cause less hazard and delay than grade intersections. Route transfer at grade separations is accommodated by interchange facilities consisting of ramps. Interchange ramps are classified as Direct, Semi-Direct and Indirect. Interchanges are described by the patterns of the various turning roadways or ramps. The interchange configurations are designed in such a way to accommodate the traffic requirements of the flow economically, an operation of the crossing facilities, physical requirements of the topography, adjoining land use, type of controls, right-of-way and direction of movements (Crawford, 2011).

To consider the effectiveness of a two-level crossing, it can consider two points. The first concerns about the impact on total travel time for all vehicles passing through the intersection that established a general over/underpass for vehicles. The second focuses on evaluating traffic conditions of an at-grade intersection before and after the

2.1.1. Urban traffic flow in developing countries

Developing countries are characterized by a high travel demand, chaotic traffic behavior and a low supply of networks and means. Although fewer legal restraints exist for the use of new technologies, the transport sector as a whole is not likely to be innovative: capital is scarce, and the number of involved stakeholders is limited. The lack of adequate and accessible transportation options causes a high share of non-motorized transport. This stressed mobility situation in developing countries results in premature congestion, a deteriorating environment and a high incident rate (G.William, april 2003). It has to be noted that these characteristics concern the average of the whole group of developing countries. Individual exceptions of countries that have different mobility characteristics exist.

2.1.2. Mobility characteristics in Addis Ababa city

The mobility problems in Addis Ababa are emergent, since the recent state of road traffic management is considerably poor.It can be seen that Addis Ababa has a relatively high population density and a high urban population growth; both facts combined with a low GDP per capita put high stresses on the quality of mobility services. This stress is reflected by the very low supply of infrastructure: the current road density measured in kilometer of road per 1000 habitants in Addis Ababa is significantly lower than the average of developing countries; moreover, it is only one third of the average African. The public transport plays a dominant role in urban mobility in Ethiopia. In general, for every additional 1000 people in developing world cities, an increase of 350-400 public transport trips will be realized per day. Similarly, for every square kilometer of urban growth, an increase of 500 public transport, trips will be realized per day, it can be concluded that the current supply of infrastructure is significantly below average and the demand is significantly increasing. An extension of infrastructure is necessary; however, the basic state of the economic development and the institutional challenges will make a development of infrastructure a complex and long-term solution. To be able to maximize the use of the current infrastructure on the short term, the poor road traffic management has to be improved (J.W.Zwarteveen, 2011).

2.1.3. Mobility improvement, economic growth, and sustainable development

The effect of congestion reduction in the economy has different short term and long term effects. In the short term, improved travel times will reduce the costs of traveling. Therefore, the number of consumers that can purchase the service of transportation for the price that is less or equal to the amount they would be willing to pay increases. Not only the number of trips will increase, but also the length of trips is likely to increase when traveling time decreases. Historical research by Schafer and Victor, 1999 and Filarski, 2004 indicate that travelers have a constant travel time budget. This means that when the speed of travel increases, the traveler will increase its travel distance to reach its original travel time budget. On the long-term, traffic congestion is likely to occur when the demand reaches the supply. The economic difference, however, is the realized value by the increased number of trips. Therefore, reducing the congestion is economically justifiable, both on the long term and on the short term.

Economic growth in developing countries is an important subject. However, economic growth has both positive and negative effects. Therefore, the economic development has to be evaluated from a global sustainable development point of view. Many argue that global economic growth is unsustainable its according to meadows, 1972, during 1992.

However, economic growth has significant benefits concerning the quality of life, an essential aspect of social sustainability. Considerable benefits are occurring in premature economic development. Congestion prevention to cause economic growth has considerable benefits from a sustainable development point of view.

2.2. General characteristics of vehicle contribute conflict on the traffic flow

Vehicle types in traffic flow are one of the most important factors which affect intersection performance. The effect of different types of vehicles in the flow can be reflected by using the passenger car equivalence (PCE) values. Heavy vehicles affect the traffic flow at an intersection in two critical ways:

i. Heavy vehicles occupy large road surfaces (gaps) at a road cross section due to their sizes, and also their durations of using an intersection are very long.

ii. Heavy vehicles are behind passenger cars especially in acceleration, deceleration, and maintaining their high velocities

The heavy vehicles in the minor and major flows affect intersection performance differently. The heavy vehicles in the major flow obstruct the entrance of the minor flow for a longer period, thereby increasing the amount of queuing in the minor flow. On the other hand, those heavy vehicles which will enter the major flow of the minor flow form long queues in the minor flow than passenger cars due to their low mobility (Roger P.Roses, 2004). Giving rise to gap, forcing or reverse priority conditions, this causes those vehicles which will enter the intersection from the minor flow to block the major flow by accepting very small gaps and leads to the decreasing of the intersection capacity. In the literature, heavy vehicles are used in two categories:

i. Trucks and buses

ii. Vehicles like RVs.

Trucks and buses mostly have similar characteristics and are evaluated in the same category in capacity analyses. The composition of traffic flow is one of the most important factors which affect operations at intersections. The effect of different vehicle types in a flow may be reflected by using the passenger car equivalence (PCE) values.

Characteristic of a vehicle is one of the major factors which contribute to the Conflicts occurred when traffic streams were moving in different directions interfere with each other. Most of the times long truck and old vehicles are causing conflicts at the intersection. The three types of conflicts are merging, diverging, and crossing. Figure 2.1 shows the different conflict points that exist at a three-approach un-signalized intersection. There are 9 conflict points but when it changed to roundabout the conflict point reduced to 6. The numbers of possible conflict points at any intersection depend on the number of approaches, the turning movements, and the type of traffic control at the intersection.

The primary objective in the design of a traffic control system at an intersection is to reduce the number of significant conflict points. In designing such a system, it is first necessary to undertake an analysis of the turning movements at the intersection, which will indicate the significant types of conflicts. Factors that influence the significance of a conflict include the type of conflict, the number and type of vehicles in each of the conflicting streams, and the speeds of the vehicles in these streams. Crossing conflicts, however, tend to have the most severe effect on traffic flow and should be reduced to a minimum whenever possible.

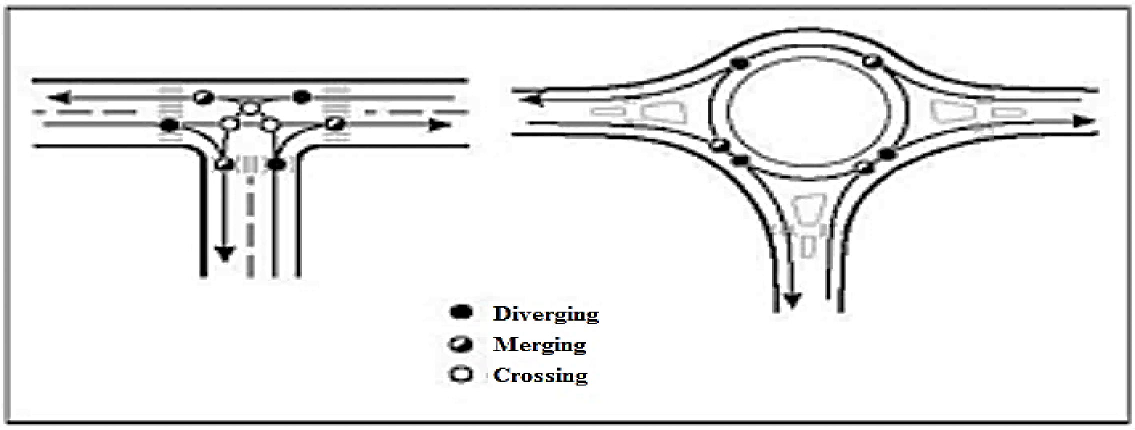


Figure 2.1: Conflict points at 3- legged with and without roundabout Un-Signalized Intersections (Source: HCM 2000)

2.3. Performance of the Traffic Flow (Travel Time and Delay)

A parameter to describe the traffic performance at intersections is the saturation flow during the green phase. The saturation flow expresses how much traffic the infrastructure can process. It is an indication of the maximum flow of a junction during this green phase when operating under ideal conditions (J.W.Zwarteveen, 2011). Therefore, it is an important performance indicator. However, no unique definition or calculation method for the saturation flow exists. The flow of traffic can be expressed in vehicles per hour or Passenger Car Unit per hour (PCU/h or PCE/h). Similar to saturation flow, different definitions and calculation methods concerning the PCU exist. Numerous studies have described the saturation flow at intersections in developing countries.

The usual way of solving operational problems involving traffic flow at the intersections is to ensure that the average capacity can handle the average flow so that persistent traffic jams do not occur. However, because flow fluctuates, guaranteeing that highway capacity can handle the traffic demand on the average does not preclude the formation of bottlenecks. The quality of traffic flow i. e. Level of service (LOS) at an intersection is usually represented by control delay. It is the average delay of a vehicle caused by the type of intersection control type (stop sign, traffic signal) consisting of queue delay and geometric delay.

Table 2-1: Levels of level of Service Criteria for Intersections

Level of Service	Signalized Intersection	Un-Signalized Intersections
	Average control delay (sec/hr)	
A	≤ 10	0 – 10
B	> 10 – 20	> 10 – 15
C	>20 – 35	> 15 – 25
D	>35 – 55	> 25 – 35
E	>55 – 80	> 35 – 50
F	> 80	> 50

(Source: Highway Capacity Manual, 2000)

The geometric delay is caused by decelerating, accelerating and merging the intersection. Some parts of the geometric delay are already included in the queue delay. The average queue delay is a function of flow intensity in major and minor stream *qp*and *qm*, proportion of free flow vehicles and the distribution of platoon size length in the minor and major streams. The queuing theory deals with these problems so that the delay estimations are based on the distributions of arrivals and service times. All models which use gap acceptance theory are based on the queuing theory.

2.3.1. Application of Travel Time and Delay Data

The data obtained from the travel time and delay analysis is used in any one of the following traffic engineering tasks

- Determination of the efficiency of the route concerning its ability to carry traffic.
- Identification of locations with high delay and cause of those delays.
- Performance of before and after studies to evaluate the effectiveness of traffic operation improvements.
- Determination of the relative efficiency of a route by developing sufficiency ratings or congestion indices.
- Determination of travel time on specific links for use in trip assignment models.
- Performance of economic studies in the evaluation of traffic operation alternatives that reduce travel time.

2.3.2. SIDRA intersection software

SIDRA intersection is a computer software package that models traffic intersection, including light vehicles, heavy vehicles, and pedestrian. The purpose of the software is to model various scenarios for both existing and future intersections to determine their performance under a range of conditions.The software allows many parameters to be inputted which make allowances for the varying conditions, including geometrical, vehicular and human characteristics applicable for each intersection.

Sidra Intersection is a micro-analytical traffic evaluation tool that employs lane-by-lane and vehicle drive cycle models. It can be used to compare alternative treatments of individual intersections and networks of intersections involving signalized intersections(fixed time/ pretimed and actuated), roundabouts (un-signalized), roundabouts with metering signals, fully signalized roundabouts, two-way stop and give-way (yield) sign control, all-way (4-way and 3-way) stop sign control, merging, single-point urban interchanges, traditional diamond and diverging diamond interchanges, basic freeway segments, signalized and un-signalized midblock crossings for pedestrians, and merging analysis.

2.4. Comparison of Different Traffic Flow Control System

2.4.1. Common Types of Intersection Control

An old type intersection control is officer control. In developed countries, this approach is hardly applied. However, in developing countries, where wages are low, officer control is very common. As a result of its unique character, officer control will be considered as a separate control strategy. Not all types of control apply to all traffic modes. Under saturated traffic flow can be controlled in many ways, while oversaturated flow is hard to control (Roger P.Roses, 2004).

Officer control can be considered as single intersection traffic responsive control. Intersection control by traffic officers has numerous advantages compared to signal control.

- Officer control can deal with variations in the volume of traffic
- Officer control can give each street the right proportion of time needed at that exact moment
- Officer control can give a special treatment of specific vehicles
- Officer control can aid turning traffic to weave it through the traffic from the opposite direction without entirely stopping either line
- Officer control can deal with an unusual condition or emergency

However, the advantages of officer control will decrease at the more complicated intersections as the number, volume, and regularity of different kinds of movements increase. The disadvantages of officer control are:

- No coordination or communication with other intersections possible
- Disobedience of traffic due to bad visibility of officer
- Distraction of officers as a result of answering questions, social chatting or law enforcement
- Leaving of officers in case of emergency
- Learning time of an officer how to control efficiently
- Personal differences between officers
- High costs of officer control

2.4.1.1 Fixed-time control

Fixed-time control for an isolated intersection is the most basic non-human type of control. Each of the involved lanes receives the right-of-way for a fixed-time. No sensors are needed. Based on different optimization methods, the length of the right-of-way periods is set to minimize the delay at each approach. A maximum cycle and a minimum-green constraint are taken into account. Different phases of the day can have different fixed-time strategies. By optimizing the fixed-time settings of multiple intersections and taking travel times in between the junctions into account, green waves can be created. During green waves, a vehicle will not encounter a red signal. This type of control can only be applied to under-saturated conditions (Hon, 2005)

2.4.1.2. Traffic Responsive Control (Traffic Signal)

Traffic-responsive strategies make use of real-time measurements provided by inductive loop detectors. Most of the responsive control strategies for a single intersection function according to the same basic principle. Minimum green phases are assigned to each approach. These minimum green phases can be extended as a result of a higher traffic demand. The green phases are limited by the maximum-green value. At the end of the green phase, either caused by a decreased traffic demand or by the maximum-green value, the right-of-way will change. In case of oversaturated conditions of all streams of an intersection, the length of the green-phases equals the maximum-green value. Traffic responsive control can also be applied to networks. A central system will measure the demand and supply in the network and will calculate the optimal lengths of green phases.

The conclusion was that only in specific cases the application of a more advanced responsive system would result in a better traffic performance. Properly designed, located, operated, and maintained traffic control signals might offer the following:

- Allow for the orderly movement of traffic.
- Increase the traffic-handling capacity of the intersection.
- Reduce the frequency of severe crashes, especially right-angle crashes.
- Can be coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given corridor under favorable conditions.
- Can be used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross.
- Can be preempted to allow emergency vehicle passage.

Traffic control signals are not the solution for all intersection traffic concerns. Indiscriminate installation of signals can adversely affect the safety and efficiency of a vehicle, bicycle, and pedestrian traffic.

As a result, installation of a traffic control signal is to meet specific “warrants,” which are found in the MUTCD. A signal warrant is a minimum condition in which a signal may be installed. Satisfying a signal warrant does not mandate the installation of a traffic signal; it only indicates that an engineering study, as described in this chapter, is needed to determine whether the signal is an appropriate traffic control solution.

Some crashes are usually not correctable with the installation of a traffic signal; in fact, the installation of a signal often increases rear-end crashes. These types of crashes are only used to satisfy the crash warrant in special circumstances. If they are used, including an explanation of the conditions that supports using them to satisfy the crash experience warrant (MUTCD ,2003).

2.4.1.3. Roundabout

Roundabouts are nearly circular at grade traffic control system, but can be a variety of shapes and sizes. Properly designed, located, and maintained roundabouts are an effective intersection type that normally offer the following:

- Fewer conflict points.
- Lower speeds.
- An alternative for areas where wrong-way driving is a concern.
- Reduced fatal- and severe-injury crashes.
- Reduced traffic delays.
- Traffic-calming.
- More capacity than a two-way or multi-way stop.
- More consistent delay relative to another intersection treatments.
- The ability to serve high turning volumes.
- Improved operations where space for queuing is limited.
- At ramp terminals where left-turn volumes are high, improved capacity without widening the structure.
- Facilitation of U-turn movements.

Roundabouts are site-specific solutions. There are no warranting conditions; each is justified on its own merits as the most appropriate choice (MUTCD,2003).

2.4.1.4. Road Over/underpass Structure the Traffic Flow

Minimizing the delay and conflict at an intersection is a major aim of the grade separating structure of the highway. Obviously the cost for the construction of the grade separating structure is higher than the remain alternatives like a traffic light, roundabout and the officer controlled traffic control system but as the result of different research indicates the grades separating of the traffic movement highly reduce the traffic problem(MUTCD ,2010).

The construction of a road overpass structure has a lot of benefit to the traffic flow management, mostly at the intersection. Some of the benefits are the:

- Reduce conflict at intersection
- Avoiding congestion delay
- Reducing risk traffic movements at X and T intersection

- Overcomes the costly requirement of running at-grade traffic control hardware
- Minimize emergency response time implementation.

2.5. Traffic Management Measures to Minimize Congestion at existing Road

There are different problems related to traffic congestion on the existing road of Addis Ababa city such as too narrow width, road side parking, unavailability of alternative roads, roadside parking, and road expansion work, operators not using the available alternative roads, poor road condition, unavailability of a traffic sign, unavailability of sufficient pedestrian walkways, entering and exiting of heavy trucks in the area, too narrow road and too many vehicles at a time. All of these are the cause of traffic congestions in Addis Ababa city (Addis Ababa Transport Bureau, 2014). In addition to this, according to (Hagere Yilma, 2014), the cause of congestion are presented as follows, depending on the percentage of the respondents from the questioner among various causes of traffic congestion in the city, 89% of the respondents indicated that concentration of work trip in time and 83% of the respondents put unplanned stoppage and parking of cars on the road side as major causes of traffic congestion in Addis. Correspondingly, more than 50% of the respondents have put shortage on infrastructure supply, too narrow roads, reduction of road space due to road construction and maintenance, street trading, traffic rule violation, population and economic growth as major contributors to the occurrence of traffic congestion.

(Yilma, June 2014)For road transport tactical traffic management involves monitoring the actual traffic situation in real time, including volumes, speeds, incidents, etc. And then controlling or influencing the flow using that information in order to reduce congestion, deal with incidents and improve network efficiency, safety and environmental performance and on a broader scale, strategic traffic management involves managing whole networks at a macro level as well as integrating or linking different networks. Traffic Management is the planning, monitoring and control or influencing of traffic. It aims to

- Maximize the effectiveness of the use of existing infrastructures
- Ensure reliable and safe operation of transport
- Address environmental goals
- Ensure fair allocation of infrastructure space (road space, rail slots, etc.) among competing users

It is therefore an essential element in increasing the efficiency and safety of transport networks and operation (Yilma, June 2014).

Many previously worked researches identified different traffic congestion mitigation measures depends on the causes of traffic congestion. From those researches Managing Urban Traffic Congestion, 2007 conclude there is no prescribed specific congestion management strategies since the appropriateness and applicability of these depends largely on the local context. The report suggests three strategic congestion management principles that should serve to guide policies in this field.

- Ensure that land use planning, and the community objectives it embodies, is coordinated with congestion management policies;
- Deliver predictable travel times; and
- Manage highly trafficked roadways to preserve adequate system performance.

Transportation engineers and planners of Cambridge systematics, Inc. And Texas transportation institute has developed a strategy to control congestion. The strategies are grouped into three as follows and each group has key strategies to address congestion:

1. Adding more capacity for highway, transit and railroads by
    - Adding travel lanes on major freeways and streets (including truck climbing lanes on grades)
    - Adding capacity to the transit system (buses, urban rail or commuter rail systems)
    - Closing gaps in the street network
    - Removing bottlenecks
    - Overpasses or underpasses at congested intersections
    - High-occupancy vehicle (HOV) lanes
    - Increasing intercity freight rail capacity to reduce truck use of highways

2. Operating existing capacity more efficiently by
    - Optimizing the timing of traffic signals
    - Faster and anticipatory responses to traffic incidents
    - Providing travelers with information on travel conditions as well as alternative routes and modes
    - Improved management of work zones
    - Geometric improvements to roads and intersections

- Converting streets to one-way operations
- Access management.

3. Encouraging travelers to use the system in less congestion-producing ways by

- Programs that encourage transit use and ridesharing
- Curbside and parking management
- Flexible work hours
- Telecommuting programs

2.5.1 The Role of Traffic Management on Traffic Flow Problems

The principal focus of traffic management and control systems is to ensure the safe and efficient movement of traffic on roadways. This is indeed a challenging task since incidents, of varying degrees of magnitude, can routinely impact the flow of traffic. These incidents need to be identified, and responded to in a timely fashion.

(John, 2000) According to John, 2000, stressed that urban traffic management use to make the most productive use of the existing road based transport system by adjusting, adapting, managing and improving the system. Specifically, traffic management is designed to improve the movement of people and goods; to improve the quality and safety of the traffic and transport system; and to contribute to the improvement of the urban environment. Traffic management can assist poverty reduction by improving travel for "people" and it also improves the flow of traffic and enhances mobility, thereby reducing emissions and fuel consumption.

Institute for Transport Studies (2010) describes the benefit of traffic management in two perspectives i.e. for the public and individual. Hence the public will profit from the measures because the road infrastructure is used more efficiently through traffic management, congestion can be addressed and, thus, negative impacts of traffic (e.g. pollution, noise, accidents) can be reduced. This is possible without investing in new road infrastructure. If breakdowns occasionally occur in the transport network or large scale events are taking place, traffic can be re-routed accordingly. Unnecessary mileage driven searching for available parking spaces is reduced.

Access and parking management measures can be enforced more efficiently and, therefore, the positive effects of these actions will be enhanced. Also the reliability and the quality of service of public transport can be improved, affording passengers time savings. Furthermore, the road safety can be improved when dangerous locations and situations that can cause accidents are identified and improved with the help of the tools described. And Individuals can benefit from less congestion and reduced travel times affected by the improved traffic management (Yilma, June 2014).

2.5.2 Traffic Management and Congestion

There is no absolute solution to fully eradicate the traffic congestion problem from the society as it is fully related with individual land use pattern and existing transport policies to each urban region. Congestion coexisted with the economic activity and hence fully eradicating roadway congestion is neither an affordable, nor feasible goal in economically dynamic. However, a well framed process addressing the all aspects of congestion is required for long term benefit. According to ECMT (2007), the process should address four broad aspects which are; understanding what congestion is and how it affects the urban region, developing and monitoring relevant congestion indicators, intervening to improve the reliability of urban travel, to release existing capacity or to provide new infrastructure and, perhaps most importantly and managing demand for road and parking space consistent with a shared vision on how the city should develop. Many literatures for example (Ramon, 2000) have systematically classified congestion management measures into two groups, namely supply-side measures and demand-side measures. On the basis of this classification, common management measures for relieving congestion are described underneath.

2.5.2.1. Supply-side Management

Engineering theory of traffic congestion concentrated on increasing the traffic capacity of road links, junctions, and whole urban networks by restrictions on parking, pedestrians, access, and even public transport, as well as new road construction (Thomson, 1998). The European Conference of Ministers of Transport, ECMT (2007), proposes some supply side congestion management measures which are; improving traffic operations, improving public transport, implementing mobility management, modifying existing infrastructure etc.

2.5.2.1.1 Improving Public Transport

Improving public transport is an important supply management strategy of the transport system for congestion mitigation as it can transport more people than individual cars for a given amount of road space (ECMT, 2007). This can be done in various ways; cities can construct additional mass transit networks. Or, some road lanes are provided for public transport use, such as bus lanes, in order to save more time for public transport users (Hon, 2005). By promoting public transport, it can take lone drivers out of private vehicles and make more efficient use of road space, thereby relieving congestion problems (Hon, 2005). However, literature (Downs, 1992; Black, 2003; Hon, 2005; ECMT, 2007) suggests numerous ways of improving public transport such as; Developing mass transit, bus lanes/High Occupancy vehicle (HOV) lanes, better public transport services, more peak and ride facilities, extending services, adopting fee structures, operational improvement, public transport information provision etc.

2.5.2.1.2 Improving Traffic Operation

According to, European Conference of Ministers of Transport, ECMT (2007), typical congestion mitigation measures includes planning and coordination of roadworks, speedy response to defective traffic signals and to disruptions caused by accidents and debris. These approaches can be very attractive as they can rapidly deliver perceivable benefits to road users for a relatively small investment especially when compared to the cost of new infrastructure whose impacts on overall travel times may not always be perceived by road users. Efficient and coordinated traffic control systems, can timely adjust the road capacity to accommodate additional traffic and reduce unnecessary travel delays (Hon, 2005). Improving traffic operation typically consists of the use of traffic signals, implementation of contingency plans, provision of real time traffic information, pre-trip guidance, monitoring and management of traffic flows (Judycki et al., 1992; Black, 2003; Hon, 2005; ECMT, 2007).

2.5.2.1.3 Mobility Management

There are numerous mobility management strategies that can, when successful, reduce car use in urban areas. These include ride-sharing, promoting bicycling and pedestrian travel or supporting mobility management efforts targeting large trip generators such as companies (ECMT, 2007)

2.5.2.2. Demand-side Management Measures

Demand-side congestion management measures are also important for relieving congestion problems as it reduces the demand for the vehicle user. ECMT (2007) suggested three related demand side management approach; access management, parking management and pricing policies. ECMT (2007) also suggested ensuring that land use planning, and the community objectives it embodies, is coordinated with congestion management policies. Access management and parking management are regulatory measures and pricing policies are economic measures. So, ECMT actually describes three aspects of demand side congestion management; economic, regulatory and land-use. These three aspects are also described by (Hon,2005) as effective demand side congestion mitigation measures.

2.5.2.2.1. Regulatory Measures

Regulatory measures refer to administrative measures, policies, regulations or even legislations that directly alter the travelers' behaviors (Hon, 2005). Regulatory measures include; access management, parking control, restrictions on vehicle use, traffic calming and flexible working hours. Regulatory measures have many constraints. First, to the public, these measures, especially the restrictions on automobile use, narrow down individual choices and are too rigid to human freedom. These may not be applicable to every community. Secondly, these measures often adversely affect economic well-beings by altering normal traffic flows (Hon, 2005).

2.5.2.2.2 Land use Policies

Transport and land use policies are closely related. Land uses gives rise to trip generation and influence regional trip patterns. So, it is necessary to co-ordinate long term land use and transport planning (ECMT, 2007). To address congestion problems in the long run, land use policies for adjusting that imbalance is necessary. Through planning, land uses should be re-located in such a way that the need and the amount of travel can be minimized. With optimal land use and development policies, the demand for travel can be reduced to the least level (Hon, 2005).

2.6. Critique of the Existing Literature Relevant to Study the Current Literature

The study under intersection without and with road overpass is not yet undertaken. It would require developing throughout the Year with the enhancement of technology. The previous study shows that road overpass at an intersection is vital to the traffic flow. The literature which is reviewed in this chapter is as follows;

- ✓ The positive effects of a road overpass structure of the traffic flow.
- ✓ General characteristics of vehicle contribute conflict on the traffic flow.
- ✓ The travel time and average delay analysis.
- ✓ The traffic management systems which are applied in the present time.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Overview

The chapter mainly explains how the study was conducted, the applied methods and techniques in review previous research, define problem, data collection, the reasons for which they were used according to the research objectives.

3.2. Description of the Study Area

The study was conducted in Addis Ababa City, the Central City in Ethiopia. Its geographical coordinates are 9^0 0ʿ19.4436" N latitude and 38°45'48.9996" E longitude with an estimated area of 527 Sq. Km. The City is found in an area of average altitude, of about 2,355m (7,726ft) above sea level.

The specific area of the study is Wellosefer intersection, which composed of road underpass and roundabout. This intersection was entirely controlled by traffic enforcers to manage the traffic movements of different streams.

"Before" improvement of Wellosefer intersection, it was Un-signalized T-intersection and no underpass structure. The lane width of the through lane was 2.7 meters, while the turning lane (from the left and right movements) was 3.0 meters. The current geometric configuration "after "improvement of the intersection, the total width of asphalt pavement has 40 meters, a 3.62 meters wide for each lane and two lanes per direction. Previous data showed that Wellosefer intersection was one of the most congested corridors in Addis Ababa City. The main corridors along this intersection are those roads which came from Bole International Airport, Meskel Square and Ethio- China Street.

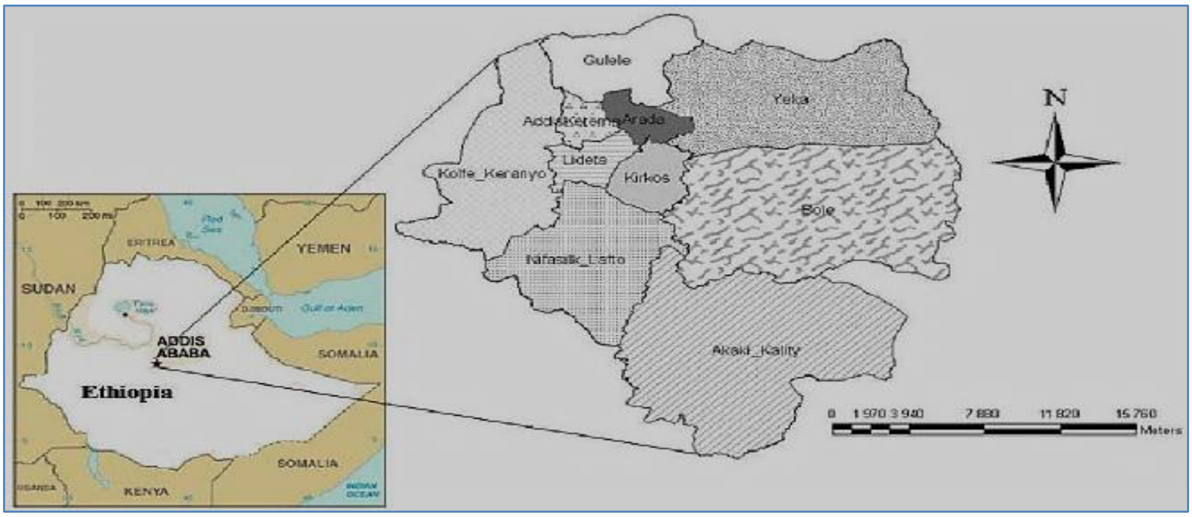


Figure 3.1: Map of Ethiopia (source: Website, August, 2017)

Figure 3.2: Road Corridor Before and After Improvement

(Source: Jan. Willem Zwarteveen, 2011 and picture taken on August 8, 2017)

In Figure 3.2, it shows Wellosefer intersection "before" and "after" improvement. It can be viewed the traffic flow at the intersection, there was evidence of traffic conflict movements from different approaches of the Un-signalized T-Intersection.

3.3 Research design

The research had been conducted by using both descriptive and analytical methods. It was designed in the way that important and exact information could be acquired to analyze travel time and delay of vehicles related to the different intersection design control alternatives.

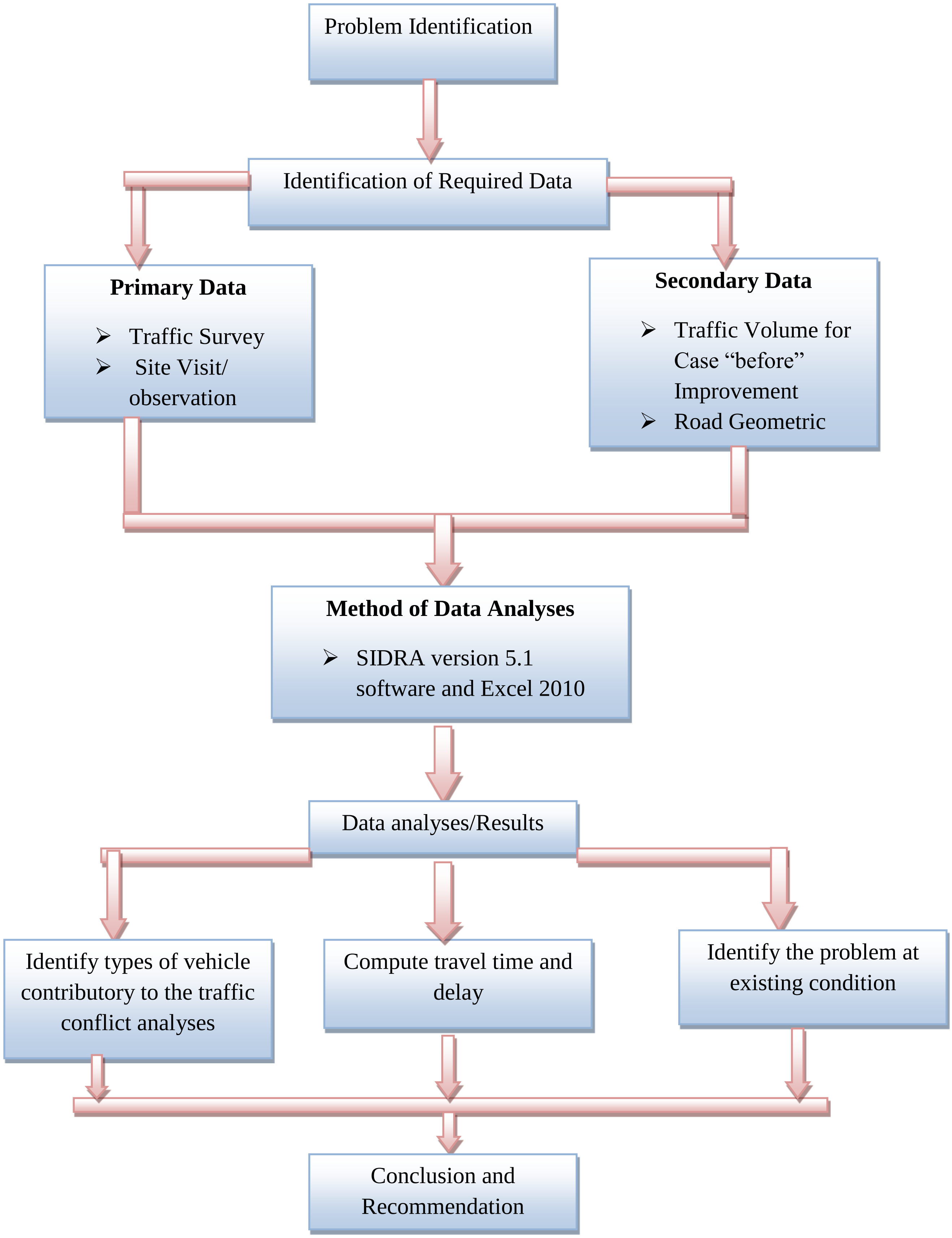


Figure 3.3: Research Design

3.4. Population

The population considered in this study consisted of all intersections "with" road underpass and overpass structures which is found in the City of Addis Ababa. All intersections were visited and observed the behavior of the traffic movements that was the most problematic intersection. From here, it was trimmed down the number of major intersections in one, to confine the data gathering during the duration of the traffic study intersection. The population enabled to decide which intersection to be evaluated in this research study. Based on the list of major intersections, Wellosefer intersection was selected as the specific study area considering for the case “Before” and “After” improvement.

3.4.1. Sample Size and Selection

In this study two cases of the intersection considered wherein the case "Before" and "After” improvement had been evaluated relative of its effectiveness of the road underpass construction. Actual observations in the road network of Addis Ababa City were undertaken to decide and consider only one major intersection due to its brodeness. Wellosefer intersection is composed of 3-legged approaches while the underpass structure was passing through the intersection towards West to East directions and vice versa. In this intersection, the researcher had analyzed the effects of the road underpass structure on traffic flow using Sidra software.

3.4.2. Sampling Technique and Procedures

Based on its nature and goal of the study to be attained, the researcher was applied purposive sampling method which was used in determining the sampled area on the study in Addis Ababa City. The selected intersection was Wellosefer intersection, which was observed to be more challenging than other intersections as perceived by the researcher based on previous traffic data which showed high traffic congestion in the intersection. Also this segment is a major road in the city due to its surroundings composed of business area, and where we can find different embassis due to its proximity to Ethiopian International Airport. In addition to this, tThe preliminary information from the Transport Branch Office of Addis Ababa showed only one of the ten areas of the city that comprised high traffic volume in the sub-city at which the study area existed.

Among these ten areas, the researcher decided to select the intersection of Wellosefer which was known to be more congested and problematic “Before” improvement. Nowadays, the existing geometric layout of Wellosefer is Road Underpass “with” Roundabout at the upper level to control traffic from entering and passing the intersection. The Road Underpass is separating traffic flow from West to East direction and vice versa.

The analysis in this research study focused on vehicle’s travel time and delay for all types of vehicles crossing the intersection considering the case "before” and “after” improvement.

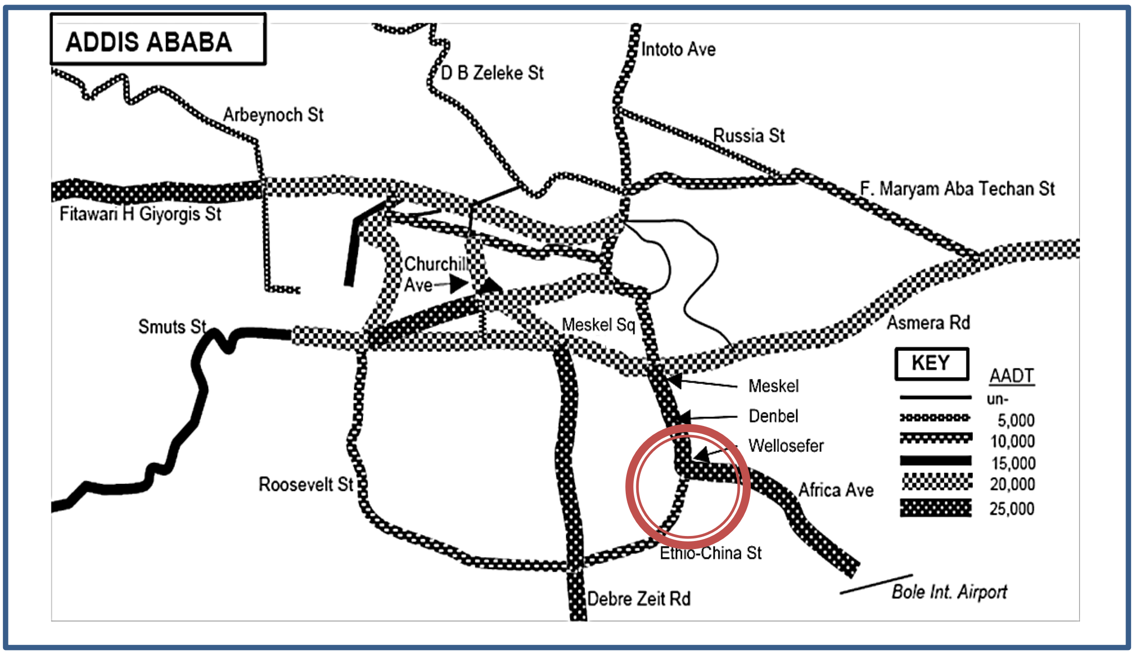


Figure 3.4 :Major routes and traffic volumes in Addis Ababa, measured as Annual Average Daily Traffic. (Source: The World Bank, 2002).

3.5. Data Collection Method

The general objective of this study is to analyze the effectiveness of the road underpass structure of the traffic flow. The data gathering involved different types of data which will satisfy the requirements of the analysis using traffic parameters. These data were collected through both primary and secondary data which entails Quantitative and Qualitative types of research methods. Quantitative Research was used traffic surveys to uncover trends, for example, previous traffic data relating traffic volume in a particular week, which will be used to dive deeper into the problem in the study area.

Qualitative data collection methods used as informal interviews, and field observations. The other data collected and analyzed include geometric road characteristics and its environment, causes of congestion and measures taken "before" this research conducted, to reduce the occurrence of traffic congestion. These data are listed, explained and each of them relates how they contribute to traffic congestion and other related problem. While, Quantitative Research was used to quantify the traffic problem in Wellosefer intersection by way of generating traffic volume, vehicle types to transform into charts and tables for the analysis. It utilized measurable data, such as parameters to formulate facts and uncover patterns of traffic movements in this research study. The quantitative data are used to explain the general characteristics of the traffic flow condition of Wellosefer intersection "before" and "after" the improvement by comparing the three alternatives:

a) "Before" Improvement
   1. Un-signalized T-Intersection
b) "After" Improvement
   1. Road underpass with roundabout at the upper level
   2. Signalized T-Intersection
   3. Roundabout Only

3.5.1. Primary data

Field surveys at Wellosefer intersection had been conducted to gather the primary data on the traffic volume count for the determination of travel time and delay using Sidra Software and measured the geometrical features of the intersection including some lanes, lane width, grade, and width of a median.

3.5.1.1 Traffic Volume Count

Traffic Volume count at Wellosefer intersection video is used to record some vehicles with the corresponding types of vehicles at Wellosefer intersection. The traffic volume count was undertaken August 7-11, 2017, Monday to Friday of the week, a 5-day collection period, which started from 7:00AM-7:00 PM at the 15-minute time interval. The vehicles were recorded in a category such as cars and utilities, buses and trucks.

Traffic volume count data are very important to compute average speed, flow, capacity, delay, level of service, to forecast trends, and to identify congestion problems. Traffic volume studies are conducted to determine the number, movements, and classifications of roadway vehicles at a given location. These data help to identify the critical flow period, determine the influence of large vehicles or pedestrians on vehicular traffic flow or document traffic volume trends. The recorded total traffic volume was converted to passenger's equivalent unit to proceed with the analysis by applying the corresponding Passenger's Equivalent Factor for each type of vehicle.

3.5.2. Secondary data

The secondary data had been considered "before" improvement of Wellosefer intersection, including field observations and informal interviews about the causes of traffic congestion before improvements of the intersection. Journals also used as reference to substantiate traffic data in the study area. The secondary data was collected July 11-15,2017 – August 14-18, 2017 (2009 E.C) from Addis Ababa Traffic Management Office, AACRA and Engineer Zewde Consulting Office and research paper of J. Willem Zwarteveen 2011.

3.6. Study Variables

Dependent Variable

- Effectiveness of road underpass structure of the traffic flow using Travel Time and delay

Independent Variables

- Traffic volume
- Geometric Features
- Geometric layout

3.7. Method of Data analysis

A common method for evaluating the effectiveness of improvement in the field is the "before" and "after" study, which measures system performance of the implemented project changes. For case "before" and "after" improvement there are two ways to evaluate its effectiveness; these are: “what if “ type analysis and “with and without improvement” type of analysis. But in this study, “what if” type analysis is applied.

The data collected from Wellosefer intersection was analyzed using SIDRA version 5.1 Software and supplemented by Microsoft excel 2010 for travel time and delay for each legged or approach of the intersection. Also, a simple existing Road Audit was conducted to clarify the problem at-already completed Road Underpass structure in the study area.

3.8. Data quality assurance

For the achievement of objectives of this study, all traffic data, necessary as well as geometric features were collected accordingly. The traffic volume counting and recording were undertaken by installing a camera at the place where clearness to see each leg from all directions of the intersection from Monday to Friday, 7:00AM – 6:00PM.

The secondary data was collected by the researcher from the concerned organizations and agency to analyze traffic conditions of Wellosefer intersection “before” improvement.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presented the results and discussion of the traffic flow at the intersections with the case "Before" and "After" improvement had been made. The results of the analysis for case "Before" improvement considered two types of intersections. These intersections are Un-Signalized T-Intersection and Signalized T-Intersection without altering the previous existing geometric lay-out. While the results of the analysis "After" improvement was focused on the current or existing traffic condition considering "After" improvement using Road Underpass structure with Roundabout at the upper level and roundabout only case.

4.2 Overview of the Characteristics of Traffic Flow

Traffic studies were carried out to analyze the traffic characteristics in the study area. This will help to come up with a better geometric design, lay-out and traffic control device which will provide safe and efficient traffic movements. Addis Ababa consists of a road network, exists of links and nodes (i.e. Intersections). Along with many corridors of Addis Ababa city, Wellosefer intersection had been observed with long travel time and delays "before" improvement had been implemented. From Figure 4.1, it shows the number of vehicle in Ethiopia, which has been considered to have a significant effect on the traffic situation in Addis Ababa City.

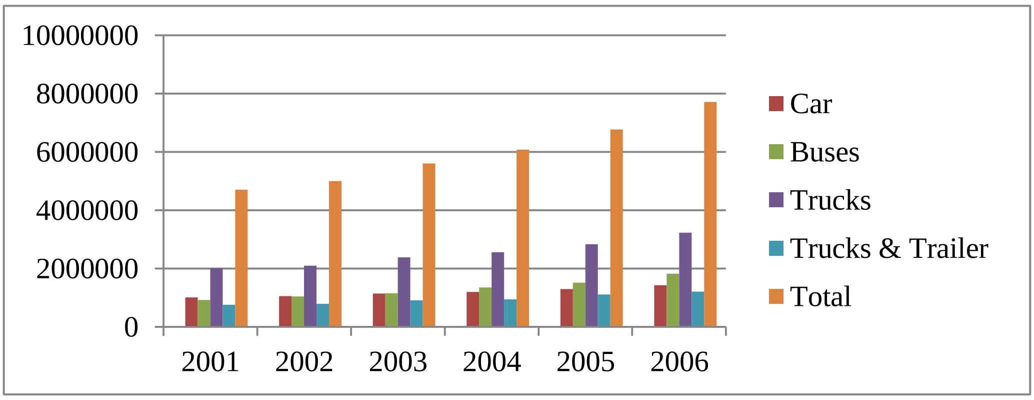


Figure 4.1:Number of Vehicle in Ethiopia (Source: Ethiopian Road Authority)

Out of those numbers of vehicles, the majority of the vehicles is located in the City. It can be seen the traffic problem in the City was mainly due to a yearly increasing number of vehicles using the data from 2001 to 2006, which could not match the existing geometric lay-out, and poor traffic control system used at the intersection during these years of traffic operation.

Table 4-1: Number of Vehicles in Ethiopia

Year	Cars & Utilities	Buses	Trucks	Total	% Difference
2001	1,016,433	925,044	2,770,212	4,711,689	-
2002	1,060,742	1,048,375	2,898,334	5,007,451	6.28%
2003	1,148,282	1,156,776	3,299,340	5,604,398	11.92%
2004	1,206,267	1,357,122	3,513,695	6,077,084	8.43%
2005	1,299,660	1,518,197	3,951,567	6,769,424	11.39%
2006	1,433,782	1,829,093	4,452,522	7,715,397	13.97%

(Source: Ethiopian Road Authority)

The total exact number of vehicles per year with the corresponding percent difference between each year from 2001 – 2006 are tabulated in Table 4.1. It appeared that in 2002, there was an increase of 6.28%, while in 2003, 11.92% increased representing the 2nd highest from the study period 2001 to 2006. The highest percentage occurred in 2006 comprising 13.97%. Based on this trends, ERA estimated the average annual traffic growth rate for all types of vehicles from the same period of about 10.40%.

On the other hand, the Traffic volume count needed for further analysis of Wellosefer intersection considering the case "Before" improvement had been utilized. This data from the Road Project Consultant Office indicated that the traffic volume count was undertaken from 7:00 AM to 7:00 PM, Monday to Sunday in June 6-12, 2006 G.C.

Hereunder is the traffic data collected from Road Project Consultant Office of engineer Zewde presented as follows:

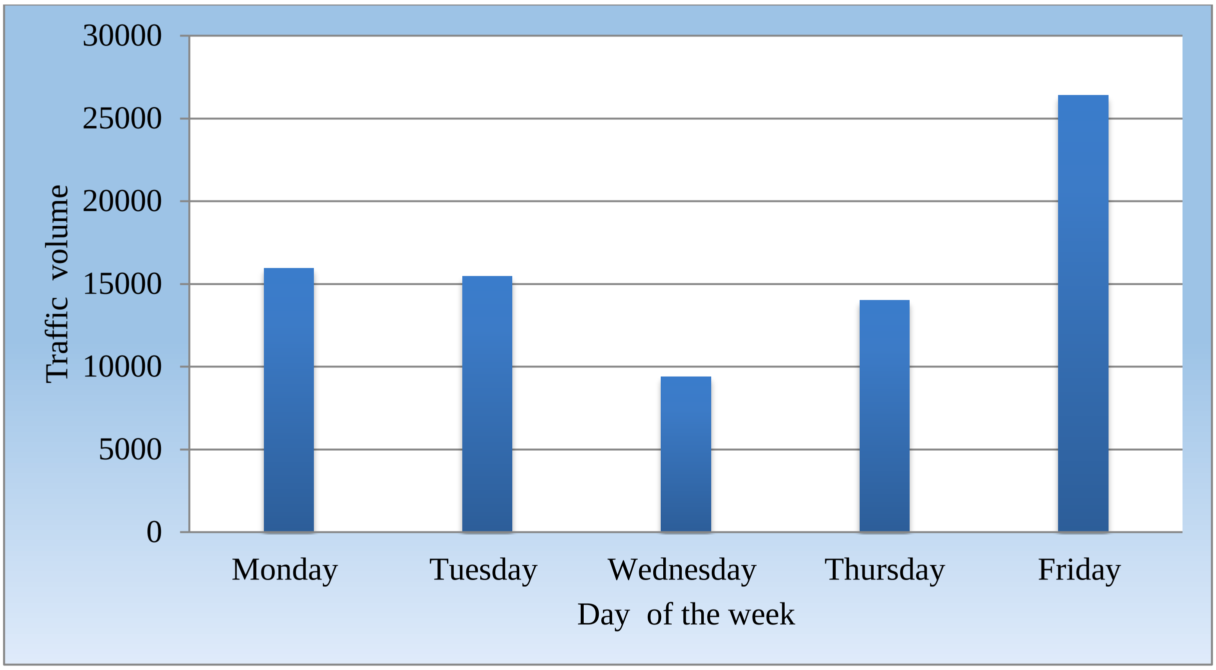


Figure 4.2: Daily Traffic Flow Flow level at Right Turn Movement (Source: engineer Zewde road Consultant, 2006)

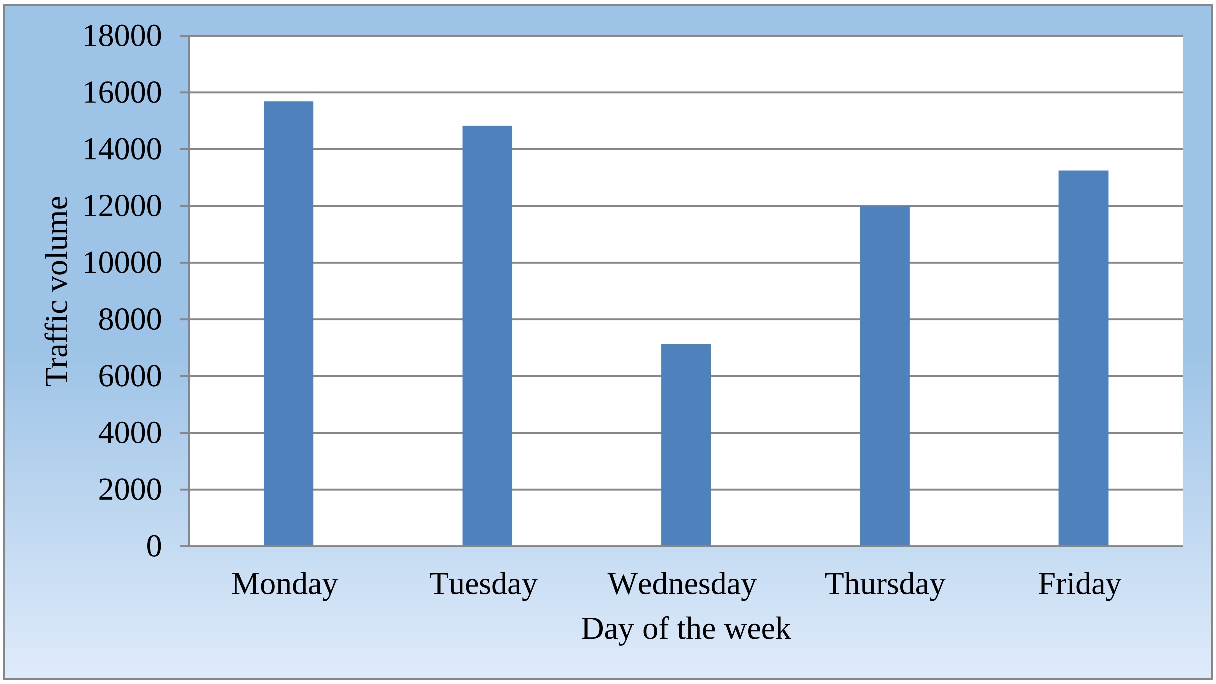


Figure 4.3: Daily Traffic Flow Levels at Left Turn Movement (Source: Engineer Zewde road consultant, 2006)

The above figure 4.2 and 4.3 presented the variations of daily traffic volume for the right and left turn movements of the Un-Signalized T-intersection. The highest traffic volume of the week occurred Friday for right turn movement which were dissipated from Meskel Square and China Street, while the lowest traffic volume was observed Wednesday. Likewise, the highest traffic volume for left turn movement dissipated from Bole and China Street happened Monday of the week, and Wednesday had the lowest traffic volume. This means that the highest traffic volume for left turn and right turn movements varied within the week, but not on the lowest traffic volume which was happened Wednesday of the week during the observation period.

In Table 4.2, it showed the Annual Average Daily Traffic (AADT) based on the observation period of Road Project Consultant 2006 . From the traffic volume data, the annual average daily traffic was calculated, and the result is summarized hereunder.

Table 4-2: Annual Average Daily Traffic of Before improvement

Group time	Car	L . Trafic	M . Trafic	H . Trafic	Articulated
Monday	30825	770	30	5	1
Tuesday	29475	771	32	2	2
Wednesday	16065	425	32	1	0
Thursday	22950	510	31	2	0
Friday	38690	916	44	3	1
Total	138,005	3392	169	13	4
E-factor	1.15	1.15	1.15	1.15	1.15
16 hour count	158,706	3901	194	15	5
M-factor	345	345	345	345	345
Annual Traffic	54,753,484	1,345,776	67,051	5,157	1,587
AADT	150,009	3,687	184	14	4

(Source: Engineer Zewde road consultant , 2006)

4.3 Types of Vehicle which are Contributory to Conflicting in the Traffic Flow

This research utilized the data from the published research of Jan William Zwarteveen, 2011, to identify the types of vehicle which were contributory to the conflict of the traffic flow in the study area.

In this study, it was observed that the flow of vehicles in a discharging queue was classified into either non-following vehicles (i.e., Slow vehicles with a time headway of more than 4 seconds) and following vehicles (i.e., Vehicles with a time headway smaller than 4 seconds). According to Minh, et al., 2009, The share of non-following vehicles appeared to have significant influence on the flow rate. Table 4.3 showed the effect of a share of non-following vehicles from 0 to 15 percent on the flow rate, measured in PCU/hr. Since passenger transport forms the main share of the transport at Wellosefer intersection, the interference flow is also expressed in passenger/h. The other influences on the saturation flow are kept constant and equal to the average observed value. It is clear that a decrease of the share of non-following vehicles results in an increase of both the vehicle flow rate and the passenger flow rate. From this, a decrease to a share of 5% of non-following vehicles would result in an increase of the PCU flow rate.
A detailed study showed that non-following behavior happens throughout the whole green period (beginning, middle, and end) and with all considered vehicle types (cars, minibuses, heavy vehicles).

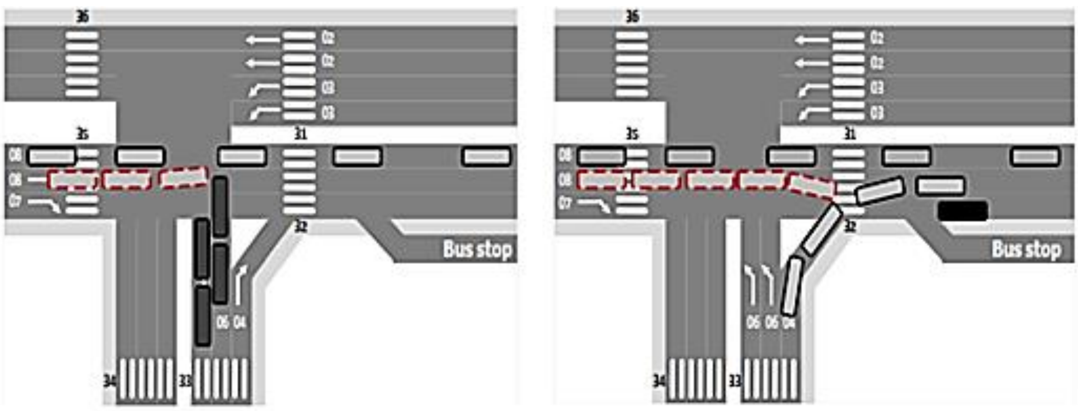
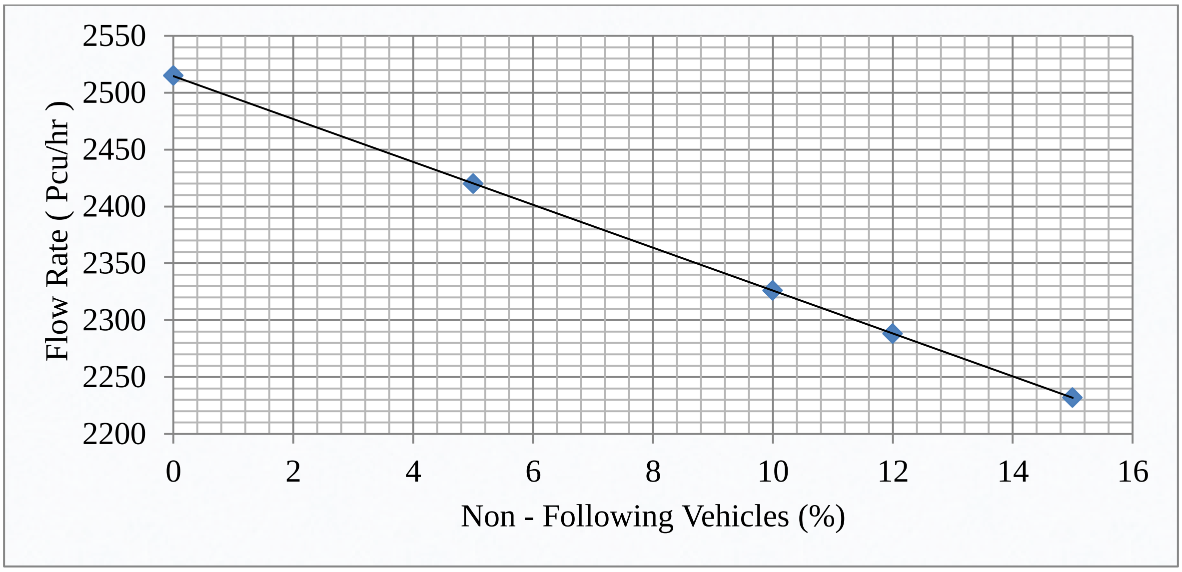


Figure 4.4: Conflicts between vehicles at the intersection

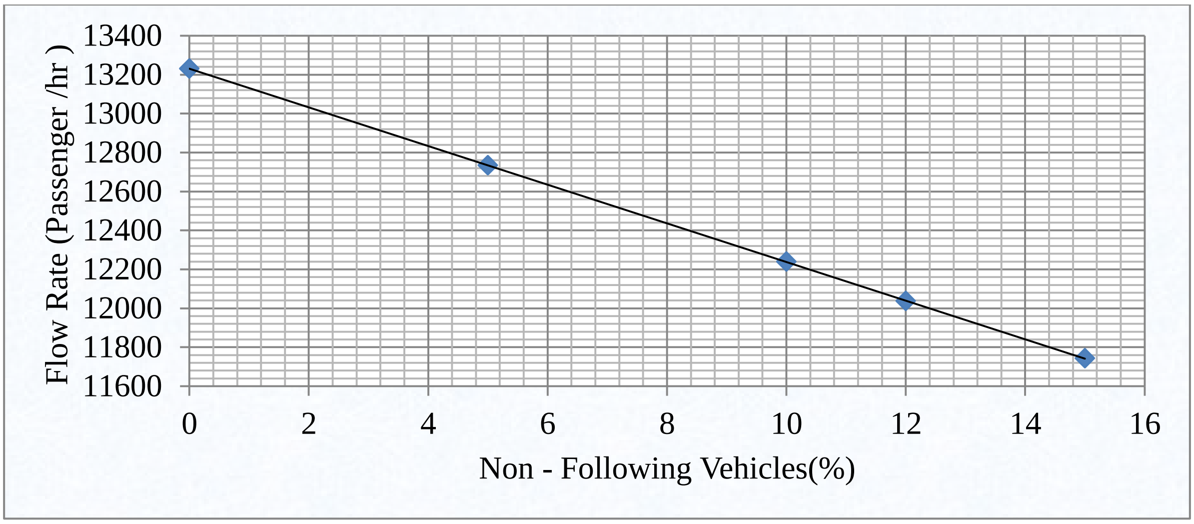
(Source: J. W. Zwarteveen, 2011)

Table 4-3: The interference flow in passenger car per hour and passenger per hour versus share of non-following vehicles

Non - Following Vehicle (%)	Interference Flow (pcu /hr)	Interference Flow (Passengers/hr)
0.0	2515	13230
5.0	2420	12734
10.0	2326	12238
12.0	2288	12036
15.0	2232	11742



(a)



(b)

Figure 4.5: The interference flow in PCU/hr (a) and passenger/hr (b) versus share of non-following vehicles.

Based on the data , there were two main reasons to cause non-following vehicles. These are low accelerating capacities of old vehicles and slow responding driving time before improvement of the intersection but after the improvement the site observation and the data taken from the consultant company of the road project indicate that the cause for conflict of the vehicles and passengers are the narrow width of the entry and exit lane , parking space and the presence of heavy long vehicles .therefore , this problem can be reduced if measures would be implemented such as Change / separate lane for the old and slow responding vehicles if there are intersection which poses conflict due to low accelerating capacity of old vehicles, slow responding driving and heavy long vehicles and Improving of driver's response to changing situations and driver retraining.

4.4. Travel Time and Delay Analyses for "Before" and "After" Improvement

4.4.1. Passenger Car Unit Analysis Before improvement

Passenger car unit analysis is important because it considers different characteristics of a car like a width, length, and the height that cause serious variations in the traffic stream. Due to different types of the length, width and height of the car each vehicle type has different effects on the traffic flow. PCU values are based on headway method analysis. The study intersection four vehicle types were classified as shown in Table 4.4.

Table 4-4: PCU Values per Vehicle Class, Grouped Per Location and Per Direction of Traffic Flow.

Location	**Vehicle type**	**PCU factor**
Wellosefer-Intersection		
Straight/ Through movement	Minibus	0.92
	Heavy vehicle	1.11
Turning movement	Minibus	0.82
	Heavy vehicle	0.94

(Source: J. W. Zwarteveen, 2011)

4.4.2. Traffic Volume at Wellosefer Intersection "before" improvement

This intersection is located at the center of the city and considered as the most congested intersection based on the informal interviews of road users (i.e motorists and commuters), and the Consulting Office of the Road Project. In addition, the research of J.W. Zwarteveen 2011, the analysis presented traffic volume count for 2-hours only, starting from the occurrence of heavy to saturated flow condition on each approach. The result is summarized in the table below

Table 4-5: Vehicle Composition, Grouped Per Direction of Traffic Flow

Location Wellosefer intersection	Number of cars (%)	Number of minibuses (%)	Number of heavy vehicles (%)
Straight/ Through movements	2356 (71%)	916(27%)	66(2%)
Turning movements	1681(91%)	114 (6%)	59(3%)

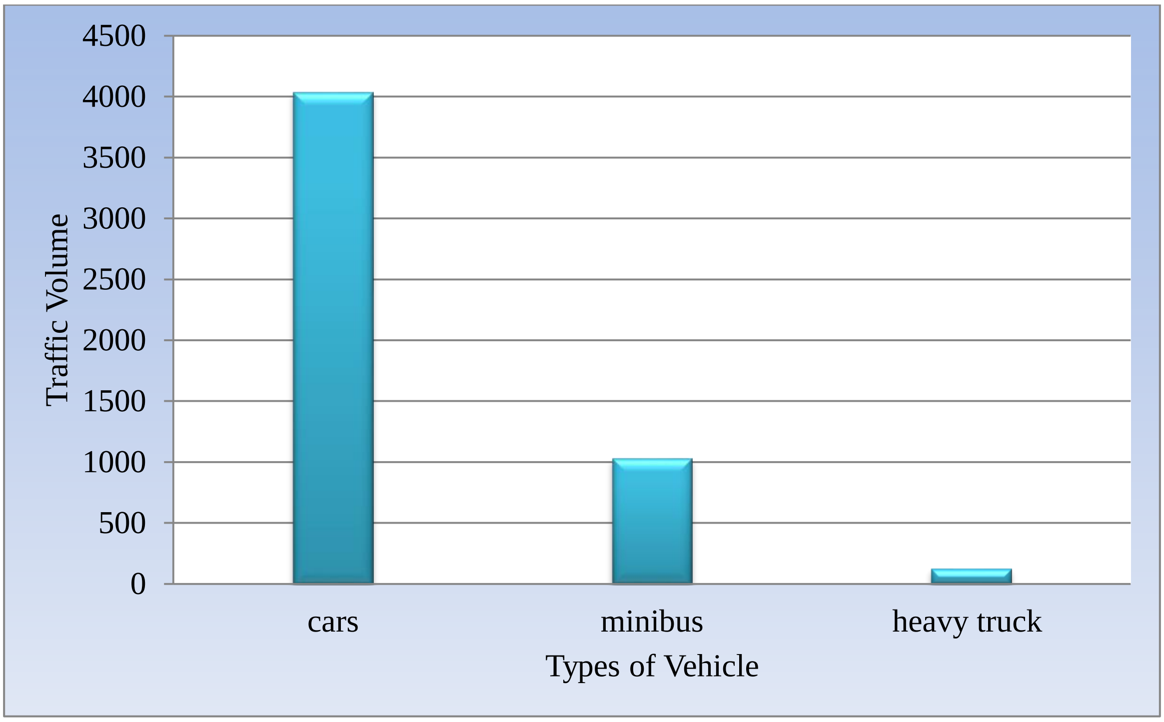


Figure 4.6: Traffic Volume by Vehicle Type "before" Improvement (Un-signalized)

Table 4-6: Vehicle counts at one Conflict group at Wellosefer intersection for 2 hour

Stream	Direction	PCU (No. Vehicles)
03 Left + Right	Turning	1166 (1150)
06 Left + Right	Turning	424 (418.20)
08 Left + Right	Straight/ Through	2128 (3663)
07	Turning	264 (260)
02 left +right	Straight/ Through	1210(1193)
04	Turning	282(280)

Table 4.6 presented the 2-Hours recorded number of vehicles comprising the saturated traffic mode per stream. The flow includes all vehicle types. The highest recorded number of vehicles in the conflict group was 2128 vehicle or 3663 PCU.

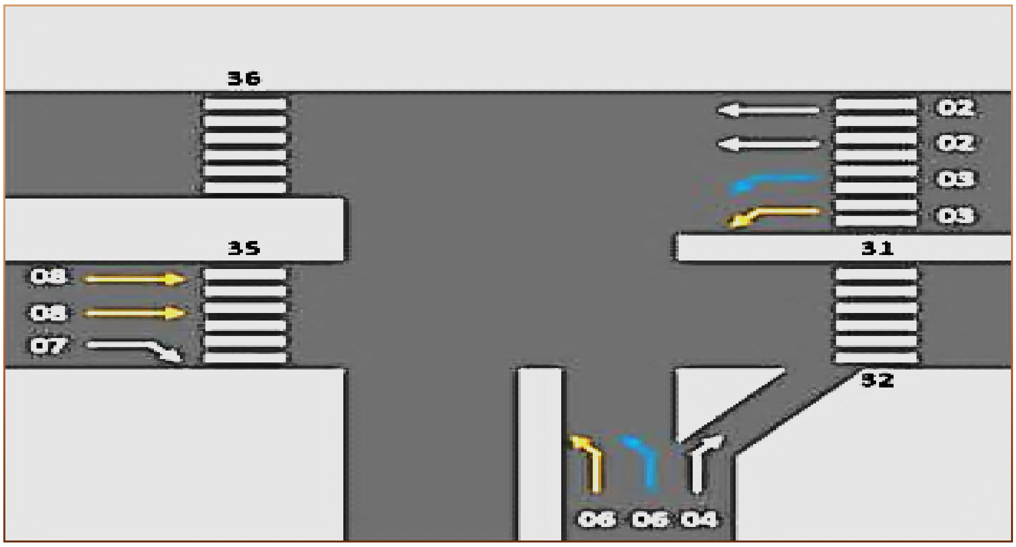


Figure 4.7: Lanes Layout of Un-signalized T-intersection, Wellosefer intersection

(Source: J.W. Zwarteveen, 2011)

All the above traffic volumes were taken from previously published research of this intersection. The idea of incorporating these data to the present study (i.e. tables and figures) was to come up with complete information about Wellosefer intersection considering the case "before" improvement.

4.4.3. Average Delay and Travel Time Analyses for before improvement

Congestion analysis was made based on the travel time and average delay approach for the determination of congestion measures. These congestion measures are average travel speed, travel rate, delay rate, travel time, total segment delay, delay ratio, average travel time, and delay. Vehicle counts at the Wellosefer intersection on the duration of 2-Hours for heavy vehicles to saturated traffic mode per stream was taken for the analysis. The flow included all types of vehicles. Accordingly, the analysis of each congestion measure was presented in the following sections and summarized in the attached Annex B.

For the analyses of the traffic flow “before” implementation of the improvement, SIDRA intersection version 5.1 Software was utilized, and supplemented Microsoft office excel 2010 for the summary of data.

In addition, directional traffic hourly flow data, heavy vehicle percentage, number of lanes, lane width, median width from previously published research work used for the analysis of delay and travel time. However, the default values like base saturation flow had been utilized as input data for the analysis based on the facility type. Also, the left turning movement factor of 5 used as the conversion factor from HCM 2010 Manual. This factor was considered because the left lane is shared lane for vehicles. The input data in the Software program are summarized in Table 4.7. The analysis generated by running the program and the results are outlined in Table 4.8 below Using HCM 2010. The outputs and detail input values of the analysis of each approach legged attached in Annex B-1.

Table 4-7: Input Data for the Analysis of Average Travel Time and Delay

Wellosefer intersection					**Total traffic volume (veh/hr)**			**Heavy vehicle factor (%)**		
Approach legged	Number of entry lane	Number of exit lane	Lane width (m)	Median width (m)	TH	LT	RT	TH	LT	RT
Meskel square	3	3	2.7	2	1832	-	130	2	-	3
Bole	4	4	2.7	2	596	575	-	2	3	-

China street	2	3	3	2	-	212	140	-	3	3

The approach legged from Bole considering the total vehicles of Left turn and Through movements indicated the highest number of vehicles than the other approach legged, but Meskel Square approach showed the more number of vehicles crossing through the intersection.

Table 4-8: Output for the Analysis of Average Travel Time and Delay

Wellosefer Intersection Approach legged	Average delay (second/veh)	Average Travel time (second)
Meskel square	20.7	19.9
Bole	1014.8	365.6
Chain street	607.5	34.0
Intersection (Total)	535.7	574.7

From the output of the analysis, the average delay and the average travel time are 535.7 Seconds and 574.7 Seconds, respectively. These results are relatively high delay and travel time incurred by the travelers, of which this situation may depend on the use or purpose of using the road as discussed in the sampling technique. From data alone, it could suffice that the road is very essential for the motorists and commuters that requires as much as possible the travel time and delay should be minimized.

4.4.4. Traffic Volume at the Intersection After Improvement

The case “after” improvement considering signalized intersection and roundabout intersection independently were applied and analyzed to do the evaluation more interesting by taking the traffic volume of the actual data gathered from the intersection Monday to Friday in August 7-11, 2017. It means the current condition of Wellosefer intersection wherein there is already underpass and roundabout at the upper level. The idea in this part of the analysis is to come up with the performance level of Wellosefer intersection at the prevailing traffic condition, if signalized intersection or roundabout had been considered as the improvement. The results compared the control average delay and travel time with the current set up of the geometrical layout of the intersection.

Table 4-9: Traffic Volume of Day in a Week

Day of the Week	Traffic volume (veh)	% Difference
Monday	54791	-
Tuesday	53307	(-)2.7%
Wednesday	35614	(-)33.19%
Thursday	45237	(+)27.02%
Friday	50889	(+)12.59%

From Table 4.9, it showed the erratic decreased and increased of traffic volume from Monday to Friday. The highest recorded traffic volume of the day was Monday with 54,791 vehicles. While the traffic volume in Wednesday dropped to about 33.19%, which has the lowest traffic volume of 35,614 vehicles from the 5-day duration of field survey.

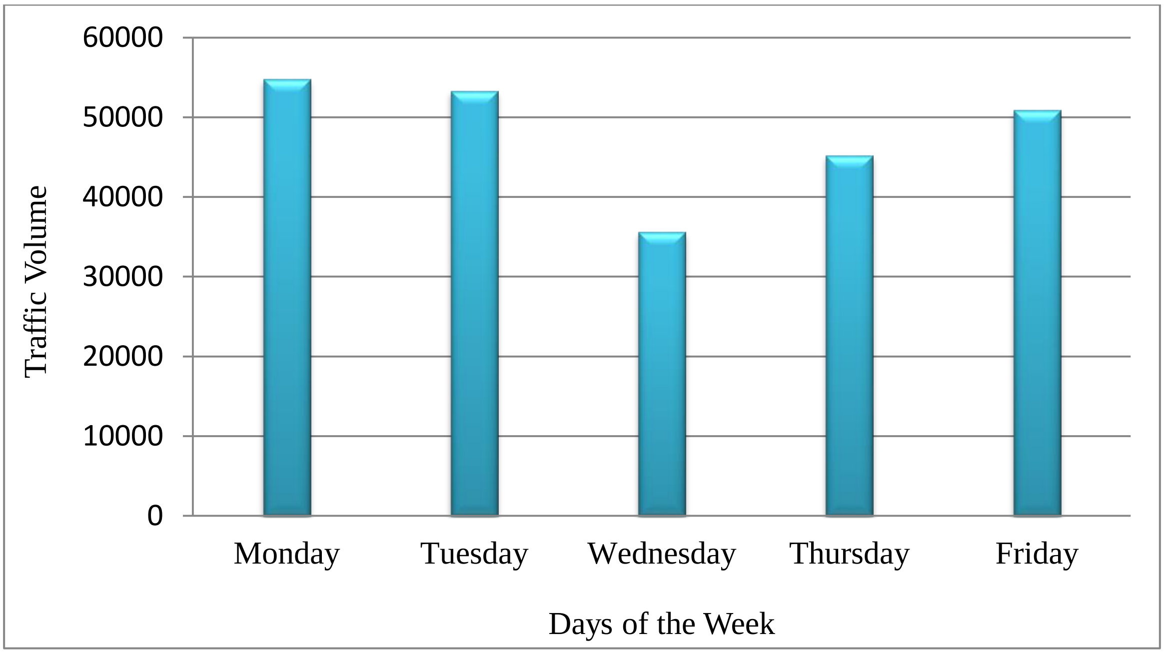


Figure 4.8: Traffic Volume of the Day in a Week Day “after” Improvement

Considering Figure 4.8, it was plotted to show the approach legged of Wellosefer intersection which was reconciled in the plotted curves in Figure 4.9.

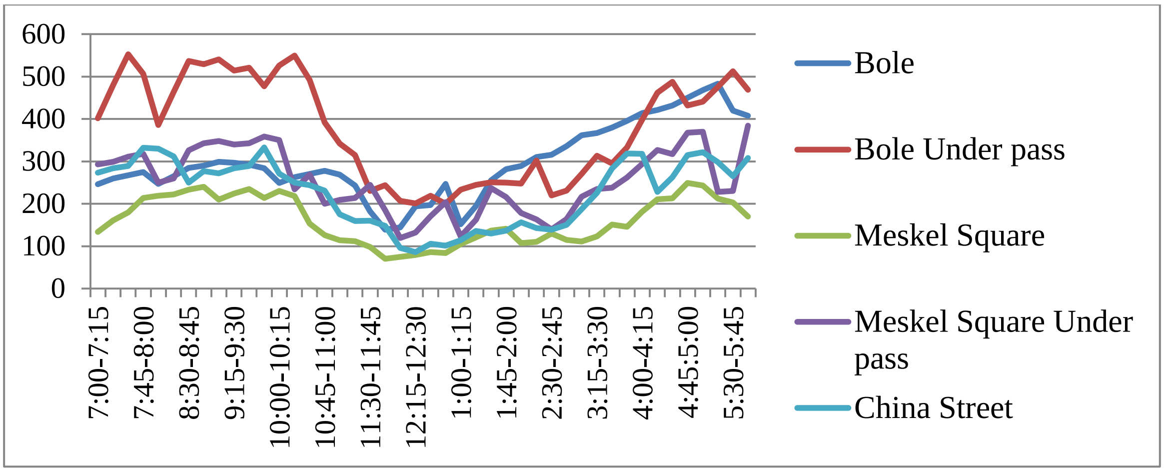


Figure 4.9: Traffic Volume Every 15minutes interval

From the results of the survey and plotted in Figure 4.9, 7:30 AM -7:45 AM and 10:15 AM – 10:30 AM indicated the peak period which gave the highest traffic volume for the 12-hours traffic volume counting, represented the road underpass. The number of vehicles from Bole road using the underpass is higher than the number of vehicles using the other approaches of Wellosefer intersection. In other words, the traffic generated on this approach was due to its proximity area around the Bole International Airport that attracts motorists and commuters to use this intersection.

Table 4-10: Hourly Traffic Variation of different vehicle types "after" improvement

Time	Car, 4DW, and taxi	Minibus	Light Truck	Bus	Total
7:00-8:00	5050	914	82	31	6077
8:00-9:00	5207	975	61	22	6265
9:00-10:00	5183	1441	32	18	6674
10:00-11:00	4416	1330	33	18	5797
11:00-12:00	2920	861	10	11	3802
12:00-1:00	2817	682	4	8	3511
1:00-2:00	2714	502	10	4	3230
2:00-3:00	3110	762	18	11	3901
3:00-4:00	4069	1094	28	23	5214

4:00-5:00	5328	1394	32	27	6781
5:00-6:00	5542	1319	34	16	6911

In addition, Table 4.10 shows the peak period started 9:00 AM-10:00 AM, and peak period in the afternoon from 5:00 PM-6:00 PM in the day of monday.

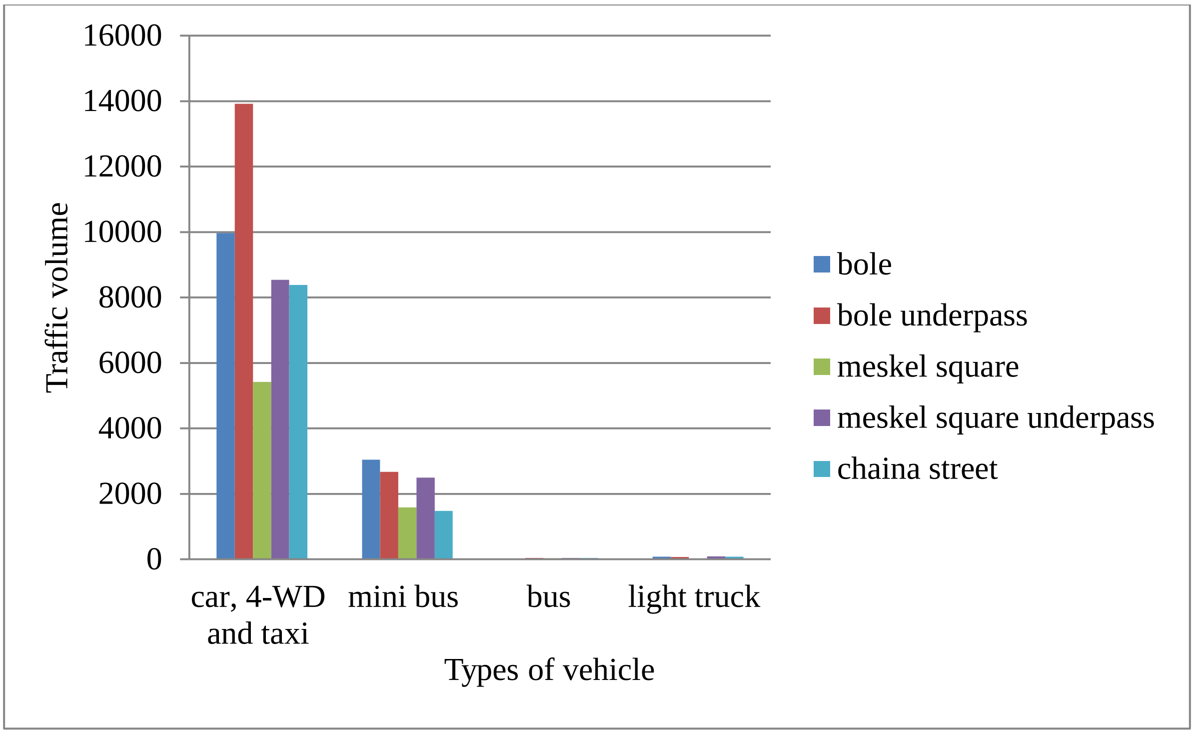


Figure 4.10: Traffic Volume by vehicle type "after" improvement

The above figure presented the passenger car such as car, 4-WD and taxi that shared large number of vehicle's percentage of vehicle type. Through follow-up field visit, it was observed that the composition of shared large number of vehicles in the study area, were due to the presence of various establishments such as embassies, shops, and residential houses. The same area whereby Bole International Airport is in a short distance. The obervations also support the findings that only few large vehicles using this section of road as compared to passenger cars and mini buses.

And the average annual daily traffic volume is predicted using E- factor and M- factors and presented as follows

Table 4-11: Annual Average Daily Traffic After Improvement of the Intersection

Day	Pc	Mini Bus	Light Truck	Bus
Monday	46356	11274	344	189
Tuseday	42627	10532	404	226
Wednesday	29801	7303	276	152
Thursday	36190	9219	341	196
Friday	43324	9941	403	276
Total	198298	48269	1768	1039
E- factor	1.15	1.15	1.15	1.15
16 hour count	2,280423	55,509	2,033	1,194
M - Factor	345	345	345	345
Annual Traffic	78,674,731.5	19,150,726	701,454	412,223
AADT	215547	52467	1921	1129

As we can see from the table 4-11 the AADT of the passenger car is very high when it compared to the other vehicle type because of the above reseaons.and also when we compare the AADT for the before and after improvement it shows the highy increasing of vehicle number from year to year , the comparision is presented as follows

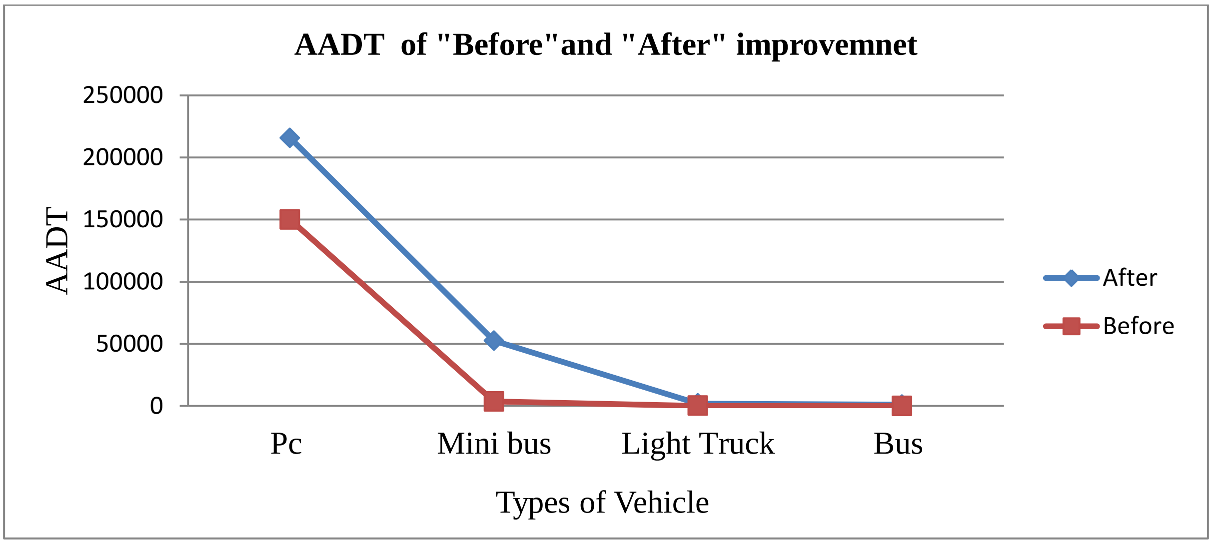


Figure 4.11: AADT for “Before’’and “After’’ Improvement

4.4.5 Heavy Vehicle Percentage analyse After Improvement

The percentage of heavy vehicles are needed for calculation the capacity and performance of the study intersection. This is necessary because of the major difference between heavy and light vehicles in terms of traffic movement. In Table 4.12, indicated the collected data from the actual traffic survey for heavy vehicles.

Table 4-12: Heavy Vehicle Percentage

Approach legged	Heavy Vehicle (%)		
	TH	LT	RT
Meskel Square	1.33	-	0.63
Underpass from Meskel square	1.24	-	-
Bole	1.38	0.45	-
Underpass from Bole	0.66	-	-
China Street	-	0.76	1.38

4.4.6 . Passenger car unit analyses After Improvement

Passenger car unit was considered to measure the impact that a mode of transport has on traffic variables such as headway, speed, density compared to a single standard passenger car. As described in section 4.4.1, Passenger car unit analysis is important because it considers different characteristics of a vehicle like a width, length, and the height that cause serious variations in the traffic stream. Due to different types of the length, width and height, each vehicle type has different effects on the traffic flow. For this analysis, the passenger car unit factors are taken from HCM 2010.

Table 4-13: Passenger car unit values

Types of vehicles	PCU
Car, 4WD, taxi and pick up	1
Cycle and motorcycle	0.5
Mini bus	2
Bus and truck	3.0

(Source: HCM 2010)

Using the above value of PCU factor, it was converted the number of vehicles to passenger car unit value for each movement type with the corresponding approach legged.And this values is taken from the gathered data of traffic volume count for a peak period of 7:00-8:00 AM .

Table 4-14: Traffic volume in passenger car unit

Approaches /Legged	Traffic volume (PCU/hr)
Meskel square	
Through	414
Right	651
Underpass from Meskel	1843
Bole	
Through	818
Left	1288
Underpass from bole	2384
China street	
Right	1320
Left	242

4.4.7. Peak Hour Factor Analysis for After Improvement

Daily traffic volumes, while it is useful for planning purpose, it cannot be used alone for design or operational analysis purposes. Volumes vary considerably over the 24 hours of the day, with time or period in which the highest flow occurring during the morning and afternoon had been observed during "rush hours". The single hour of the day that has the highest hourly volume is referred to as the peak hour. The peak hour volume is generally stated as a directional volume (i.e., each direction of flow is counted separately in this study). Highway and controls must be designed to adequately serve the peak hour traffic volume in the peak directional of flow.

The relationship between the hourly volume and the maximum rate of flow within the hour is defined by the peak hour factor, as follows

$$\mathrm{PHF} = \frac{\text{Hourly volume}}{\text{Maximum rate of flow}}$$

Then for the standard 15-minute analysis period, it becomes:

$$\mathrm{PHF} = \frac{V}{4 * V15} \ ,$$

Where: PHF = peak hour factor.

V = hourly volume, in veh

V_{m15}= maximum 15-minute volume within the hour, in veh

Using the above formula, the PHF is calculated for each movement type at the intersection using the peak hour or high traffic volume. Table 4.15 shows the peak hour factor for each approach legged and the movement type.

Table 4-15: Peak hour factor values

Approaches /Leg	PHF
Meskel square	
Through	0.88
Right	0.91
Underpass from Meskel	0.97
Bole	
Through	0.96
Left	0.91
Underpass from bole	0.96
China street	
Right	0.94
Left	0.64

4.4.8. Travel time and Delay Analysis for Signalized T- intersection

For the analysis of the signalized intersection, the traffic volume was taken by adding the traffic volume of the road underpass and roundabout at the upper level. The result of the analyses were guided by the questions: what if the intersection was improved by traffic light? then what will be the average delay and travel time at the intersection nowadays?

Table 4-16: Input Data for the Analysis of Average Travel Time and Delay

Signalized intersection										
Wellosefer intersection					**Total traffic volume**			**Heavy vehicle factor (%)**		
Approach legged	Number of entry lane	Number of exit lane	Lane width (m)	Median width (m)	TH	LT	RT	TH	LT	RT
Meskel square	3	3	2.7	1	2257	-	651	0.46	-	0.35
Bole	4	4	2.7	1	3202	1288	-	1.04	0.4	-
China street	2	3	3.0	1	-	242	1320	-	0.6	0.93

From Table 4.16, these are the input values by adding the traffic volume at the road underpass and the traffic volume of the roundabout at the upper level. This means the geometric layout is similar for the Un-signalized intersection when the traffic light installed for the analysis. The additional parameters which are applicable only for signalized intersection were also taken such as phasing and timing in addition to traffic volume and road geometry.

4.4.8.1. Phasing and Timing

According to (Roger P.Roses, 2004), phasing represents the fundamental method by which a traffic signal accommodates the various users at an intersection in a safe and efficient manner.

The traffic signal design process should recognize and accommodate signal timing consideration to ensure the effective operation of the intersection. A robust detection system is needed for a traffic signal to be able to respond to changes in traffic conditions. Detection system sense when pedestrian and vehicles are at a traffic signal and use that information to determine who will be served next and how long the phase is served. The quality of intersection operation is mainly dependent on the relationships between the detection layout and the signal controller settings. For optimum performance, the detector layout and signal settings should be tuned to the geometry of the intersection. The tuning process consists of finding a balance between detector location (relative to stop line), detector length, passenger time and minimum green time for prevailing conditions.

In this case, split phasing is phase type for the analyses input because split phasing can be used effectively if Left turn movement are extremely heavy on opposing approaches, and both are nearly equal to the adjacent through movement critical lane volume.

On the other hand, the phase time for maximum green time, the values are taken from the MUTCD recommended value including yellow and all red time interval from commonly used value of 3 seconds and 2 seconds, respectively.

Table 4-17: Values for Maximum Green Duration

Phase	Facility Type	Maximum Green Time (Sec)
Through	Major arterial (speed limit exceed 40mph)	50 to 70
	Major arterial (speed limit 40mph or less)	40 to 60
	Minor arterial	30 to 50
	Collector, local drive way	20 to 40
Left turn	Any	15 to 30

(Source: Manual Uniform Traffic Control Design)

The facility type of the study intersection is major arterial which speed limit is exceed 40mph therefore the maximum green time is taken anaaverage of 50 sec and 70 sec 60 seconds and also it is consider the traffic volume of at the intersection.

Signal- fixed time, cycle time =165 seconds (practical cycle time)

- □ Phase time determined by the program:

    Sequence: Split Phasing

    Input Sequence: A, B, C

    Output Sequence: A, B, C

Table 4-18: Phase Time Determined using SIDRA Program

Phase	**A**	**B**	**C**
Green time (sec)	60	60	35
Yellow time (sec)	3	3	3
All-red time (sec)	2	2	2
Phase time (sec)	65	65	40
Phase split	46%	46%	20%

Figure 4.12: Diagram of Signal Phasing of Intersection

The output of the program is presented as follows, while the detailed analysis is attached in Annex B-4.

Table 4-19: Output for the Analysis of Average Delay and Travel Time for Signalized

Wellosefer Intersection Approach legged	**Average delay (second)**	**Travel time (second)**
Meskel square	700.6	548.6
Bole	154.5	168.8
Chain street	29.8	13.4
Intersection (Total)	344.3	365.0

The result indicated the average delay of 344.3 seconds that may be incurred by the motorists and communters, with corresponding travel time of 365.0 seconds. This average delay is lower than the computed value for Un-signalized intersection "before" the improvement. This support the condition, once the intersection provided with traffic signal control, there is a significant improvement of the traffic flow than the Un-signalized intersection of the study area.

4.4.9. Travel Time and Delay Analysis for the case of Roundabout only

The analysis on this part considers if the intersection is improved by a roundabout, then what will be the performance of the intersection at the present condition of traffic volume.

In this case, the underpass volume and the upper-level road traffic volume was added and add lane for the approach from Meskel square to Bole The assumptions in this analysis, all approach legged at the same level, and then increase the number of lanes and widened the width and the geometric values are taken by comprising the existing underpass and roundabout and remove the underpass road. Details of input values presented in Annex B-5.

Table 4-20: Input values for the analyses of average delay and travel time for the case of roundabout only

Roundabout										
Wellosefer intersection					**Total traffic volume**			**Heavy vehicle factor (%)**		
Approach legged	Number of entry lane	Number of exit lane	Lane width (m)	Median width (m)	TH	LT	RT	TH	LT	RT
Meskel square	4	4	3.62	1	2257	-	651	0.46	-	0.35
Bole	4	4	3.62	1	3202	1288	-	1.04	0.4	-
Chain street	3	2	3.62	1	-	242	1320	-	0.6	0.93

Table 4-21: Additional Input Values

Geometric Data	
Circulating lane width(m)	4.81
Number of Circulating lane	4
Lane length (m)	317
Island diameter(m)	20

The above Table 4.21 indicated values for the additional geometric parameters for the roundabout which were used in the Software program using HCM 2010.

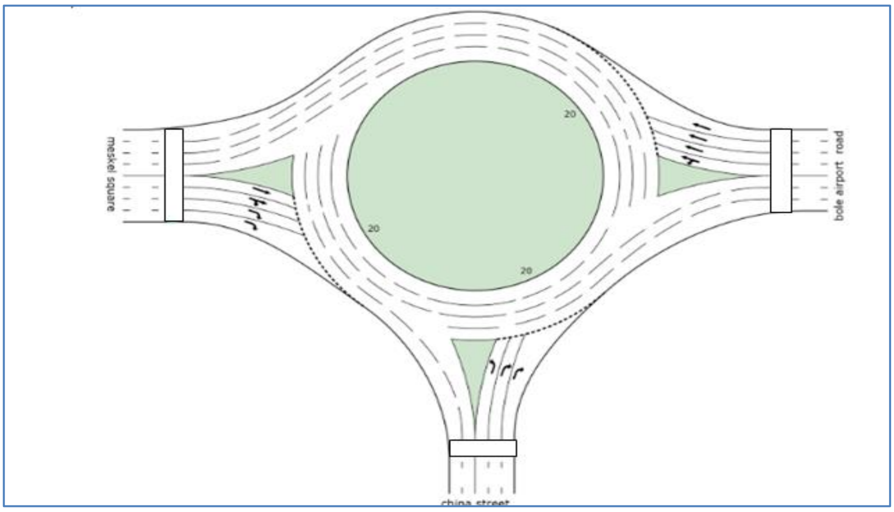


Figure 4.13: Lane layout for the case of Roundabout only

From the above figure, it showed the island diameter, number of circulating lane, number of entry lane and number of exit lanes.

Table 4-22: Output for the Analysis of Average Delay and Travel Time for roundabout only

Wellosefer Intersection Approach legged	Average delay (second)	Travel time (second)
Meskel square	453.5	368.8
Bole	8.0	44.5
China street	1250.2	362.1
Intersection (Total)	355.8	394.0

The above table showed the average delay and travel time were 355.8 seconds and 394.0 seconds, respectively. From this result, improvement of the intersection with roundabout only was not good enough to reduce the average delay and the travel time that would be experiencing by the motorists and commuters, when it compared with the Signalized T-intersection. However, in case the improvement was roundabout only, the lane width and the number of lanes had to increase to four lanes. Analyzing further by introducing additional lanes, it showed that the average delay and the travel time are still higher than the signalized one. Therefore, recommending a roundabout as improvement of the intersection is not effective for a good traffic flow.

4.4.10. Travel Time and Delay Analysis for Road Underpass With Roundabout

As described in the analysis considering “after” improvement, travel time and average delay are used as performance measures in this study.

In this case the analyses were made separately for the Roundabout at the upper level and the road underpass. The number of lanes for the underpass is two in one direction, while 2-lanes in the with 3-approach legged as shown in figure 4.14.

Figure 4.14: Intersection View after Improvement (Source: Photo Taken August 8/2017)

4.4.10.1.Travel time and Delay Analysis for Roundabout

Delay is one of the important parameters in congestion measure analysis. Delay is the amount of extra time spent in congestion compared to the time it would take under ideal or free-flow conditions. The quantity can be used to estimate the difference between system performance and the expectation for those system elements, which can be used to prioritize alternative improvement. In the case of "after" improvement, Wellosefer intersection comprising road underpass and roundabout was analyzed separately.

Table 4-23: Input Data for the Analysis of Average Delay and Travel Time

Roundabout										
Wellosefer intersection					**Total traffic volume**			**Heavy vehicle factor (%)**		
Approach legged	Number of entry lane	Number of exit lane	Lane width (m)	Median width (m)	TH	LT	RT	TH	LT	RT
Meskel square	2	2	3.62	1	414	-	651	0.46	-	0.35
Bole	2	2	3.62	1	818	1288	-	1.04	0.4	-
Chain street	2	2	3.62	1	-	242	1320	-	0.6	0.93

Table 4-24: Additional Input Values for Roundabout

Geometric Data	
Circulating lane width(m)	4.81
Circulating lane	2
Lane length (m)	317
Island diameter(m)	40

In the case of road underpass with roundabout at the upper level, the traffic volume was taken from the current condition of the intersection and additional inputs are presented in Tables 4.23 and 4.24. The condition where road underpass with roundabout was a major concern of this study. This was done by evaluating the road underpass with roundabout and compared the results with un-signalized, signalized, and roundabout only.

Table 4-25: Output for the Analysis of Average Delay and Travel Time "after" improvement

Wellosefer Intersection Approach legged	Average delay (second)	Travel time (Second)
Meskel square	8.9	6.9
Bole	9.2	18.0
Chain street	7.2	12.9
Intersection (Total)	8.5	48.1

Table 4-26: Input Values for Road Underpass

Road Underpass									
Wellosefer intersection				Total traffic volume			Heavy vehicle factor (%)		
Approach leg	Number of lanes	Lane width (m)	Median width (m)	TH	LT	RT	TH	LT	RT
Meskel square	2	3.62	1	1843	-	-	0.46	-	-
Bole	2	3.62	1	2384	-	-	1.04	-	-

The traffic flow at the road underpass is directed from Meskel square to Bole, and Bole to Meskel square comprising 2 lanes in one direction with 3.62 meters lane width. Also, the traffic volume in this case was taken from the current condition of the intersection of the underpass.

Table 4-27: Output for the Analysis of Average Delay and Travel Time at road underpass

Wellosefer Intersection Approach legged	Average delay (second)	Travel time (Second)
Meskel square to bole	0.08	11.1
Bole to Meskel square	0.11	16.9
Intersection (Total)	0.15	36.4

Based on the analysis of the current condition of the intersection, the average delay and the travel time indicated 8.5 second and 48.1 seconds, respectively. While, the average delay and the travel time of the road underpass were 0.15 second and 36.4 seconds. This revealed from the above mentioned alternatives of intersection improvements, the road underpass with roundabout is more effective than the other improvement alternatives.

4.4.12. Comparison of Average Travel Time and Average Delay based on the Type of Intersection

According to the objective of the study, the results discussed the effectiveness of a road underpass on the traffic flow, relating the different traffic control systems and improvement options at Wellosefer intersection. One of which was the provision of a traffic signal light at the intersection. Nowadays in Addis Ababa City, traffic light installations at intersections are introduced at highly congested intersections by removing the existing roundabouts. This research study provided a good indication to which improvement method would be the most effective alternative by comparing the results using options of three different types of an intersection as a basis for evaluation.

The result implied the average delay and the travel time for each type of intersection are varied as presented in table 4.28, figure 4.15 and figure 4.16 below.

Table 4-28: Average Delay and Travel Time Values for different Types of Intersection

Types of Intersection (Evaluation Alternatives)	Average Delay (Sec)	Travel Time (Sec)
1] "Before" Improvement		
Un-signalized	535.7	574.7
2] "After" Improvement		
a) Signalized	344.3	365.0
b) Roundabout only	355.8	394.0
c) Roundabout with Road Underpass	8.5	65.8

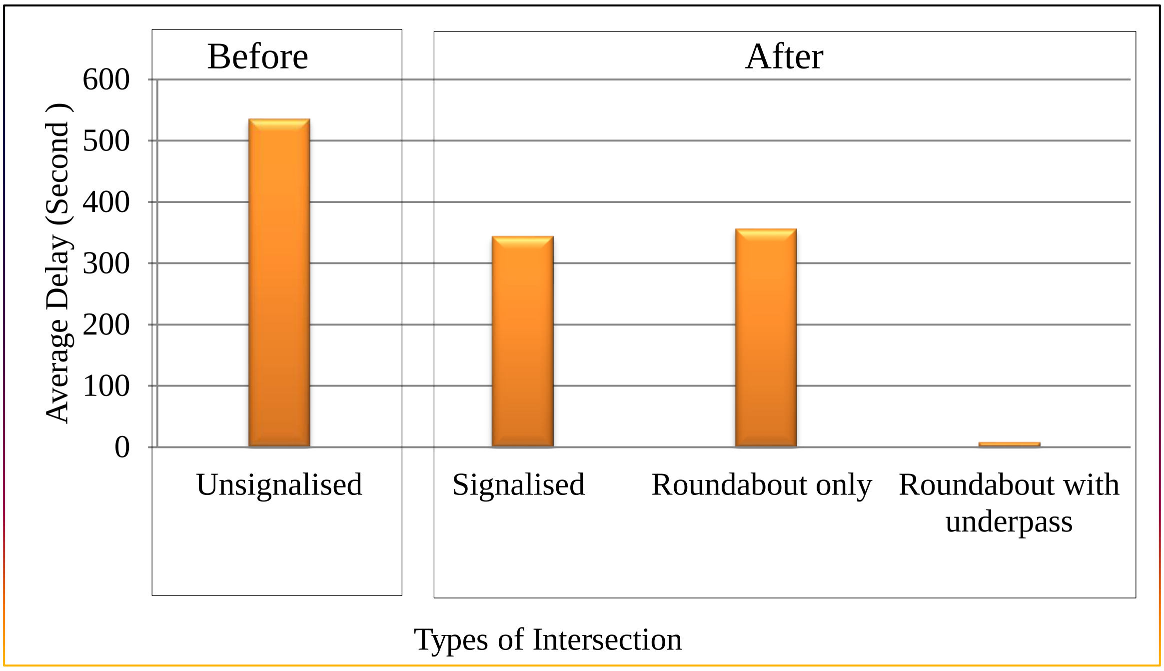


Figure 4.15: Average Delay "Before" and "After" Improvement

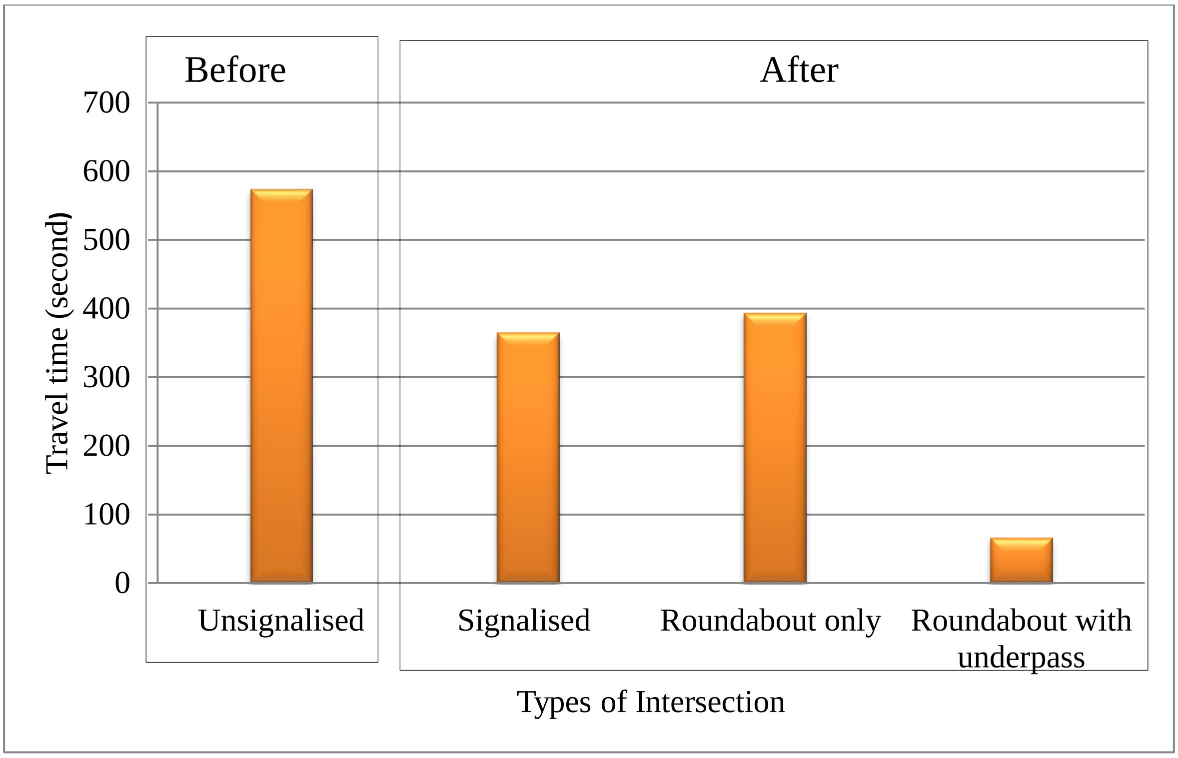


Figure 4.16: Travel Time "Before" and "After" Improvement of Wellosefer Intersection

The results from figures 4.15 and 4.16 demonstrated cases on average delay and travel time of vehicles "before" and "after" the improvement of Wellosefer intersection. The traffic condition "before" improvement considering Un-Signalized T-intersection indicated the average delay of vehicles of about 535.7 seconds, while the travel time of vehicles of about 574.7 seconds. Likewise, the case "after" improvement considering the signalized T - intersection, the average delay and travel time indicated 344.3 seconds and 365.0 seconds, respectively. This means that there was a reduction of 15.4 % in average delay when a signalized intersection had been implemented.

On the other hand, the case "after" improvement considering the existing geometric layout of Road Underpass with Roundabout at the upper level, there was a great reduction in average delay of vehicles of about 42% from the Un-Signalized T-Intersection.

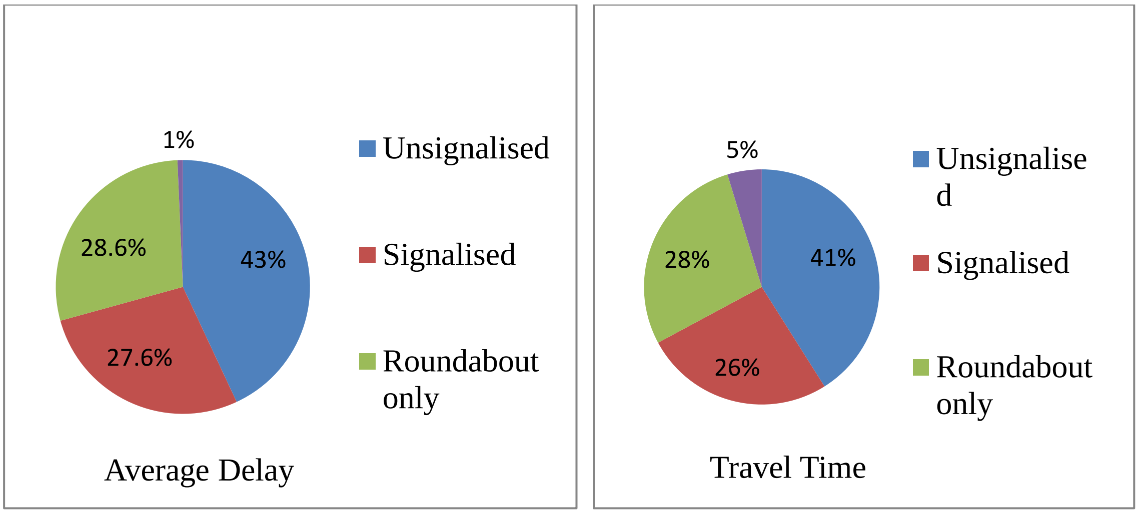


Figure 4.17: Percentage of average type and travel time for each types of intersection

Based on the above chart, the average delay demonstrated the reduction of of about 15.4 %, 14.4 % and 42 % for signalized, roundabout only, and road underpass with roundabout respectively, when these results were compared to un-signalized intersection considering the traffic volume after the improvement. On the other hand, the average travel time is reduced by 15%, 13% and 36% for signalized, roundabout only and road underpass with roundabout, respectively. This will show that a combination of road underpass with roundabout at the upper level is almost 3 times effective than the other two improvement alternatives in terms of the reduction of average delay to be incurred by the motorists.

The researcher assumed in the analysis that there was no Road Underpass of the existing Roundabout to configure traffic situation using the same traffic volume used for the case of Signalized intersection and the Road Underpass with Roundabout "after" improvement. Based on the results of the analysis for Roundabout only, the average delay of vehicles indicated a very problematic of 355.8 seconds, while the travel time is 394.0 seconds to pass the intersection. This means that it is no longer viable to use a roundabout in Wellosefer intersection at present traffic condition.

4.5 Problems At-Already Completed Underpass and Countermeasures for the intersection

In this section the general problem occurs at-already completed road underpass with roundabout at upper level is discussed. As presented in literature review there are different problems related to traffic congestion on the existing road of Addis Ababa city such as too narrow width, road side parking, unavailability of alternative roads, roadside parking, and road expansion work, operators not using the available alternative roads, poor road condition, unavailability of a traffic sign, unavailability of sufficient pedestrian walkways, entering and exiting of heavy trucks in the area, too narrow road and too many vehicles at a time. All of these are the cause of traffic congestions in Addis Ababa city (Addis Ababa Transport Bureau, 2014).

In this research, the audit covered physical features of the study area which may affect road users safety as well as causing the congestion problem. Also, it has been sought to identify potential safety hazards. For this case, site observation of the study area and informal interview with the traffic police and consultant of the road project had been conducted to identify the occurring problems at Wellosefer intersection. The guidelines used to identify problems were taken from AACRA manual,2013.

Generally the problems and countermeasures are presented as follows in tabular form.

Table 4-29: Observed problems on the existing road condition around the study area

No	Observations	Possible Countermeasures
1	Narrow entry and exit lane (it does not satisfy a minimum requirement of the recommended value in ERA manual 2013)	• The entry and exit lanes should be widen as possible to reduce conflict between vehicles.
2	No bus stop lane before the approach of Meskel square approach and china street approach (there are two lanes before and after the underpass, the bus covers entirely the one lane when stopped. It obstructed the smooth flow of traffic causing a big problem in the future.	• Provide bus stop lane separately from the major road.

3	Lack of proper shoulders which tends to reduce the level of safety of cyclists, pedestrians, and to a certain degree motorcyclist to travel on this road. (2.5m the standard)	• Provide and expand shoulder width
4	Faded road markings	• Maintain the road marking to guide the motorists
5	Insufficient visibility of traffic signs	• Install to proper location where the drivers can recognize
6	This road section may pose problems for vehicles sharing the road with slow-moving vehicles (eg., farm machinery), since passing Opportunities are limited.	• Consider upgrading and/or surfacing of shoulders; widening of lanes.
7	The intersection at Bole Street and Meskel square Street are experiencing large volumes of traffic on a daily basis, and areas of congestion regularly form during peak hours. Congestion and high traffic volume levels will continue to pose a safety issue.	• . Long-term planning should promote alternate links to connect the Meskel square to Bole direction. • . Increase signal visibility (eg. Target boards) and crosswalk visibility (eg. Zebra stripes)
8	As congestion levels at intersections increase, driver frustration often results in increased risk-taking. It is therefore important to manage congestion as effectively as possible. Congestion on Regent Street between Meskel square and Bole airport Streets are particularly acute during the evening peak hour.	• Removal of parking on Regent Street to provide additional capacity
9	The width of circulatory lane did not meet the minimum requirement of 9 meters for two lanes.	• Provide additional lane the circulatory lane if possible

10	Limited road right of way when we compare it with standard, and when we consider the increasing number of vehicles it will cause congestion at the intersection.	• Right of way should be as much as possible it have to be 50 meters
11	Conflicts between turning vehicles and parked vehicle in the direction of China street	• Make the area prohibited to park or better if the parking area has some distance from the intersection

During the observation period, photos were taken at the occurring problems which identified that will affect the smooth flow of traffic including pedestrians.

(a) Pedestrian crosswalk not visible

(b)Inadequate Entry Lane

(c)Too narrow width

(d)Improper finishing of pedestrian crosswalk

Figure 4.18: Observed problem around the intersection (Source: site observation, 2017)

Actual observations at the study area indicated that there were some occurring problems around the intersection, such as those causing obstruction or restrict the traffic flow, which are contributory to the dely of vehciles. Some of these are roadside parking on the road of China Street, and narrow width at the exit lanes of the road underpass. Such information were substantiated through informal interview from the Engineer Zewde road consulting office . This is because of the increasing population which is tantamount to the increase number of car's ownership. Hence, different countermeasures have to be implemented to minimize the foreseen problems, in addition with the above-mentioned countermeasure by the researcher.

All the above-mentioned occurring problems are based on the observations "after" improvement of Wellosefer intersection by grade-separated structure (i.e road underpass structure) with roundabout at the upper level.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research study carried out analyses of traffic flow considering cases "before" and "after" improvement of Wellosefer intersection. The case "before" improvement provided information about the results for Un-Signalized T-Intersection, while the cases "after" improvement of intersection provided results for Signalized T-Intersection, Roundabout only, and Road Underpass with Roundabout at the upper level. The presentation of analyses in Chapter four using different alternatives have been carefully evaluated its effectiveness on the condition of traffic flow at Wellosefer intersection.

Based on the findings of this research study, the following conclusions are drawn to answer the research questions:

A] A Case “Before” Improvement of Wellosefer Un-Signalized T-Intersection
Record showed that the types of vehicles, mostly affecting the traffic flow were old vehicles and slow responding drivers, which are in conflict with the other types of vehicles while maneuvering left turn and right turn movements from Bole Road, Meskel Square and China Street. Therefore, it was considered this as one factor on the occurrence of delay of vehicles in the intersection. Also, it can be substantiated the effect from the analysis, of which the intersection indicated with an average delay of vehicles of about 535.7 seconds, while the travel time of vehicles of about 574.7 seconds.

B] A Cases “After” Improvement of Wellosefer considering Signalized T-Intersection, Roundabout only, and Road Underpass with Roundabout at the upper level

The findings of the research study revealed that the case “after” improvement using traffic volume from the traffic survey conducted last August 7-11, 2017, the analysis for the Signalized T-intersection, showed the average delay and travel time indicated 344.3 seconds and 365.0 seconds, respectively. From this result, there was a 15.4% reduction in average delay when signalized intersection had been implemented in the present condition of traffic volume.

Therefore, it can be postulated that provision of traffic signal lights at the intersection will improve the operational level in terms of the reduction of average delay.
Likewise, for the case "after" improvement considering the existing geometric layout of Road Underpass with Roundabout at the upper level. Based on the findings of this study, there was a significant reduction in average delay of vehicles of about 42 % from Un-Signalized T-Intersection as the baseline for evaluation. Therefore, comparing this result with the Signalized intersection using the same traffic data, it indicated that there was a significant decrease in average delay.

More so, the researcher had extended the analysis for the case of Roundabout only considering the same traffic data gathered last August 7-11, 2017, "after" improvement had been done to check the traffic condition. Based on the results, the motorists and commuters could be experiencing average delay of about 355.8 seconds and avergae travel time of 390.0 seconds. Therefore, it would be concluded that a roundabout as improvement alternative for the current set up is not advisable. The delay of vehicles are not already within the tolerable limit at Wellosefer intersection.

Therefore, to compare the different results using different intersection design control alternatives, a combination of Road Underpass and Roundabout at the upper level has an advantage as in the case of Wellosefer intersection. It is the most effective alternative for a certain problematic intersection, but subject to some constraints such as the occurring problems observed around the study area. It can be said the intersection design controls and construction of different structures as an alternatives are not enough to make better movements of the traffic flow. It can be eased the traffic malady, but it will recur in the future. Careful and effective detailed design incorporating all factors within the project area including other intersections should be applied.

5.2 Recommendations

To ease traffic congestion and to avoid crashes at an intersection, specifically Wellosefer intersection, the researcher had been evaluated alternatives on traffic conditions with changing the geometric layout of an intersection to seek an answer whether or not such improvement is effective.

Hereunder are the recommendations to be forwarded:

To decrease the share of slow vehicles, the following two measures are recommended

- Decrease the number of old vehicles, with low acceleration capacities. Strict rules to remove old cars or separate the lane of old and slow vehicles.
- Improving of driver's response to changing situations and driver's seminar or retraining might support this measure.

Provision of Road Underpass structure with Roundabout at the upper level or Traffic signal lights at ground level with Overpass structure is very effective way to decongest traffic flow at major intersections within the road network of Addis Ababa City as evidence of the results and findings of this research study.

However, if the major intersection is still within or nearly beyond the tolerable limit of the average delay, a traffic management scheme could be recommended by providing traffic signal lights, but subject for proper monitoring and deployment of traffic enforcers in the subject intersection or area to avoid untoward incidents caused by un-discipline drivers and simply to avoid possible accidents. Also, provide sufficient number of lanes and bay length for the left turn and right turn movements so that traffic conflict will be minimized. Informative and warnings signs at least 150 meters away from stopped-line be installed to forewarn all drivers before approaching the intersection. If possible, old vehicles should not be allowed to pass the intersection during the peak hour of the day. This is because the findings revealed that heavy trucks were the most contributory vehicles to the traffic conflict within the intersection. Implementation of a Vehicle's plate number ending code from Monday to Friday will help to improve the performance of the intersection with traffic signal light control, including all intersections in Addis Ababa City. Traffic signs on prohibition of roadside parking, and provision of bus stop lane must be undertaken. Moreover, to make it better the movements within the road network, traffic rules and regulations must be strictly implemented.

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Annexes

Annex-A: Traffic Volume at the intersection "after" improvement

Table A-1:15 Minute Traffic Volume of each approach and movement type at the intersection

Date : Augest 7/2017													
Meskel square approach													
Through						Right Turn							
Time	Pc	Mini bus	Light Truck	Bus	PCU	Time	Pc	Mini bus	Light Truck	Bus	PCU	Pedistrian
7:00-7:15	19	6	1	1	37	7:00-7:15	78	21	1	1	126	124
7:15-7:30	32	5	0	0	42	7:15-7:30	82	18	0	2	124	89
7:30-7:45	30	7	2	3	59	7:30-7:45	86	34	1	0	157	98
7:45-8:00	23	3	0	2	35	7:45-8:00	74	23	0	0	120	148
8:00-8:15	14	22	0	1	61	8:00-8:15	88	47	2	1	191	235
8:15-8:30	18	20	0	1	61	8:15-8:30	104	42	1	0	191	176
8:30-8:45	43	13	0	0	69	8:30-8:45	90	34	0	0	158	68
8:45-9:00	51	12	0	0	75	8:45-9:00	98	31	0	0	160	111
9:00-9:15	53	24	1	2	110	9:00-9:15	61	28	1	0	120	56
9:15-9:30	63	27	0	0	117	9:15-9:30	57	25	0	0	107	67
9:30-9:45	55	19	0	0	93	9:30-9:45	52	30	0	0	112	94
9:45-10:00	39	26	1	0	94	9:45-10:00	58	18	0	0	94	118
10:00-10:15	25	18	1	1	67	10:00-10:15	82	11	0	0	104	74
10:15-10:30	28	21	1	0	73	10:15-10:30	80	18	1	0	119	43
10:30-10:45	20	15	0	0	50	10:30-10:45	70	12	0	0	94	35
10:45-11:00	29	13	0	0	55	10:45-11:00	76	8	1	0	95	21
11:00-11:15	26	9	0	0	44	11:00-11:15	49	5	1	1	65	35
11:15-11:30	23	13	0	1	52	11:15-11:30	44	7	0	0	58	46
11:30-11:45	18	12	0	0	42	11:30-11:45	46	9	0	0	64	28
11:45-12:00	22	8	0	0	38	11:45-12:00	35	17	0	0	69	33
12:00-12:15	10	5	0	1	23	12:00-12:15	19	17	0	0	53	20
12:15-12:30	12	10	0	0	32	12:15-12:30	23	6	0	0	35	18
12:30-12:45	16	13	1	0	45	12:30-12:45	20	15	1	0	53	11
12:45-1:00	12	7	1	0	29	12:45-1:00	28	22	0	0	72	15
1:00-1:15	32	5	0	0	42	1:00-1:15	32	20	2	0	78	20
1:15-1:30	30	10	0	0	50	1:15-1:30	41	14	0	0	69	24
1:30-1:45	38	4	1	0	49	1:30-1:45	38	18	0	0	74	23
1:45-2:00	26	7	0	0	40	1:45-2:00	32	26	0	0	84	64
2:00-2:15	19	10	0	1	42	2:00-2:15	15	5	0	0	25	76
2:15-2:30	30	8	0	0	46	2:15-2:30	26	11	0	0	48	62
2:30-2:45	28	14	0	0	56	2:30-2:45	33	7	0	0	47	88
2:45-3:00	43	15	0	0	73	2:45-3:00	27	13	0	0	53	70
3:00-3:15	33	11	0	0	55	3:00-3:15	55	16	1	1	93	44
3:15-3:30	28	5	0	0	38	3:15-3:30	58	21	0	0	100	75
3:30-3:45	33	9	0	0	51	3:30-3:45	57	13	0	0	83	124
3:45-4:00	42	7	0	0	56	3:45-4:00	62	11	0	0	84	110
4:00-4:15	39	12	0	1	66	4:00-4:15	40	23	1	1	92	91
4:15-4:30	35	16	0	0	67	4:15-4:30	56	16	0	0	88	73
4:30-4:45	45	20	0	0	85	4:30-4:45	52	11	0	1	77	96
4:45:5:00	51	18	0	0	87	4:45:5:00	58	15	1	0	91	141
5:00-5:15	50	21	1	0	95	5:00-5:15	60	17	0	0	94	281
5:15-5:30	61	18	0	0	97	5:15-5:30	67	25	0	1	120	266
5:30-5:45	52	17	0	1	89	5:30-5:45	80	22	0	0	124	240
5:45-6:00	58	26	0	0	110	5:45-6:00	77	26	0	0	129	253

China Street Approach												
Right Turn						Left Turn						
	Pc	Mini bus	Light Truck	Bus	PCU		Pc	Mini bus	Light Truck	Bus	PCU	Pedistrian
7:00-7:15	228	27	13	1	324	7:00-7:15	17	4	0	0	25	5
7:15-7:30	241	32	7	2	332	7:15-7:30	13	5	1	0	26	8
7:30-7:45	253	30	3	0	322	7:30-7:45	15	2	0	0	19	15
7:45-8:00	232	35	2	1	311	7:45-8:00	12	1	1	0	17	16
8:00-8:15	244	34	11	2	351	8:00-8:15	10	1	1	1	18	45
8:15-8:30	236	43	6	1	343	8:15-8:30	8	0	0	0	8	25
8:30-8:45	267	27	3	0	330	8:30-8:45	7	2	0	0	11	12
8:45-9:00	224	33	1	1	296	8:45-9:00	8	1	0	0	10	9
9:00-9:15	213	37	2	2	299	9:00-9:15	21	1	2	0	29	16
9:15-9:30	197	29	1	1	261	9:15-9:30	43	5	0	0	53	35
9:30-9:45	175	23	0	4	233	9:30-9:45	58	4	0	0	66	20
9:45-10:00	227	37	1	2	310	9:45-10:00	78	8	0	0	94	11
10:00-10:15	192	37	1	1	272	10:00-10:15	45	9	1	1	69	5
10:15-10:30	178	30	0	0	238	10:15-10:30	34	7	0	1	51	9
10:30-10:45	166	23	0	2	218	10:30-10:45	29	10	1	0	52	10
10:45-11:00	174	28	0	0	230	10:45-11:00	22	3	1	0	31	6
11:00-11:15	87	17	0	2	127	11:00-11:15	26	5	0	0	36	9
11:15-11:30	98	16	0	0	130	11:15-11:30	24	7	0	0	38	6
11:30-11:45	112	14	0	0	140	11:30-11:45	38	6	0	0	50	4
11:45-12:00	123	11	0	1	148	11:45-12:00	42	12	0	0	66	14
12:00-12:15	57	19	1	1	101	12:00-12:15	44	10	0	0	64	8
12:15-12:30	45	13	0	0	71	12:15-12:30	33	13	0	0	59	5
12:30-12:45	36	12	0	0	60	12:30-12:45	20	8	0	0	36	1
12:45-1:00	27	9	0	1	48	12:45-1:00	27	14	0	0	55	13
1:00-1:15	54	14	1	0	85	1:00-1:15	30	15	0	0	60	18
1:15-1:30	84	10	0	1	107	1:15-1:30	25	11	0	0	47	6
1:30-1:45	77	12	0	0	101	1:30-1:45	31	9	0	0	49	20
1:45-2:00	83	6	0	0	95	1:45-2:00	36	21	0	0	78	3
2:00-2:15	81	8	1	1	103	2:00-2:15	34	20	0	0	74	9
2:15-2:30	69	15	2	0	105	2:15-2:30	31	16	0	0	63	11
2:30-2:45	92	11	0	0	114	2:30-2:45	38	14	0	0	66	10
2:45-3:00	79	16	0	0	111	2:45-3:00	48	12	0	0	72	7
3:00-3:15	111	21	2	2	165	3:00-3:15	88	17	1	0	125	4
3:15-3:30	113	24	1	2	170	3:15-3:30	93	9	0	0	111	15
3:30-3:45	118	26	1	1	176	3:30-3:45	103	8	0	0	119	22
3:45-4:00	130	37	3	2	219	3:45-4:00	96	5	1	0	109	18
4:00-4:15	175	38	1	1	257	4:00-4:15	71	9	0	0	89	26
4:15-4:30	197	33	0	1	266	4:15-4:30	65	11	0	0	87	23
4:30-4:45	167	29	1	0	228	4:30-4:45	56	14	0	0	84	9
4:45:5:00	160	40	0	0	240	4:45:5:00	52	13	0	0	78	10
5:00-5:15	208	28	2	0	270	5:00-5:15	32	12	0	1	59	14
5:15-5:30	210	22	1	1	260	5:15-5:30	30	16	0	0	62	21
5:30-5:45	223	34	2	0	297	5:30-5:45	29	18	1	0	68	17
5:45-6:00	238	42	2	0	328	5:45-6:00	23	21	0	0	65	35

Bole Approach												
Through						Left Turn						Pedistrian
	Pc	Mini bus	Light Truck	Bus	PCU		Pc	Mini bus	Light Truck	Bus	PCU	
7:00-7:15	115	23	4	1	176	7:00-7:15	87	19	0	0	125	60
7:15-7:30	121	24	5	2	190	7:15-7:30	89	20	1	0	132	50
7:30-7:45	113	29	7	0	192	7:30-7:45	94	24	0	0	142	82
7:45-8:00	117	34	4	0	197	7:45-8:00	90	22	0	0	134	95
8:00-8:15	125	28	3	2	196	8:00-8:15	97	4	11	0	138	100
8:15-8:30	130	31	4	1	207	8:15-8:30	104	6	0	0	116	42
8:30-8:45	140	30	2	2	212	8:30-8:45	110	3	1	0	119	63
8:45-9:00	136	32	1	0	203	8:45-9:00	119	1	0	0	121	36
9:00-9:15	72	51	2	0	180	9:00-9:15	128	24	2	0	182	54
9:15-9:30	50	50	1	0	153	9:15-9:30	159	26	1	0	214	57
9:30-9:45	60	55	0	1	173	9:30-9:45	170	41	0	0	252	65
9:45-10:00	54	59	1	0	175	9:45-10:00	87	48	1	0	186	44
10:00-10:15	76	34	2	1	153	10:00-10:15	81	57	2	1	204	26
10:15-10:30	84	31	1	0	149	10:15-10:30	82	68	1	0	221	23
10:30-10:45	91	21	1	0	136	10:30-10:45	68	74	2	0	222	14
10:45-11:00	82	26	1	0	137	10:45-11:00	98	84	2	0	272	22
11:00-11:15	49	18	0	0	85	11:00-11:15	93	49	0	0	191	18
11:15-11:30	37	25	1	0	90	11:15-11:30	91	44	0	0	179	11
11:30-11:45	30	22	1	0	77	11:30-11:45	86	39	1	0	167	24
11:45-12:00	36	21	0	0	78	11:45-12:00	84	41	0	0	166	14
12:00-12:15	73	23	1	0	122	12:00-12:15	80	16	1	0	115	12
12:15-12:30	76	27	0	0	130	12:15-12:30	77	21	0	0	119	6
12:30-12:45	84	38	0	0	160	12:30-12:45	75	14	0	0	103	14
12:45-1:00	88	42	1	0	175	12:45-1:00	104	12	0	0	128	19
1:00-1:15	55	26	0	1	110	1:00-1:15	116	7	1	1	136	15
1:15-1:30	47	28	0	0	103	1:15-1:30	143	11	2	0	171	22
1:30-1:45	51	17	0	0	85	1:30-1:45	185	9	0	0	203	34
1:45-2:00	52	20	0	0	92	1:45-2:00	104	8	0	0	120	45
2:00-2:15	57	38	1	2	142	2:00-2:15	194	22	0	0	238	38
2:15-2:30	53	35	0	0	123	2:15-2:30	192	28	0	0	248	49
2:30-2:45	48	37	0	0	122	2:30-2:45	197	33	0	0	263	40
2:45-3:00	38	42	0	0	122	2:45-3:00	208	26	0	0	260	24
3:00-3:15	79	47	2	1	182	3:00-3:15	197	35	0	1	270	45
3:15-3:30	93	50	0	2	199	3:15-3:30	195	42	0	0	279	73
3:30-3:45	90	55	0	1	203	3:30-3:45	191	48	0	0	287	64
3:45-4:00	96	61	0	0	218	3:45-4:00	188	39	0	0	266	57
4:00-4:15	87	63	1	1	219	4:00-4:15	209	34	2	0	283	48
4:15-4:30	80	61	2	0	208	4:15-4:30	239	30	1	0	302	53
4:30-4:45	76	64	1	2	213	4:30-4:45	268	38	1	1	350	76
4:45:5:00	78	70	1	0	221	4:45:5:00	263	42	2	0	353	148
5:00-5:15	81	69	0	1	222	5:00-5:15	269	12	1	0	296	144
5:15-5:30	83	72	0	0	227	5:15-5:30	275	16	2	0	313	130
5:30-5:45	75	64	1	0	206	5:30-5:45	280	20	1	1	326	149
5:45-6:00	85	70	0	0	225	5:45-6:00	278	22	1	0	325	118

From Bole underpass						From Meskel square underpass					
Through						Through					
Time interval	Pc	Mini bus	Light Trucl	Bus	PCU	Time interval	Pc	Mini bus	Light Trucl	Bus	PCU
7:00-7:15	378	61	3	2	515	7:00-7:15	240	38	5	1	334
7:15-7:30	412	57	2	3	541	7:15-7:30	246	46	3	3	356
7:30-7:45	420	66	4	0	564	7:30-7:45	252	51	4	1	369
7:45-8:00	466	63	2	2	604	7:45-8:00	263	62	5	1	405
8:00-8:15	468	55	4	2	596	8:00-8:15	224	56	3	2	351
8:15-8:30	453	48	5	0	564	8:15-8:30	233	64	7	1	385
8:30-8:45	374	52	3	1	490	8:30-8:45	230	53	2	0	342
8:45-9:00	384	65	2	0	520	8:45-9:00	235	67	1	1	375
9:00-9:15	436	63	2	1	571	9:00-9:15	238	96	2	2	442
9:15-9:30	433	72	1	1	583	9:15-9:30	243	104	4	0	463
9:30-9:45	429	84	4	0	609	9:30-9:45	231	110	3	2	466
9:45-10:00	434	92	1	0	621	9:45-10:00	239	115	1	0	472
10:00-10:15	379	89	1	1	563	10:00-10:15	202	66	1	2	343
10:15-10:30	388	85	2	2	570	10:15-10:30	180	73	2	1	335
10:30-10:45	420	81	3	2	597	10:30-10:45	176	81	3	2	353
10:45-11:00	417	91	0	0	599	10:45-11:00	173	90	1	0	356
11:00-11:15	226	61	2	2	360	11:00-11:15	151	40	2	2	243
11:15-11:30	237	66	1	2	378	11:15-11:30	166	37	1	0	243
11:30-11:45	210	52	0	0	314	11:30-11:45	173	53	0	0	279
11:45-12:00	216	56	0	0	328	11:45-12:00	182	46	0	0	274
12:00-12:15	185	29	0	1	246	12:00-12:15	129	15	2	0	165
12:15-12:30	191	32	0	0	255	12:15-12:30	132	21	0	0	174
12:30-12:45	162	18	0	0	198	12:30-12:45	144	23	0	0	190
12:45-1:00	192	17	0	0	226	12:45-1:00	135	25	0	0	185
1:00-1:15	197	37	1	2	280	1:00-1:15	147	29	1	1	211
1:15-1:30	203	40	0	0	283	1:15-1:30	153	34	0	0	221
1:30-1:45	211	43	0	0	297	1:30-1:45	142	38	0	0	218
1:45-2:00	199	46	0	0	291	1:45-2:00	164	24	0	0	212
2:00-2:15	205	40	2	3	300	2:00-2:15	120	28	3	1	188
2:15-2:30	214	36	0	0	286	2:15-2:30	131	30	4	0	203
2:30-2:45	198	45	2	1	297	2:30-2:45	138	27	2	0	198
2:45-3:00	203	52	0	0	307	2:45-3:00	133	26	1	1	191
3:00-3:15	229	51	1	1	337	3:00-3:15	157	58	4	2	291
3:15-3:30	243	53	0	2	355	3:15-3:30	172	63	5	3	322
3:30-3:45	259	49	3	0	366	3:30-3:45	183	67	1	2	326
3:45-4:00	264	57	0	0	378	3:45-4:00	174	59	2	2	304
4:00-4:15	318	58	2	2	446	4:00-4:15	198	80	1	2	367
4:15-4:30	339	65	3	3	487	4:15-4:30	219	85	3	3	407
4:30-4:45	398	86	1	1	576	4:30-4:45	248	97	2	3	457
4:45:5:00	364	92	2	2	560	4:45:5:00	272	89	2	1	459
5:00-5:15	382	95	3	2	587	5:00-5:15	244	57	2	1	367
5:15-5:30	379	86	2	0	557	5:15-5:30	234	60	3	2	369
5:30-5:45	388	88	1	0	567	5:30-5:45	250	49	2	0	354
5:45-6:00	375	93	3	2	576	5:45-6:00	247	56	3	2	374

Annex - B. Input and Output Data's for the Analyses

Annex - B-1 InputDataforBefore (Un-Signalized)

Intersection Parameters	
Title	unsignalised corrected 2
Intersection ID	1
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	30 minutes

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	china street	Two-way	3	2	2.00	0.0
East	bole	Two-way	4	3	–	0.0
West	meskel square	Two-way	3	4	–	0.0

Geometry - Approach Lane Data

Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
South china street						
App. Lane 1	Normal	L	1800	–	–	0.0
App. Lane 2	Normal	R	1800	–	–	0.0
App. Lane 3	Normal	R	1800	–	–	0.0
East bole						
App. Lane 1	Normal	LT	1800	–	–	0.0
App. Lane 2	Normal	T	1800	–	–	0.0
App. Lane 3	Normal	T	1800	–	–	0.0
App. Lane 4	Normal	T	1800	–	–	0.0
West meskel square						
App. Lane 1	Normal	T	1800	–	–	0.0
App. Lane 2	Normal	TR	1800	–	–	0.0
App. Lane 3	Normal	R	1800	–	–	0.0

Geometry - Approach & Exit Lane Data

Lane Number		Lane Width m	Lane Length m	Grade %	SL Type
South	china street				
App. Lane 1		3.00	500.0	0.00	–
App. Lane 2		3.00	500.0	0.00	–
App. Lane 3		3.00	500.0	0.00	–
Exit Lane 1		3.30	500.0	0.00	–
Exit Lane 2		3.30	500.0	0.00	–
East	bole				
App. Lane 1		2.70	500.0	0.00	–
App. Lane 2		3.30	500.0	0.00	–
App. Lane 3		3.30	500.0	0.00	–
App. Lane 4		3.30	500.0	0.00	–
Exit Lane 1		3.30	500.0	0.00	–
Exit Lane 2		3.30	500.0	0.00	–
Exit Lane 3		3.30	500.0	0.00	–
West	meskel square				
App. Lane 1		2.70	500.0	0.00	–
App. Lane 2		3.30	500.0	0.00	–
App. Lane 3		3.30	500.0	0.00	–
Exit Lane 1		3.30	500.0	0.00	–
Exit Lane 2		3.30	500.0	0.00	–
Exit Lane 3		3.30	500.0	0.00	–
Exit Lane 4		3.30	500.0	0.00	–

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South	china street					
West	212.0	3.00	95.0	1.20	100.00	6.68
East	132.0	3.00	95.0	1.20	100.00	6.68
From: East	bole					
South	575.0	3.00	95.0	1.20	100.00	6.68
West	596.0	2.00	95.0	1.20	100.00	6.68
From: West	meskel square					
East	1832.0	2.00	95.0	1.20	100.00	6.68
South	130.0	3.00	95.0	1.20	100.00	6.68

Gap Acceptance

Movement		Critical Gap sec	Follow-up Headway sec	Min. Departures veh/min	Exiting Flow Effect %
South	china street				
L		5.500	3.000	1.00	50
R		4.500	3.000	1.00	50
East	bole				
L		5.500	3.000	1.00	0
T		4.500	2.500	1.00	0
West	meskel square				
T		4.500	2.500	1.00	0
R		4.500	2.500	1.00	0

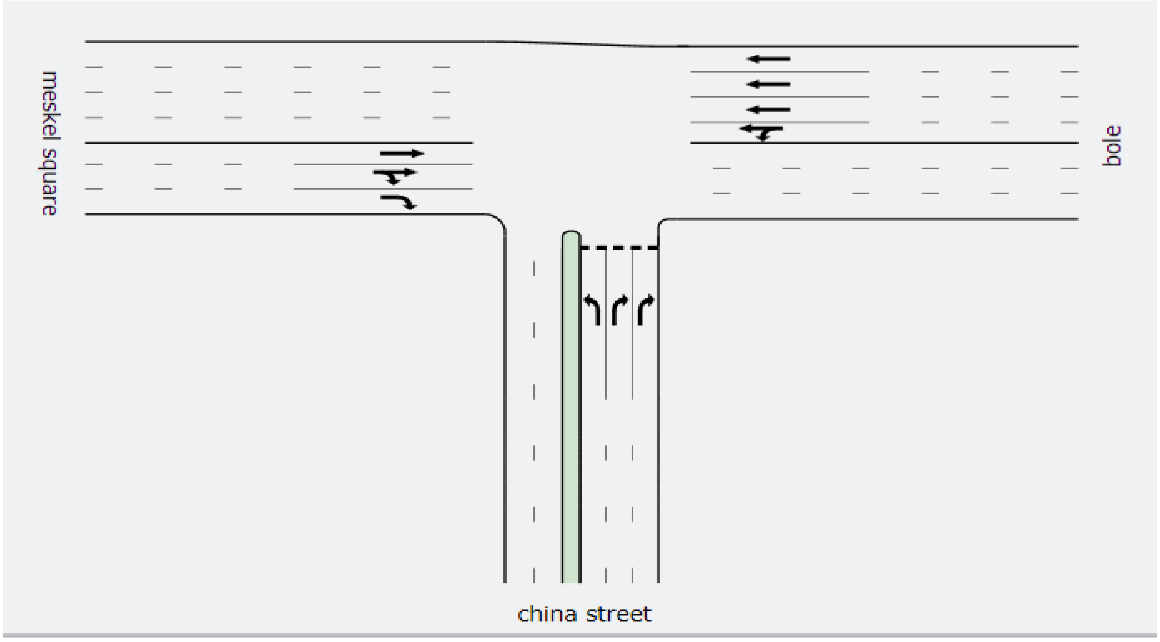


Figure 1: Layout for un-signalized intersection

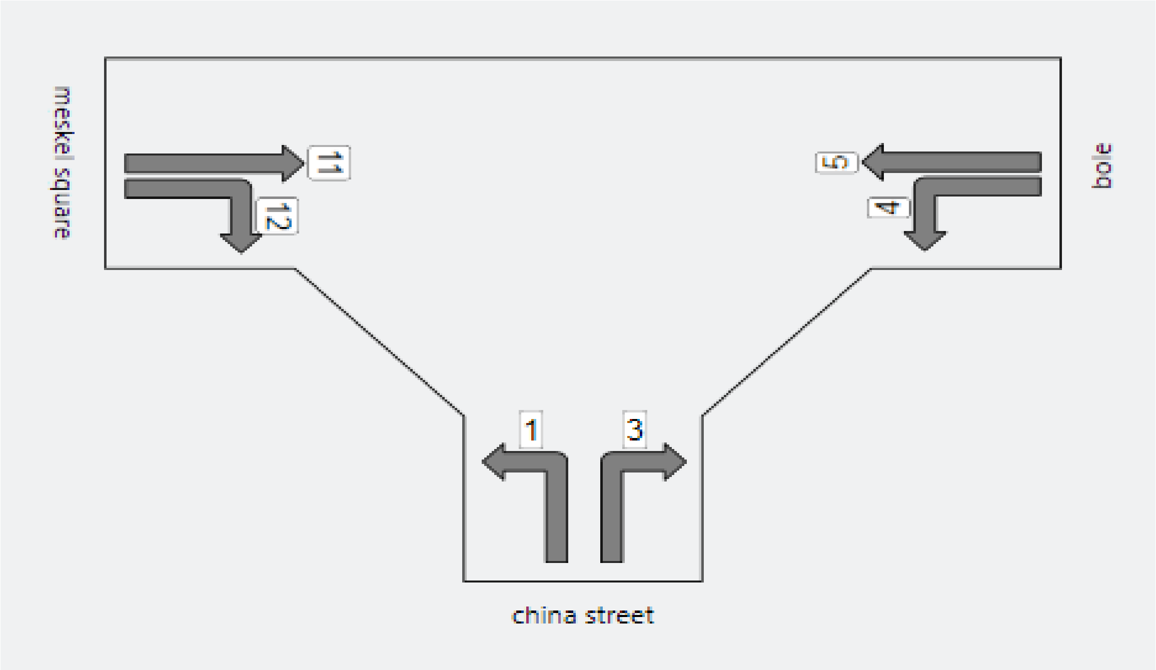


Figure 2: Intersection Movement ID of un–signalized Intersection

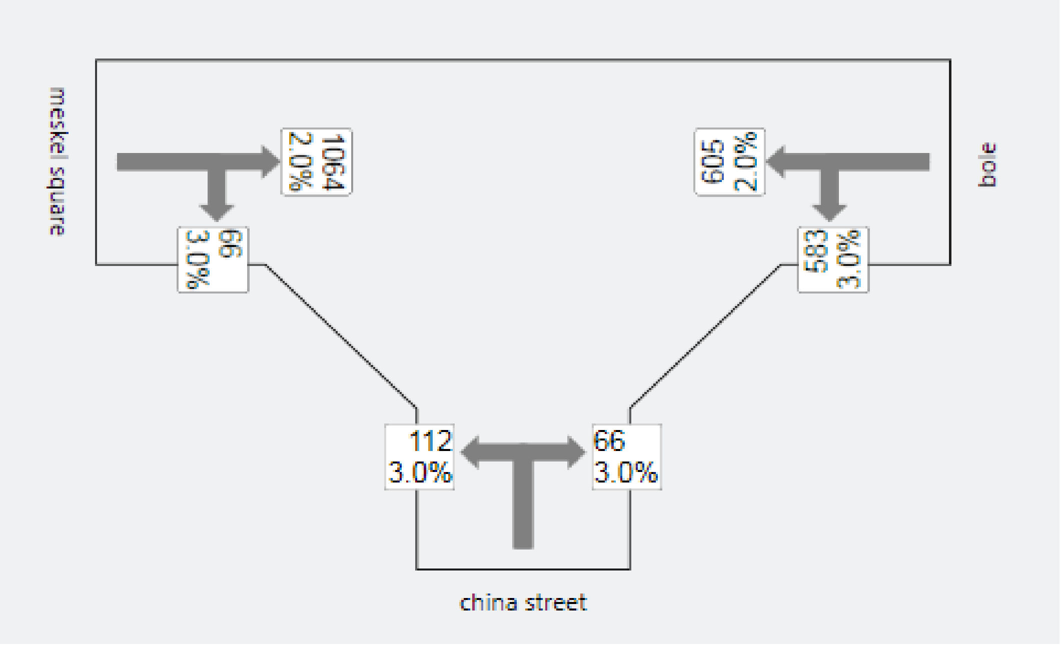


Figure 3: Traffic Volume Distribution and Truck Percentage at Intersection

Annex - B-2: Output of the Analyses for Un- signalized

Intersection Performance - Hourly Values		
Performance Measure	**Vehicles**	**Persons**
Demand Flows (Total)	2627 veh/h	3153 pers/h
Percent Heavy Vehicles	2.3 %	
Degree of Saturation	3.255	
Practical Spare Capacity	-75.4 %	
Effective Intersection Capacity	807 veh/h	
Control Delay (Total)	390.97 veh-h/h	469.16 pers-h/h
Control Delay (Average)	535.7 sec	535.7 sec
Control Delay (Worst Lane)	2067.4 sec	
Control Delay (Worst Movement)	2067.4 sec	2067.4 sec
Geometric Delay (Average)	P sec	
Stop-Line Delay (Average)	P sec	
Intersection Level of Service (LOS)	NA	
95% Back of Queue - Vehicles (Worst Lane)	277.8 veh	
95% Back of Queue - Distance (Worst Lane)	1994.3 m	
Total Effective Stops	7166 veh/h	8599 pers/h
Effective Stop Rate	2.73 per veh	2.73 per pers
Proportion Queued	0.76	0.76
Performance Index	598.5	598.5
Travel Distance (Total)	1586.6 veh-km/h	1903.9 pers-km/h
Travel Distance (Average)	604 m	604 m
Travel Time (Total)	419.4 veh-h/h	503.3 pers-h/h
Travel Time (Average)	574.7 sec	574.7 sec
Travel Speed	3.8 km/h	3.8 km/h
Cost (Total)	12009.57 $/h	12009.57 $/h
Fuel Consumption (Total)	725.7 L/h	
Carbon Dioxide (Total)	1816.3 kg/h	
Hydrocarbons (Total)	3.908 kg/h	
Carbon Monoxide (Total)	61.63 kg/h	
NOx (Total)	2.003 kg/h	

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: china street											
1	L	118	3.0	1.503	1913.4	LOS F	103.7	744.8	1.00	8.59	1.0
3	R	69	3.0	0.038	5.5	LOS A	0.0	0.0	0.00	0.57	40.1
Approach		187	3.0	1.503	1206.0	LOS F	103.7	744.8	0.63	5.62	1.6
East: bole											
4	L	614	3.0	1.000[4]	10.0	LOS B	3.7	26.6	1.00	0.80	44.8
5	T	637	2.0	0.110	0.0	LOS A	0.0	0.0	0.00	0.00	60.0
Approach		1251	2.5	1.000	4.9	NA	3.7	26.6	0.49	0.39	51.4
West: meskel square											
11	T	1120	2.0	0.865	18.2	LOS C	12.5	89.0	0.90	1.63	37.8
12	R	69	3.0	0.038	8.3	LOS A	0.0	0.0	0.00	0.67	49.0
Approach		1189	2.1	0.865	17.6	NA	12.5	89.0	0.85	1.57	38.3
All Vehicles		2627	2.3	1.503	96.3	NA	103.7	744.8	0.66	1.30	16.1

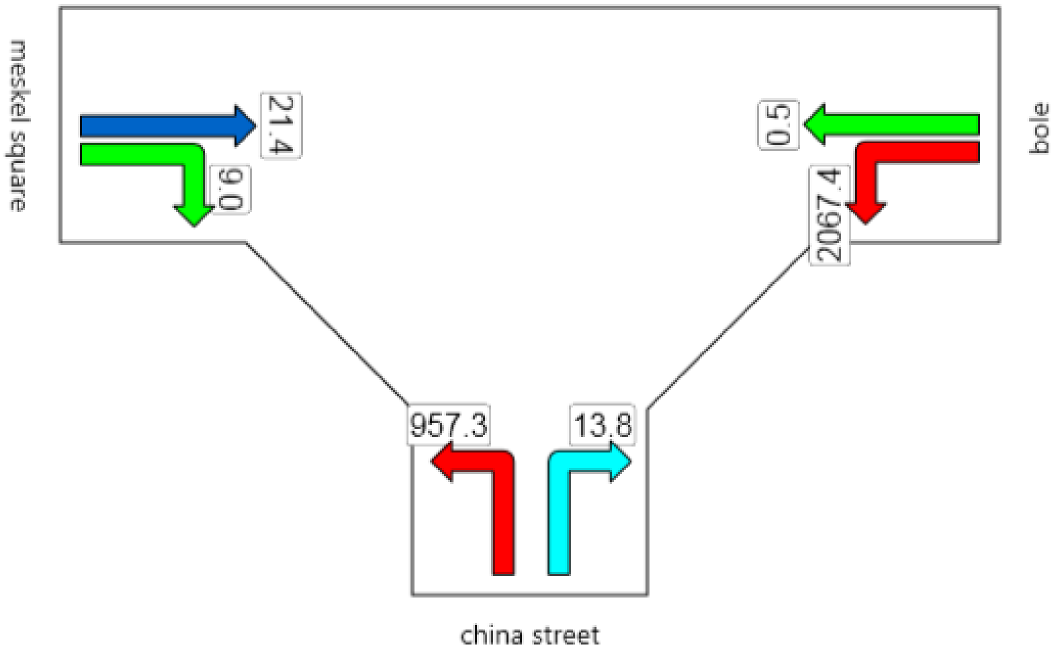


Figure 4: Average delay for un-signalized intersection

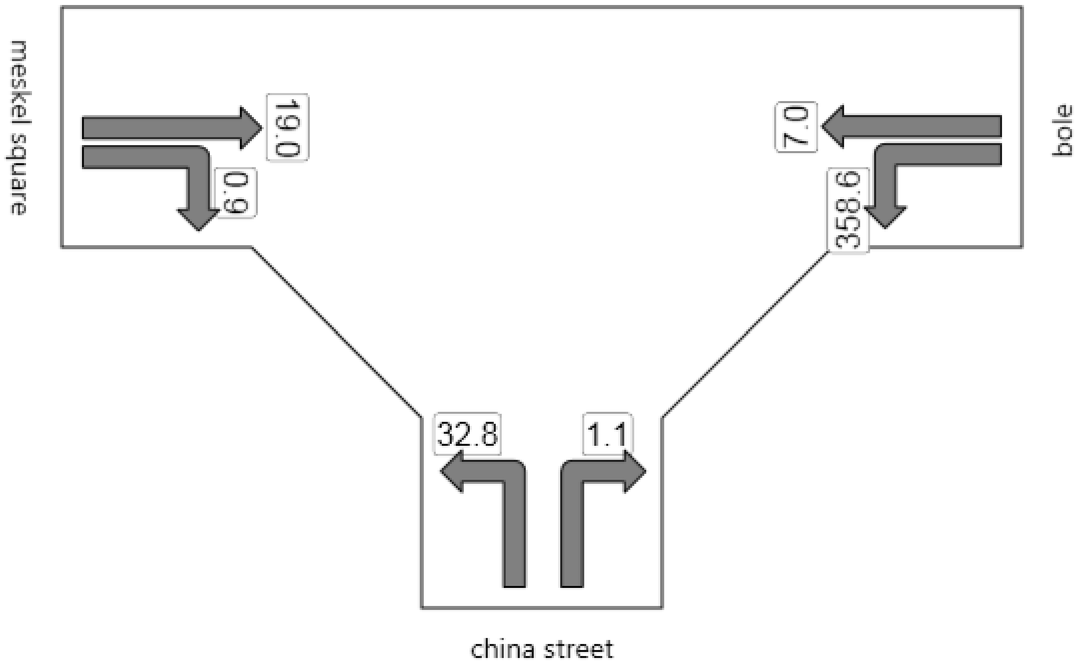


Figure 5: Average travel time for un-signalized intersection

Annex - B-3: Input Data for Signalized Intersection

Intersection Parameters	
Title	signalised
Intersection ID	1
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	30 minutes
Signal Analysis Method	Fixed Time

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	china street	Two-way	3	2	2.00	0.0
East	bole	Two-way	4	3	2.00	0.0
West	meskel square	Two-way	3	4	2.00	0.0

Geometry - Approach Lane Data - Signalised

Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %	Buses Stopping veh/h	Parking Man. veh/h	SL Green Constraint	Free Queue L veh	Free Queue T veh	Free Queue R veh
South	china street											
App. Lane 1	Normal	L	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 2	Normal	R	1800	–	–	0.0	–	0	No	0	0	0
App. Lane 3	Normal	R	1800	–	–	0.0	–	–	No	0	0	0
East	bole											
App. Lane 1	Normal	LT	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 2	Normal	T	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 3	Normal	T	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 4	Normal	T	1800	–	–	0.0	–	–	No	0	0	0
West	meskel square											
App. Lane 1	Normal	T	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 2	Normal	T	1800	–	–	0.0	–	–	No	0	0	0
App. Lane 3	Normal	TR	1800	–	–	0.0	–	–	No	0	0	0

Geometry - Approach & Exit Lane Data

Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South	china street			
App. Lane 1	3.30	200.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
App. Lane 3	3.62	200.0	2.00	–
Exit Lane 1	3.30	500.0	0.00	–
Exit Lane 2	3.30	500.0	0.00	–
East	bole			
App. Lane 1	2.70	500.0	0.00	–
App. Lane 2	3.30	500.0	0.00	–
App. Lane 3	3.62	500.0	0.00	–
App. Lane 4	3.30	500.0	0.00	–
Exit Lane 1	3.30	500.0	0.00	–
Exit Lane 2	3.30	500.0	0.00	–
Exit Lane 3	3.30	500.0	0.00	–
West	meskel square			
App. Lane 1	2.70	500.0	0.00	–
App. Lane 2	3.30	500.0	0.00	–
App. Lane 3	3.30	500.0	0.00	–
Exit Lane 1	3.30	500.0	0.00	–
Exit Lane 2	3.30	500.0	0.00	–
Exit Lane 3	3.30	500.0	0.00	–
Exit Lane 4	3.62	500.0	0.00	–

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South	china street					
West	242.0	0.60	64.0	1.20	100.00	6.68
East	1320.0	0.93	94.0	1.20	100.00	6.68
From: East	bole					
South	1288.0	0.40	91.0	1.20	100.00	6.68
West	3202.0	1.04	97.0	1.20	100.00	6.68
From: West	meskel square					
East	2257.0	0.46	97.0	1.20	100.00	6.68
South	651.0	0.35	91.0	1.20	100.00	6.68

Gap Acceptance

Movement		Critical Gap sec	Follow-up Headway sec	End Departures veh	Exiting Flow Effect %
South	china street				
L		5.500	3.000	2.20	0
R		4.500	3.000	2.50	0
East	bole				
L		5.500	3.000	2.20	0
West	meskel square				
R		4.000	2.000	2.50	0

Phasing Data

Current Sequence: Split Phasing

Name	Phase Time sec	Yellow Time sec	All-Red Time sec	Dummy Movement Parameters: Specified	Min Green sec	Max Green sec	Movements Running in Phase: S	SE	E	NE	N	NW	W	SW
A	0	3	2	Yes	50	70	–	–	T	–	–	–	TR,P7	–
B	0	3	2	Yes	50	70	R	–	LT,P3	–	–	–	–	–
C	0	3	2	Yes	50	70	LR,P1	–	–	–	–	–	R	–

Sequence Data

Current Sequence	Split Phasing
Cycle Time Option	Practical Cycle Time
Max Cycle Time	150 sec
Cycle Rounding	10 sec
Green Split Option	
Green Split Priority	No

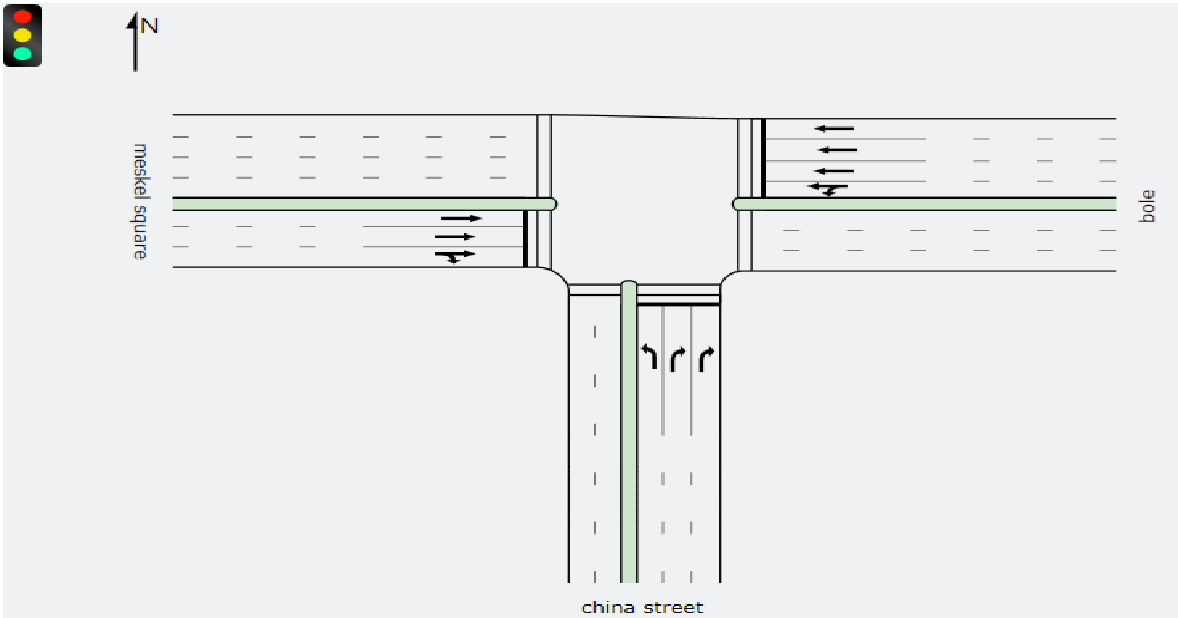


Figure 6: **Layout for signalized intersection**

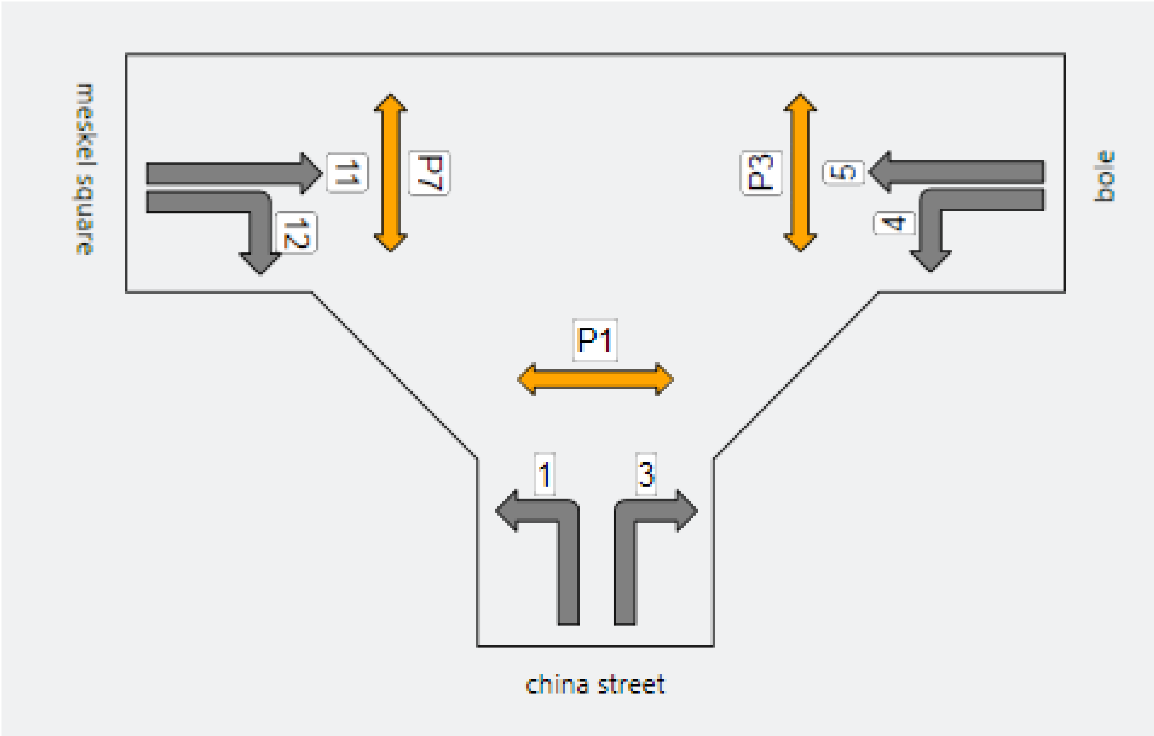


Figure 7: **Intersection Movement ID of Intersection**

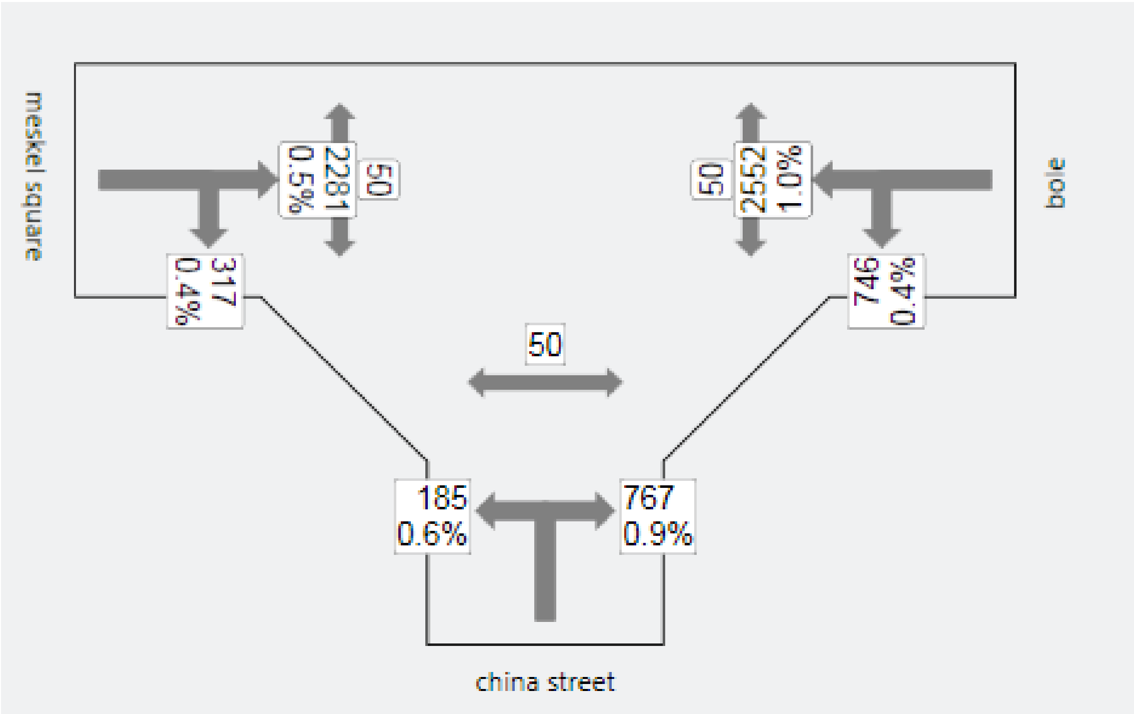


Figure 8: **Traffic Volume Distribution and Truck Percentage at Intersection**

Annex - B-4: Output Data for Signalized T - Intersection

Intersection Performance - Hourly Values

Performance Measure	Vehicles	Pedestrians	Persons
Demand Flows (Total)	7208 veh/h	159 ped/h	8809 pers/h
Percent Heavy Vehicles	0.7 %		
Degree of Saturation	1.691	0.024	
Practical Spare Capacity	-46.8 %		
Effective Intersection Capacity	4263 veh/h		
Control Delay (Total)	689.50 veh-h/h	2.38 ped-h/h	829.78 pers-h/h
Control Delay (Average)	344.3 sec	53.9 sec	339.1 sec
Control Delay (Worst Lane)	710.7 sec		
Control Delay (Worst Movement)	702.6 sec	55.2 sec	702.6 sec
Geometric Delay (Average)	2.4 sec		
Stop-Line Delay (Average)	342.0 sec		
Intersection Level of Service (LOS)	LOS F	LOS E	
95% Back of Queue - Vehicles (Worst Lane)	237.5 veh		
95% Back of Queue - Distance (Worst Lane)	1668.7 m		
Total Effective Stops	11188 veh/h	128 ped/h	13554 pers/h
Effective Stop Rate	1.55 per veh	0.81 per ped	1.54 per pers
Proportion Queued	0.86	0.81	0.86
Performance Index	1439.9	4.6	1444.5
Travel Distance (Total)	2209.8 veh-km/h	7.1 ped-km/h	2659.0 pers-km/h
Travel Distance (Average)	307 m	45 m	302 m
Travel Time (Total)	730.8 veh-h/h	3.9 ped-h/h	880.9 pers-h/h
Travel Time (Average)	365.0 sec	88.4 sec	360.0 sec
Travel Speed	3.0 km/h	1.8 km/h	3.0 km/h
Cost (Total)	21434.79 $/h	82.04 $/h	21516.82 $/h
Fuel Consumption (Total)	1342.9 L/h		
Carbon Dioxide (Total)	3357.8 kg/h		
Hydrocarbons (Total)	7.460 kg/h		
Carbon Monoxide (Total)	159.33 kg/h		
NOx (Total)	4.348 kg/h		

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: china street											
1	L	195	0.6	0.377	56.2	LOS E	12.2	86.0	0.84	0.81	14.9
3	R	807	0.9	0.388	23.4	LOS C	16.0	113.0	0.52	0.79	26.3
Approach		1002	0.9	0.388	29.8	LOS C	16.0	113.0	0.58	0.79	22.8
East: bole											
4	L	785	0.4	1.565	604.7	LOS F	188.3	1322.2	1.00	1.90	1.8
5	T	2686	1.0	0.783	22.9	LOS C	51.6	364.2	0.79	0.74	25.0
Approach		3472	0.9	1.565	154.5	LOS F	188.3	1322.2	0.84	1.00	6.3
West: meskel square											
11	T	2401	0.5	1.691	702.6	LOS F	237.5	1668.7	1.00	2.60	1.5
12	R	334	0.4	1.691	686.6	LOS F	211.2	1484.1	1.00	2.04	1.6
Approach		2735	0.4	1.691	700.6	LOS F	237.5	1668.7	1.00	2.53	1.5
All Vehicles		7208	0.7	1.691	344.3	LOS F	237.5	1668.7	0.86	1.55	3.0

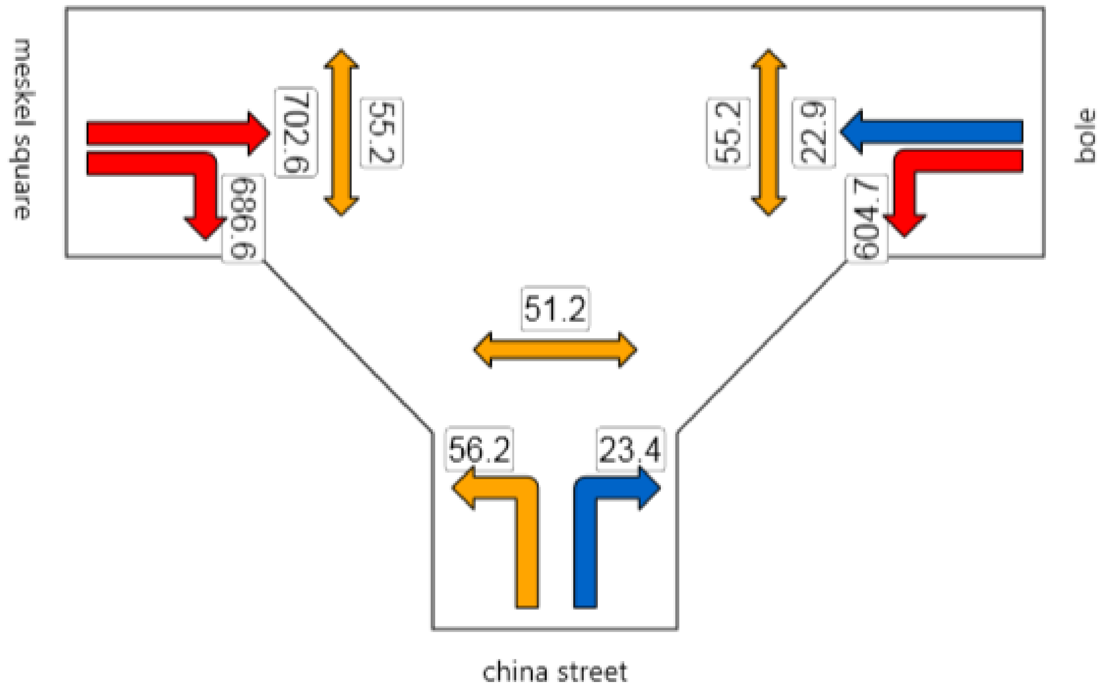


Figure 9: **Average delay for signalized intersection**

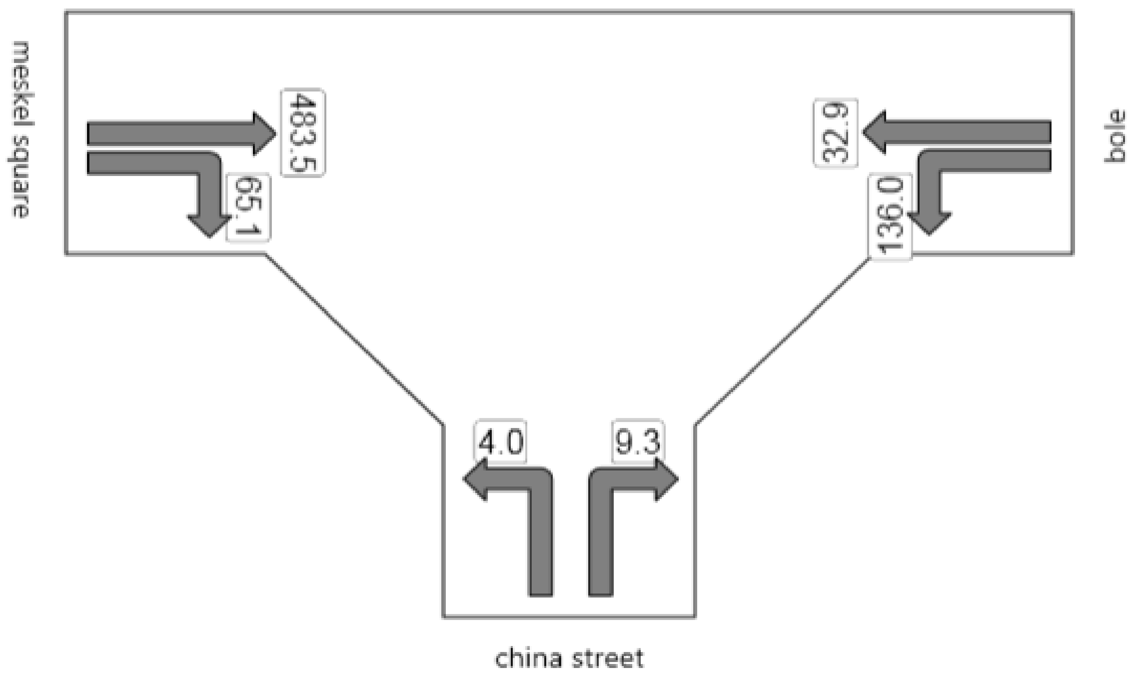


Figure 10: **Average travel time for signalized intersection**

Annex - B-5: Input data In Roundabout only case

Intersection Parameters	
Title	roundabout only
Intersection ID	1
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	30 minutes

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	china street	Two-way	3	2	2.00	0.0
East	bole airport road	Two-way	4	3	2.00	0.0
West	meskel square	Two-way	4	4	-	0.0

Geometry - Roundabout Data

Location	Name	Island Diameter m	Circ. Width m	Circ. Lanes	Entry Radius m	Entry Angle degrees	Env. Factor	Entry/Circ. Flow Adjust.
South	china street	20.00	19.24	4	20.0	30.0	1.0000	Medium
East	bole airport road	20.00	19.24	4	20.0	30.0	1.0000	Medium
West	meskel square	20.00	19.24	4	20.0	30.0	1.0000	Medium

Geometry - Approach & Exit Lane Data

Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South china street				
App. Lane 1	3.62	500.0	0.00	-
App. Lane 2	3.62	500.0	0.00	-
App. Lane 3	3.62	500.0	0.00	-
Exit Lane 1	3.62	500.0	0.00	-
Exit Lane 2	3.62	500.0	0.00	-
East bole airport road				
App. Lane 1	3.62	500.0	0.00	-
App. Lane 2	3.62	500.0	0.00	-
App. Lane 3	3.62	500.0	0.00	-
App. Lane 4	3.62	500.0	0.00	-
Exit Lane 1	3.62	500.0	0.00	-
Exit Lane 2	3.62	500.0	0.00	-
Exit Lane 3	3.62	500.0	0.00	-
West meskel square				
App. Lane 1	2.70	500.0	0.00	-
App. Lane 2	3.62	500.0	0.00	-
App. Lane 3	3.62	500.0	0.00	-
App. Lane 4	3.62	500.0	0.00	-
Exit Lane 1	3.62	500.0	0.00	-
Exit Lane 2	2.70	500.0	0.00	-
Exit Lane 3	3.62	500.0	0.00	-
Exit Lane 4	3.62	500.0	0.00	-

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South	china street					
West	185.0	0.50	94.0	1.20	100.00	6.68
East	767.0	0.90	94.0	1.20	100.00	6.68
From: East	bole airport road					
South	746.0	0.40	98.0	1.20	100.00	6.68
West	2552.0	1.00	98.0	1.20	100.00	6.68
From: West	meskel square					
East	2281.0	0.46	96.0	1.20	100.00	6.68
South	317.0	0.00	96.0	1.20	100.00	6.68

Gap Acceptance

Movement		Critical Gap sec	Follow-up Headway sec	Min. Departures veh/min	Exiting Flow Effect %
South	china street				
	L	5.500	3.000	2.50	0
	R	5.500	3.000	2.50	0
East	bole airport road				
	L	5.500	3.000	2.50	0
	T	–	–	2.50	0
West	meskel square				
	T	–	–	2.50	0
	R	5.000	3.000	2.50	0

Pedestrians

Mov. ID	Volume ped	Peak Flow %	Flow Scale %	Growth Rate %/year	Crossing Distance m	App. Trav. Distance m	Downst. Distance m	Walking Speed m/sec	Queue Space m	P.Deg. Satn
South	chaina street									
P1	98.0	95.0	100.00	2.00	16.80	10.0	10.0	1.30	1.00	0.900
East	bole									
P3	541.0	95.0	100.00	2.00	16.80	10.0	10.0	1.30	1.00	0.900
West	meskel square									
P7	1040.0	95.0	100.00	2.00	16.80	10.0	10.0	1.30	1.00	0.900

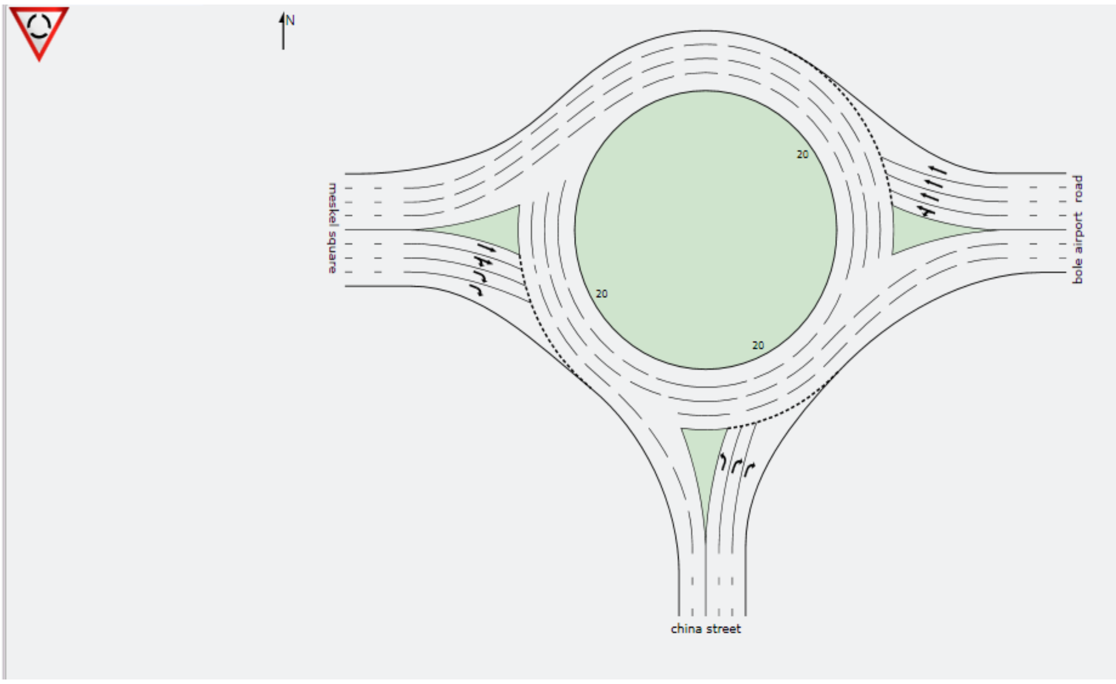


Figure 11: **Layout for roundabout only case intersection**

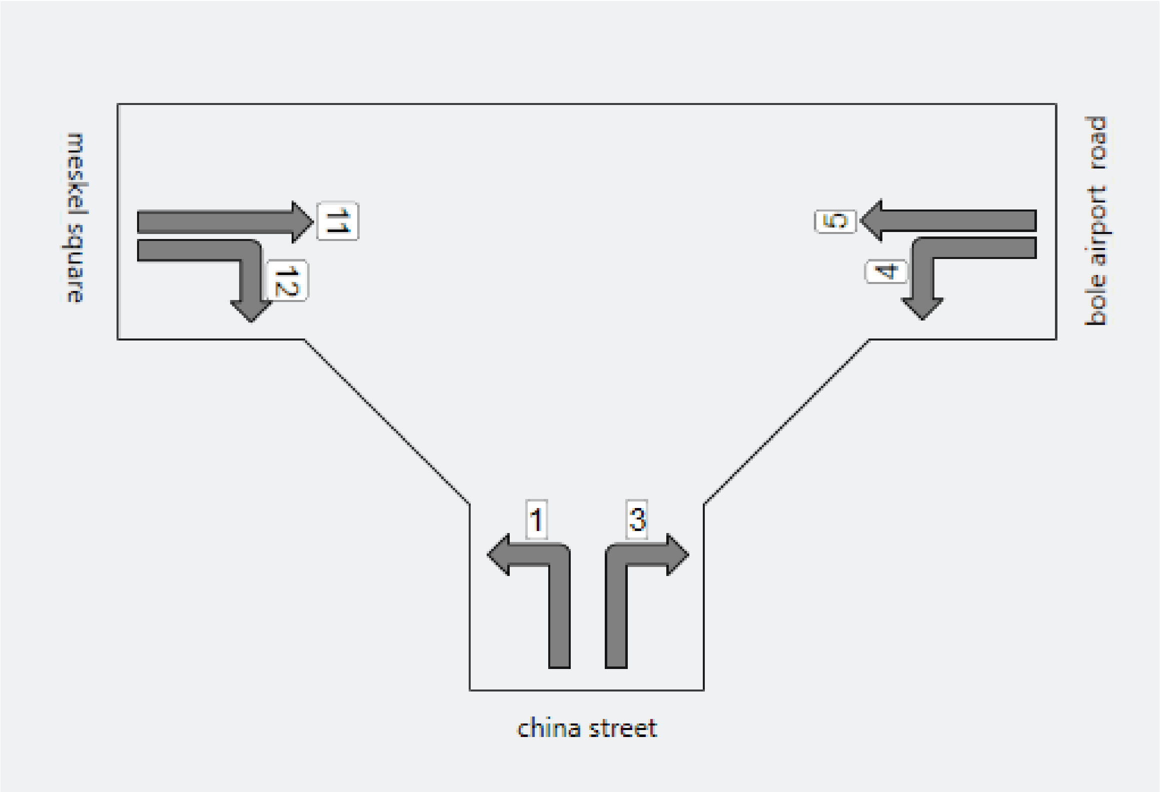


Figure 12: **Intersection Movement ID of Intersection for roundabout**

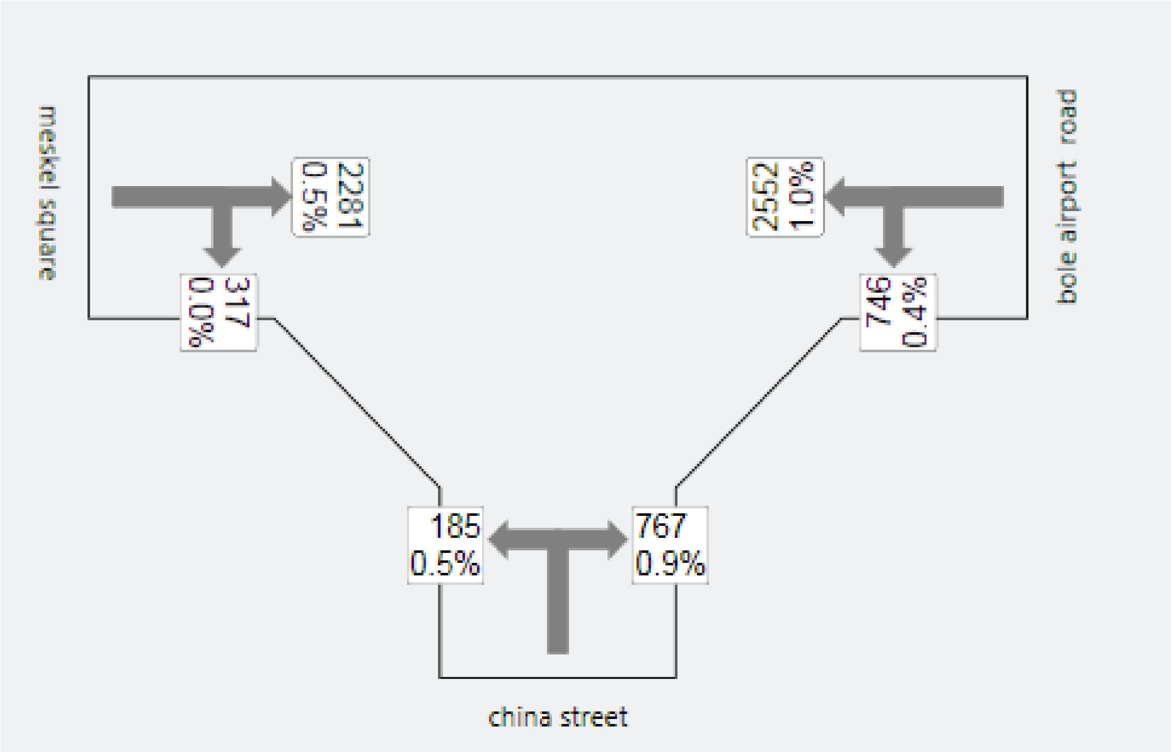


Figure 13: Traffic Volume Distribution and Truck Percentage at Intersection

Annex - B-6: Output Data for Roundabout only

Intersection Performance - Hourly Values		
Performance Measure	**Vehicles**	**Persons**
Demand Flows (Total)	7084 veh/h	8501 pers/h
Percent Heavy Vehicles	0.7 %	
Degree of Saturation	2.606	
Practical Spare Capacity	-67.4 %	
Effective Intersection Capacity	2718 veh/h	
Control Delay (Total)	700.16 veh-h/h	840.19 pers-h/h
Control Delay (Average)	355.8 sec	355.8 sec
Control Delay (Worst Lane)	1480.4 sec	
Control Delay (Worst Movement)	1480.4 sec	1480.4 sec
Geometric Delay (Average)	6.1 sec	
Stop-Line Delay (Average)	349.6 sec	
Intersection Level of Service (LOS)	LOS F	
95% Back of Queue - Vehicles (Worst Lane)	312.2 veh	
95% Back of Queue - Distance (Worst Lane)	2194.2 m	
Total Effective Stops	26792 veh/h	32151 pers/h
Effective Stop Rate	3.78 per veh	3.78 per pers
Proportion Queued	0.81	0.81
Performance Index	1315.4	1315.4
Travel Distance (Total)	4405.8 veh-km/h	5287.0 pers-km/h
Travel Distance (Average)	622 m	622 m
Travel Time (Total)	775.4 veh-h/h	930.5 pers-h/h
Travel Time (Average)	394.0 sec	394.0 sec
Travel Speed	5.7 km/h	5.7 km/h
Cost (Total)	22783.22 $/h	22783.22 $/h
Fuel Consumption (Total)	1544.5 L/h	
Carbon Dioxide (Total)	3862.3 kg/h	
Hydrocarbons (Total)	8.256 kg/h	
Carbon Monoxide (Total)	194.71 kg/h	
NOx (Total)	5.515 kg/h	

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: china street											
1	L	197	0.5	1.257	295.4	LOS F	33.4	234.7	1.00	2.53	7.0
3	R	816	0.9	2.606	1480.4	LOS F	170.4	1202.3	1.00	5.09	1.4
Approach		1013	0.8	2.606	1250.2	LOS F	170.4	1202.3	1.00	4.60	1.7
East: bole airport road											
4	L	761	0.4	0.783	15.1	LOS B	11.5	80.6	0.87	0.73	43.1
5	T	2604	1.0	0.633	6.0	LOS A	5.8	40.8	0.52	0.52	48.9
Approach		3365	0.9	0.783	8.0	LOS A	11.5	80.6	0.60	0.57	47.4
West: meskel square											
11	T	2376	0.5	1.553	513.9	LOS F	312.2	2194.2	1.00	8.37	4.0
12	R	330	0.0	0.642	19.4	LOS B	5.7	39.9	0.93	1.07	39.1
Approach		2706	0.4	1.553	453.5	LOS F	312.2	2194.2	0.99	7.48	4.5
All Vehicles		7084	0.7	2.606	355.8	LOS F	312.2	2194.2	0.81	3.78	5.7

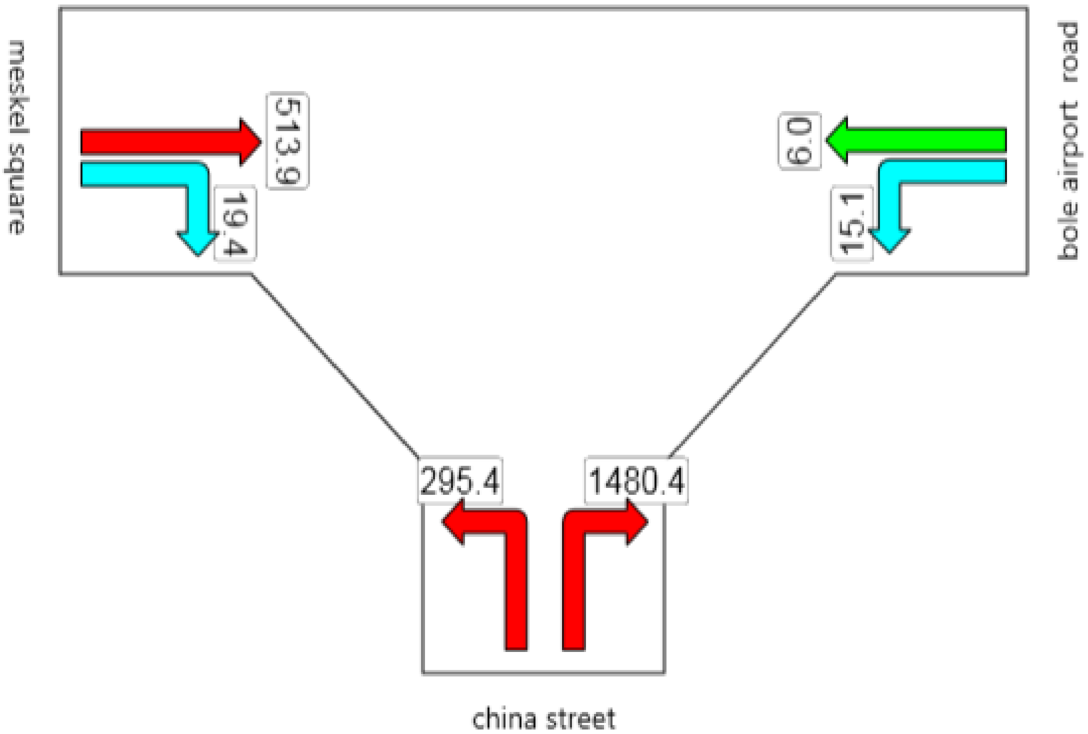


Figure 14: Average delay for roundabout intersection

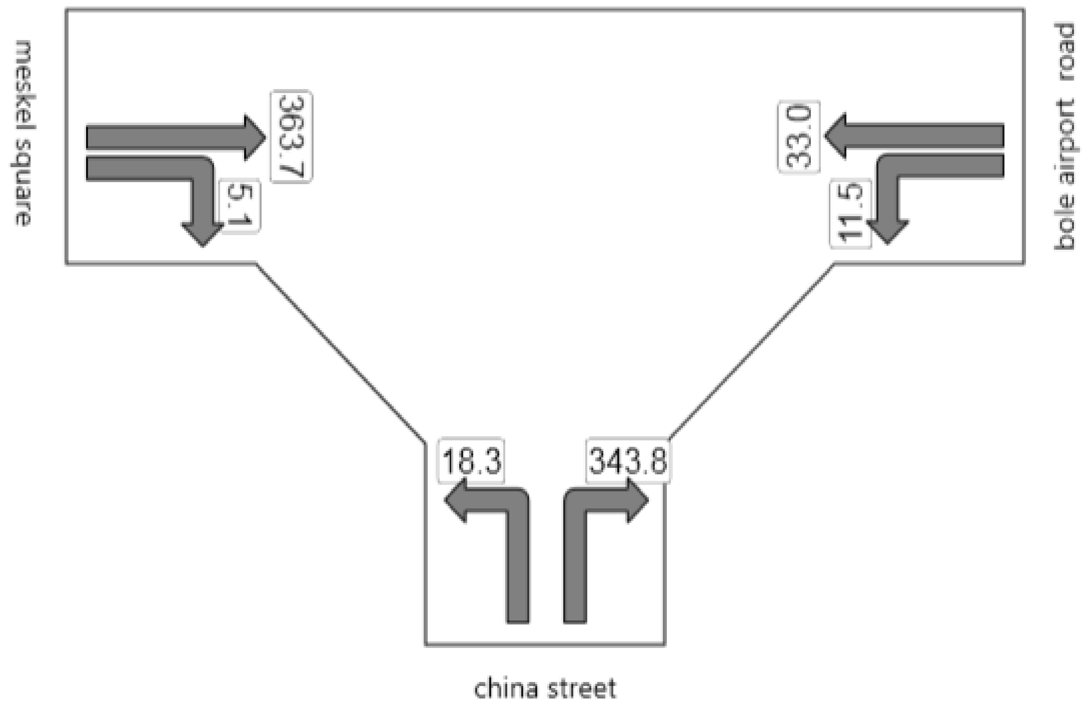


Figure 15: Average Travel Time for Roundabout

Annex - B-7: Input data for Road Underpass with Roundabout case

Intersection Parameters	
Title	roundabout
Intersection ID	1
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	30 minutes

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	chaina street	Two-way	2	2	1.00	0.0
East	bole	Two-way	2	2	1.00	0.0
West	meskel square	Two-way	2	2	–	0.0

Geometry - Roundabout Data

Location	Name	Island Diameter m	Circ. Width m	Circ. Lanes	Entry Radius m	Entry Angle degrees	Env. Factor	Entry/Circ. Flow Adjust.
South	chaina street	40.00	9.62	2	20.0	30.0	1.0000	Medium
East	bole	40.00	9.62	2	20.0	30.0	1.0000	Medium
West	meskel square	40.00	9.62	2	20.0	30.0	1.0000	Medium

Geometry - Approach & Exit Lane Data

Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South chaina street				
App. Lane 1	3.62	500.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
Exit Lane 1	3.62	500.0	0.00	–
Exit Lane 2	3.62	500.0	0.00	–
East bole				
App. Lane 1	3.62	500.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
Exit Lane 1	3.62	500.0	0.00	–
Exit Lane 2	3.62	500.0	0.00	–
West meskel square				
App. Lane 1	3.62	500.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
Exit Lane 1	3.62	500.0	0.00	–
Exit Lane 2	3.62	500.0	0.00	–

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South chaina street						
West	180.0	0.61	95.0	1.20	100.00	6.68
East	767.0	0.93	95.0	1.20	100.00	6.68
From: East bole						
South	746.0	0.39	95.0	1.20	100.00	6.68
West	483.0	1.04	95.0	1.20	100.00	6.68
From: West meskel square						
East	194.0	0.46	95.0	1.20	100.00	6.68
South	317.0	0.35	95.0	1.20	100.00	6.68

Gap Acceptance

Movement	Critical Gap sec	Follow-up Headway sec	Min. Departures veh/min	Exiting Flow Effect %
South chaina street				
L	5.000	3.000	2.50	0
R	4.500	3.000	2.50	0
East bole				
L	5.000	3.000	2.50	0
T	5.000	3.000	2.50	0
West meskel square				
T	5.000	3.000	2.50	0
R	4.000	2.000	2.50	0

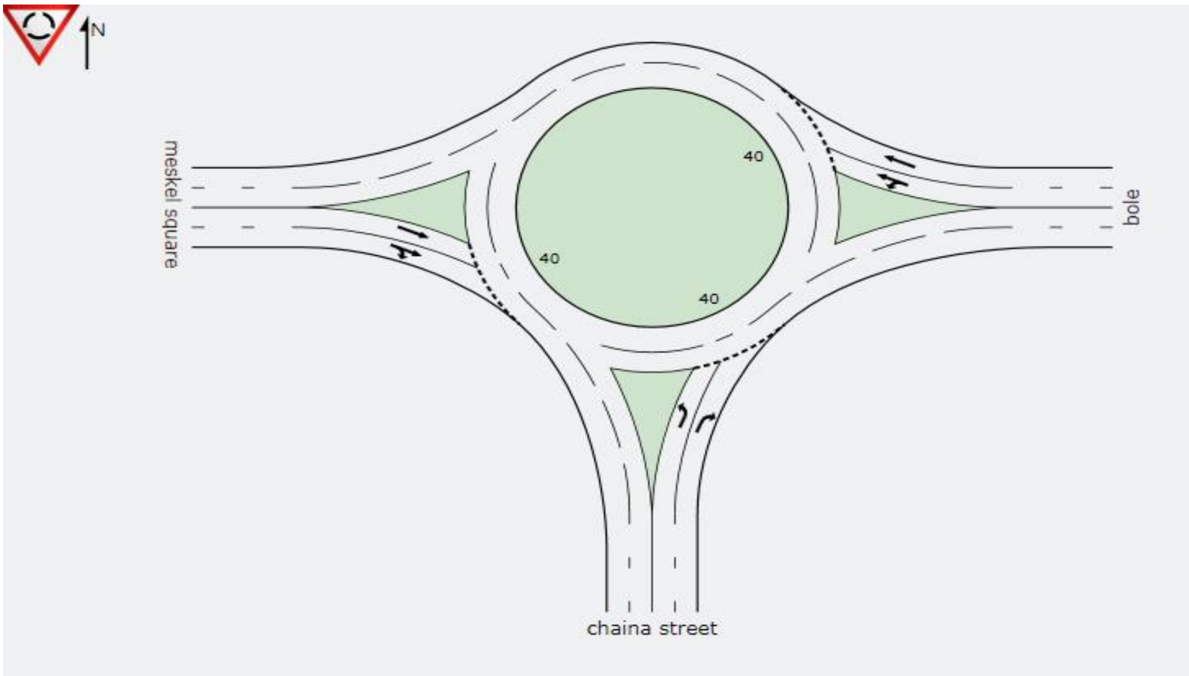


Figure 16: **Layout for roundabout intersection**

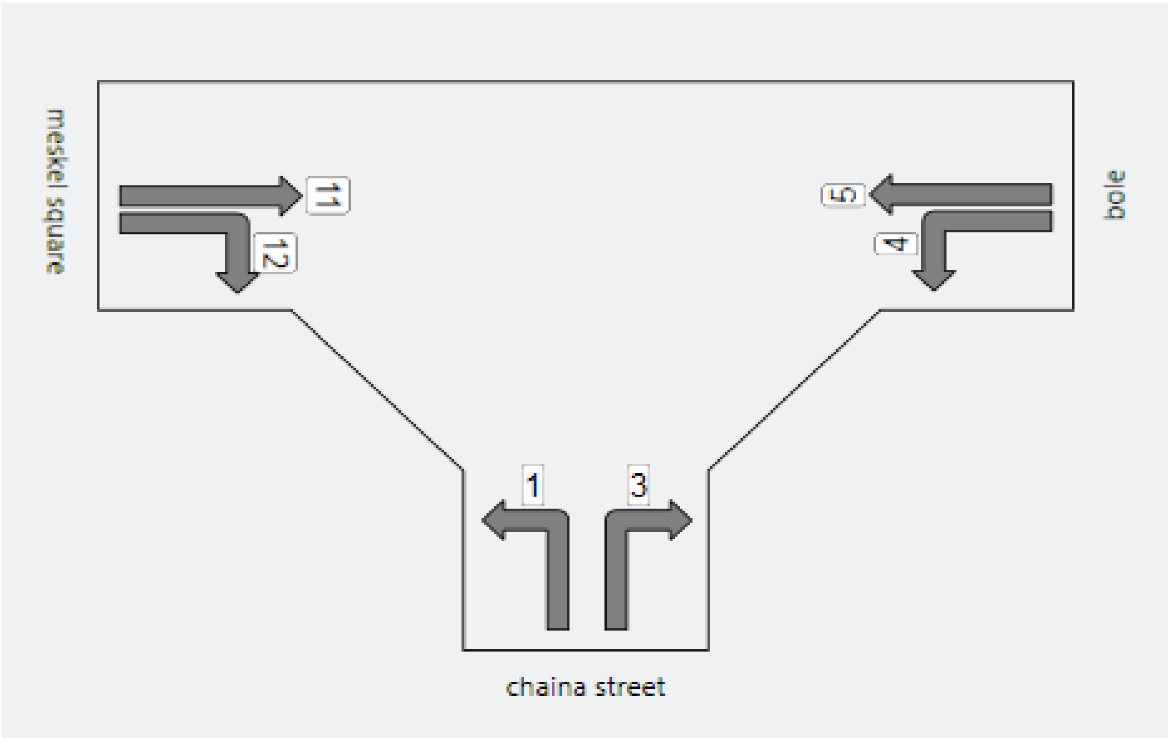


Figure 17: **Intersection Movement** ID **of Intersection for roundabout**

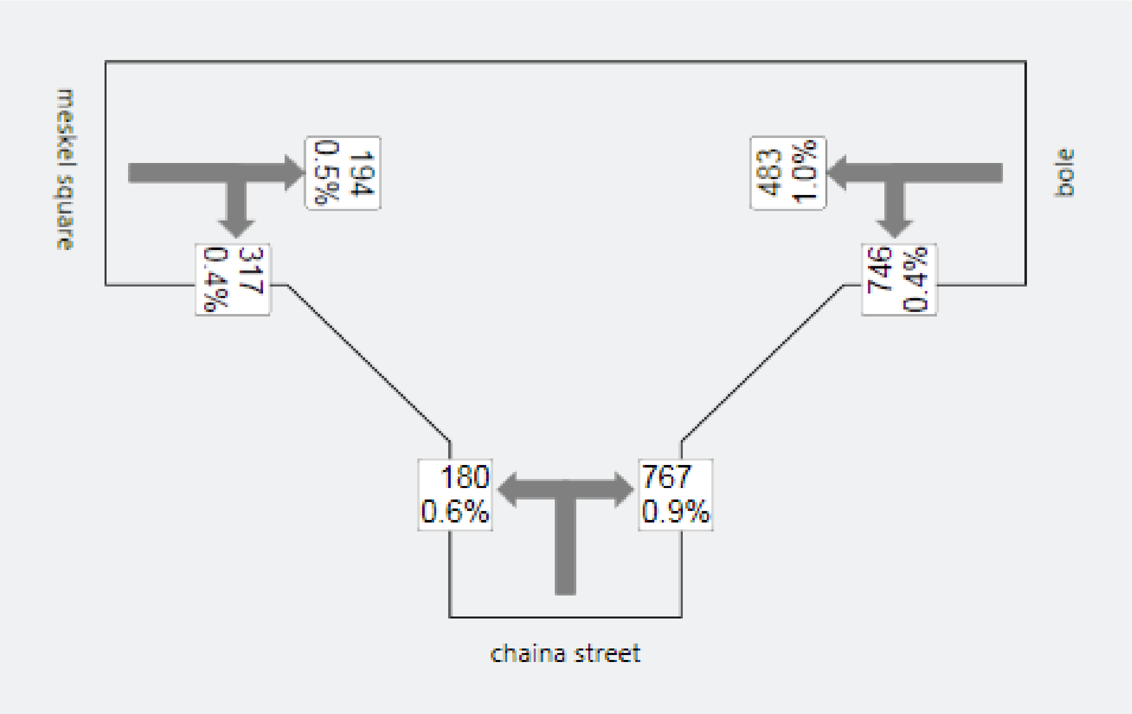


Figure 18: **Traffic Volume Distribution and Truck Percentage at Intersection**

Annex - B-8: Output Data for underpass with Roundabout

Intersection Performance - Hourly Values		
Performance Measure	**Vehicles**	**Persons**
Demand Flows (Total)	2828 veh/h	3394 pers/h
Percent Heavy Vehicles	0.7 %	
Degree of Saturation	0.836	
Practical Spare Capacity	1.6 %	
Effective Intersection Capacity	3381 veh/h	
Control Delay (Total)	9.11 veh-h/h	10.93 pers-h/h
Control Delay (Average)	11.6 sec	11.6 sec
Control Delay (Worst Lane)	16.2 sec	
Control Delay (Worst Movement)	16.2 sec	16.2 sec
Geometric Delay (Average)	6.7 sec	
Stop-Line Delay (Average)	4.9 sec	
Intersection Level of Service (LOS)	LOS B	
95% Back of Queue - Vehicles (Worst Lane)	12.8 veh	
95% Back of Queue - Distance (Worst Lane)	90.7 m	
Total Effective Stops	2187 veh/h	2624 pers/h
Effective Stop Rate	0.77 per veh	0.77 per pers
Proportion Queued	0.79	0.79
Performance Index	66.0	66.0
Travel Distance (Total)	1788.5 veh-km/h	2146.2 pers-km/h
Travel Distance (Average)	632 m	632 m
Travel Time (Total)	39.3 veh-h/h	47.2 pers-h/h
Travel Time (Average)	50.1 sec	50.1 sec
Travel Speed	45.5 km/h	45.5 km/h
Cost (Total)	1382.28 $/h	1382.28 $/h
Fuel Consumption (Total)	199.5 L/h	
Carbon Dioxide (Total)	498.9 kg/h	
Hydrocarbons (Total)	0.837 kg/h	
Carbon Monoxide (Total)	38.83 kg/h	
NOx (Total)	1.185 kg/h	

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: chaina street											
1	L	189	0.6	0.201	12.4	LOS B	1.1	7.6	0.43	0.67	45.0
3	R	807	0.9	0.836	10.2	LOS B	12.8	90.7	0.90	0.82	46.6
Approach		997	0.9	0.836	10.6	LOS B	12.8	90.7	0.81	0.79	46.3
East: bole											
4	L	785	0.4	0.802	16.2	LOS B	11.3	79.5	0.83	0.80	42.9
5	T	508	1.0	0.519	5.0	LOS A	3.6	25.3	0.53	0.48	50.3
Approach		1294	0.6	0.802	11.8	LOS B	11.3	79.5	0.71	0.67	45.4
West: meskel square											
11	T	204	0.5	0.491	14.1	LOS B	3.6	25.3	0.91	1.00	43.4
12	R	334	0.4	0.493	12.2	LOS B	4.8	33.4	1.00	0.97	44.9
Approach		538	0.4	0.493	12.9	LOS B	4.8	33.4	0.97	0.98	44.3
All Vehicles		2828	0.7	0.836	11.6	LOS B	12.8	90.7	0.79	0.77	45.5

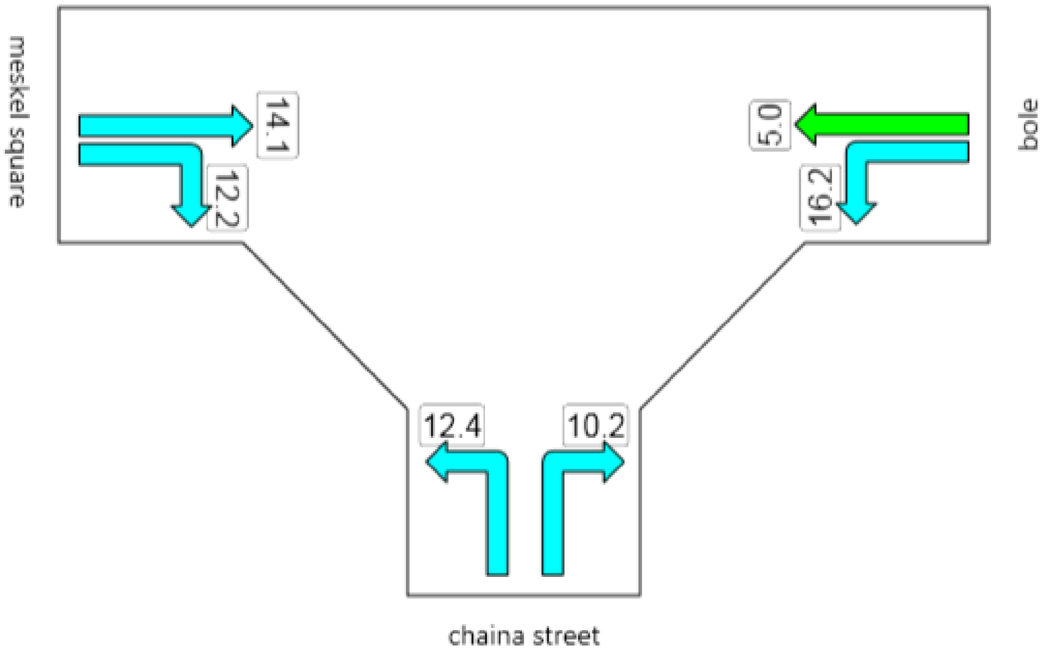


Figure19: Average Delay For underpass with roundabout Road

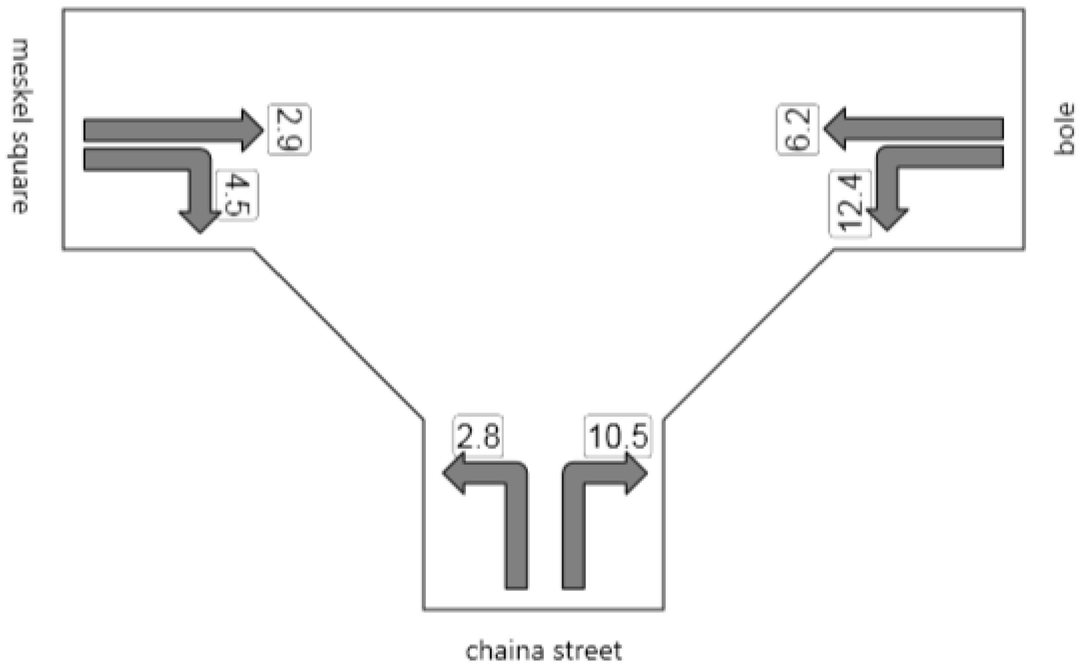


Figure 20: Travel Time Summary for underpass with roundabout Road

Input values for underpass road

Intersection Parameters	
Title	underpass
Intersection ID	1
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	30 minutes

Geometry - Approach Data

Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
East	bole	Two-way	2	2	1.00	0.0
West	meskel square	Two-way	2	2	–	0.0

Geometry - Approach Lane Data

Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
East bole						
App. Lane 1	Normal	T	1800	–	–	0.0
App. Lane 2	Normal	T	1800	–	–	0.0
West meskel square						
App. Lane 1	Normal	T	1800	–	–	0.0
App. Lane 2	Normal	T	1800	–	–	0.0

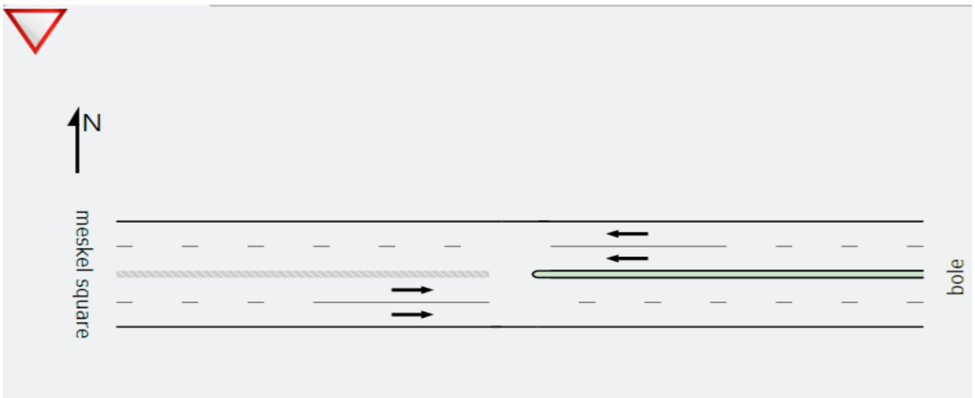
Geometry - Approach & Exit Lane Data

Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
East bole				
App. Lane 1	3.62	500.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
Exit Lane 1	3.62	500.0	0.00	–
Exit Lane 2	3.62	500.0	0.00	–
West meskel square				
App. Lane 1	3.62	500.0	0.00	–
App. Lane 2	3.62	500.0	0.00	–
Exit Lane 1	3.62	500.0	0.00	–
Exit Lane 2	3.62	500.0	0.00	–

Lanes are numbered from left to right in the direction of travel.

Volumes

To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: East	bole					
West	1586.0	0.42	95.0	1.20	100.00	6.68
From: West	meskel square					
East	1044.0	0.89	95.0	1.20	100.00	6.68



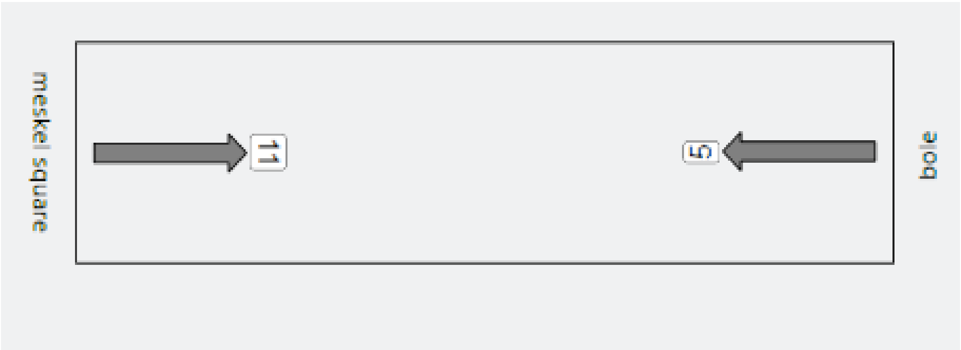


Figure 21: Layout and Intersection Movement ID of Intersection for roundabout

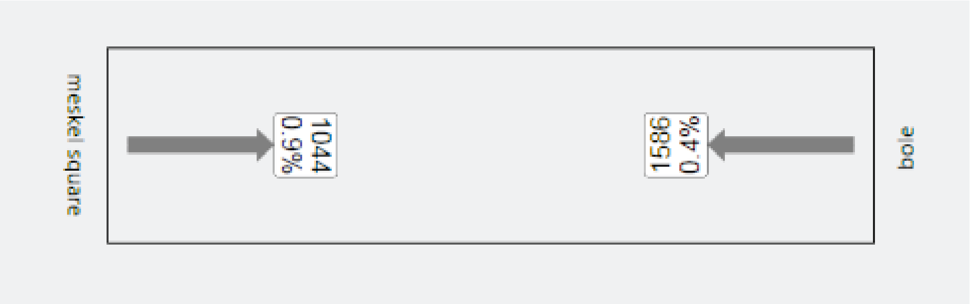


Figure 22: Traffic Volume Distribution and Truck Percentage at Intersection

Output for the underpass

Intersection Performance - Hourly Values		
Performance Measure	**Vehicles**	**Persons**
Demand Flows (Total)	2768 veh/h	3322 pers/h
Percent Heavy Vehicles	0.6 %	
Degree of Saturation	0.465	
Practical Spare Capacity	72.0 %	
Effective Intersection Capacity	5953 veh/h	
Control Delay (Total)	0.00 veh-h/h	0.00 pers-h/h
Control Delay (Average)	0.0 sec	0.0 sec
Control Delay (Worst Lane)	0.0 sec	
Control Delay (Worst Movement)	0.0 sec	0.0 sec
Geometric Delay (Average)	P sec	
Stop-Line Delay (Average)	P sec	
Intersection Level of Service (LOS)	NA	
95% Back of Queue - Vehicles (Worst Lane)	0.0 veh	
95% Back of Queue - Distance (Worst Lane)	0.0 m	
Total Effective Stops	0 veh/h	0 pers/h
Effective Stop Rate	0.00 per veh	0.00 per pers
Proportion Queued	0.00	0.00
Performance Index	28.0	28.0
Travel Distance (Total)	1678.9 veh-km/h	2014.7 pers-km/h
Travel Distance (Average)	606 m	606 m
Travel Time (Total)	28.0 veh-h/h	33.6 pers-h/h
Travel Time (Average)	36.4 sec	36.4 sec
Travel Speed	60.0 km/h	60.0 km/h
Cost (Total)	941.76 $/h	941.76 $/h
Fuel Consumption (Total)	121.1 L/h	
Carbon Dioxide (Total)	302.7 kg/h	
Hydrocarbons (Total)	0.412 kg/h	
Carbon Monoxide (Total)	8.63 kg/h	
NOx (Total)	0.542 kg/h	

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
East: bole											
5	T	1669	0.4	0.465	0.0	LOS A	0.0	0.0	0.00	0.00	60.0
Approach		1669	0.4	0.465	0.0	NA	0.0	0.0	0.00	0.00	60.0
West: meskel square											
11	T	1099	0.9	0.307	0.0	LOS A	0.0	0.0	0.00	0.00	60.0
Approach		1099	0.9	0.307	0.0	NA	0.0	0.0	0.00	0.00	60.0
All Vehicles		2768	0.6	0.465	0.0	NA	0.0	0.0	0.00	0.00	60.0

Figure 23: Average delay for underpass road

Figure 24: Average travel time for underpass road

Annex C: Recommended Values of Basic Saturation Flow and Extra Bunching Values

Table C-1: Basic Saturation Flow Parameters For Urban Roads

Criterion	Road						Street			
	Arterial road			Sub arterial road			Collector street		Local street	
	Highway	Arte rial	Arterial main street	Traffic distributer	Controlled distributor	Sub arterial main street	Major collector	Minor collector	Access street	Access place
Basic saturation flow (veh /hr)	1800	180 0	1500	1500	1500	900	450	300	120	30

Table C-2: Maximum Values For Extra Bunching

Distance to upstream signals (m)	<100	100-200	200-400	400-600	600-800	>800
Extra punching (%)	25	20	15	10	5	0

Annex D: Recommended Values of Gap Acceptance

Table D-1:**Gap acceptance parameters for sign controlled intersection**

Types of movement	<70 km/hr		71- 100km/hr		> 100km/hr	
	Critical gap (sec)	Follow- up headway (sec)	Critical gap (sec)	Follow- up headway (sec)	Critical gap (sec)	Follow-up headway (sec)
Left turn						
1-lane opposing	4.5	3	6.5	4.5	8.0	5.5
2- lane or more opposing	5.0	3.0	7.0	4.5	9.0	5.5
Through movement crossing one- way road						
1-lane one way	4.0	2.0	6.0	3.0	7.5	3.5
2- lane one way	4.5	2.5	6.5	3.5	8.0	4.5
3- lane one way	6.0	3.0	8.5	4.5	11.0	5.5
Through movement crossing two - way road						
2- lane two way	5.0	3.0	7.0	4.5	9.0	5.5
3- lane two way	6.5	4.0	9.0	6.0	11.5	7.5
4- lane two way	8.0	5.0	11.5	7.0	14.5	9.0
Right urn from major road						
Across 1 lane	4.0	2.0	6.0	3.0	7.5	3.5
Across 2 lane	5.0	3.0	7.0	4.5	9.0	5.5
Right turn from minor road						
One way	4.5	3.0	6.5	4.5	8.0	5.5
2-lane (two way)	5.5	3.5	8.0	5.0	10.0	6.5
3-lane (two way)	6.5	4.0	9.0	6.0	11.5	7.5
4-lane (two way)	8.0	5.0	11.5	7.0	14.5	9.0
Merge from acceleration lane	3.0	2.0	3.0	2.0	3.0	2.0

Table D-2: **Gap acceptance parameters for roundabout and signalized intersection**

Types of movement	Signalized		Round about	
	Critical gap (sec)	Follow-up headway (sec)	Critical gap (sec)	Follow-up headway (sec)
Left turn				
1-lane opposing	4.5	3.0	Estimated by SIDRA	
2-laneormore opposing	5.0	3.0	Estimated by SIDRA	
Through movement crossing one- way road				
1-lane one way	4.0	2.0	Estimated by SIDRA	
2- lane one way	4.5	2.5	Estimated by SIDRA	
3- lane one way	6.0	3.0	Estimated by SIDRA	
Through movement crossing a two - way road				
2- lane two way	5.0	3.0	Estimated by SIDRA	
3- lane two way	6.5	4.0	Estimated by SIDRA	
4- lane two way	8.0	5.0	Estimated by SIDRA	
Right turn from the major road				
Across 1 lane	4.0	2.0	Estimated by SIDRA	
Across 2 lane	5.0	3.0	Estimated by SIDRA	
Right turn from the minor road				
One way	4.5	3.0	Estimated by SIDRA	
2-lane (two way)	5.5	3.5	Estimated by SIDRA	
3-lane (two way)	6.5	4.0	Estimated by SIDRA	
4-lane (two way)	8.0	5.0	Estimated by SIDRA	
Merge from acceleration lane	3.0	2.0	Estimated by SIDRA	

Table D- 3: **Exiting Flow Effects**

Types of movement	Existing flow effects (%)
Sign control intersection	
Minor road - left turn	50
Minor road- through	50
Minor road - right turn	50
Turn from major road	0
Slip lane from minor road	50
Slip lane from major road	0
Signals	
All movements	0
Roundabouts	
All movements	0