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SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

EVALUATION OF VEHICLE TIME DELAY AT SELECTED SIGNAL CONTROLLED INTERSECTIONS IN ADDIS ABABA

A Thesis in Road and Transport Engineering Stream

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UNDERTAKING

I certify that this research work titled "Evaluation of vehicle time delay at selected signal controlled intersections in Addis Ababa" is my own work. The work has not been presented elsewhere for assessment. All material used from other sources has been properly acknowledged / referred.

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ACRONYMS /ABBREVIATIONS

A.A	Addis Ababa
AACRA	Addis Ababa City Road Authority
FHWA	Federal Highway Agency
HCM	Highway Capacity Manual
LOS	Level of Service
LCV	Light commercial vehicle
MAV	Multi axel vehicle
PCE	Passagers Car Equivalent
PCU	Passenger Car Unit
PHF	Peak Hour Factor
PHV	Peak Hour Volume
Std	Standard
SFR	Saturation Flow Rate
Vp15min.	Peak 15minute Volume
SIDRA	Signalized (un-Signalized) Intersection Design and Research Aid

ABSTRACT

There are two types of traffic facilities, interrupted and uninterrupted flow facilities. The interrupted flow facility incorporates fixed external interruptions in their design and operation. The most frequent and operation only significant external interruption in interrupted flow facility is a traffic signal.

Traffic signals are one of the most effective and flexible active controls of traffic flow. They are widely used in several cities worldwide. The conflicts arising from movements of traffic in different directions are addressed by time-sharing principle. Besides, its controller unit is either pre-timed or actuated control. Pre-timed control consists of fixed sequence of phases displayed in a repetitive order. Actuated control consists of intervals that are called and extended in response to vehicle detectors.

Traffic congestion is experienced in urban areas due to economic and social developments. Addis Ababa is one of the places with rapid economic development which exhibit a higher amount of traffic congestion problem at different intersections and the urban street of the road.

Vehicle delay is the most important parameter used by transportation professionals in evaluating the performance of a signalized intersection.

In this research, three pre-timed signalized intersections in Addis Ababa are selected based on data availability and discussion with Addis Ababa city administration transport bureau as they experience congestion.

The objective of this paper is evaluating vehicle delay in Addis Ababa at selected Intersection and evaluating selected intersection by sensitivity analysis using highway capacity manual and SIDRA intersection software. To achieve the objective of the research, the collection of primary and secondary data was conducted. The traffic volume data were collected from Addis Ababa city administration transport bureau. The count was conducted for five days and twelve hours with a fifteen-minute interval of time. Data on geometric elements signal timings and phasing were measured through field survey and Google map. Peak hour volume is used for analysis after determining the peak hour of the intersections.

As per the analysis of results, all intersections are serving in poor condition of level of service F, vehicle per capacity ratio greater than one and the average delay experienced 126 sec for Jacros, 431.4 sec for Lebu and 710.4 sec for imperial intersection. From sensitivity analysis, base saturation has reduced delay by 29.53% at Lebu, 39.12% at Jacros and 26.87% for Imperial intersection. Heavy vehicle restriction reduces delay by 46.05% at Lebu, 57.14% at Jacros and 10.78 % at Imperial intersection in addition adding one through lanes reduces delay by 47.72% at Lebu, 68.01% at Jacros and 34.41% Imperial intersection as compared to other parameters.

1. INTRODUCTION

1.1 Background

An intersection is an area shared by two or more roads whose main function is to provide for change of route directions. Intersections vary in complexity from a simple intersection, which has only two roads crossing at a right angle to each other, to a more complex intersection, at which three or more roads cross within the same area. There are different types of intersection; one of them is signal control intersection (D.May, 1990). Signal control intersection is one of the most important elements of the urban transportation network and its timing plan would influence traffic efficiency in that area (Zhou, 2014). Signals deal the maximum degree of control at intersections, communicate messages for both allowed and not allowed to pass the intersection. The main function of any traffic signal is to assign right of way to conflicting movements of traffic at an intersection. It does this by permitting conflicting streams of traffic to share the same intersection by means of time separation. For evaluating the performance of signalized intersection, delay is the most important parameter used by transportation professionals. This is because it directly relates to the time loss that a vehicle experiences while crossing an intersection (Haduzzaman, 2014).

In Addis Ababa, most signalized intersections are congested and experience delay during peak hours. Hence, evaluation of vehicle time delay is important because it affects

1. Fuel consumption,
2. Environmental pollution and
3. Productivity at large.

In addition, we can identify performance and capacity of the road; propose method for better utilization of traffic flow based on evaluation results.

1.2 Statement of the Problem

Due to economic and social developments in urban areas, congestion is occurring. This traffic congestion has impacts such as incremental delay, excessive fuel consumption, social, economic and environmental cost (Muneera, 2018).

Addis Ababa is one of the places with rapid economic developments which become bases for congestion. Addis Ababa city show a higher amount of traffic congestion problem at different places of intersections and urban street of the road (Admasu N. , 2017). From observations made, most of intersections in Addis Ababa have high traffic of pedestrians and motorized vehicle including truck during peak hours so that the performance of intersection is highly affected. In addition to this, rising vehicular and pedestrian traffic in the city may also reduce performance of the intersections more than ever in the near future. All these difficulties which most of the people of uses this intersection meeting under different degrees and circumstances directly associated with the existing road traffic congestion and delay.

Accordingly, the above problem this study intended to asses vehicle time delay at signalized intersection in Addis Ababa to answer the specific objective of the research.

1.3 Objectives of the Study

1.3.1. General Objective

The general objective of this study is to evaluate present vehicle time delay in Addis Ababa at selected signalized intersection and to determine the factors that are causing the delay, based on which recommendations for delay reduction will be given.

1.3.2. Specific Objectives

The specific objectives of this study are:

- To evaluate traffic performance and operation at selected signal control intersections,
- To determine the contributory factors for delay in the study areas,
- To give conclusion and recommendations for promising future considerations during signalized intersection design in Addis Ababa based on the result of analysis.

1.4. Scope of study

The research identified vehicle time delay at signal control intersection in Addis Ababa, to reason out the causes of delay and suggesting measures to be taken for improved traffic operation using Highway Capacity Manual.

1.5. Significance of the study

It would be known that the output of this study will be added to the existing academic knowledge and enable to understand the subject matter as it overlays the way for further investigation on the topic. Moreover, it can benefit other parties of the society through:-

It will allow the researcher to assess the current condition and impact of traffic delay on the city thereby build academic knowledge and provide base for further career improvement and the City Administration of Addis Ababa can use the finding of this research work for its social and economic policy formulation and right decision making based on truthful and newest information, so that, the City Administration would use its resources efficiently to ensure the City's sustainability by solving the problem of traffic congestion delay.

2. LITERATURE REVIEW

2.1. Introduction

Traffic delay is one of the major criteria in determining the level of service or the effectiveness of traffic operations at signalized intersections. The overall level of congestion, vehicle gas consumption and average loss of travel time, among others, can all be attributed to traffic delay. Traffic delay is also an area of concern in traffic planning, signal design and traffic control management (Haduzzaman, 2014).

2.2. Traffic facilities

Traffic facilities are broadly separated into two principal categories:

- Uninterrupted flow
- Interrupted flow

Uninterrupted flow facilities have no external interruptions to the traffic stream. Pure uninterrupted flow exists primarily on freeways, where there are no intersections at grade, traffic signals, STOP or YIELD signs or other interruptions external to the traffic stream itself .Because such facilities have full control of access, there are no intersections at grade, driveways, or any forms of direct access to abutting lands. Thus the characteristics of the traffic stream are based solely on the intersections among vehicles and with the roadway and the general environment. (Rose, 2004)

Interrupted flow: facilities are those that incorporate fixed external interruptions in to their design and operation. The most frequent and operationally significant external interruption is the traffic signal. The traffic signal alternatively starts and stops a given traffic stream creating a platen of vehicles Progressing down the facility. Other fixed interruptions include, stop and yield signs, un-signalized at-grade intersections, driveways, curb parking maneuvers and other land-access operations virtually all urban surface streets and highways are interrupted flow facilities. (Rose, 2004).

2.3. Intersections

Intersections are an important part of a highway facility because, to a great extent, the efficiency, safety, speed, cost of operation, and capacity of the facility depends on their design. Each intersection involves through- or cross-traffic movements on one or more of the highways and may involve turning movements between these highways. Such movements may be facilitated by various geometric design and traffic control, depending on the type of intersection. (Abdulkareem, 2016)

The intersection is a significant service within the city traffic network. The intersection capacity controls the productivity of the city traffic system. With the aim of investigation the faces of movement flow of the intersection, various replication models are recommended. Oversaturation has been a severe problem for urban intersections, particularly the jam intersections that cause queue spillover and network holdup (Bichi, 2018).

Intersections are critical piece of an urban street way system and they significantly affect the operation and execution of the movement framework (Simha, 2017).

2.4. Signalized intersection

Traffic signals are one of the most effective and flexible active control of traffic and is widely used in several cities worldwide. The conflicts arising from movements of traffic in different directions are addressed by time sharing principle. The advantages of traffic signal include an orderly movement of traffic, an increased capacity of the intersection and require only simple geometric design. However, the disadvantages of the signalized intersection are large stopped delays, and complexity in the design and implementation. (Mathew, 2014)

Traffic signals are traffic control devices used to manage the flow of traffic through intersections in a safe and efficient manner. Whether it is for designing new timing plans (to allocate green times) or operational analysis (to determine level of service) of existing ones, traffic engineers require an accurate estimate of the capacity of the signal. (Hamad, 2015).

2.4.1. Types of Traffic Signal Control

There are two types of traffic signal controller unit they are broadly categorized as pre-timed or actuated according to the type of control they provide.

- **Pre-timed control** consists of a fixed sequence of phases that are displayed in repetitive order. The duration of each phase is fixed. However, the green interval duration can be changed by time of day or week to accommodate traffic variations (Highway Capacity Manual, 2010).
- **Actuated control** consists of a defined phase sequence in which the presentation of each phase depends on whether the phase is on recall or the associated traffic movement has submitted a call for service through a detector. The green interval duration is determined by the traffic demand information obtained from the detector, subject to preset minimum and maximum limits. The termination of an actuated phase requires a call for service from a conflicting traffic movement. An actuated phase may be skipped if no demand is detected (Highway Capacity Manual, 2010).

2.4.2. Signal Timing

(Knoonce, 2008), The signal timing of an intersection also plays an important role in its operational performance. In this regard, key factors include:

Effective green time - Effective green time represents the amount of usable time available to serve vehicular movements during a phase of a cycle. It is equal to the displayed green time minus startup loss time plus end gain. The effective green time for each phase is generally determined based on the proportion of volume in the critical lane (the lane in a lane group or approach that has the highest degree of saturation and places the highest demand on green time) for that phase relative to the total critical volume (the volume that determine the capacity and timing requirements of a signalized intersection) of the intersection. If not enough green time is provided, vehicle queues will not be able to clear the intersection, and cycle failures (numbers of queued vehicles are unable to depart due to insufficient capacity during a signal cycle) will occur. If too much green time is provided, portions of the cycle will be unused resulting in inefficient operations and frustration for drivers on the adjacent approaches.

Clearance interval - The clearance interval represents the amount of time needed for vehicles to safely clear the intersection and includes the yellow change and red clearance intervals. The capacity effect of the clearance interval is dependent upon the loss time.

Loss time - Loss time represents the unused portion of a vehicle phase. Loss time occurs twice during a phase: at the beginning when vehicles are accelerating from a stopped position and at the end when vehicles decelerate in anticipation of the red indication. Longer loss times reduce the amount of effective green time available and thus reduce the capacity of the intersection. Wide intersections and intersections with skewed approaches or unusual geometrics typically experience greater loss times than conventional intersections.

Cycle length - Cycle length determines how frequently during the hour each movement is served. It is a direct input, in the case of pre-timed or coordinated signal systems running a common cycle length, or an output of vehicle actuations, minimum and maximum green settings, and clearance intervals. Cycle lengths that are too short do not provide adequate green time for all phases and result in cycle failures. Longer cycle lengths result in increased delay and queues for all users.

Progression - Progression is the movement of vehicle platoons from one signalized intersection to the next. A well-progressed or well-coordinated system moves platoons of vehicles so that they arrive during the green phase of the downstream intersection. When this occurs, fewer vehicles arrive on red, and vehicle delay and queues are minimized. A poorly coordinated system moves platoons such that vehicles arrive on red, which increases the delay and queues for those movements beyond what would be experienced if random arrivals occurred.

Startup loss time- The additional time consumed by the first few vehicles in a queue whose headway exceeds the saturation headway because of the need to react to the initiation of the green interval and accelerate (Highway Capacity Manual, 2010).

End gain- Time between the end of the displayed green interval and the end of the effective green period for a movement, which is associated with additional departures after the end of green interval (Knoonce, 2008) .

2.4.3. Signalized Intersection Flow Characteristics

For a given approach at signalized intersection, three signal indications are seen: green, yellow, and red. The indication may include a short period during which all indications are red, referred to as an all-red interval, which with the yellow indication forms the change and clearance interval between two green phases. Figure 2-1 presents some fundamental attributes of flow at signalized intersection. The diagram represents a simple situation of one-way approach to signalized intersection having two phases in the cycle. (Highway Capacity Manual, 2010).

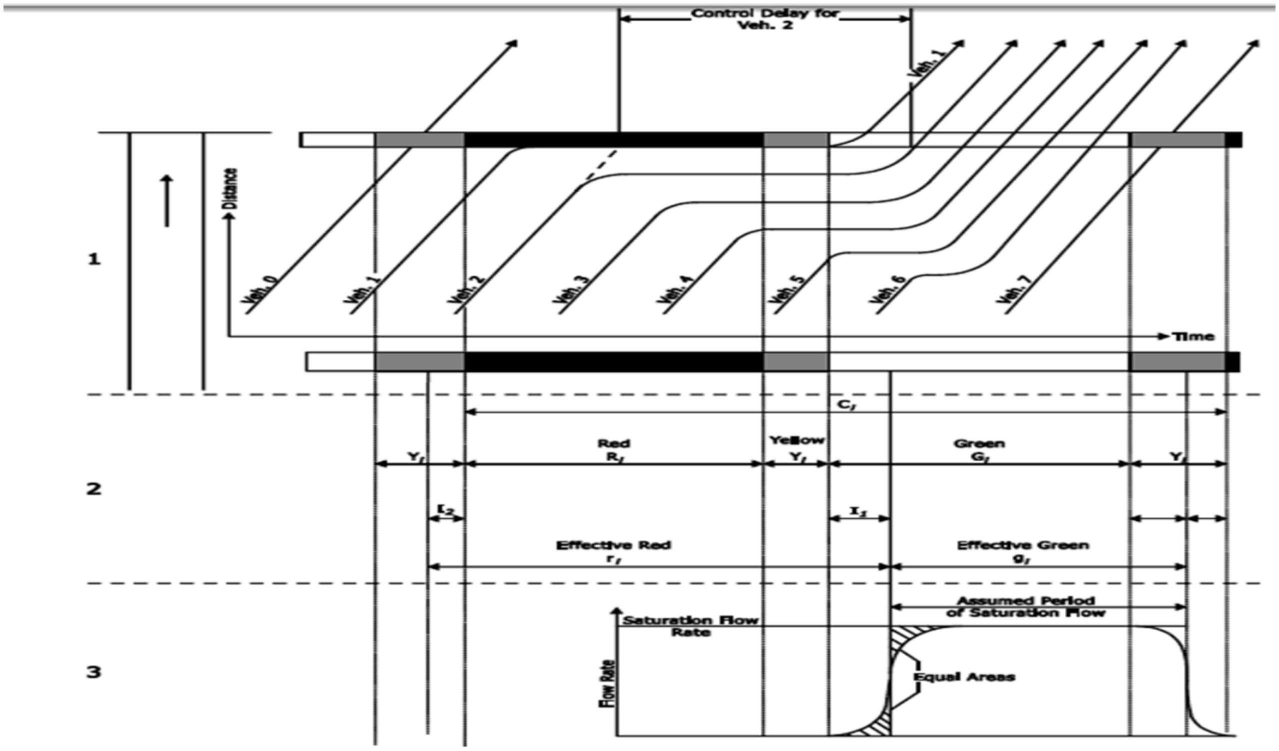


Figure 2-1 Fundamental Attributes of Traffic Flow at Signalized Intersections (Highway Capacity Manual, 2010)

2.5.Intersection geometry

The complete topography of an intersection defines its capacity towards productivity and carefully serving road user request. Pedestrians are regularly passing paths of traffic, while transfer, bikes, and vehicles traffic are utilizing the movement paths offered by the intersection. The sum of traffic lanes accommodated by each phase make a major effect on the ability of the intersection then, subsequently, the capacity for sign control timing to effectively serve the request. For instance, traffic discharged by two lanes as opposed to one lane has a greater capacity and in this manner needs less green time to meet the demand. Nevertheless, increasing the lanes on a specific approach of the crossing point similarly increments the least pedestrian passing time through that approach, which through adding clearance times would counterbalance some of the increment in capacity (Bichi, 2018).

2.6. Traffic Congestion at Intersection

Congestion can generally be defined as excess demand for road travel. Supply of road travel infrastructure is not sufficient to meet demand levels to a given level of service. As a consequence, travel speeds fall and delays are explained. This general definition of congestion implies that it can be measured in various ways. Average speed, flow/density, delay and travel time variability can be used to measure the level of congestion (Hauz, 2016).

Traffic congestion originates from the problems encountered with traffic flow. Traffic flow is the movement of individual drivers and vehicles between two points and the interactions they make with one another. The problem of traffic congestion in urban areas is worse at road intersections. (Aderamo, 2012).

Traffic congestion refers to incremental delays and vehicle operating costs caused by interactions among vehicles, particularly as traffic volumes approach roadway capacity Congestion prevents traffic from moving freely, quickly and/or predictably. When the vehicular volume on a transportation facility (street or highway) exceeds the capacity of that facility, the result is a state of congestion. Traffic congestion occurs when travel demand exceeds the existing road system capacity. Congestion is a condition in which the number of vehicles attempting to use a roadway at any time exceeds the ability of the roadway to carry the load at generally acceptable service levels. (Hauz, 2016).

Congestion at the intersection is a major problem in the urban area. It is a result of unbalance among travel time (the time necessary to traverse a route between any two points of interest), road capacity and transportation demands. Through realistic organizing intersection movement flow, we can assign traffic right and Increase traffic effectiveness to reduce traffic jam**.** (Bichi, 2018)**.**

2.7. Performance Measures

2.7.1. Capacity and Volume to Capacity Ratio

Capacity at a signalized intersection is defined for each approach. Intersection approach capacity is the maximum flow rate (for the approach under consideration) which may pass through the intersection under prevailing roadway, traffic and signalization conditions. (Nicolas Garber, 2009).Typically, capacity is defined for a particular user group without other user groups present. Thus, for example, motor vehicular capacity is stated in terms of vehicles per hour, under the assumption that no other flows (pedestrians, bicycles) are detracting from such capacity (Massachusetts Highway Department, 2006).

The factors which affect capacity out lined by Khalil, SAAD Mohsen in Modeling of Traffic Queues and Delay listed as follows :

- Physical and operation factor Includes parking condition, width of approaches, one -way or two-way operation and number of lanes.
- Traffic characteristics: Consist of traffic signals (length of cycle time and green to cycle time ratio for each approach) and marking of approach lanes.
- Environmental factors: Include degree of utilization of an individual approach, variation of demand during the peak hour and the location of the intersection within the metropolitan area.
- Control measures Involve turning movements and vehicles composition Cars, buses and trucks).
- Area type: the saturation flow in central business district (CBD), where intersection geometry, pedestrian flow, and roadside friction are more restrictive, is less than the saturation in other areas.

Capacity for a particular movement of a signalized intersection is characterized by two components: saturation flow rate of the vehicles passing through a particular point in a period under predominant situations and the proportion of time through which automobiles can cross the intersection (Bichi, 2018).

The v/c ratio, also referred to as degree of saturation, represents the sufficiency of an intersection to accommodate the vehicular demand. A v/c ratio less than 0.85 generally indicate that adequate capacity is available and vehicles are not expected to experience significant queues and delays. As the v/c ratio approaches 1.0, traffic flow may become unstable, and delay and queuing conditions may occur. Once the demand exceeds the capacity (a v/c ratio greater than 1.0), traffic flow is unstable and excessive delay and queuing is expected (Knoonce, 2008).

(Nedevska, 2016) The capacity, for each lane group, can be calculated by the following equation:

$C_i = Si\frac{gi}{C}$…………………………………………………………………………… (1)

Where:

Si – saturation flow rate for lane group i,

gi/C – effective green ratio for lane group i.

. The volume to capacity ratio is presented by the symbol X and is referred to as a degree of saturation.

Xi=(v/c))i

$= =\frac{Vi\ C}{Si\ gi}$………………………………………………………………………………… (2)

Where:

Vi – demand flow rate for lane group,

Si – saturation flow rate for lane group,

gi – effective green time for lane group,

C – Cycle length.

2.7.2. Saturation Flow

Saturation flow is a very important road traffic performance measure of the maximum rate of flow of traffic (Chad, 2017). It is used extensively in signalized intersection control and design. Saturation flow describes the number of passenger car units (pcu) in a dense flow of traffic for a specific intersection lane group. In other words, if an intersection’s approach signal were to stay green for an entire hour and the flow of traffic through this intersection were as dense as could be expected, the saturation flow rate would be the amount of passenger car units that passed through this intersection during that hour. Saturation flow is the basis for the determination of traffic signal timings and for the evaluation of intersection performance (Meyers, 2007).

Saturation flow is a significant factor used to estimate delay. It happens to be a measure of the concentrated rate of traffic flow which might be attained if possibly hundred percentage green time was given to an individual approach. In the current research, the saturation flow of the selected intersections was obtained based on traffic count of different classes of vehicles, as they pass across the stop line as an unbroken queue during the green (Preethi, 2016)

Table 2-1 Principal Factors Affecting Saturation Flow (Khalil, 2013)

Factors	Element Affecting Saturation Flow
Geometric Condition	• Approach width • Width of lanes • Number of lanes • Grade • Turning Radius • Length of turn bay
Operating Condition	• Signal timing and phasing arrangements • Peaking characteristics • Parking activities • Bus stop operations
Traffic Characteristics	• Traffic composition • Turning movements • Pedestrian activity
Environmental and other factors	• Weather • Driver behaviour • Roadway surface condition • Adjacent land use

2.7.3. Saturation Flow Rate and Saturated Headway

Saturation Flow Rate, which is a fundamental parameter to determine signalized intersection capacity, can be calculated by the average saturated headway (SH), which can directly be measured with field study. The mathematical relation between SFR (S) and saturation head way (SH (hs)) is as follows (Dündar, 2018).

S= 3600/hs Where:

S = saturation flow rate (vehicle /hour)

hs= saturation head way (second)

The saturation headway is constant average headway (time gap) between vehicles which occurs after the fourth or fifth vehicle in the queue and continuing until the last vehicle in the queue clears that intersection (Hamad, 2015).

The base saturation flow rate represents the saturation flow rate for a traffic lane that is 12ft wide and has no heavy vehicles, a flat grade, no parking, no buses that stop at the intersection, even lane utilization, and no turning vehicles (Yi Wang, 2020). Saturation flow rate may vary significantly among intersections with similar lane groups because of differences in lane width, traffic composition (i.e., percent heavy vehicles), grade, parking, bus stops, lane use, and turning vehicle operation (Highway Capacity Manual, 2010).According to HCM 2010 computed saturation flow rate is refers to as adjusted saturation flow rate and it is calculated as follows.

$S = S_0\, f_w\, f_{Hv}\, f_g\, f_p\, f_{bb}\, f_a\, f_{lu}\, f_{lT}\, f_{RT}\, f_{lpb}\, f_{Rpb}$

Where

s = adjusted saturation flow rate (veh/h/ln),

s_0 = base saturation flow rate (pc/h/ln),

f_w = adjustment factor for lane width,

f_{HV} = adjustment factor for heavy vehicles in traffic stream,

f_g = adjustment factor for approach grade,

f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group,

f_{bb} = adjustment factor for blocking effect of local buses that stop within Intersection area,

f_a = adjustment factor for area type,

f_{LU} = adjustment factor for lane utilization,

f_{LT} = adjustment factor for left-turn vehicle presence in a lane group,

f_{RT} = adjustment factor for right-turn vehicle presence in a lane group,

f_{Lpb} = pedestrian adjustment factor for left-turn groups, and

f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn groups.

2.7.4. Traffic Delay at intersection

Delay is an important measure of effectiveness that traffic engineers use to evaluate the traffic operations of signalized intersections. It is the primary measure of effectiveness used in the HCM to define intersection level of service (Kebab, 2017) .

Delay is the additional travel time experienced by a vehicle or pedestrian with reference to a base travel time (e.g. free-flow travel time).The delay to a vehicle which decelerates from the approach cruise speed to a full stop (due to a reason such as a red signal, a queue ahead, or lack of an acceptable gap), waits and then accelerates to the exit cruise speed is considered to include the delay due to a deceleration from the approach cruise speed down to an approach negotiation speed and then to zero speed, idling time, acceleration to an exit negotiation speed along the negotiation distance, travelling the rest of the negotiation distance (if any) at the constant exit negotiation speed, and then acceleration to the exit cruise speed. (Hassen, 2015)

Delay within the perimeter of intersections under signal control is related to vehicle and driver time lost as a result of the procedure of the sign in addition to the existing geometric feature and traffic situations of the intersection. Whereas delay based on the HCM 2000 manual is outlined as the distinction between the traveled time spent and the reference traveled time that may result throughout ideal circumstances; when there is no traffic sign control, no geometric delay, no any incidents, and in the absence of other associated vehicles on the roadway (Darama, 2005).

2.7.5. Control Delay

Control delay is the portion of the total delay attributed to traffic signal. Control delay includes movements at slower speeds and stops on intersection approaches as vehicles move up in queue position or slow down upstream of an intersection. Control is the summation of uniform delay, incremental delay and initial delay with respect to progression factor (those factors the proportion of vehicles arriving on green) (Sukanta Karati, 2014).

Uniform Delay: Uniform delay is another type of delay which is occurred in presence of uniform arrivals, stable flow, and no initial queue. It is based on the first term of Webster's delay formulation and is widely accepted as an accurate depiction of delay for the idealized case of uniform arrivals (Minnosota Mannual, 2017)**.**

The incremental Delay: Incremental delay is other type of delay which occurs at signalized intersections due to non-uniform arrivals and temporary cycle failures (random delay) as well as delay caused by sustained periods of oversaturation (oversaturation delay). It is sensitive to the degree of saturation of the lane group, the duration of the analysis period (T), the capacity of the lane group, and the type of signal control, as reflected by the control parameter (Minnosota Mannual, 2017).

Initial Delay: It also occurs at the signalized intersection. When a residual queue from a previous time period causes an initial queue to occur at the start of the analysis period (T), additional delay is experienced by vehicles arriving in the period since the initial queue must first clear the intersection. This procedure is also extended to analyses of delay over multiple time periods, each having a duration T, in which an unmet demand may be carried from one time period to the next. If this is not the case, a value of zero is used for initial delay. (Sukanta Karati, 2014)

2.7.6. Forms of Delay

HCM defines control delay as the difference in travel time experienced by a vehicle affected by intersection control and the same vehicle if it were unaffected by intersection control (i.e., if it were raveling under free-flow conditions) (Kebab, 2017)**.**

Movement delay at an intersection is commonly computed in the subsequent forms:

- Stopped delay: Is the period when a vehicle is stationary while waiting to cross an Intersection.
- Approach delay: Is the time waste when a car slowdown from its average speeds to stop and when accelerating from the stop to its usual speed.
- Travel-time delay: Is the variance among the real time that it takes a vehicle to cross an intersection and the time spent for a vehicle to cross the intersection when the drivers are allowed to move with their desired speed.
- Time-in-queue delay: Is the overall time spent by a vehicle when joining a queue to its discharge to cross the stop line of an intersection (Bichi, 2018)

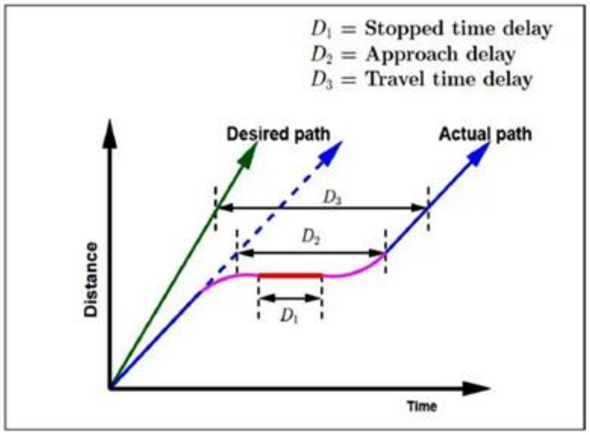


Figure 2-2 Illustrations of Delay Measures (Khalil, 2013)

2.7.7. Delay Components by HCM 2010

Delay, according to HCM, is one of the most basic measures of performance used for the purpose of evaluation the LOS at signalized intersections. The average control delay brought on the vehicles at signalized intersections is an essential criterion in the assessment of LOS.

The HCM version 2010 proposed the method to determining control delay, which is based on the direct observation of the vehicle in queue counts at signalized intersection. The delay that was accomplished by all the vehicles that arrive during the examination period is demonstrated as an average control delay, which is presented in Equation

$$d = d1+d2+d3 \qquad \text{.......... (3)}$$

Where: *d*= control delay (s/veh),

*d*1 = uniform delay (s/veh),

*d*2 = incremental delay (s/veh), and

*d*3 = initial queue delay (s/veh)

- **Uniform Delay**

The uniform delay is established upon the uniform arrivals trough the cycle with no individual cycle failures. Arrivals are indeed selected from the most often platooned and best random as a result of coordinated signal systems. Equation 2 represents the formula to calculate uniform delay.

$$d1=\frac{0.5C\left(1-\frac{g}{C}\right)2}{1-(\min(1,X)g/C}\text{ ……………………………………………………………… (4)}$$

Where: $d1$ = delay due to uniform arrivals (s/veh)

C = cycle length (second)

g= effective green time for lane group (second)

X = Volume / Capacity ratio for lane group

- **Incremental Delay**

  Incremental delay is the combination of two delay components. The influence of random is the first segment which can be defined as the cycle by cycle variation in traffic flow that sometimes exceeds the capacity. This delay exhibits the overflow queue towards the end of green interval (i.e., cycle failure). The second component demonstrates delay due to the continuous oversaturation all through the examination period. This delay component takes place when the aggregate demand exceeds aggregate capacity amid the analysis period. Incremental delay can be calculated by Equation

$$d2= 900T\ [(X-1) + \sqrt{(X-1)2+\frac{8kIX}{cT}}\ ]\text{……………………………………………(5)}$$

Where: $d2$ = delay due to random arrivals (s/veh),

T = duration of analysis period (hour),

K = delay adjustment factor that is dependent on signal controller mode,

I = upstream filtering/metering adjustment factor,

c = lane group capacity (veh/hr),

X = v/c ratio for lane group.

- **Initial Queue Delay**

  The initial queue delay is the extra delay that happens due to the initial queue. This queue happened due to un-met demand in the previous phase or series of phases the initial queue does not involve any vehicles that possibly remain in queue because of random; cycle by cycle fluctuations in demand after that rarely exceeding capacity. If no lane group has this delay, the initial queue can be considered as 0. s/veh. This delay can be calculated by Equation

$$d3 = \frac{3600}{vT} (t_A \frac{Qb+Qe-Qeo}{2} + \frac{Qe^2+Qea^2-Qb^2}{2CA} \quad \text{......} (6)$$

With:

If V ≥ C A then: Qe = Qb + tA (V-CA)... (7)

Qeo= T (v-CA)

tA = T

If V< CA then: Qeo = 0.0. veh

tA = Qb/(CA –V) ≤ T

Where: *d3* = delay due to initial queue delay (s/veh)

T = duration of analysis period (hour),

υ = demand flow rate (veh/h),

*t*A = adjustment duration of un-met demand in the analysis period (hour),

cA = average lane group capacity (veh/h),

Qb = initial queue at the start of the analysis period (veh),

Qe = initial queue at the end of the analysis period (veh),

Qeo = initial queue at the end of the analysis period when $\upsilon>cA$ and Qb=0.0 (veh).

2.7.8. Level of Service

An index of the operational performance of traffic on a given roadway, traffic lane, approach, intersection, route or network, based on measures such as delay, degree of saturation, density, speed, congestion coefficient, speed efficiency or travel time index during a given flow period. This provides a quantitative stratification of a performance measure or measures that represent quality of service, measured on an A to F scale, with LOS A representing the best operating conditions from the traveler's perspective and LOS F the worst. (Ashutosh Arun, 2016). Control delay includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. Specifically, LOS criteria for traffic signals are stated in terms of the average control delay per vehicle, typically for a 15-min analysis period. The criteria are given in the table below. Delay is a complex measure and is dependent on a number of variables, including the quality of progression, the cycle length, the green ratio (the ratio of effective green and cycle length g/C), and the v/c ratio for the lane group in question. (Minnosota Mannual, 2017).

Table 2-2 Delay in each LOS for intersections

Source (Highway Capacity Manual 2010)

LOS	At signalized intersection (second/vehicle)	At un-signalized intersection (second/vehicle)	At Streets/roads (Using queue)
A	<10	<10	<15
B	10 – 20	10 – 15	15 – 30
C	20 - 35	15 – 25	30 – 55
D	35 – 55	25 – 35	55 – 85
E	55 – 80	35 – 50	85 - 120
F	>80	>50	Unstable

Level-of-service A**:** Individual vehicles flow freely, not affected by others.

Level-of-service B**:** though it is in a stable flow condition, obviously additional vehicles joining the traffic stream will affect traffic movement. However, there is a relatively freedom in speeds.

Level-of-service C***:*** There is a relative stable flow, but individual vehicles influence the flow immediately and become significantly affected by interactions with other vehicles in the traffic stream.

Level-of-service D**:** It is a crowded roadway situation as mobility and a stable flow is restricting with a large number of vehicles. Speed and freedom to movement are harshly restricted.

Level-of-service E**:** Roadway accommodates nearly to its full capacity, low speed, and small increment in the traffic volume will affect the traffic movement more.

Level-of-service F***:*** Vehicles move in a locked each other with in front and beyond condition. Speed is mostly to zero, and the travel time cannot be predicted (Highway Capacity Manual, 2010).

The base criteria for determining the average delay per vehicle as per the Highway Capacity manual have been using in our country Ethiopia since Level of Service (LOS) is directly related to the delay value. The standard criteria as per the Highway Capacity Manual for the signalized intersection are listed in the following table.

Table 2-3 Level of Service criteria for vehicles at signalized intersection

Source [Highway Capacity Manual 2010]

LOS Types	Delay per Vehicle (sec/veh)
A	≤ 10
B	10 – 20
C	20 – 35
D	35 – 55
E	55 – 80
F	>80

Table 2-4 Level of Service criteria for signalized intersection

Source [Highway Capacity Manual 2010]

Control Delay per vehicle (sec)	Level of Service by v/c ratio V/C < 1	V/C >1.0
≤ 10	A	F
20-Oct	B	F
20 - 30	C	F
30 - 40	D	F
40 - 60	E	F
>60	F	F

2.7.9. Queue length

Queue lengths are important parameters in traffic engineering for judging the capacity and traffic quality of Traffic control equipment. At signalized intersections, queue length at the end of red time (red-end) is very important for dimensioning the length of lanes. While the average queue length reflects the capacity of traffic signals, the so-called 95^{th} and 99^{th} percentile of queue lengths at red end are usually used for determining the length of turning lanes, such that a blockage in the through lanes could be avoided as far as possible (Wu, 1998).

Queue length could be an estimation of the road space cars would occupy while holding up to pass across a junction. It is generally utilized to estimate the total capacity essential for turn paths and to decide whether the motor vehicles from one interchange will substantially overflow into a connecting intersection. Numerous line length approximations are commonly utilized with signalized crossing points. Normal queues, as well as 95thpercentile line, are usually assessed for the time interval for which the control sign turn red. Though, it is occasionally valuable to incorporate the queue founding that happens during green whereas the front of the line is discharging and receiving incoming vehicles from the back. Lines measured in this manner are frequently famous as normal back of the queue (Koonce, 2008).

Delay and back of queue(which refers to the number of vehicles queued at an approach to a signalized intersection due to the arrival patterns of vehicles and to vehicles being unable to clear the intersection during a given green phase; that is overflow) are not always consistent in terms of magnitude. Low average delay can be associated with a long back of queue as a result of a high arrival flow rate, large green time ratio (relatively short red period) and low degree of saturation. Large proportion of vehicles may be un-delayed, and therefore the cycle-average queue could be small. In contrast, the case of short back of queue may be associated with a large average delay as a result of a low arrival flow rate, small green time ratio (relatively long red period) and a high degree of saturation (Hassen, 2015).

2.8.Parameters which affect Intersection performance

Signalized intersections performance is affected by different parameters, such as signal timing, vehicle composition, and geometric condition.

2.8.1 Effect of cycle length on delay

Cycle length is composed of the total signal time to serve all of the signal phases including the green time plus any change interval. Longer cycles will accommodate more vehicles per hour but that will also produce higher average delays. The best way is using the shortest practical cycle length that will serve the traffic demand. The cycle length includes the green time plus the vehicle signal change interval for each phase totaled to include all signal phases (Kumala, 2016) .

2.8.2 Effect of Heavy Vehicle on delay

Large trucks (those considerably larger than pickup trucks) have considerably different size and performance characteristics than passenger cars. Consequently, these trucks can have a significant impact on traffic operations. It is therefore essential to properly account for this impact in the traffic operations analysis to reflect the operational quality of the roadway as accurately as possible (Mohammad Al Eisaeia, 2017).

Signalized intersections are one roadway facility that can be particularly sensitive to the presence of truck traffic. As for other roadway facilities, the longer physical space consumed by trucks relative to passenger vehicles has a negative impact on the capacity of a signalized intersection. However, the lower performance characteristics of trucks have an even greater impact on signalized intersections than uninterrupted flow facilities due to the broader range of speed through which vehicles must accelerate and decelerate (from a stop to cruise speed and vice versa). Furthermore, given the longer delays incurred by trucks and imparted to other vehicles through acceleration and deceleration, the presence of trucks can have implications on signal coordination, particularly if trucks are present at the front of a discharging queue (Washburn, 2010).

Although heavy vehicle has an important role in economy and it comprise a small proportion of traffic stream, they have an important effect on traffic flow and produce a disproportionate effect particularly during heavy traffic conditions. Heavy vehicles impose physical and psychological effects on surrounding traffic. These effects are the results of physical characteristics of heavy vehicles (length and size) and their operational characteristics (acceleration/deceleration and maneuverability). The effect of heavy vehicles' operational characteristics becomes prominent under heavy traffic conditions (Sara Moridpour, 2014).

2.8.4 Effect of heavy vehicle on saturation flow

The saturation flow rate is a fundamental parameter to measure the intersection. It is taken to be the reciprocal of the average headway of the fifth vehicle through to the last vehicle that was in the queue at the beginning of that green period. (Liu, 2012). A slowly-accelerating heavy vehicle at the head of the queue results in greater headways for itself and for vehicles behind it. This would result in increased startup loss and contributing on saturation flow rates by reducing it.

2.8.5 Effect of number of lane on delay

One method sometimes used to increase the capacity of signalized intersections is to widen the roadways through the intersections to provide additional through lanes. The degree to which these additional through lanes actually improve the efficiency of traffic operations at the intersections depends on the extent to which they are used by through vehicles (Tobin, 2010)

2.9 Sensitivity Analysis

Sensitivity analysis is the technique used to determine how independent variable values will impact a particular dependent variable under a given set of assumptions is defined as sensitive analysis. The sensitivity analysis used to obtain estimation of capacity and performance statistics as a function of different parameters.

2.10 Overview of the Sidra Software

Signalized /and un-signalized**/** Intersection Design and Research Aid (SIDRA) software is an advanced lane-based micro analytical tool for design and evaluation of individual intersections and networks of intersections including modeling of separate movement classes (light vehicles , heavy vehicles , buses , bicycles, large trucks , light rail/trams and so on). It provides estimates of capacity, level of service and a wide range of performance measures including delay, queue length and stops for vehicles and pedestrians, as well as fuel consumption, pollutant emissions and operating cost.

2.11 Summery and Gap analysis

One of the significance is the traffic delay and congestion issue as a global phenomenon in the management of capital cities, giving the level of population and activity concentration. Traffic congestion continues to remain a major problem in most cities around the world, especially in developing regions resulting in massive delays, increase fuel wastage, environmental pollution increase, and monetary losses.

Traffic congestion has various negative impacts ranging from economic losses to adverse environmental and social impacts. Congestion causes increased costs for travelers and freight movement, loss of time, accidents, increase transport cost, increase vehicle operating cost and psychological strain. These researches focus evaluation of vehicle time delay at signal control intersection. The analysis can determine total delay spent on signalized intersection and can also relate to congestion problems.

The need of this research we can predict what will happen in the future, due to the fact that every person living working or even who made a visit within the city is affected or touched differently by the existing road traffic congestions, leaving aside its general impact on people’s economic impact in the city. It has expecting to show how the traffic congestion has affected the residents of Addis Ababa city socially and economically. The research provided relevant recommendations and suggestions in accordance to the nature of the findings. Also, the research pointed some areas which require future investigation in the future on condition that there will be a gap between it and other studies on the problem.

3. METHODOLOGY

3.1. Data Collection

In order to calculate delay of signal control intersection in selected study areas, field observations including geometric data, signal data and other necessary data have to be collected. In addition, traffic volume data collected by Addis Ababa City Administration Transport Bureau was be used for this research.

3.2. Description of the Study area

Addis Ababa is the capital city of Ethiopia, which is located within the horn of Africa with geographical coordinates of $9^{o}1'48''$ North and $38^{o}44'24''$ East and with an average elevation of 2355m above sea level. The city has a total area of about 530.14 km^2. The city is divided into 10 administrative sub cities and 99 Kebeles. It is the most important business and commercial center of the country. The rapid increase of the Addis Ababa population (according to 2007 Census Report the annual growth rate for 2007 was 2.1% and as estimated the population will be about 5 million by 2020) is the main cause of the increasing demand for transportation and mobility. This may create major operational problems, especially during the peak periods (Federal Democratic Republic Of Ethiopia, August 2011). Figure 3.1 below shows administrative units of Addis Ababa.

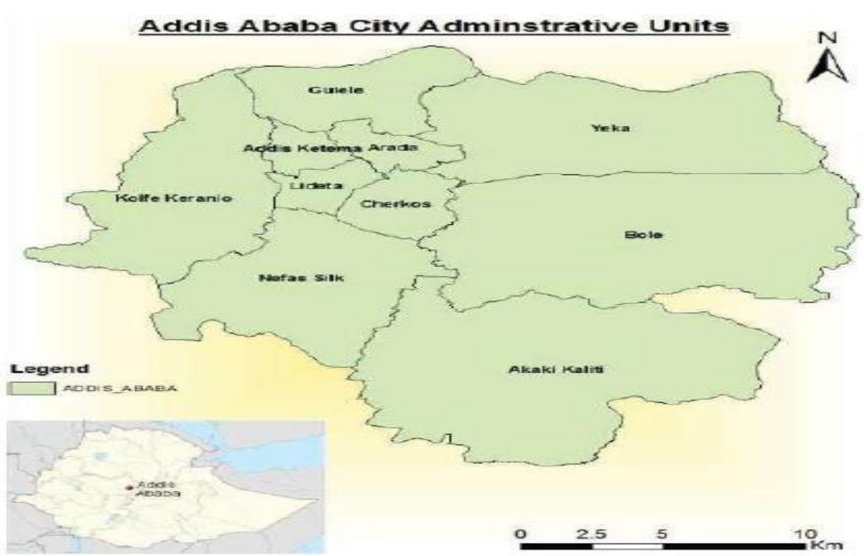


Figure: 3-1 Addis Ababa administrative units.

Even though there are many signalized intersections, experiencing delay, in Addis Ababa due to time constraints and data availability, it is difficult to evaluate the whole intersection in this research. So, the researcher selects only three intersections having four and three approach legs after having discussion with Addis Ababa City Administration Transport Bureau.

The selected intersections for this research are positioned in East Corridor and South West corridor of Bole Sub City and at Nifas Silk Lafto Sub City. These areas are highly populated residential areas with much new housing and real estate developments which includes New Hope real estate, Tracon real estate, 20/80 condominium, Imperial 40/60 condominium, Tourist 40/60 condominium, Ehil nigid 40/60 condominium and apartment buildings and town house buildings. The three selected signalized intersections for this research are:

- Lebu Mebrat Haile intersection
- Imperial intersection
- Jakros intersection

The Google Earth images of the selected intersections are shown below.

Figure: 3-2 Lebu Mebrat Haile Signalized Intersection

Figure: 3-3 Imperial Signalized Intersections

Figure 3-4 Jacros Signalized Intersections

3.3. Design Study

To determine vehicle time delay at selected signalized intersections, it is required to collect input parameters such as traffic data, road geometry, and signal data (cycle length, green time, red time, and yellow time). The input parameters are analyzed using SIDRA Intersection 8.0 software and HCM methodology.

There is different computer software to analyze different types of intersections. The software can be divided into micro-simulation and analytical model software. Micro-simulation software needs user specializations, slows for a large application, simulates the movement of an individual vehicle, and allowing network-wide analysis. Moreover, the analytical model uses traffic volume flows to a model intersection and the choice of analysis approach depends on calibration data's availability. For this research, one of the analytical models, SIDRA Intersection 8.0 programs is applied to analyze traffic operations at signal control intersection because it is a commercially available tool and relaxed to manipulate. Besides, the software is familiar to the researcher and it provides conveniences to calibrate its traffic models for local conditions. Based on the output of the analysis, the researcher discussed about the contributory factors which are causes for delay, give recommendation to reduce delay and to increase performance of the intersections.

3.4. Method of data collection

To achieve the objective of the research, both primary data and secondary data will be collected.

3.4.1. Primary data

The primary data taken from the study intersection areas are: geometric data, signal data and related field observation.

A, Geometric Data

Intersection geometry data must include all of the relevant information needed for the software including: approach grades, parking conditions, number and width of lanes, approach and exit operating speed. The existence of exclusive left and/or right-turn lanes should be noted, along with the storage lengths of such lanes.

B, Basic Signal Timing elements

At signalized intersection, three signal indications are displayed: green, yellow and red. The basic timing elements within each phase includes the green interval, the effective green time, yellow or amber interval and the all-red interval. Cycle length and number of phase for each intersection are collected via site visit as input for analysis.

C, Site Visit

In this research, a site visit was made to collect data that is relevant to SIDRA Intersection 8.0 software. These includes: Lane configuration (full length, short lane, a short lane with parking or two-segment lane), lane types (normal lane, slip/bypass, high angle or low angle) and lane control (signal, continuous or give way). Gradient, lane width, lane length, median width is also measured from the site visit. The site visit is carried out during weekdays. We take images using a camera and measurement of road geometry by a measurement tape and Google earth.

3.4.2. Secondary data

Secondary data used for the research are traffic volume data collected from the Addis Ababa city administration transport bureau, different books, journals, related thesis and internet. Traffic volume data collect for all study areas which are manually counted for five days with a 15-minute interval of time.

3.5. Data analysis method

Generally, to analyses the data some input parameters are calculated. Others are taken from observation and manual recommendation value. The parameters are set by using Highway Capacity Manual 2010 and SIDRA intersection 8.0 user manual.

The researcher used Highway Capacity Manual 2010 as it is compatible to SIDRA intersection software and Ethiopia has not yet developed its localized manual.

3.5.1 Geometric data

As per the requirement of the SIDRA Intersection Version 8.0, the collected geometric data includes; lane configuration, lane type, lane control, lane length (queue storage space available), lane width and gradient. These data are collected through site visit observations and taking measurements from at the intersections.

3.5.1.1 Approach Grades

Approach grade defines the average grade along the approach, as measured from the stop line to a point 30m upstream of the stop line along a line parallel to the direction of travel. An uphill condition has a positive grade and a downhill condition has a negative grade (Highway Capacity Manual, 2010).

Approach grades are calculated for all approaches which are expressed as in percentage desirable for all approach. The values for grades of each approaches was calculated by dividing the elevation differences of two points to the distance between the two points times 100 in order to put in percentage. The elevation difference of two points was obtained from GPS.

The grade of each approach is calculated by the formula.

Grade of each approach (G) = $\frac{\Delta z}{\Delta y}$

Sample calculation for Lebu intersection at Hana approach that was used as input for the software is presented as follows.

Elevation at stopping line of Hana approach = 2331m

Elevation at 30m back of stopping line of Hana approach = 2230m

Then grade of Hana approach (G) = $\frac{\Delta z}{\Delta y}$=$\frac{2230-2331}{30} * 100$=-3.3

Likewise, for the rest approaches the values of upstream and downstream grades are summarized in the following table 3-1.

Table 3-1 Values of up steam and downstream gradient for the study area

Junction name	Name of approaches	Upstream grade values (%)	Downstream grades values (%)
Lebu	Hana	3.3	-3.3
	Mexico	-3.3	3.3
	Jemo	3.3	-3.3
	Lafto	-3.3	3.3
Junction name	Name of approaches	Upstream grade values (%)	Downstream grades values (%)
Imperial	Bole	-3.3	3.3
	Megenagana	-3.3	3.3
	Gergi	3.33	-3.33
	hayarat	-3.3	3.33
Junction name	Name of approaches	Upstream grade values (%)	Downstream grades values (%)
Jacros	Mebrat hayle	-3.3	3.3
	Salite mihret	3.3	-3.3
	Goro	3.3	-3.3

3.5.1.2 Number and width of lane

The number of lanes represents the count of lanes provided for each intersection traffic movement and the lane width represents the width of the lanes represented in a movement group (Highway Capacity Manual, 2010). Thus, in the study intersection numerical values of the numbers and width of lanes including median width values were needed as input data for the software are summarized in Table 3-2 for each junction. Lane configuration, lane type and lane control are also recorded during site visit.

Table 3-2 Number of lane, lane width, median width and leg geometry of study area

Junction name	Approach leg	Number of lane	Lane width(m)	Median width	Leg geometry
Lebu	Hana	3	4	0.7,2.65	Two way
	Mexico	3	4	0.7,2.5	
	Lafto	3	3.3	0.85,3.5	
	Gemo	3	3.3	1.5,3.25	
Junction name	Approach leg	Number of lane	Lane width(m)	Median width	Leg geometry
Imperial	Bole	3	4	2.05,0.75	Two way
	Megenagna	3	4	2.10,0.75	
	Gergi	2	3.5	1.55,0	
	Hayarat	3	3.3	1.5,0.95	
Junction name	Approach leg	Number of lane	Lane width(m)	Median width	Leg geometry
Jacros	Mebrat hayle	3	3.3	2.4,1	Two way
	Salite mihret	3	3	0.95,0.75	
	Goro	3	3.3	1.85,1.5	

The movement-group designation is useful to construct input data. There are exclusive lanes and shared lanes which are used for analysis. Figure 3.5 shows the lane groups for analysis. The layout of study intersection with their movement direction is shown in appendix B.

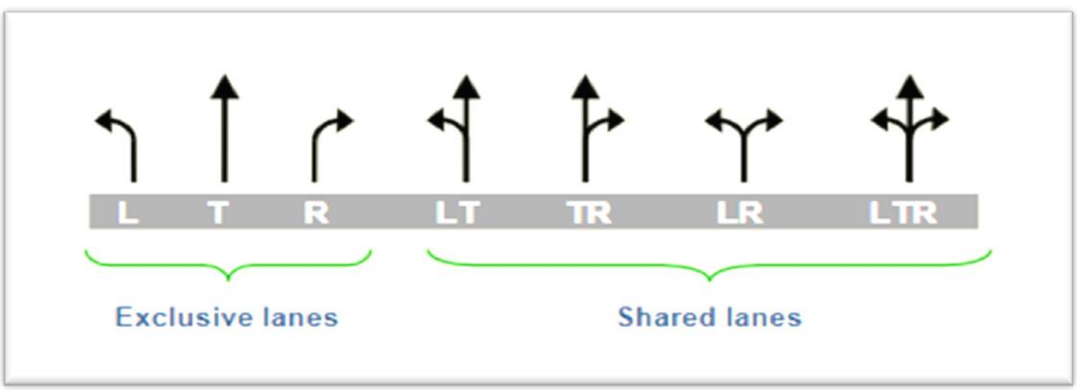


Figure: 3-5 Lane groups (L = Left, T = Through, R = Right)

3.5.1.3 Saturation Speed and Cruise Speed

Speed is defined as a rate of motion expressed as distance per unit of time, generally as kilometer per hour (Km/h) (Hassen, 2015). Delay rather than speed is the primary measure of traffic operations at the intersections and speed are parameters common to both uninterrupted- and interrupted-flow facilities (Highway Capacity Manual, 2010). SIDRA intersection 8.0 requires saturation speed, approach and exit cruise speed. Saturation speed is the steady speed value associated with queue discharge (saturation) flow rate. This parameter indicates that vehicles do not accelerate to the speed limit during queue discharge. Exit and approach cruise speed is average uninterrupted travel speed that means the speed of vehicle without the effect of delay or speed limit of the road. Thus saturation speed is taken from related research done (Admasu K. , 2016). He determines vehicular speed for three types of intersection that is roundabout, signalized and un-signalized intersection by taking 360 vehicles for analysis. From the analysis of the results there is minimum, maximum and average saturation speed for each movement listed in the table 3-3. The researcher took the average value of saturation speed at signalized intersection for software analysis.

Table 3-3 Vehicular speed at intersection

Movement	Average speed	Maximum speed	Minimum speed
Left	17.12	28.39	8.93
Through	21.30	31.83	11.33
Right	18.64	33.41	13.50

Cruise speed is posted speed of road; taking posted speed 70kmh for ring road and 50kmh for other road.

3.5.1.4 Basic saturation flow rates

Likewise saturation speed saturation flow determined by (Admasu K. , 2016) is taken for this research. He is calculated saturation flows after surveying 1394 headways at different times of the day and at four intersections of different characteristics. Accordingly, he concludes saturation flow rates of Addis Ababa's multi-lane highways range from 1789 to 1820 with 95% confidence interval. The researcher had taken the average value of the range which is 1804 pc/hr/ lane. But the software uses this value as a base and adjusted by different factor based on input data such as area type, lane width, grade, parking, bus stopping, and heavy vehicle percentage. The adjusted value of the saturation flow rate is shown in Appendix B.

3.5.2. Traffic data

Traffic volume count data are very important to determine and understand the flow pattern in the capability, to determine the peak hour volume and peak hours, Hence, obtaining traffic volume data at selected intersections in the study were obligatory, the traffic volume count was made for 12 hours by video Recording at 15 minutes interval by Addis Ababa city administration transport bureau for five days and twelve hour. The vehicles were counted by classifying by different vehicle type which are private vehicle (car and taxi, 4wd, two wheeler and Bajaj), public transport (mini bus taxi, mini/mid bus and standard bus), goods vehicle (pick up, LCV, 2/3 axle and MAV > 3 axle). For this research, the traffic data is collected into the 3 classes by considering mass, speed and road space requirements. These are car, bus and trucks to simplify for analysis. Car (car and taxi, minibus taxi, 4wd and pick up), bus (mini/ mid bus and std bus) and finally trucks (LCV, 2/3 axle and MAV > 3 axle) This count is done by considering different movement types (Through, Left and Right).Pedestrian volume also has significant effect for estimating the effect of pedestrians on vehicle movement capacities and signal timing at intersection. The total number of counted pedestrians at peak hour of intersection is shown figure 3-7 counted at fifteen minute interval of time by considering in ward & out ward in each arm. For detailed information of volume counts of pedestrian and vehicle is shown in the Appendix A.

For analysis of intersection peak hour must be identified. The peak hour volume is the volume of traffic that uses the approach, lane, or lane group in question during the hour of the day that observes the highest traffic volumes for that intersection. The peak hour volume would be the volume of passenger car units during rush hour and such mixed traffic must converted into passenger car units.

3.5.2.1 Passenger Car Unit (PCU)

PCU is the number of passenger cars that will result in the same operational conditions as a single vehicle of a particular type under identical roadway, traffic, and control conditions (Administration, August 2018). Passenger Car Unit (PCU) is the metric used to convert heterogeneous traffic into homogeneous traffic (Sugandhi, 2017). Thus, the traffic flow with any vehicular composition can be expressed in terms of its equivalent Passenger Car Unit. Many studies have been performed to determine reasonable values for PCU under different road and traffic conditions because of its dynamic property.

The PCU value of a passenger car was identified as 1.0 because of ease maneuverability in any directions. Each vehicle type was given a single PCU equivalent to represent its relative disturbance to the flow under the prevailing traffic condition (Pothula sanyasi Naidu, 2015).

To change all vehicles into a passenger car, passenger car unit (PCU) for each vehicle is needed. Actually PCU varies according to different factors like speed, time head way and overall length of vehicle, overall width of vehicle, engine power, weight, acceleration, deceleration, braking and other maneuvering characteristics. But in this research adopting pcu which is done in Ethiopia by head way approach in Addis Ababa (Admasu N. , 2017) which is listed in table 3-4. For analysis Bajaj and motor cycle are considered as light vehicle by changing into passenger car and minibus, midi bus, standard bus considers as bus and trucks are considered as heavy vehicles

Table: 3-4 PCU values based on head way approach.

class of vehicle	Bajaj	car and taxi	4wd	minibus taxi	mini/midi bus	Std bus	small trucks	mid trucks	largest truks
PCU	0.8	1	1.1	1.1	1.3	2.1	1.3	1.7	1.9
average		1.05		1.5			1.6		

Using the above factors, each vehicle class is converted to the total pcu for each 15min interval of time to determine the peak hour of intersection because capacity and other traffic analyses typically focus on the peak-hour traffic volume because it represents the most critical period for operations and has the highest capacity requirements. So the researcher identify peak hour from five days average passenger car for each intersection at fifteen minute interval is as shown appendix A.

Average of five days passenger car for three signalized intersections was summarized for all vehicles types described in table 3-5.

Table 3-5 Five days average pcu of each intersection

Time	Lebu	Imperial	Jackros
6:00-7:00Am	2710	2523	1910
7:00-8:00 Am	4567	4193	2669
8:00-9:00 Am	4911	4621	2440
9:00-10:00 Am	4765	4725	2502
10:00-11:00 Am	5115	4545	2644
11:00Am-12:00Pm	**5122**	4576	**2795**
12:001:00Pm	5094	4371	2495
1:00-2:00Pm	4585	4391	2524
2:00-3:00Pm	4991	4852	2715
3:00-4:00Pm	4627	4842	2395
4:00-5:00Pm	4885	4837	2782
5:00-6:00Pm	5035	**6027**	2699

The above average PCU in Table 3-5 is helpful to specify the peak hour period of each intersection. The peak hour of jackros and lebu intersection is from 11:00AM-12:00PM and the peak hour of imperial intersection were 5:00PM-6:00 PM. Figure 3.6 below show the peak hour during the time period of survey at three intersections.

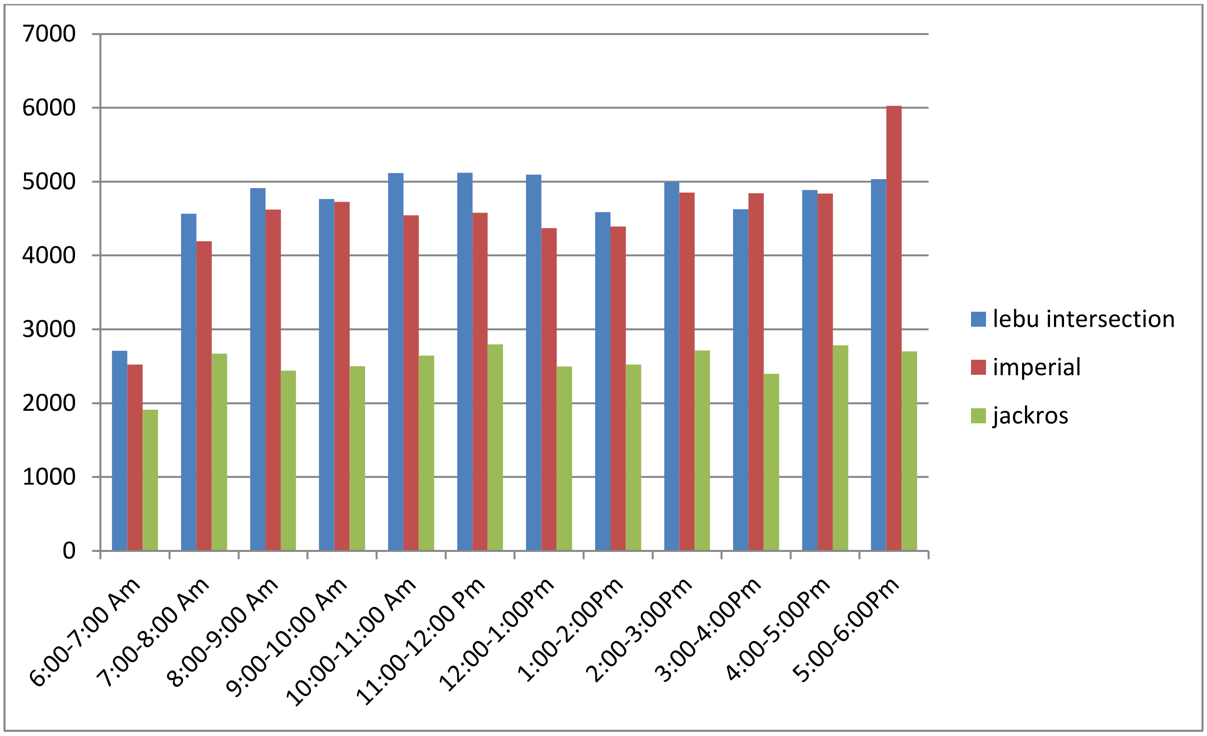


Figure 3-6 average pcu versus counting times at three signalized intersection.

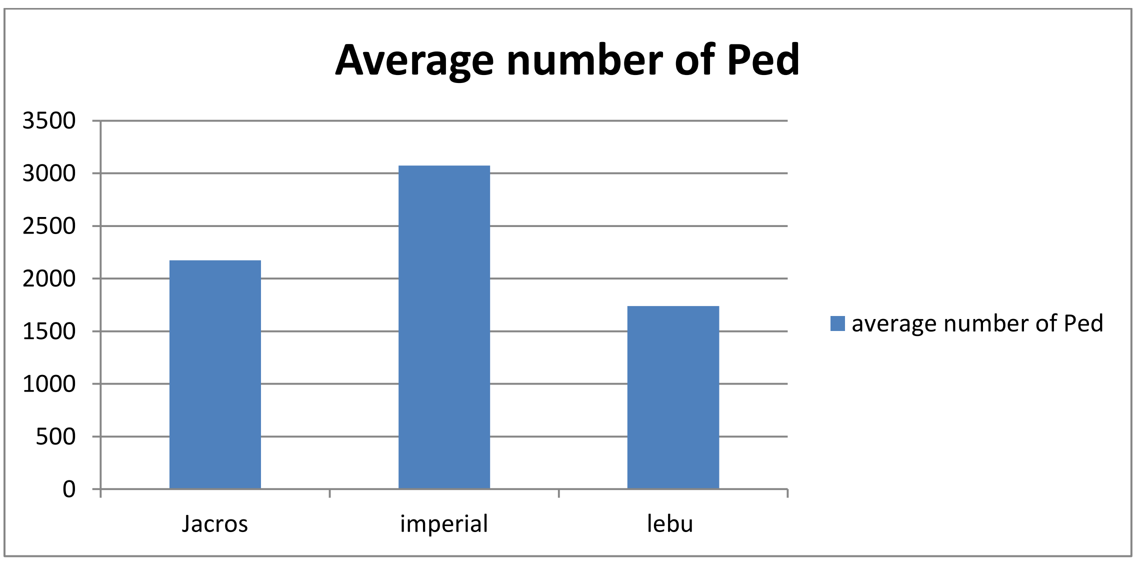


Figure 3-7 Average pedestrian counted data per hour of each approaches

There are three methods used for identifying and demonstrating the Vehicles data for different movement classes in using the software are:

- **Separate:** separate volumes will be specified for individual movement classes, e.g Light vehicles: 900 veh, Heavy vehicles: 90 veh and buses: 10 veh (total 1000 veh will be calculated and displayed)
- **Total and %:** Total volume and percent value for movement classes other than light vehicles will be specified, e.g Total 1000 veh, heavy vehicles 9 % and buses 1 %(Light vehicles 90% will be calculated and displayed)
- **Total and vehicles:** Total volume and volumes for movement other than light vehicle will be specified, e.g Total 1000 veh, Heavy vehicles: 100 veh and buses: 10 veh (Light vehicles: 900 veh will be calculated and displayed).

Therefore; the researcher selected the first rule for identifying and demonstrating average vehicle data from five days and twelve hour count as inputs for the software and the traffic data arranged as heavy vehicle, light vehicle and buses in different movement directions. In addition the software needs growth rate of intersection location then growth rate of vehicles population is (6.5%) for all intersection taken from AACRA pavement design manual by considering economic growth zone which is laid under economic zones three shown in figure 3.8 and table 3.6 .

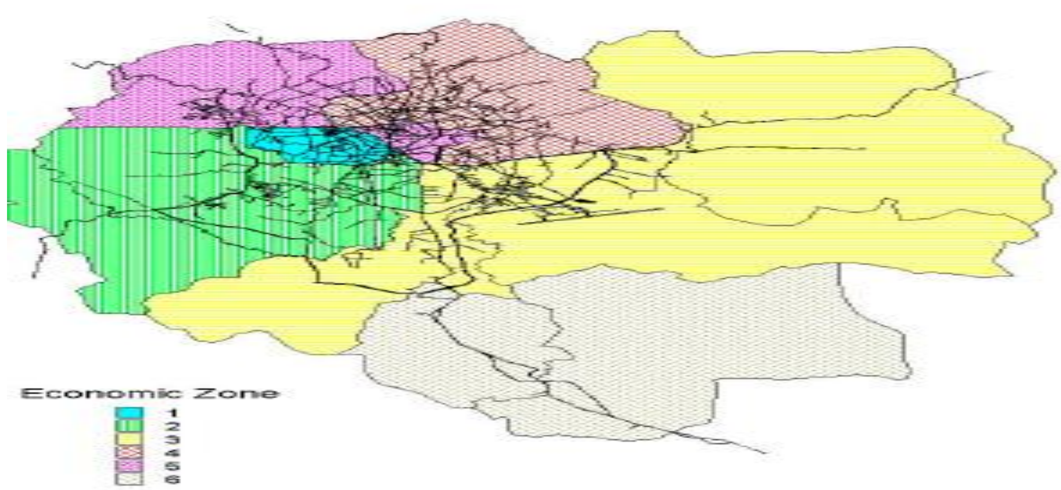


Figure: 3-8 Economic growth zones in Addis Ababa

Table 3-6 Growth Rate Matrix (% pa) **(Authority, 2004)**

Road classification	Economic Growth Zone					
	1	2	3	4	5	6
Arterial	7.0	11.2	7.0	11.1	7.2	9.3
Sub-Arterial	6.5	9.3	6.5	9.2	6.6	8.2
collector	6.0	7.4	6.0	7.4	6.1	6.8
Local	5.5	5.5	5.5	5.5	5.5	5.5

As it was observed, there are four legs at Lebu and Imperial intersection and three legs at jackros intersection in which the vehicles can arrive or/and dissolves. Among the three intersections Lebu intersection has the highest traffic volume.

Table 3-7 Summarized average peak hour traffic movements at three intersection

Jackros signalized intersection

leg name	left			Right			Through		
	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus
Salitemihret	20	71	10				48	394	74
Goro	73	389	118	29	104	8			
Mebrathaile				210	576	256	110	688	152

Imperial signalized intersection

leg name	left			Right			Through		
	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus
Bole	12	98	24	56	708	351	87	649	613
Megenagna	8	153	111	3	86	18	48	503	306
Hayarat	4	150	22	26	316	99	9	274	28
Gergi	16	175	108	7	88	62	2	183	32

Lebu signalized intersection

leg name	left			Right			Through		
	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus	Heavy vehicle	Light vehicle	Bus
Lafto	16	88	18	25	215	70	26	360	25
Jemo	19	225	35	121	266	96	23	356	31
Hana	96	227	104	12	65	11	322	441	265
Mexico	23	156	40	14	213	36	330	465	287

The values in table 3-7 are the final traffic input data used in the software.

3.5.2.2 Peak Hour Factor

PHF is a measure of traffic demand variation within the analysis hour and describes the relationship between full hourly volume and the peak 15-min flow rate within the hour (Administration, August 2018).

The PHF is the ratio of total hourly volume to the peak flow rate within the hour and is computed by

$$PHF = \frac{\text{Hourly Volume(V)}}{\text{Peak flow rate within hour}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.1)$$

The peak hour volume is just the sum of the volumes of the four 15 minute intervals within the peak hour (Highway Capacity Manual, 2010)

If 15-min periods are used, the PHF may be computed by Equation: -

$$PHF = \frac{V}{4 * V15min} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3.2)$$

Where

PHF= peak-hour factor,

V= hourly volume (veh/h),

V15 = volume during the peak 15 min of the peak hour (veh/15 min).

When the PHF is known, it can convert a peak-hour volume to a peak flow rate by Equation:-

$$v = \frac{V}{PHF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.3)$$

Where

v= flow rate for a peak 15-min period (veh/h),

V = peak-hour volume (veh/h), and

PHF= peak-hour factor

The peak hour factor is found for each intersection is by summing up peak hour volume (hourly volume) and divided by four times the maximum flow rate. Peak hour volume is average passenger car unit of peak hour with respect to 15 minutes interval of time which is used for determination of peak hour factor listed on table 3.8.

Table 3-8 summarized counted average PCU with respect to 15 minute interval for each approach

Lebu intersection				
	Leg name			
Time	Mexico	Hana	Lafto	Jemo
11:00-11:15 am	419	381	226	314
11:15-11:30 am	370	367	198	283
11:30-11:45 am	406	422	204	289
11:45-11:00 am	369	373	215	286
Jackros intersection				
	Leg name			
Time	Mebrathayle	Salitemihret	Goro	
11:00-11:15 am	450	164	187	
11:15-11:30 am	487	158	175	
11:30-11:45 am	519	149	155	
11:45-11:00 am	536	146	164	
Imperial intersection				
	Leg name			
Time	Bole	Megenagna	Gergi	Hayarat
5:00-5:15 pm	445	335	174	226
5:15-5:30 pm	456	273	186	171
5:30-5:45 pm	501	329	172	342
5:45-6:00 pm	1196	299	141	189

Sample calculation for Lebu intersection at Mexico approach:

Peak hour volume (PHV) = sum of four peak 15minutes= 419+370+406+369=1564pcu

Peak 15minuts volume (Vp15min) = maximum 15minute volume =419pcu.

Peak Hour Factor (PHF) = PHV/ (4*Vp15min.) = 1564/ (4*419) = 0.93

Likewise, for the remaining approach of intersection the sample calculation was summarized in the following table.

Table 3-9 Calculated peak hour factor for three intersection

Lebu intersection

Leg name	PHV(pcu)	$V_{15min(pcu)}$	PHF=($\frac{PHV}{4xV15min}$)
Mexico	1564	419	0.93
Hana	1543	422	0.91
Jemo	1172	314	0.93
Lafto	843	226	0.93

Jackros intersection

Leg name	PHV(pcu)	$V_{15min(pcu)}$	PHF=($\frac{PHV}{4xV15min}$)
Salitemihret	617	164	0.94
Mebrathayle	1992	536	0.93
Goro	681	187	0.91

Imperial intersection

Leg name	PHV(pcu)	$V_{15min(pcu)}$	PHF=($\frac{PHV}{4xV15min}$)
Bole	2596	1196	0.54
Megenagna	1236	335	0.92
Gergi	673	186	0.90
Hayarat	928	342	0.68

According to HCM 2010 lower PHF values signify greater variability of flow, while higher values signify less flow variation within the hour. PHFs in urban areas generally range between0.80 and 0.98. PHFs over 0.95 are often indicative of high traffic volumes, sometimes with capacity constraints on flow during the peak hour. PHFs under 0.80 occur in locations with highly peaked demand, such as schools, factories with shift changes, and venues with scheduled events.

Therefore; almost all approaches had the value within range in urban areas except Imperial intersection at bole and Hayarat approach this specifies that there is greater variability of flow within the subject hour on the other hand there are no PHFs over 0.95 which means that no high traffic volume as identified in table 3.9.

3.5.3 Basic signal timing elements

At the study area of a signalized intersection, three signal indications are displaying: green, yellow, and red. The basic timing elements within each phase include the green interval, yellow or amber interval, and the all-red interval.

SIDRA software needs practical cycle length of intersection from field observation, thus from field observation the values of cycle length for Lebu is 190 sec, for Imperial intersection 213sec with five phase sequence and 140 sec for Jacros intersection with three phase sequence all intersection have 3 sec yellow time interval and 2 sec for all-red interval.

3.5.4 Other necessary data needed to the software.

Table 3-10 Lane utilization factor

Lane group movement	Number of Lanes in lane Group(ln)	Traffic in most Heavily Travelled lane (100%)	Lane Utilization adjustment factor flu
Exclusive through	1	100	1
	2	52.5	0.952
	3	36.7	0.908
Exclusive left turn	1	100	1
	2	51.5	0.971
Exclusive right turn	1	100	1
	2	56.5	0.885

Based on lane discipline of among three intersections the value of lane utilization factor is taken from table 3.10 directly from HCM 2010

3.5.4.1 Bus stopping and parking manoeuvre

Bus stopping

The bus stopping rate represents the number of local buses that stop and block traffic flow in a movement group within 250 ft of the stop line (upstream or downstream), as measured during the analysis period. (Highway Capacity Manual, 2010). In this research the bus stopping rate is taken from SIDRA Manual which is shown in Table 3.11 with respect to street type. The value of bus stopping rate for study area is twelve because the street type of all selected intersection is in central business district area.

Table 3-11 Bus stopping rate based on street type

Street type	Average bus headway(minutes)	Buses stopping per hour in about 80m(or 250ft) upstream or downstream of stop line
CBD	5	60/5=12
Other	30	60/30=2

Parking manoeuvre

The parking maneuver rate represents the count of influential parking maneuvers that occur on an intersection leg, as measured during the analysis period. An influential maneuver occurs directly adjacent to a movement group, within a zone that extends from the stop line to a point 250ft upstream of its (Highway Capacity Manual, 2010).Parking maneuver rate taken from SIDRA Manual which is shown in table 3.12. In Addis Ababa there is no parking time limit hour so the researcher takes the average value of parking maneuvers per hour for parking limit hour of one hour and two hour.

Table 3-12 Parking Maneuver Rate

Number of spaces in about 80m (or 250ft) upstream of stop line	Number of manoeuvres per space per turnover	Parking time limit (hours)	Turnover rate per hour	Parking manoeuvres per hour
10	2x0.8=1.6	1	1	10x1.6x1.0=18
		2	0.5	10x1.6x0.5=8

The values in the table are determined using the following method for estimating the number of parking maneuvers per hour from the number of parking spaces within about 80 m (or 250ft) upstream of the stop line and the average turnover rate per space:

- The number of parking spaces is estimated by assuming about 8m (or 25ft) per space.
- It is assumed that parking spaces are 80 per cent occupied.
- Each turnover (one car leaving and one car arriving) generates 2 parking maneuvers.

3.4.5.2 Platoon Ratio

Platoon ratio is used to describe the quality of signal progression for the corresponding movement group. It is computed as the demand flow rate during the green indication divided by the average demand flow rate. Values for the platoon ratio typically range from 0.33 to 2.0 (Highway Capacity Manual, 2010). An important traffic characteristic that must be quantified to complete an operational analysis of a signalized intersection is the quality of the progression

In SIDRA software there is an option to determine signal sequence such as arrival type and percent green. In this research the signal sequence is selected arrival type. Arrival type is expressed in terms of platoon ratio.

The platoon ratio for a movement group can be estimated from field data with the following equation:

$$Rp=\frac{P}{g/C}$$

Where

Rp= platoon ratio,

P=proportion of vehicles arriving during the green indication (decimal),

g=effective green time (s), and

C=cycle length (s).

Proportion of vehicles arriving during the green indication, p is calculated with the following equation

$$P=\frac{ng}{qd\ C}$$

Where

P =proportion of vehicles arriving during the green indication,

n_g=arrival count during green (veh),

q_d= arrival flow rate for downstream lane group (veh/s), and

C= cycle length (s).

But according to HCM 2010 the upstream intersection is not signalized (or it is signalized but not coordinated with the downstream boundary intersection), then the proportion arriving during the green is equal to the effective green-to-cycle-length ratio. By simple linearity the platoon ratio of for each movement of the selected intersection is one and its arrival type is three and progression quality is random as listed in table 3.13.

Table 3-13 : Relationship between arrival type with progression quality and platoon ratio values.

Platoon Ratio	Arrival type	Progression Quality
0.33	1	Very poor
0.67	2	Unfavourable
1	3	Random arrivals
1.33	4	favourable
1.67	5	Highly favourable
2	6	Exceptionally favourable

Area type factor- Is general parameter for signals used as a saturation flow adjustment factor for the effect of environment. It applies to all lanes of the approach and HCM 2010 recommends 0.9 for CBD area type. This parameter could also be used as simple saturation flow calibration parameter which can be specified per approach. So in this research for all intersection area type factors is taken a value of 0.9. Because, selected intersections are Central business district areas.

3.4.5.3 Gap Acceptance

Critical gap: is the minimum time (headway) between successive vehicles in the opposing (major) traffic stream that is acceptable for entry by opposed (minor) stream vehicles

- ✓ Critical gap =5seconds

Follow-up Headway: - is the average headway between successive opposed (minor) stream vehicles entering a gap available in the opposing (major) traffic stream

- ✓ Follow up headway = 3seconds

Start Loss: is the time between the start of the displayed green period and the start of effective green period for the movement.

End Departures represents the maximum number of vehicles that can depart after the end of the displayed green period at signalised intersections.

- ✓ End departures = 1 vehicles
- ✓ Start loss = 2sec.

End gain: is the time between the end of displayed green period and the end of the effective green period for the movement.

- ✓ End gain =2sec.

Early cut off Interval is used at the end of a phase to terminate some movements earlier than other movements in the same phase.

- ✓ Early cut off =3sec.

4. ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

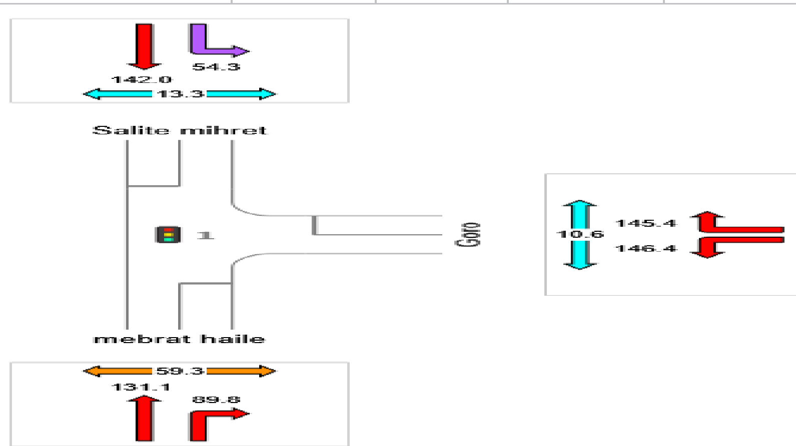
The analysis for three signalized intersections is done using Highway Capacity Manual (HCM 2010) methodology. It is the most widely applied method for analysis of signalized intersections. The HCM defines signalized intersection performance in terms of average vehicle delay (seconds per vehicle) and level of service. The analysis of primary and secondary data of the intersections using Sidra Intersection 8.0 software is described in this chapter.

4.2 Analysis of Jacros intersection

4.2.1 Average delay

Table 4-1 Summarized average delay of Jacros intersection

	Approaches			Intersection
	South	East	North	
Control Delay (Seconds)	115.6	146.2	127.7	126.0
LOS	F	F	F	F



Color code based on Level of Service

LOS A LOS B LOS C LOS D LOS E LOS F

Figure 4-1 Average control delay of vehicles and pedestrians (sec)

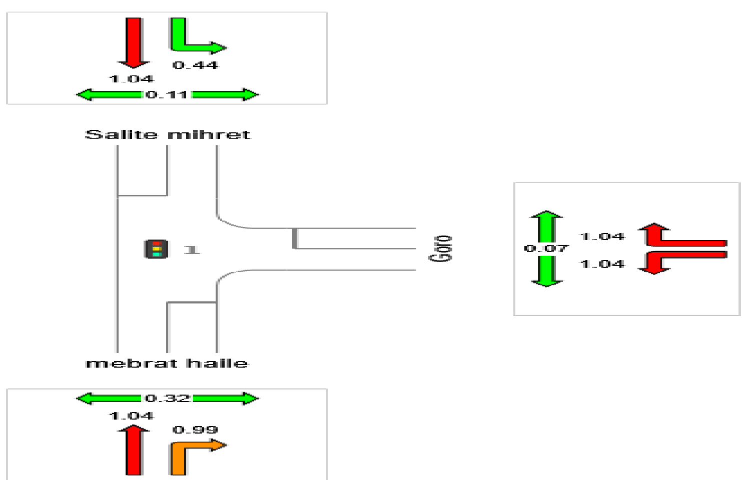
The average delay for each lane groups as analyzed by software are displayed in front of respective arrows. The weighted delay of approaches and the intersection are computed by the software and presented in the table above. From table 4-1, relatively high delays were observed on the Eastern (Goro) approach which is 146.2 sec. Average delay of intersection is 126 seconds per vehicles.

Even though evaluating pedestrian delay is not among objectives of this research, the software by default analyzed pedestrian delay for each approaches and display with arrows along pedestrian crossing lines.

4.2.2 Degree of saturation

Table 4-2 Summarized degree of saturation at Jacros intersection

	Approaches			Intersection
	South	East	North	
Degree of Saturation	1.04	1.04	1.04	1.04



Color code based on Degree of Saturation

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

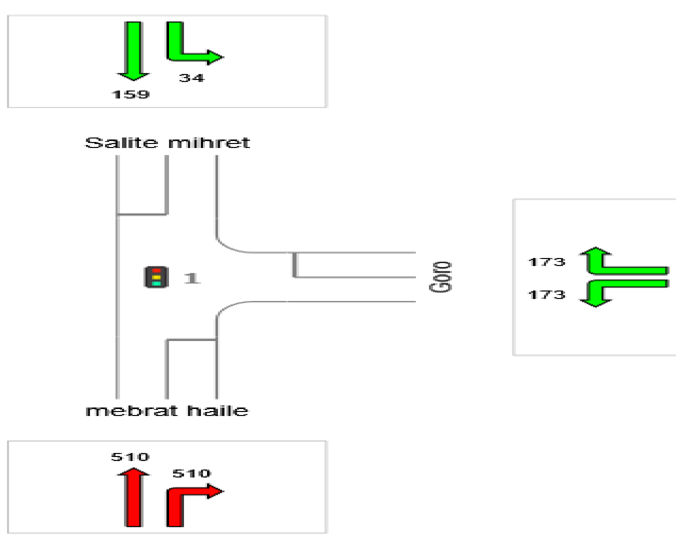
Figure 4-2 Demand Volume to Capacity (v/c) ratio at Jacros signalized intersection.

The volume to capacity ratio of Jacros intersection and its' approach legs was greater than one except for mebrat haile right turn and salite mihret left turn movement as shown in table 4-2 above. This indicates the demand exceeds the available capacity of the intersection: delay and queuing are anticipated. The intersection experience delay and operate under congested traffic flow condition. If volume-to-capacity ratio is less than 0.85 like salite mihret left turn, the leg is operating under capacity and delays are not experienced. The software by default analyzed degree of saturation for pedestrian for each approaches and display with arrows along pedestrian crossing lines.

4.2.3 Queue length

Table 4-3 Summarized average queue length at Jacros intersection

	Approaches			Intersection
	South	East	North	
Queue Length (Aver)	510	173	159	510



Color code based on Queue Storage Ratio

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

Figure 4-3 Average queue length at Jacros intersection

Queue storage ratio represents the proportion of the available queue storage distance occupied at the point in the cycle when the back-of-queue position is reached. If the ratio exceeds 1.0 according to HCM 2010, the storage space will overflow and queued vehicles may block other vehicles from moving forward. Figure 4-3 shows vehicle queue length of Goro and Salite mihret approaches are relatively small compared to mebrat haile approach which has longer back of queue.

Delay and back of queue often are not correlated in terms of magnitude. Low average delay can be related with a long back of queue as a result of a high arrival flow rate, large green time ratio and low degree of saturation. Relatively short back of queue, like in Salite mihret and Goro approaches , may depict a large average delay due to low arrival flow rate, small green time ratio (relatively long red period) and a high degree of saturation. Delay and degree of saturation analysis results above for Salite mihret and Goro approach demonstrate such scenario.

4.2.4 Level of Service

Table 4-4 Level of service of Jacros intersection

	Approaches			Intersection
	South	East	North	
LOS	F	F	F	F

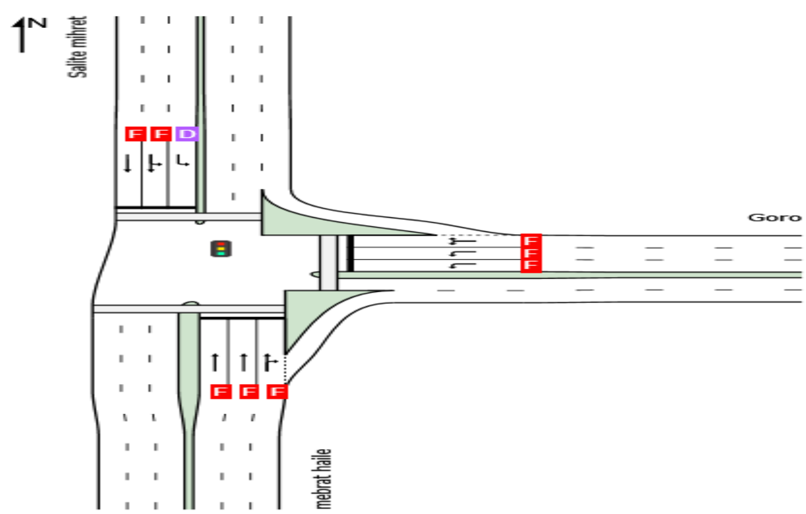


Figure 4-4 The Level of service of Jacros intersection

Level of service indicates the operating quality of existing intersection under a given demand. It is used to evaluate the performance and visualize the quality of intersection. The level of services Jacros intersection was F as shown in table 4-4 above. Hence, the intersection experiences high average delay as per HCM standard criteria. From figure 4.4 above, we can visualize salite mihret approach left turn movement has level of service D despite the intersection level of service F. These legs have relatively low delay than other legs.

4.2.5 Phase timing

Phase is a timing process with the signal controller that facilitates serving one or more movements at the same time. In this intersection, there are three phase sequence; A, B, and C. Each phase allows corresponding approach leg traffic to move in all possible directions. Mebrat haile approach phase repeat two times while the other two approaches appear once in a cycle length. Phase timing output is shown in table below.

Input Phase Sequence: A, B, C

Output Phase Sequence: A, B, C

Table 4-5 Phase timing summary of Jacros intersection

Phase	**A**	**B**	**C**
Phase Change Time (sec)	0	35	101
Green Time (sec)	30	61	34
Phase Time (sec)	35	66	39
Phase Split	25 %	47 %	28 %

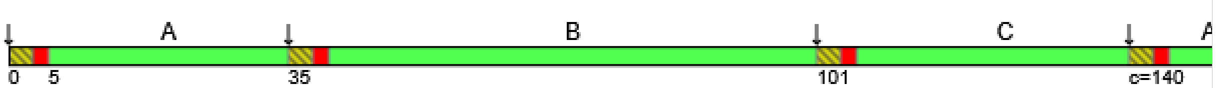


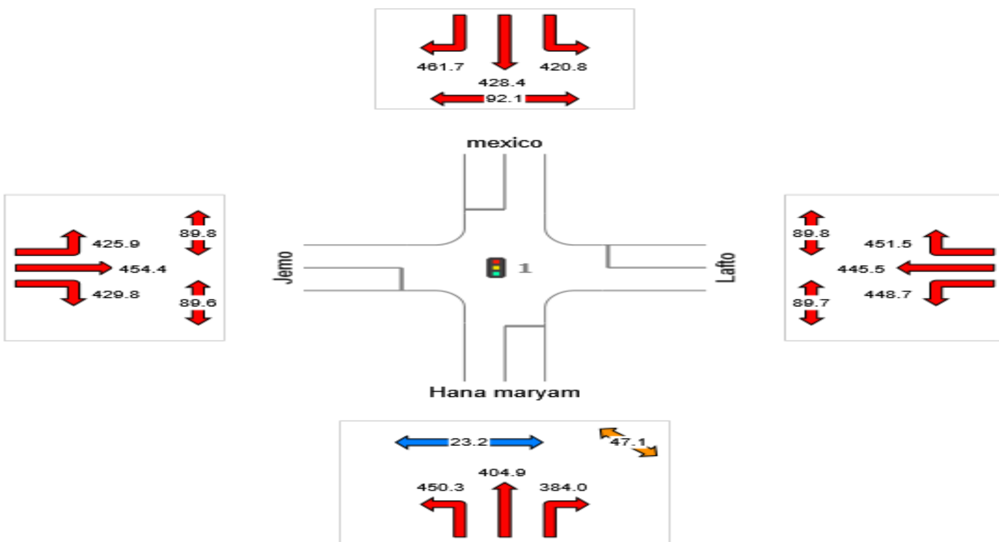
Figure 4-5 Displayed Signal Timing – Phases of Jacros intersection

4.3 Analysis of Lebu Intersection

4.3.1 Average Delay

Table 4-6 average delay of Lebu intersection

	Approaches				Intersection
	South	East	North	West	
Control Delay (Seconds)	416.3	448.1	433.0	437.5	431.4
LOS	F	F	F	F	F



Color code based on Level of Service

LOS A LOS B LOS C LOS D LOS E LOS F

Figure 4-6 Average control delay of vehicles and pedestrians (sec) at Lebu intersection

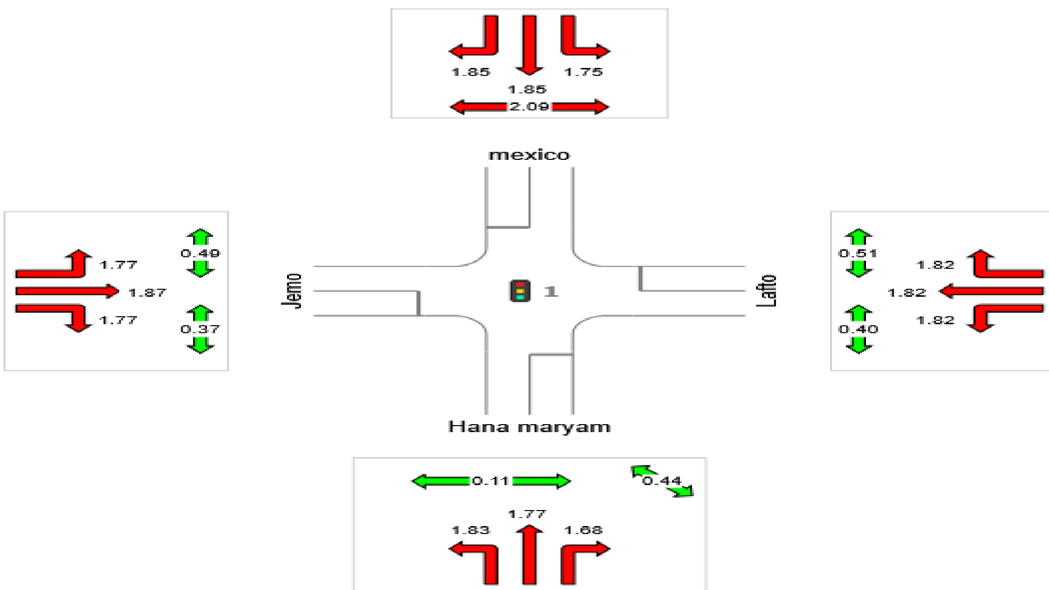
The average delay for each lane groups as analyzed by software are displayed in front of respective arrows. The weighted delay of approaches and the intersection are computed by the software and presented in the table above. From table 4-6, relatively high delays were observed on the Eastern (Lafto) approach which is 448.1 sec. Average delay of intersection is 431.4 seconds per vehicles.

Even though evaluating pedestrian delay is not among objectives of this research, the software by default analyzed pedestrian delay for each approaches and display with arrows along pedestrian crossing lines.

4.3.2 Degree of saturation

Table 4-7 Summarized degree of saturation at Lebu intersection

	Approaches				Intersection
	South	East	North	West	
Degree of Saturation	1.83	1.82	1.85	1.87	1.87



Color code based on Degree of Saturation

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

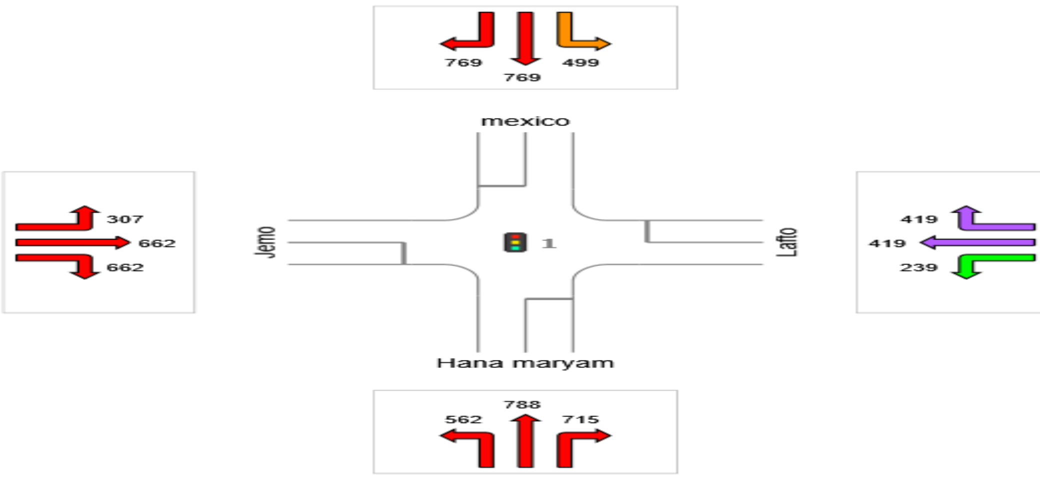
Figure 4-7 Demand Volume to Capacity (v/c) ratio at Lebu signalized intersection

The volume to capacity ratio of Lebu intersection and its' approach legs was greater than one as shown in table 4-7 above. This indicates the demand exceeds the available capacity of the intersection: delay and queuing are expected. The intersection experience delay and operate under congested traffic flow condition. The software by default analyzed degree of saturation for pedestrian for each approaches and display with arrows along pedestrian crossing lines.

4.3.3 Queue Length

Table 4-8 Summarized average queue length at Lebu intersection

	Approaches				Intersection
	South	East	North	West	
Queue length (Aver)	788	419	769	662	788



Color code based on Queue Storage Ratio

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

Figure 4-8 Average queue length at Lebu intersection

The queue length of the intersection is 788M as shown in table 4-8 and its queue storage ratio is greater than one for all approaches except for west (Lafto) approach as shown in figure 4-8. When the ratio exceeds 1.0 according to HCM 2010, the storage space will overflow and queued vehicles may block other vehicles from moving forward.

4.3.4 Level of Service

Table 4-9 Level of service of Lebu intersection

	Approaches				Intersection
	South	East	North	West	
LOS	F	F	F	F	F

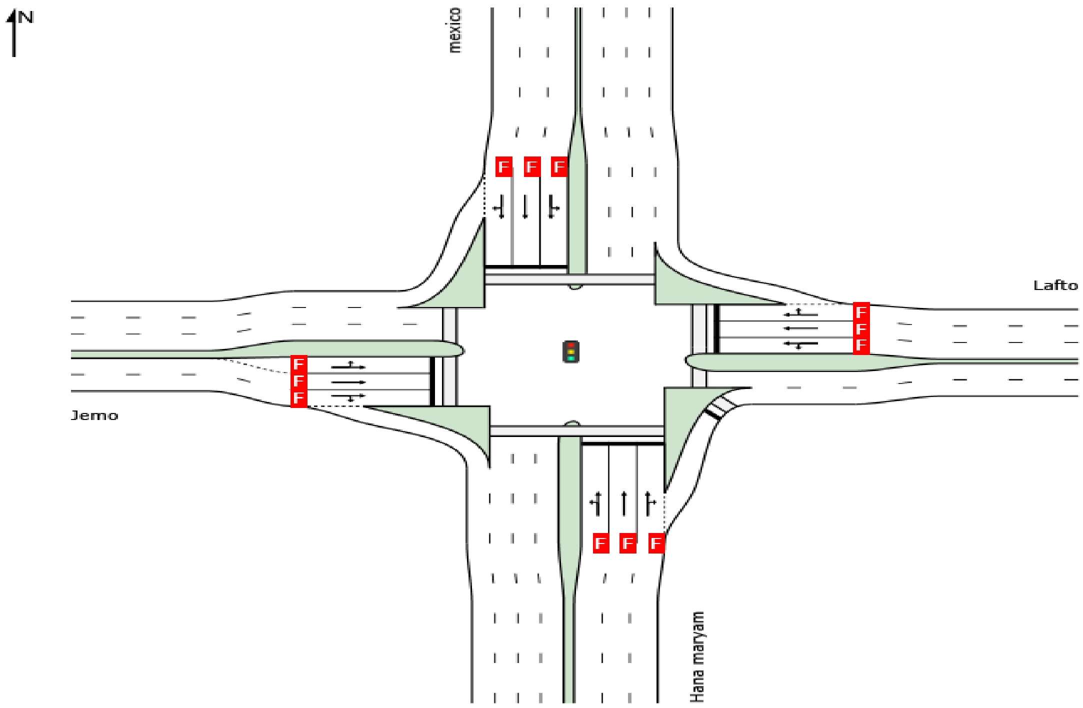


Figure 4-9 Level of service of Lebu intersection

The level of service is used to evaluate the performance and visualize the quality of intersection. The level of services Lebu intersection was F as shown in table 4-9 above. Hence, the intersection experiences high average delay as per HCM standard criteria.

4.3.5 Phase Timing

Phase is a timing process with the signal controller that facilitates serving one or more movements at the same time. Lebu intersection has five phase sequences; A, B, C, D and E.

Input Phase Sequence: A, B, C, D, And E Output Phase Sequence: A, B, C, D, And E

Table 4-10 Phase timing summary of Lebu intersection

Phase	**A**	**B**	**C**	**D**	**E**
Phase Change Time (sec)	A	B	C	D	E
Green Time (sec)	0	61	79	125	153
Phase Time (sec)	56	13	41	23	32
Phase Split	61	18	46	28	37

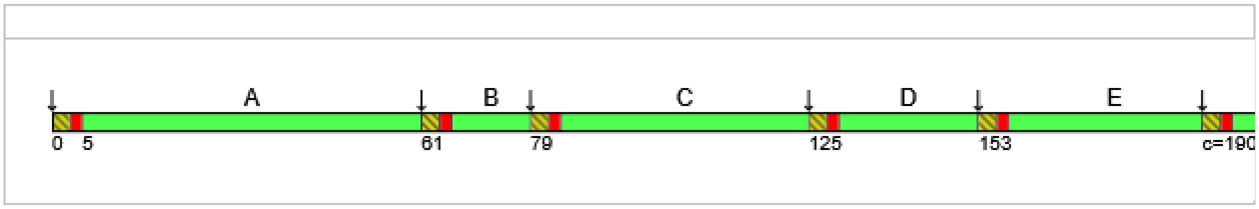


Figure 4-10 Displayed Signal Timing – Phases at Lebu intersection

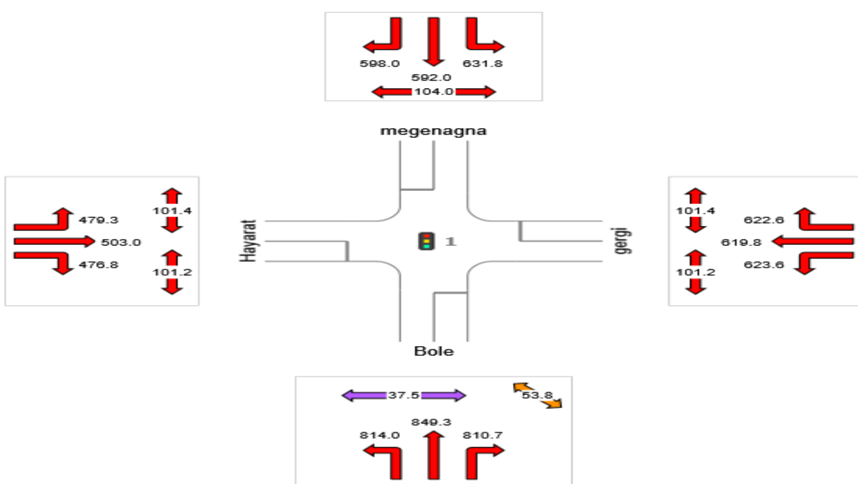
Phase A gives south approach right to move in all direction while South and North through movements are served during Phase B. Phase C permits north approach right to move in all direction. Phase D and Phase E are dedicated to all movement from east and west approaches respectively. Phase timing summary of intersection listed to table 4-10.

4.4 Analysis of Imperial Intersection

4.4.1 Average Delay

Table 4-11 average delay of Imperial intersection

	Approaches				Intersection
	South	East	North	West	
Control Delay (Seconds)	833.8	622.1	601.3	486.1	710.4
LOS	F	F	F	F	F



Color code based on Level of Service

LOS A LOS B LOS C LOS D LOS E LOS F

Figure 4-11 Average control delay of vehicles and pedestrians (sec) at Imperial intersection

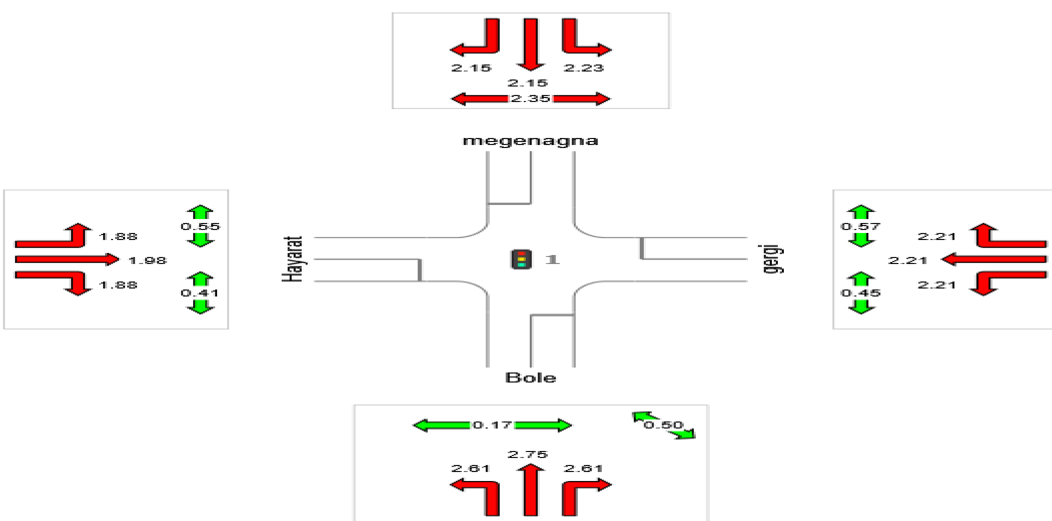
The average delay for each lane groups as analyzed by software are displayed in front of respective arrows. The weighted delay of approaches and the intersection are computed by the software and presented in the table above. From table 4-11, relatively high delays were observed on the South approach which is 833.8 sec. Average delay of intersection is 710.4 seconds per vehicles. Among the three intersections under study, Imperial intersection has the highest average delay value.

Even though evaluating pedestrian delay is not among objectives of this research, the software by default analyzed pedestrian delay for each approaches and display with arrows along pedestrian crossing lines.

4.4.2 Degree of Saturation

Table 4-12 Summarized degree of saturation at Imperial intersection

	Approaches				Intersection
	South	East	North	West	
Degree of Saturation	2.75	2.21	2.23	1.98	2.75



Color code based on Degree of Saturation

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

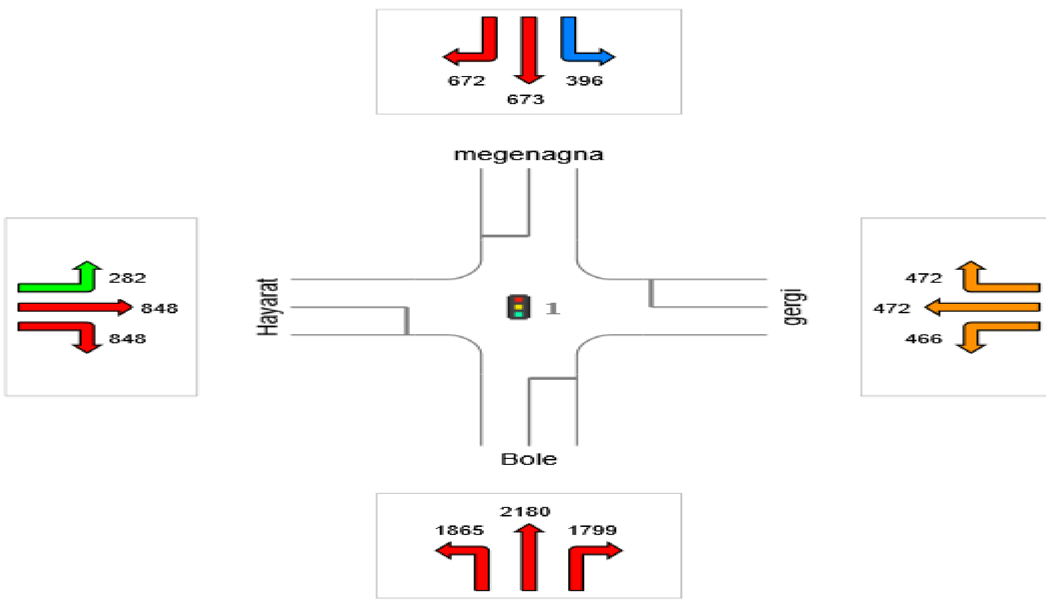
Figure 4-12 Demand Volume to Capacity (v/c) ratio at Imperial signalized intersection

The volume to capacity ratio of Imperial intersection and its' approach legs was greater than one like that of Lebu intersection. The results of analysis are shown in table 4-12 and Figure 4-13above. The intersection experience delay and operate under congested traffic flow condition. The software by default analyzed degree of saturation for pedestrian for each approaches and display with arrows along pedestrian crossing lines.

4.4.3 Queue Length

Table 4-13 Summarized average queue length at Imperial intersection

	Approaches				Intersection
	South	East	North	West	
Queue length (Aver)	2180	472	673	848	2180



Color code based on Queue Storage Ratio

[< 0.6] [0.6 – 0.7] [0.7 – 0.8] [0.8 – 0.9] [0.9 – 1.0] [> 1.0]

Figure 4-13 Average queue length at Imperial intersection

The queue length of the intersection is 2180M as shown in table 4-13. The queue storage ratio is greater than one for all approaches except for: east (Gergi) approach and left turn movements of hayarat and megenagna approaches as shown in figure 4-13. When the ratio exceeds 1.0 according to HCM 2010, the storage space will overflow and queued vehicles may block other vehicles from moving forward.

4.4.4 Level of Service

Table 4-14 Level of service of Imperial intersection

	Approaches				Intersection
	South	East	North	West	
LOS	F	F	F	F	F

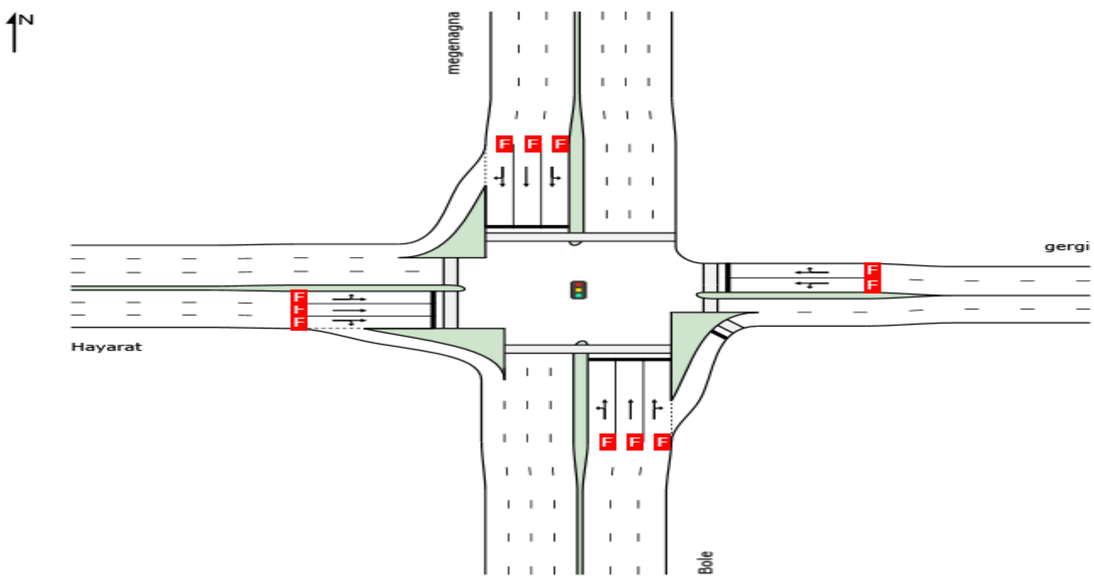


Figure 4-14 Level Of Service at Imperial intersection

Level of service indicates the operating quality of existing intersection under a given demand. The level of service is used to evaluate the performance and visualize the quality of intersection. The level of services Imperial intersection was F as shown in table 4-14 above. Hence, the intersection experiences high average delay as per HCM standard criteria.

4.4.5 Phase Timing

Phase is a timing process with the signal controller that facilitates serving one or more movements at the same time. Imperial intersection has five phase sequences; A, B, C, D and E.

Input Phase Sequence: A, B, C, D, E

Output Phase Sequence: A, B, C, D, E

Table 4-15 Phase timing summary of Imperial intersection

Phase	**A**	**B**	**C**	**D**	**E**
Phase Change Time (sec)	0	91	109	141	181
Green Time (sec)	86	13	27	35	27
Phase Time (sec)	91	18	32	40	32
Phase Split	43 %	8 %	15 %	19 %	15 %

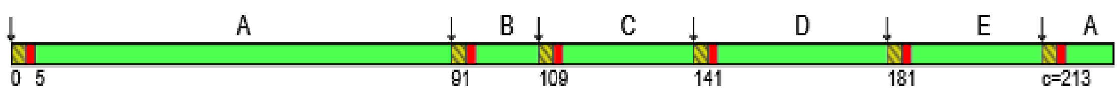


Figure 4-15 Displayed Signal Timing – Phases at Imperial intersection

Phase A gives south approach right to move in all direction while south and north through movements are served during Phase B. Phase C permits north approach right to move in all direction. Phase D and Phase E are dedicated to all movement from east and west approaches respectively. Phase timing summary of intersection listed to table 4-15.

4.5 Sensitivity Analysis

In Sidra software, there is sensitivity analysis package for assessing how the model out puts change in response to change in model inputs and implemented by varying one input at a time over its reasonable range while holding all other inputs are constant. The software uses the following parameters for sensitivity analysis:

- Critical gap and follow up headway,
- Basic saturation flow,

- Lane width,
- Lane utilization ratio,
- Cruise speed,
- Vehicle queue space

The required changes in each parameter (scale factors) are specified as a range of percentage values, with a Lower limit (FL), an upper Limit (FU) and an increment (ΔF). Using these parameters, the program will determine a list of scale factors as (FL, FL+ ΔF, FL+2 ΔF..., FU). The researcher uses FL= 90, FU= 110 and ΔF= 4 so the scale factors are calculated by the program.

The relevant sensitivity parameter values are multiplied by this factor. For example, using the scale factor of 110 percent for base saturation flow of 1750 tcu/h, it becomes 1.10 x 1750 =1925 tcu/h or base saturation flow of 1750 becomes 1925). Likewise, other parameters are change by scale factor.

For this research by changing all the above parameter using scale factor and re analyzing as a function of each parameter, the result taken from software after sensitivity analysis is shown in tables below.

Table 4-16 Delay comparison before and after sensitivity analysis at Lebu intersection

Intersection	Parameter	Average Delay		Degree of saturation		LOS		Queue length	
		Before	After	Before	After	Before	After	Before	After
Lebu	Critical Gap & Follow-up Headway	431.4	431.4	1.87	1.87	F	F	788	788
	Basic saturation flow	431.4	304	1.87	1.56	F	F	788	703
	Lane width	431.4	403.9	1.87	1.81	F	F	788	769
	Lane utilization ratio	431.4	431.5	1.87	1.82	F	F	788	751
	Cruise speed	431.4	430.8	1.87	1.87	F	F	788	788
	Vehicle Queue space	431.4	429.9	1.87	1.85	F	F	788	945

Table 4-17 Delay comparison before and after sensitivity analysis at Jacros intersection

Intersection	Parameter	Average Delay		Degree of saturation		LOS		Queue length	
		Before	After	Before	After	Before	After	Before	After
Jacros	Critical Gap & Follow-up Headway	126	126	1.04	1.04	F	F	510	510
	Basic saturation flow	126	76.7	1.04	0.95	F	E	510	279
	Lane width	126	105.5	1.04	1.01	F	F	510	436
	Lane utilization ratio	126	126	1.04	1.04	F	F	510	510
	Cruise speed	126	125.3	1.04	1.04	F	F	510	510
	Vehicle Queue space	126	126	1.04	1.04	F	F	510	408

Table 4-18 Delay comparison before and after sensitivity analysis at Imperial intersection

Inter section	Parameter	Average Delay		Degree of saturation		LOS		Queue length	
		Before	After	Before	After	Before	After	Before	After
Imperial	Critical Gap & Follow-up Headway	710.4	715.5	2.75	2.75	F	F	2180	2187
	Basic saturation flow	710.4	519.5	2.75	2.15	F	F	2180	1997
	Lane width	710.4	671.2	2.75	2.62	F	F	2180	2148
	Lane utilization ratio	710.4	724.8	2.75	2.69	F	F	2180	2093
	Cruise speed	710.4	717.1	2.75	2.78	F	F	2180	2187
	Vehicle Queue space	710.4	717.5	2.75	2.78	F	F	2180	1749

The sensitivity analysis result exhibit, basic saturation flow significantly affect delay as it is correlated to different parameters such as lane width, gradient, heavy vehicle, parking condition, bus blockage, area type, lane utilization, right turn and left turn movement.

4.6 Intersection Performance Improvement

The sensitivity analysis above dictates some but not comprehensive set of important parameters which affect delay and level of service of intersection. In this section, we discuss about other critical parameters which are not incorporated in sensitivity analysis but have the significant effect on delay and level of service.

4.7 Heavy Vehicle Restriction

In this sub section, the researcher discussed about evaluating the intersection delay by considering zero volume of heavy vehicle on each intersection and reanalyzing using Sidra Intersection 8.0. The result of reanalysis is presented in comparison with original analysis results in Table 4-19 below.

Table 4-19 Delay comparison before and after restricting heavy vehicle

Intersection	Parameter	Average delay		Degree of saturation		LOS		Queue length	
		Before	After	Before	After	Before	After	Before	After
Lebu	Heavy vehicle restriction	431.4	232.7	1.87	1.41	F	F	788	453
Jacros		126	54	1.04	0.89	F	D	510	137
Imperial		710.4	633.8	2.75	2.49	F	F	2180	1529

The reanalysis through heavy vehicle restriction reveals reduced: average delay, degree of saturation and queue length compared to the scenario before restriction for all signalized intersections. The level of service for Jacros intersection gets improved to LOS D after reanalysis.

Even though heavy vehicle restriction outcome better performance for the intersections, it is not a simple measure to be taken by transport bureau. It needs integration management with other stake holders as this will directly affect the economic activities in the city. Addis Ababa City administration transport bureau has tried this approach before and it showed positive results on the LOS of the road network. But the problem with this approach was that it affected businesses and the construction sector. Hence, such large scale changes like restricting heavy vehicles will need engagement with all stakeholders and preparation for alternative scenarios before implementation.

4.8 Adding One Through Lane

The sensitivity analysis output shows, increasing lane width have a significant effect on delay and level of service. In this sub section, the researcher discussed about evaluating the intersection delay by adding one lane on each intersection and reanalyzing using Sidra Intersection 8.0. The result of reanalysis is shown in Table 4-20.

Table 4 20 Delay comparison after adding lane at three intersection in each leg

Intersection	Parameter	Average delay		Degree of saturation		LOS		Queue length	
	Adding one through lane	Before	After	Before	After	Before	After	Before	After
Lebu		431.4	225.5	1.87	1.56	F	F	788	520
Jacros		126	40.3	1.04	0.89	F	D	510	95
Imperial		710.4	465.9	2.75	2.61	F	F	2180	1666

The reanalysis by adding one through lane on each approaches results reduced: average delay, degree of saturation and queue length compared to the scenario before restriction for all signalized intersections. The level of service for Jacros intersection gets improved to LOS D from LOS F after reanalysis.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This study focused on the evaluation of vehicle time delay at signalized intersections in Addis Ababa, for selected three intersections. The selected intersections were three legs (Jacros) and four leg (Lebu and Imperial) intersections.

For evaluation of vehicle delay, Sidra Intersection 8.0 software and Highway Capacity Manual (HCM) was used. Accordingly, vehicular delay, degree of saturation, queue length and level of service are determined for each intersection, approach and lane group. In addition, sensitivity analysis was conducted by Sidra Intersection 8.0 for assessing how the model out puts responds to change in model inputs. Furthermore, effect of heavy vehicle and number of lanes are analyzed separately to investigate impact on vehicular delay, degree of saturation, queue length and level of service.

Accordingly, the following results were obtained;

- The traffic flow at three analyzed intersections were served by poor Level of Service (LOS F),
- The three signalized intersections under study have volume to capacity ratio greater than one: 1.04 for Jacros, 1.87 for Lebu and 2.75 for Imperial,
- The average delays experienced are 126 sec at Jacros, 431.4 sec at Lebu, and 710.4 sec at Imperial intersections,
- Relative to other sensitivity parameters, base saturation flow and lane width are found as major parameters which significantly affect average delay, degree of saturation, level of service and queue length,
- Heavy vehicle restriction reduces;
    - Average delay by 46.05% for Lebu intersection, 57.14% for Jacros intersection and 10.78% for Imperial intersection,
    - Degree of saturation by 24.59 % for Lebu intersection, 14.42 % for Jacros intersection and 9.45 % for Imperial intersection,
    - Queue length by 42.51 % for Lebu intersection, 73.13 % for Jacros intersection and 29.86 % for Imperial intersection,

- Adding one more through lane on each approaches of the intersections lowers;
    - Average delay by 47.72 % for Lebu intersection, 68.01 % for Jacros intersection and 34.41 % for Imperial intersection,
    - Degree of saturation by 16.57 % for Lebu intersection, 14.42 % for Jacros intersection and 5.09 % for Imperial intersection,
    - Queue length by 34 % for Lebu intersection, 81.37 % for Jacros intersection and 23.58 % for Imperial intersection.

5.2 Recommendations

Based on the results and findings, the following recommendations are drawn:

1. The analysis in this thesis results base saturation flow to be of the most contributory factors for delay and it varies from intersection to intersection. The researcher recommends Addis Ababa city administration transport bureau to conduct further studies by focusing on the local condition of the city intersections.
2. At all intersection volume to capacity ratio is greater than one that indicates the overall signal timing and geometric design provides inadequate capacity for the given demand flows. Hence, improvement is needed for each intersection by considering basic changes in intersection geometry. Adding one more lane on each approach of the three intersections can be practical with no significant right of way issue except for Gerji and Salite mihret approaches of Imperial and Jacros intersections. This can be done via: reducing median width, minor center line shift, merging classified lanes of the ring road by omitting the barrier and the likes. Although this geometric modification results better performance for intersections, detailed cost benefit analysis need to be conducted by comparing with other intersection performance measures.
3. Traffic regulation principles around the intersection area which restrict heavy vehicles not to use the roads & intersection during peak hours of the day are recommended which can have a positive influence on both traffic operation and safety. This need comprehensive stakeholder involvement to develop alternative strategies not to affected economic activities of the city while improving the performance of the intersections.

5.3. Recommendations for Future Research Areas

There are several potential areas which remain to be examined and can have significant influence on performance of signal controlled intersection. Some of the possible areas can be;

- ❖ Optimization of signal timing for each intersections in Addis Ababa,
- ❖ Calibration of Level of Service thresholds for Ethiopian Condition,
- ❖ Effect of startup loss time on delay,
- ❖ Adoption of HCM to Ethiopian Condition,

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7. APPENDIX

Appendix A Summarized Traffic Data

Table1. Jacros intersection

Time	Mebrat hayle	Goro	Salitemihret
6:00-7:00Am	**775**	**706**	**429**
Left			44
Right	398	44	
Through	377	662	385
u turn			
7:00-8:00 Am	**1216**	**859**	**594**
Left		802	47
Right	417	57	
Through	799		547
u turn			
8:00-9:00 Am	**1064**	**776**	**600**
Left		624	60
Right	344	152	
Through	720		540
u turn			
9:00-10:00 Am	**1231**	**615**	**656**
Left	779	604	89
Right	452	11	
Through			567
u turn			
10:00-11:00 Am	**1387**	**662**	**595**
Left		580	85
Right	501	82	

Through	886		510
u turn			
11:00Am-12:00Pm	**1497**	**681**	**617**
Left		540	101
Right	547	141	
Through	950		516
u turn			
12:00-1:00Pm	**1354**	**640**	**501**
Left		499	96
Right	467	141	
Through	887		405
u turn			
1:00-2:00Pm	**1364**	**683**	**477**
Left		515	89
Right	510	168	
Through	854		388
u turn			
2:00-3:00Pm	**1539**	**630**	**546**
Left		498	93
Right	500	132	
Through	1039		453
u turn			
3:00-4:00Pm	**1293**	**612**	**490**
Left		445	83
Right	409	167	
Through	884		407
u turn			
4:00-5:00Pm	**1585**	**690**	**507**
Left		528	95

Right	623	162	
Through	962		412
u turn			
5:00-6:00Pm	**1549**	**662**	**488**
Left	925	497	130
Right	624	165	
Through			358
u turn			

Table 2. Imperial intersection

Time	bole	megenagna	hayarat	gergi
6:00-7:00Am	**972**	**789**	**379**	**383**
Left	54	70	44	165
Right	244	68	276	147
Through	668	651	58	71
u turn	6		1	
7:00-8:00 Am	**1497**	**1301**	**698**	**697**
Left	102	173	76	351
Right	268	107	541	181
Through	1126	1021	79	165
u turn	1		2	
8:00-9:00 Am	**1622**	**1382**	**777**	**840**
Left	143	218	122	358
Right	289	139	512	215
Through	1190	1025	142	267
u turn	0		1	
9:00-10:00 Am	**1742**	**1360**	**803**	**820**
Left	138	230	147	350
Right	296	134	479	184
Through	1306	996	177	286
u turn	2		0	
10:00-11:00 Am	**1533**	**1396**	**848**	**768**
Left	166	224	166	325
Right	268	152	469	159
Through	1097	1020	213	284
u turn	2		0	

11:00Am-12:00Pm	**1603**	**1403**	**818**	**752**
Left	182	257	173	342
Right	259	144	429	156
Through	1160	1002	214	254
u turn	2		2	
12:00-1:00Pm	**1502**	**1316**	**790**	**763**
Left	157	314	166	331
Right	302	130	407	172
Through	1040	872	215	260
u turn	3		2	
1:00-2:00Pm	**1653**	**1354**	**664**	**720**
Left	146	277	171	306
Right	329	125	256	168
Through	1176	952	233	246
u turn	2		4	
2:00-3:00Pm	**1769**	**1411**	**908**	**764**
Left	147	299	172	336
Right	333	135	491	174
Through	1287	977	244	254
u turn	2		1	
3:00-4:00Pm	**1823**	**1423**	**855**	**741**
Left	140	288	188	320
Right	337	137	416	156
Through	1343	998	250	265
u turn	3		1	
4:00-5:00Pm	**1798**	**1417**	**902**	**720**
Left	149	288	190	334
Right	312	120	468	157
Through	1337	1009	244	229

u turn	2		1	
5:00-6:00Pm	**2618**	**1236**	**934**	**1239**
Left	134	272	176	299
Right	1115	107	441	723
Through	1349	857	311	217
u turn	20		6	

Table 3. Lebu intersection

Time	Hana Mariam	Jemo	Mexico	Lafto
6:00-7:00Am	**812**	**704**	**840**	**354**
Left	195	232	70	81
Right	23	339	74	116
Through	594	133	696	157
u turn				
7:00-8:00 Am	**1233**	**1427**	**1184**	**723**
Left	277	530	139	121
Right	59	518	104	285
Through	897	379	941	317
u turn				
8:00-9:00 Am	**1290**	**1473**	**1297**	**851**
Left	328	519	164	132
Right	68	490	159	346
Through	894	464	974	373
u turn				
9:00-10:00 Am	**1287**	**1262**	**1342**	**874**
Left	348	363	144	118
Right	59	482	183	369
Through	880	417	1015	387
u turn				
10:00-11:00 Am	**1530**	**1204**	**1480**	**901**
Left	392	316	202	155
Right	83	486	225	358
Through	1055	402	1053	388
u turn				

11:00Am-12:00Pm	**1543**	**1172**	**1564**	**843**
Left	427	279	219	122
Right	88	483	263	310
Through	1028	410	1082	411
u turn				
12:00-1:00Pm	**1554**	**1092**	**1584**	**864**
Left	446	267	234	129
Right	94	422	325	320
Through	1014	403	1025	415
u turn				
1:00-2:00Pm	**1251**	**1086**	**1401**	**847**
Left	404	244	176	130
Right	72	440	314	318
Through	775	402	911	399
u turn				
2:00-3:00Pm	**1470**	**1154**	**1497**	**870**
Left	420	279	221	162
Right	78	473	333	284
Through	972	402	943	424
u turn				
3:00-4:00Pm	**1406**	**884**	**1499**	**838**
Left	433	243	205	155
Right	71	254	345	232
Through	902	387	949	451
u turn				
4:00-5:00Pm	**1475**	**1110**	**1459**	**841**
Left	470	246	196	135
Right	80	442	393	245
Through	925	422	870	461

u turn				
5:00-6:00Pm	**1434**	**1130**	**1502**	**969**
Left	462	246	207	146
Right	74	451	497	279
Through	898	433	798	544
u turn				

Appendix B Geometric lay out and SIDRA OUT PUT

MOVEMENT SUMMARY

Site: 1 [Lebu mebrat haile]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 190 seconds (Site Practical Cycle Time)

Movement summary for lebu intersection

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flows Total veh/h	HV %	Deg.Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop.Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
South: Hana maryam												
1	L2	469	46.8	1.827	450.3	LOS F	93.5	917.2	1	1.29	2.2	6.9
2	T1	1130	57.1	1.767	404.9	LOS F	123.3	1285.4	1	1.33	2.12	7.6
3	R2	97	26.1	1.679	384	LOS F	115.2	1166.4	1	1.29	2.08	8
Approach		1696	52.5	1.827	416.3	LOS F	123.3	1285.4	1	1.32	2.14	7.4
East: Lafto												
4	L2	131	27.9	1.825	448.7	LOS F	47.3	390.4	1	1.29	2.22	6.5
5	T1	442	12.4	1.825	445.5	LOS F	79	683.7	1	1.35	2.21	6.6
6	R2	333	30.6	1.825	451.5	LOS F	79	683.7	1	1.35	2.2	6.6
Approach		906	21.4	1.825	448.1	LOS F	79	683.7	1	1.34	2.21	6.6
North: mexico												
7	L2	235	28.8	1.753	420.8	LOS F	85.5	814.3	1	1.26	2.15	7.2
8	T1	1163	57	1.846	428.4	LOS F	132.9	1255.6	1	1.33	2.16	7.2
9	R2	283	19	1.846	461.7	LOS F	132.9	1255.6	1	1.33	2.19	6.8
Approach		1682	46.7	1.846	433	LOS F	132.9	1255.6	1	1.32	2.16	7.1
West: Jemo												
10	L2	300	19.4	1.772	425.9	LOS F	61.5	500.4	1	1.36	2.17	6.9
11	T1	441	13.2	1.865	454.4	LOS F	113.5	1080.1	1	1.47	2.21	6.5
12	R2	519	44.9	1.772	429.8	LOS F	113.5	1080.1	1	1.44	2.15	7
Approach		1260	27.7	1.865	437.5	LOS F	113.5	1080.1	1	1.43	2.18	6.8
All Vehicles		5544	40	1.865	431.4	LOS F	132.9	1285.4	1	1.35	2.17	7

LANE SUMMARY

Site: 1 [Lebu mebrat haile]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 190 seconds (Site Practical Cycle Time)

Lane Use and Performance														
	Demand Flows		Cap.	Deg.	Lane		Average	Level of	95% Back of Queue		Lane	Lane	Cap.	Prob.
	Total veh/h	HV		Satn	Util.		Delay	Service	Veh	Dist	Config	Length	Adj.	Block.
		%	veh/h	v/c	%		sec			m		m	%	%
South: Hana maryam														
Lane 1	469	47	257	1.827	100		450.3	LOS F	93.5	917.2	Full	500	0	61.1
Lane 2	625	57	354	1.767	97	5	422.4	LOS F	123	1285.4	Full	500	0	94
Lane 3	602	52	358	1.679	92	5	383.4	LOS F	115	1166.4	Full	500	0	84.3
Approach	1696	53		1.827			416.3	LOS F	123	1285.4				
East: Lafto														
Lane 1	242	21	133	1.825	100		447.2	LOS F	47.3	390.4	Full	500	0	0
Lane 2	264	12	145	1.825	100		444.7	LOS F	51.4	398.2	Full	500	0	0
Lane 3	400	28	219	1.825	100		451	LOS F	79	683.7	Full	500	0	33.5
Approach	906	21		1.825			448.1	LOS F	79	683.7				
North: mexico														
Lane 1	444	42	253	1.753	95	7	417.6	LOS F	85.5	814.3	Full	500	0	49.8
Lane 2	574	57	327	1.757	95	7	416.3	LOS F	112	1164.6	Full	500	0	84.2
Lane 3	664	41	360	1.846	100		457.6	LOS F	133	1255.6	Full	500	0	91.6
Approach	1682	47		1.846			433	LOS F	133	1255.6				
West: Jemo														
Lane 1	319	19	180	1.772	95	7	425.7	LOS F	61.5	500.4	Short	120	0	NA
Lane 2	367	13	197	1.865	100		460.4	LOS F	72.7	566.3	Full	500	0	16.3
Lane 3	574	42	324	1.772	95	7	429.3	LOS F	114	1080.1	Full	500	0	76.8
Approach	1260	28		1.865			437.5	LOS F	114	1080.1				
Intersection	5544	40		1.865			431.4	LOS F	133	1285.4				

LANE LEVEL OF SERVICE

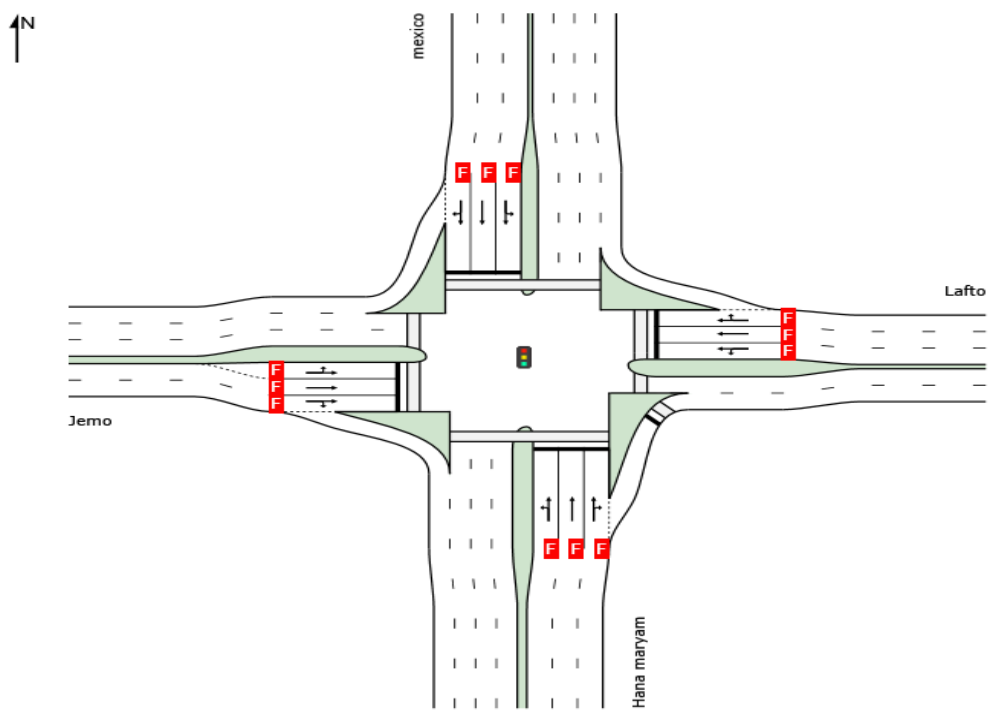
Lane Level of Service

Site: 1 [Lebu Mebrat Haile]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 190 seconds (Site Practical Cycle Time)

	Approaches				Intersection
	South	East	North	West	
LOS	F	F	F	F	F



PHASING SUMMARY

Site: 1 [Lebu Mebrat Haile]

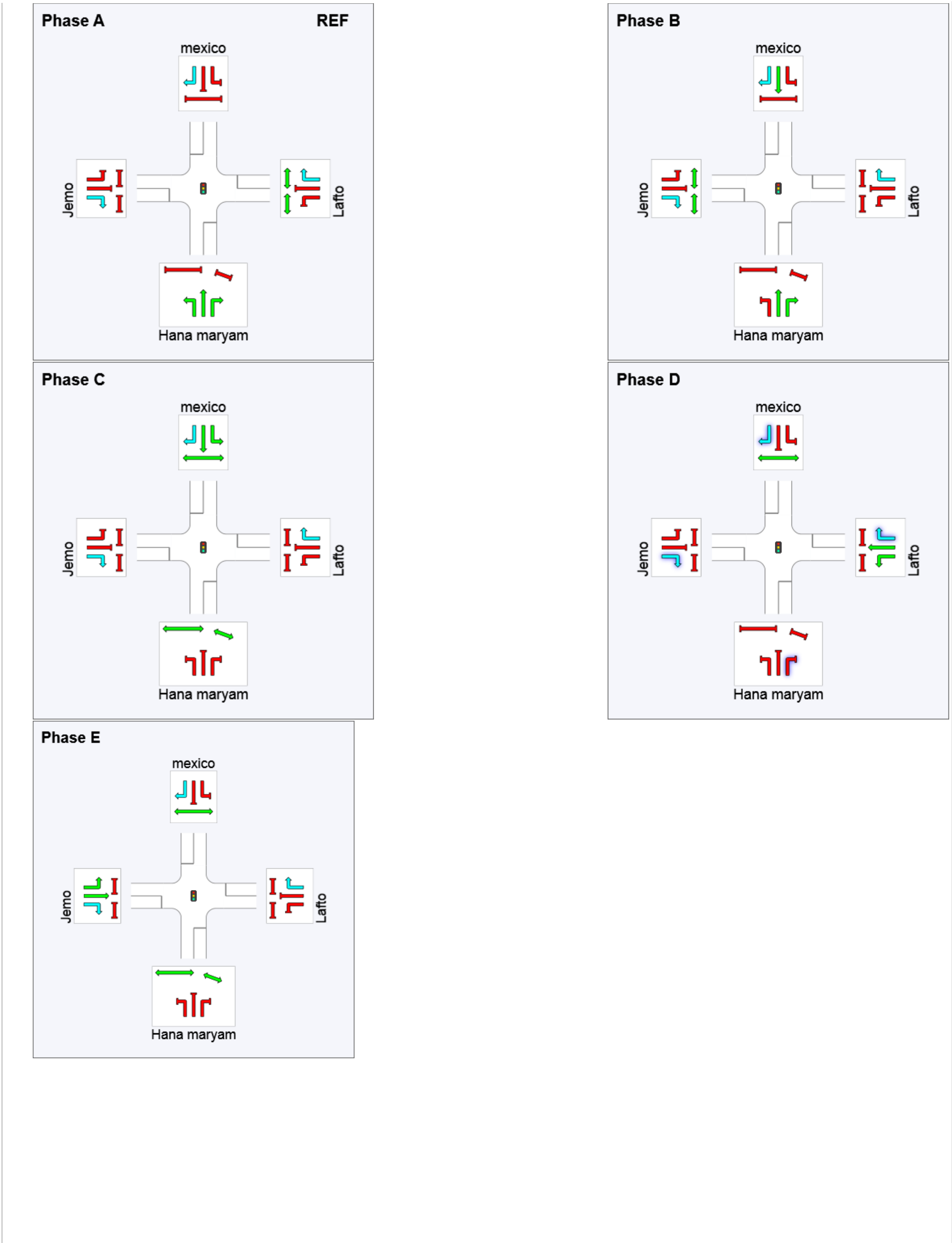
Site Category: -
Signals - Fixed Time Isolated Cycle Time = 190 seconds (Site Practical Cycle Time)

Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Split Phasing Reference Phase: Phase A Input Phase Sequence: A, B, C, D, E Output Phase Sequence: A, B, C, D, E

PHASE TIMING SUMMARY

Phase	**A**	**B**	**C**	**D**	**E**
Phase Change Time (sec)	0	61	79	125	153
Green Time (sec)	56	13	41	23	32
Phase Time (sec)	61	18	46	28	37
Phase Split	32 %	9 %	24 %	15 %	19 %

OUTPUT PHASE SEQUENCE


Phase A
REF
mexico
Jemo
Lafto
Hana maryam
Phase B
mexico
Jemo
Lafto
Hana maryam
Phase C
mexico
Jemo
Lafto
Hana maryam
Phase D
mexico
Jemo
Lafto
Hana maryam
Phase E
mexico
Jemo
Lafto
Hana maryam

MOVEMENT TIMING

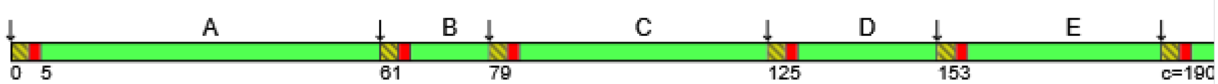
Site: 1 [Lebu Mebrat Haile]

Site Category: -

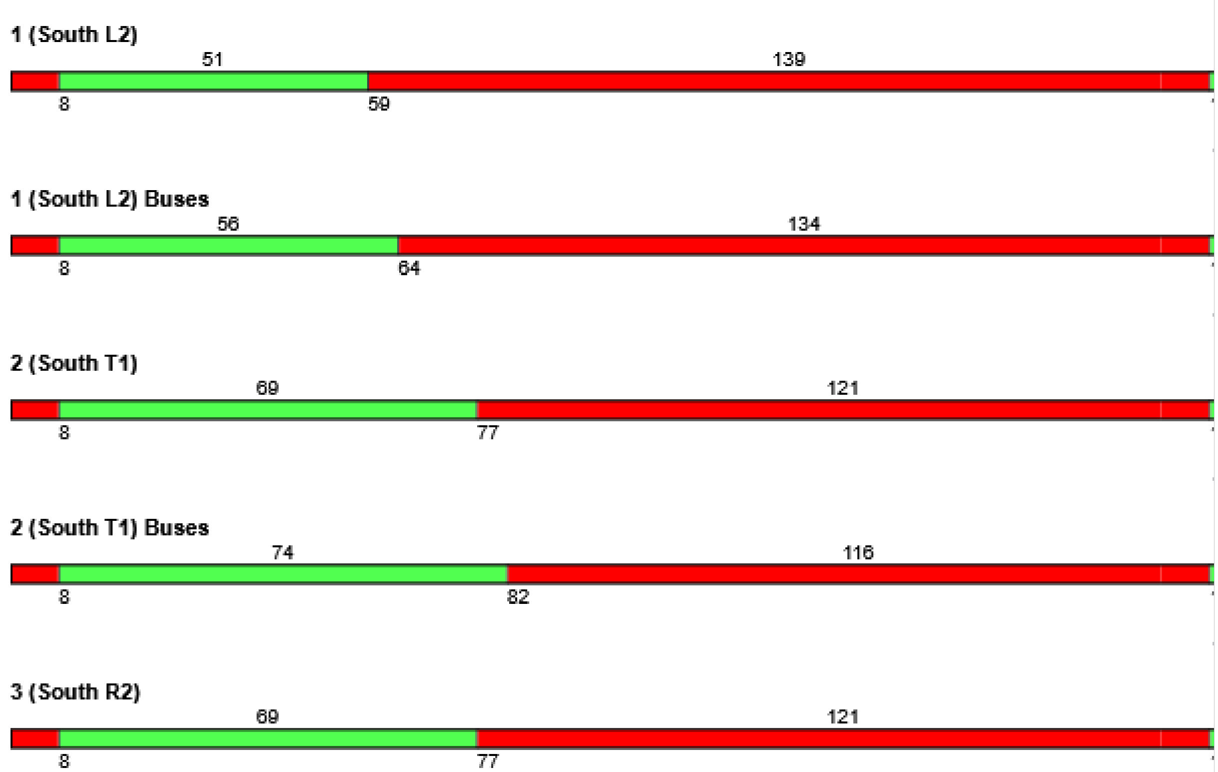
Signals - Fixed Time Isolated Cycle Time = 190 seconds (Site Practical Cycle Time)

Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Split Phasing Reference Phase: Phase A Input Phase Sequence: A, B, C, D, E Output Phase Sequence: A, B, C, D, E

DISPLAYED SIGNAL TIMING - PHASES



EFFECTIVE SIGNAL TIMING - MOVEMENTS




3 (South R2) Buses
74
116
8
82
4 (East L2)
23
167
133
156
5 (East T1)
23
167
133
156
6 (East R2)
190
0
190
7 (North L2)
41
149
87
128
8 (North T1)
59
131
69
128
9 (North R2)
190
0
190
10 (West L2)
158
32
2
160
192
11 (West T1)
158
32
2
160
192
12 (West R2)
190
0
190

MOVEMENT SUMMARY

Site: 1 [Imperial]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 213 seconds (Site Practical Cycle Time)

Movement Performance - Vehicles												
Mov	Turn	Demand Flows		Deg.	Average	Level of	95% Back of Queue		Prop.	Effective	Aver. No.	Average
ID		Total	HV	Satn	Delay	Service	Vehicles	Distance	Queued	Stop Rate	Cycles	Speed
		veh/h	%	v/c	sec		veh	m				km/h
South: Bole												
1	L2	248	27	2.62	814	LOS F	310.1	3044.3	1	1.4	2.37	4.1
2	T1	2498	52	2.75	849.3	LOS F	379.2	2936.4	1	1.46	2.39	3.9
3	R2	1459	10	2.62	810.7	LOS F	379.2	2936.4	1	1.44	2.37	4.1
Approach		4206	36	2.75	833.8	LOS F	379.2	3558.4	1	1.45	2.38	4
East: gergi												
4	L2	332	42	2.21	623.6	LOS F	81	760	1	1.33	2.26	4.9
5	T1	241	16	2.21	619.8	LOS F	88.5	769.9	1	1.36	2.26	4.9
6	R2	174	44	2.21	622.6	LOS F	88.5	769.9	1	1.37	2.26	4.9
Approach		748	34	2.21	622.1	LOS F	88.5	769.9	1	1.35	2.26	4.9
North: megenagna												
7	L2	296	44	2.23	631.8	LOS F	67.1	646.1	1	1.27	2.28	4.9
8	T1	932	41	2.15	592	LOS F	119.3	1096.5	1	1.35	2.23	5.3
9	R2	116	20	2.15	598	LOS F	119.3	1096.5	1	1.32	2.22	5.3
Approach		1343	40	2.23	601.3	LOS F	119.3	1098.3	1	1.33	2.24	5.2
West: Hayarat												
10	L2	259	15	1.88	479.3	LOS F	58.4	459.8	1	1.32	2.12	6.1
11	T1	457	12	1.98	503	LOS F	161.9	1384.3	1	1.43	2.14	5.9
12	R2	649	28	1.88	476.8	LOS F	161.9	1384.3	1	1.42	2.08	6.3
Approach		1365	20	1.98	486.1	LOS F	161.9	1384.3	1	1.4	2.11	6.1
All Vehicles		7662	34	2.75	710.4	LOS F	379.2	3558.4	1	1.41	2.3	4.5

LANE SUMMARY

Site: 1 [Imperial]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 213 seconds (Site Practical Cycle Time)

Lane Use and Performance	Demand Flows		Cap.	Deg.	Lane		Average	Level of	95% Back of Queue		Lane	Lane	Cap.	Prob.
	Total	HV		Satn	Util.		Delay	Service	Veh	Dist	Config	Length	Adj.	Block.
	veh/h	%	veh/h	v/c	%		sec			m		m	%	%
South: Bole														
Lane 1	1260	47	482	2.62	95	7	812.9	LOS F	310	3044	Full	500	0	100
Lane 2	1403	52	510	2.75	100		878	LOS F	352	3558	Full	500	0	100
Lane 3	1543	12	590	2.62	95	7	810.7	LOS F	379	2936	Full	500	0	100
Approach	4206	36		2.75			833.8	LOS F	379	3558				
East: gergi														
Lane 1	357	40	162	2.21	100		623.4	LOS F	81	760	Full	500	0	43.3
Lane 2	391	28	177	2.21	100		621	LOS F	88.5	769.9	Full	500	0	44.5
Approach	748	34		2.21			622.1	LOS F	88.5	769.9				
North: megenagna														
Lane 1	296	44	133	2.23	100		631.8	LOS F	67.1	646.1	Full	500	0	28.3
Lane 2	516	41	240	2.15	96	5	592.9	LOS F	116	1098	Full	500	0	78.4
Lane 3	532	37	248	2.15	96	5	592.5	LOS F	119	1097	Full	500	0	78.3
Approach	1343	40		2.23			601.3	LOS F	119	1098				
West: Hayarat														
Lane 1	278	15	148	1.88	95	7	478.9	LOS F	58.4	459.8	Full	500	0	0
Lane 2	321	12	162	1.98	100		516.1	LOS F	68.9	531.2	Full	500	0	10.5
Lane 3	766	26	407	1.88	95	7	476.1	LOS F	162	1384	Full	500	0	100
Approach	1365	20		1.98			486.1	LOS F	162	1384				
Intersection	7662	34		2.75			710.4	LOS F	379	3558				

LANE LEVEL OF SERVICE

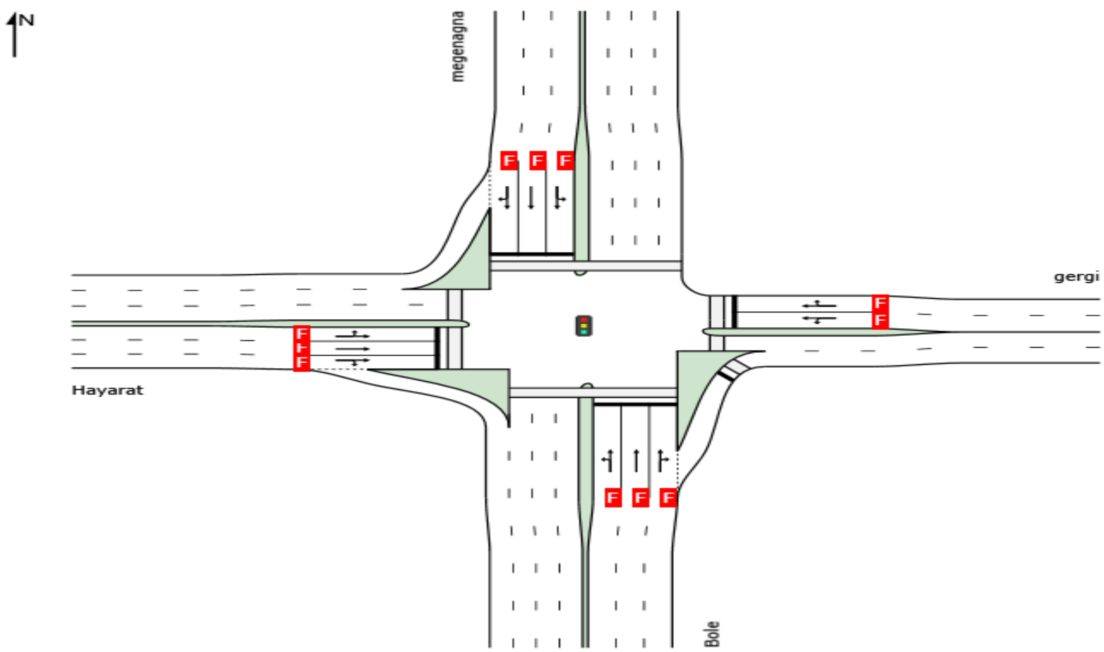
Lane Level of Service

Site: 1 [Imperial]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 213 seconds (Site Practical Cycle Time)

	Approaches				Intersection
	South	East	North	West	
LOS	F	F	F	F	F



PHASING SUMMARY

Site: 1 [Imperial]

Site Category: -

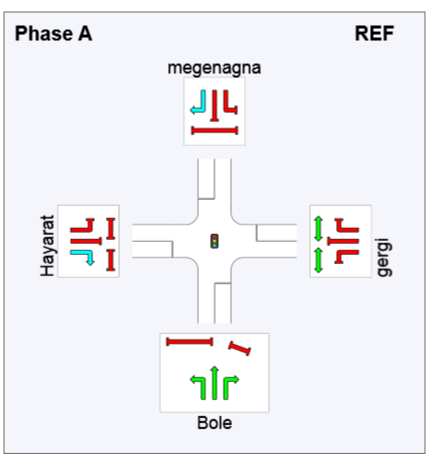
Signals - Fixed Time Isolated Cycle Time = 213 seconds (Site Practical Cycle Time)

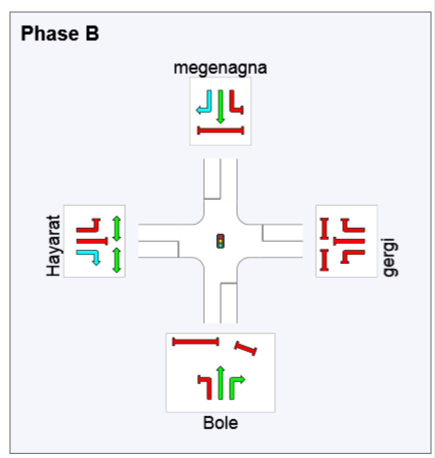
Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Split Phasing Reference Phase: Phase A Input Phase Sequence: A, B, C, D, E Output Phase Sequence: A, B, C, D, E

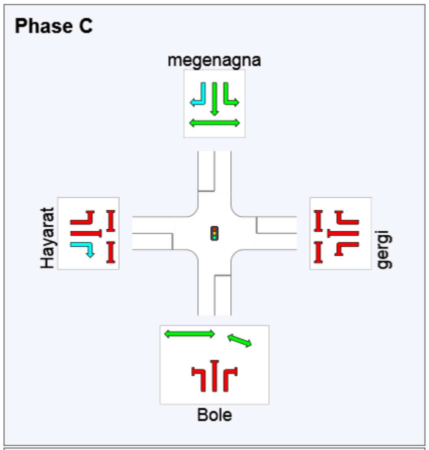
PHASE TIMING SUMMARY

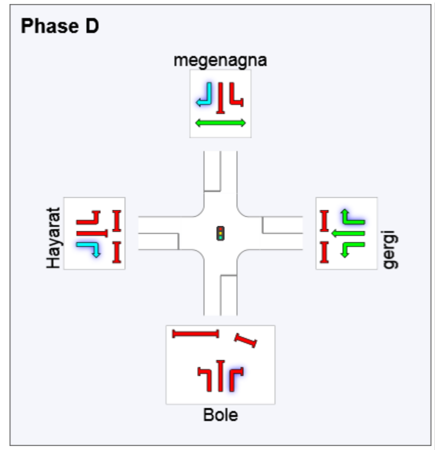
Phase	A	B	C	D	E
Phase Change Time (sec)	0	91	109	141	181
Green Time (sec)	86	13	27	35	27
Phase Time (sec)	91	18	32	40	32
Phase Split	43 %	8 %	15 %	19 %	15 %

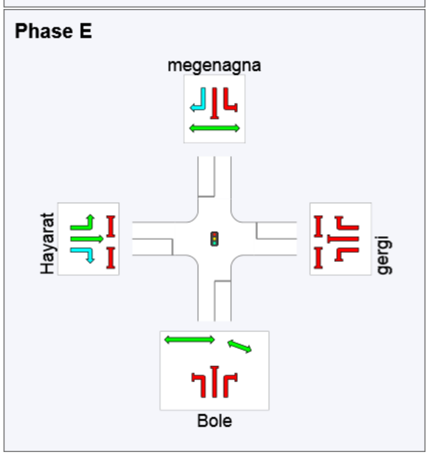
OUTPUT PHASE SEQUENCE






Phase C
megenagna
Hayarat
gergi
Bole


Phase D
megenagna
Hayarat
gergi
Bole


Phase E
megenagna
Hayarat
gergi
Bole

MOVEMENT TIMING

Site: 1 [Imperial]

Site Category: -

Signals - Fixed Time Isolated Cycle Time = 213 seconds (Site Practical Cycle Time)

Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Split Phasing Reference Phase: Phase A Input Phase Sequence: A, B, C, D, E Output Phase Sequence: A, B, C, D, E


3 (South R2) Buses
104
109
8
112
4 (East L2)
35
178
148
183
5 (East T1)
35
178
148
183
6 (East R2)
35
178
148
183
7 (North L2)
27
186
117
144
8 (North T1)
45
168
99
144
9 (North R2)
213
0
213
10 (West L2)
186
27
2
188
215
11 (West T1)
186
27
2
188
12 (West R2)
213
0
213

MOVEMENT SUMMARY

Site: 1 [Jacros T Intersection]

Three-way signalised intersection with 3 & 4-lane approaches and slip lanes

Site Category: (None)

Signals - Fixed Time Isolated Cycle Time = 140 seconds (Site Practical Cycle Time)

Movement Performance - Vehicles

Mov ID	Turn	Demand Flows Total	Demand Flows HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed
		veh/h	%	v/c	sec		veh	m				km/h
South: mebrat haile												
11	T1	1022	27.6	1.042	131.1	LOS F	70.8	832.5	1.00	1.25	1.69	17.8
12	R2	613	81.8	0.989	89.8	LOS F	70.8	832.5	1.00	1.15	1.45	22.9
Approach		1634	47.9	1.042	115.6	LOS F	70.8	832.5	1.00	1.21	1.60	19.4
East: Goro												
1	L2	637	32.9	1.043	146.4	LOS F	32.3	283.1	1.00	1.20	1.81	16.5
3	R2	155	26.2	1.043	145.4	LOS F	32.3	283.1	1.00	1.22	1.79	16.7
Approach		792	31.6	1.043	146.2	LOS F	32.3	283.1	1.00	1.20	1.81	16.5
North: Salite mihret												
4	L2	107	29.7	0.443	54.3	LOS D	6.4	56.1	0.90	0.79	0.90	28.7
5	T1	549	23.6	1.043	142.0	LOS F	30.9	260.2	1.00	1.19	1.80	16.8
Approach		656	24.6	1.043	127.7	LOS F	30.9	260.2	0.98	1.12	1.66	18.1
All Vehicles		3083	38.8	1.043	126.0	LOS F	70.8	832.5	1.00	1.19	1.67	18.3

LANE SUMMARY

Site: 1 [Jacros T Intersection]

Three-way signalized intersection with 3 & 4-lane approaches and slip lanes
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 140 seconds (Site Practical Cycle Time)

Lane Use and Performance														
	Demand Flows		Cap.	Deg.	Lane		Average	Level of	95% Back of Queue		Lane	Lane	Cap.	Prob.
	Total	HV		Satn	Util.		Delay	Service	Veh	Dist	Config	Length	Adj.	Block.
	veh/h	%	veh/h	v/c	%		sec			m		m	%	%
South: mebrat haile														
Lane 1	497	28	477	1.04	100		132.4	LOS F	58	498	Full	500	0	4.6
Lane 2	497	28	477	1.04	100		132.4	LOS F	58	498	Full	500	0	4.6
Lane 3	641	79	648	0.99	95	7	89.5	LOS F	71	833	Full	500	0	51.9
Approach	1634	48		1.04			115.6	LOS F	71	833				
East: Goro														
Lane 1	252	33	242	1.04	100		146.6	LOS F	28	252	Full	500	0	0
Lane 2	252	33	242	1.04	100		146.6	LOS F	28	252	Full	500	0	0
Lane 3	288	29	276	1.04	100		145.5	LOS F	32	283	Full	500	0	0
Approach	792	32		1.04			146.2	LOS F	32	283				
North: Salite mihret														
Lane 1	107	30	242	0.44	42	5	54.3	LOS D	6.4	56.1	Full	500	0	0
Lane 2	274	24	263	1.04	100		142	LOS F	31	260	Full	500	0	0
Lane 3	274	24	263	1.04	100		142	LOS F	31	260	Full	500	0	0
Approach	656	25		1.04			127.7	LOS F	31	260				
Intersection	3083	39		1.04			126	LOS F	71	833				

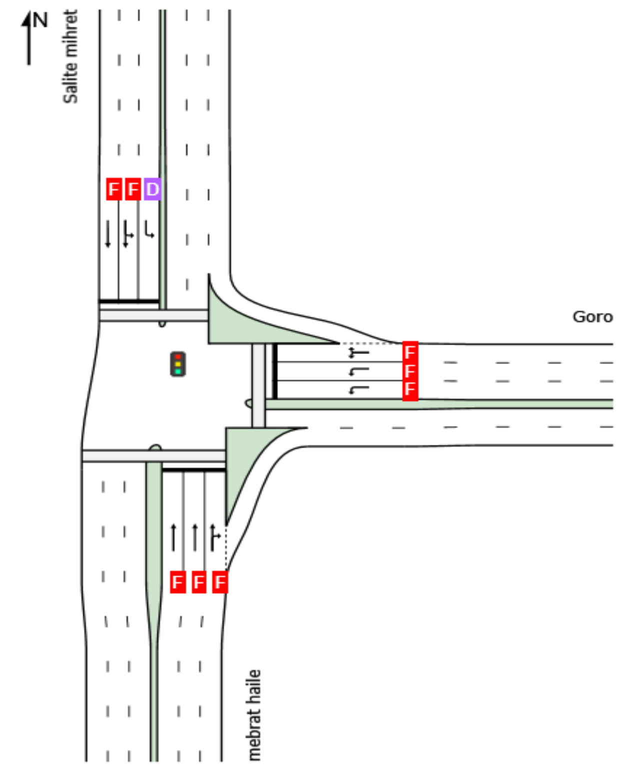
LANE LEVEL OF SERVICE

Lane Level of Service

Site: 1 [Jacros T Intersection]

Three-way signalised intersection with 3 & 4-lane approaches and slip lanes
Site Category: (None)
Signals - Fixed Time Isolated Cycle Time = 140 seconds (Site Practical Cycle Time)

	Approaches			Intersection
	South	East	North	
LOS	F	F	F	F



PHASING SUMMARY

Site: 1 [Jacros T Intersection]

Three-way signalized intersection with 3 & 4-lane approaches and slip lanes Site Category: (None)

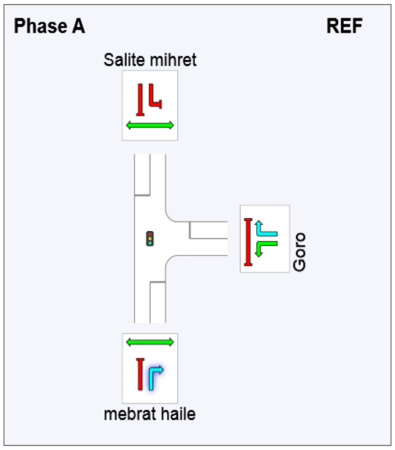
Signals - Fixed Time Isolated Cycle Time = 140 seconds (Site Practical Cycle Time)

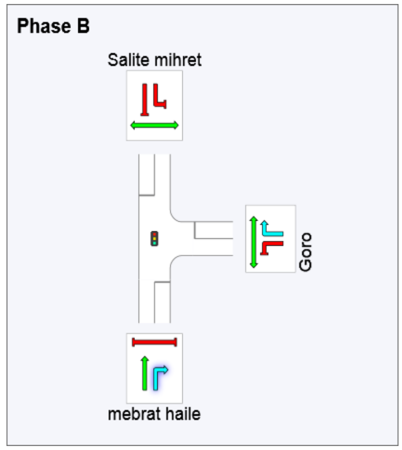
Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Leading Left Turn Reference Phase: Phase A Input Phase Sequence: A, B, C Output Phase Sequence: A, B, C

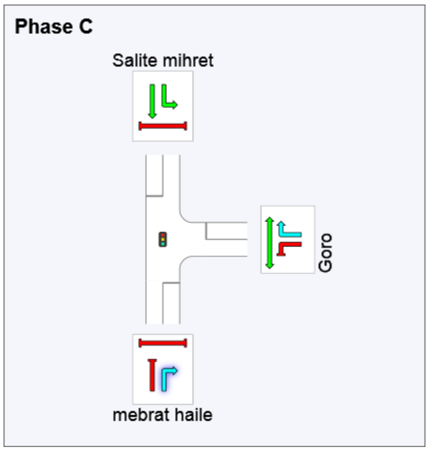
PHASE TIMING SUMMARY

Phase	**A**	**B**	**C**
Phase Change Time (sec)	0	35	101
Green Time (sec)	30	61	34
Phase Time (sec)	35	66	39
Phase Split	25 %	47 %	28 %

OUTPUT PHASE SEQUENCE


Phase A
REF
Salite mihret
Goro
mebrat haile


Phase B
Salite mihret
Goro
mebrat haile


Phase C
Salite mihret
Goro
mebrat haile

MOVEMENT TIMING

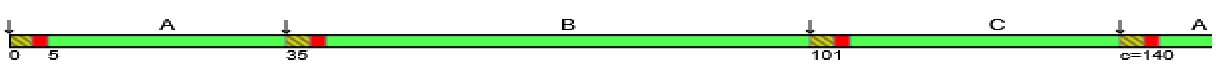
Site: 1 [Jacros T Intersection]

Three-way signalized intersection with 3 & 4-lane approaches and slip lanes

Signals - Fixed Time Isolated Cycle Time = 140 seconds (Site Practical Cycle Time)

Timings based on settings in the Site Phasing & Timing dialog Phase Times determined by the program Phase Sequence: Leading Left Turn Reference Phase: Phase A Input Phase Sequence: A, B, C Output Phase Sequence: A, B, C

DISPLAYED SIGNAL TIMING - PHASES



EFFECTIVE SIGNAL TIMING - MOVEMENTS