ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Harmonization of Light Rail Transit and Principal Arterial Streets

(A Case Study on the Addis Ababa East-West LRT Line and Principal Arterial Streets)

A Thesis submitted to

The Department of Civil Engineering

In partial fulfillment of

The requirements for degree of

Master of Science in Civil Engineering (Road & Transport Engineering)

By
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Advisor
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M.Sc. Thesis on

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DECLARATION

I certify that this research work titled "Harmonization of Light Rail Transit and Principal Arterial Streets (A Case Study on the Addis Ababa East-West LRT System and Principal Arterial Streets)" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

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ABREVIATIONS

LRT	Light Rail Transit
BRT	Bus Rail Transit
LRV	Light Rail Vehicles
PAS	Principal Arterial Streets
ERC	Ethiopian Railways Corporation
AACRA	Addis Ababa City Roads Authority
TCRP	Transit Cooperative Research Program
VTA	Santa Clara Valley Transportation Authority
HCM	Highway Capacity Manual
LOS	Level of Service
V/C	Volume to Capacity Ratio
Pc/km/ln	Passenger car per kilo meter per lane (unit of traffic density)
PCU	Passenger car unit
Veh/h	Vehicle per hour
SB	South Bound
NB	North Bound
WB	West Bound
EB	East Bound
TH	Through Traffic
RT	Right Turn Traffic
LT	Left Turn Traffic
Peds	Pedestrians
HV	Heavy Vehicle

ABSTRACT

The introduction of New Light Rail Transit Systems into a city has proven to bring positive effects on property values and it contributes an important role to the development of a city by taking a greater share of Public Transport Demand. For the case of Addis Ababa, where the public transport demand is growing at an alarming rate due to the continued rise in population, the new East-West LRT system which is under construction means a lot to the transformation of the city. The new system is believed to attract more new investment, promotes economic activity and enhances healthy living. However, these benefits will be achieved if and only if the new LRT system is properly harmonized with the Existing Arterial Streets.

The four major criteria taken to discuss harmonization of Light rail transits system and Principal Arterial Streets are **accessibility**, **safety, aesthetics and impact on traffic congestion**. As a case study, the Addis Ababa E-W Light Rail Transit System Project is assessed with respect to Harmonization in regard to location interval of LRT stations, accessibility, provision of parking lots, safety and aesthetics from the scientific stand point of view and best practices already indicated in the literature review part of this paper. In order to assess **impact on traffic congestion** (the possible additional delay to be induced) at Intersections after the introduction of new Light Rail Transit System into existing Principal Arterial Streets, primary data was collected at four selected junctions of Addis Ababa E-W corridor where the LRT crosses at grade with the existing principal street intersections. Peak hour traffic data was collected and geometric elements of the study junctions was measured for the purpose.

In the assessment of impact of traffic congestion due to the new LRT system, the result revealed that there is an additional delay to the normal control delay at the three junctions (Beshale Hotel Round About, CMC Round About and Ayat Round about) where the LRT crosses at-grade. With the existing geometric condition and future projected traffic, in 2016 the left turn movements will face about **41.7 sec/vehicle** of additional average delay after the introduction of Light Rail transit. On the other hand, the through traffic of North-South direction at these locations will experience more additional delays of about **47.7 sec/vehicle** on average. At Bambis Intersection, since the LRT is separated from the city street traffic with median curb stone and North-South Crossing is prohibited, additional delays are not observed. Instead, the through traffic of East-West direction at this junction is observed to experience less control delay than before due to the decrease in conflicts of North and South crossing traffic.

In the end, meaningful suggestions have been briefed that can help better harmonization of LRT systems and principal arterial streets for the future development of the city.

Keywords: *LRT; Light Rail Transit; Principal Arterial Streets; Intersection; Junction; Round About; Accessibility; Station; Integration; Harmonization; Impact; Control Delay*

1.0 INTRODUCTION

1.1 Background of the Study

It is a common trend that development in a city brings demand for mobility. As the population increases and development continues for a city, transportation demand increases accordingly which requires modern transit mechanisms to meet the consequent transportation demand. In the city of Addis Ababa, traffic volume is increasing at different road corridors with limited road network. Many of the intersections are serving beyond their capacity and different road sections are highly congested though vehicle ownership is lowest in the country. Especially the horizontal growth in settlement of the city calls for modern public transport system which can provide fast, reliable and convenient services by carrying passengers with in limited right of way either shared with the normal street traffic or in primarily reserved transit lanes.

Currently the Ethiopian Railway Corporation has launched a Light Rail Transit Project in the city of Addis Ababa in order to enhance urban mobility. The project under implementation (The East –West and North South LRT project) has a total length of 34.25 km. The first 17.35Km runs from West to East direction stretching from Tor Hayiloch to Ayat Village passing through Megenagna, Legahar and Mexico. And the second 16.9Km line runs from North to South through Menelik Square, Merkato, Lideta, Legahar, Meskel Square, Gotera and Kaliti. The two transit lines have a common track of about 2.8Km which stretches from Lideta to Meskel-Square. There are totally 22 stations out of which one underground station, 16 ground station, and 5 raised stations in the East-West LRT system. This research will take the East-West LRT Project as a case study.

1.2 Problem Definition

Addis Ababa, as a developing city needs modern mass transit system in order to meet the high transport demand of the people. The new LRT system to be introduced into the Existing Principal Arterial Roads is believed to play a significant role in this regard. However, the additional delay it will induce onto the street traffic system, where grade separation is not provided, is a major problem transport planners need to be aware of. On the other hand the introduction of a new LRT system should not be a barrier in terms of access, safety and aesthetics to the existing surrounding areas. Harmonization of the two systems is an important factor in the development of the city. Therefore, an assessment of best practices regarding accessibility, parking lots, safety, and aesthetics are found critical by the researcher.

At present, there has been little research that has attempted to quantify the effects of introducing Light Rail Transit (LRT) and Bus Rail Transit (BRT) Systems into the existing street traffic. This study will attempt to quantify the effects of LRT crossings on street traffic as well as to develop a methodology that will allow planners of light rail transit facilities to evaluate directly the delay impacts of LRT crossings. This will enable the responsible bodies to know the effects of introducing LRT System into the existing traffic system and help predict the potential impacts and devise a mechanism to minimize the impacts in order to have harmonized modes of LRT and Urban Street Highway systems.

1.3 Objective

The main objective of the research is to assess the proposed LRT system which runs from Tor-Hayiloch Ring Road to Ayat Round about to ensure that the overall existing road network is harmonized /integrated.

The specific objectives of the thesis will be:

- ✓ To study the problems that may face due to the introduction of LRT system on the principal arterial streets taking East –West LRT Project as a case study.
- ✓ To investigate additional delays to the regular expected delay experienced by vehicles due to frequent LRT crossings based on actual field data.
- ✓ To indicate the relevance of proper consideration of parking facilities, station intervals, accesses to stations and/or road side land uses, safety and aesthetics in regard to *harmonization* of the two systems based on best practices and scientific stand point of view.
- ✓ To come up with meaningful suggestions or solutions that can help make better integration of LRT and Highway Streets for the future development of the city.

2.0 LITRATURE REVIEW

2.1 LRT Definition

In general, there is no single definition given to Light Rail Transit system. However, among many of the common definitions given by different authorities and researchers, the common ones are those given by the American Public Transportation Association and Transportation Research Board.

The American Public Transportation Association (APTA) in its Glossary of Transit Terminology defines light rail as "*An electric railway with a 'light volume' traffic capacity compared to heavy rail which uses shared or exclusive rights-of-way, high or low platform loading and multi-car trains or single cars."*

Transportation Research Board (Transportation Systems Center-1977) on the other hand defined light rail as *"a mode of urban transportation which utilizes predominantly reserved rights-of-way and having electrically propelled rail vehicles providing a wide range of passenger capabilities and performance characteristics at moderate costs."*

2.2 LRT Historical Background

Studies revealed that the origin of the tramway can be traced back to the plate ways used in mines and quarries to ease the passage of horse-drawn wagons and the first street tramway was emerged in the City of New York in 1832.It is well stated by Michael Taplin (1998) that American promoters brought the tramway to Europe especially Paris in 1853, Birkenhead (England) in 1860 followed by London in 1861 and Copenhagen in 1863. In 1870s, the construction of horse tramways limited to animal traction was very common.

Various studies depicted that Light rail was first created in Europe. As per a report made by Thomas A. Garrett (2004), it is mentioned that the first region to adopt light rail in North America was Edmonton, whose first line opened in 1978. As to the report, Calgary and San Diego opened their first lines in 1981.The Canadian city of Edmonton built a new light rail line, partly on underused rail alignment, and partly in city subway, and operated it from 1978 with imported trams from Siemens-Duewag in Germany. This was an immediate success, and the Californian city of San Diego followed suit three years later, as did Calgary in Canada. Tramway systems were well established in the Asian region at the start of the 20th century. It is well documented in the report that the first Japanese tram line was inaugurated in 1895 as the Kyoto Electric Railroad. In India, Kolkata has the oldest operating electric tram system of Asia. In Australia, trams are used extensively only in Melbourne, and to a lesser extent, Adelaide, all other major cities having largely dismantled their networks by the 1970s. Sydney reintroduced its tram in 1997 as a modern system (Metro Light Rail), while Ballarat, Bendigo, Christchurch and Perth reintroduced their trams as heritage systems.

In Africa, only Egypt, Tunisia and South Africa have got LRT system in their cities.

2.3 Characteristics of Light Rail Transit

Light rail transit is described by Transport Research Board as *"A metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways or, occasionally, in streets, and to board and discharge passengers at track or car-floor level."*

Light rail System is part of the modern mass transit system which has a vital role in the transformation of cities. Light rail can link up existing transport modes with the city centers and suburban areas in a cost effective manner. Generally, Light Rail Transit System could be characterized as follows:

- ✓ Light rail attracts more development opportunities and provides stimulus for local economic growth.
- ✓ Light rail vehicles have much more capacity (when compared to the normal bus system).
- ✓ With priority at traffic lights, light rail can provide fast journeys and convenient interchange with other transport services.
- ✓ Light Rail Transit Services have high quality and capacity (than the traditional bus system).

2.4 Types of Light Rail Transit Systems

Light rail systems can be found in a variety of land use systems from suburbs to high-density central business district areas and they can operate in a range of right-of-way types. Because of the wide variations in operating characteristics among LRT systems, many researchers have made classification categories for the purpose of comparison. The two broad accepted classification categories are Operating speeds and alignment types.

According to Transit Cooperative Research Program (TCRP) Report 17, classifying based on the use of average speed is acceptable in that it can reflect the diversity of LRT systems even though it does not account for the use of multiple alignment types and changes in speed from block to block.

As per the MUTCD (*Manual on Uniform Traffic Control Devices for Streets and Highways)*, Light rail alignments can be classified into three broad alignment types. These are:-

i. **Exclusive**: An LRT right-of-way without at-grade crossings that is grade-separated or protected by a fence or substantial barrier, as appropriate to the location (includes subways and aerial structures). Vehicles, pedestrians and bicycles are prohibited within the right- of -way.

ii. **Semi-Exclusive:** An LRT alignment that is in a separate right-of-way or in street right-of-way where motor vehicles and/or pedestrians cross at designated crossings only.

iii. **Non-Exclusive**: An LRT corridor where LRVs operate in mixed traffic with automobiles, trucks, buses, bicycles and pedestrians.

2.5 Advantages and Disadvantages of LRT Systems

As per Action for transport (NSW) Inc., the following pros and cons are noted.

Advantages of light rail Systems compared to bus mode of transport:

- More comfortable ride
- Higher passenger capacity
- Lower operating costs
- Lower noise
- Benefit to other road users where surfaces rebuilt – i.e. fewer jolts for the buses
- Less Pollution when compared to the traditional bus system.
- Aesthetic – very well-designed trams are seen as adding visual appeal to the urban landscape
- Induce positive impact on property values
- Legibility – people including infrequent public transport users can see where it goes and feel confident something will come
- Integrates well into a pedestrian mall
- Potential for dual-current vehicles
- May suit areas where level of demand is between bus and heavy rail
- Taken as symbolic value and it could be seen as proof that a government is truly committed to public transport.

Disadvantages of light rail Transit Systems Compared to buses:

- Higher capital costs
- Generally lower proportion of seats to standees
- Inflexibility of route e.g. in case of breakdown
- Inflexibility as one tram cannot overtake another
- Disruption to traffic during construction
- Permanent inconvenience to motorists where lanes are lost or they are required to stop behind passengers getting on and off.
- Greater capacity of vehicles may mean reduced frequency compared to buses
- If coal-fired electricity is used, greenhouse emissions per passenger-km may be higher than buses
- May lead to neglect of bus routes in areas away from LRT
- Aesthetic – overhead wires are visual obstructions on important locations having good scenes.

2.6 Light Rail Transit (LRT) Versus Bus Rail Transit (BRT) Systems

BRT Implementation Guidelines defines BRT as “A flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity.”

As per the study by Bill Lambert (2012), Relative Merits of LRT versus BRT and vice versa is presented.

Merits of LRT over BRT:

- Higher ridership capacity - up to 30% or more.
- Rail attracts greater ridership especially among “captive” riders.
- More appeal to developers for transit-oriented development.
- Greater flexibility for energy sources.
- Lower operating cost per passenger-mile.
- Greater reliability.

Merits of BRT over LRT:

- Lower capital costs: stations, signalization, maintenance facility, no tracks and crossovers, power system and overhead catenaries etc.
- More flexibility in routing and can avoid transfers.
- Can use steeper grades.
- Lower cost for structures.

2.7 Principal Arterial Streets (PAS)

Principal arterial streets are among urban highway categories which provide for traffic movement from one area of the city to another, and are primarily designed to accommodate through traffic with minimum access provision to the adjoining land uses. The primary function of an arterial road is to deliver traffic from collector roads to freeways, and between urban centers at the highest level of service possible.

Arterial functional classification of Urban Streets is a means of classifying a road system into a number of categories or groups based on the intended service. Arterial functional classification is used in transportation planning as a means of communications and administrations among professionals and administrators including the individuals. A policy on Geometric Design of Highways (2001) classification of roads is based on six hierarchal travel movements. These include main movement, distribution, collection, access and termination as depicted in the figure below.

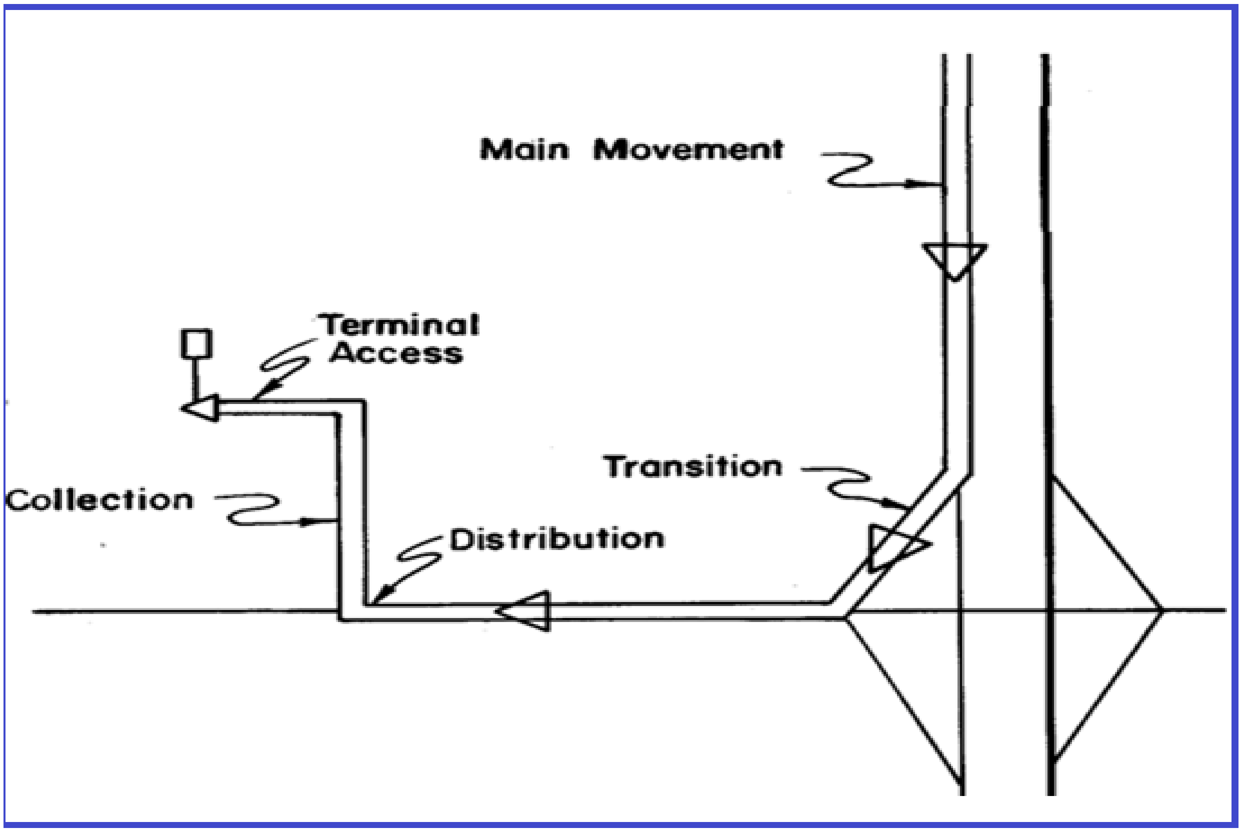


Figure 2-1: Hierarchy of Movement (Adapted from A policy on Geometric Design of Highways -2001).

The two basic criteria of functional classifications of highway and street networks are access and mobility. Practically the two basic functions could not be attained separately. A compromise between the two and the degree of limitation of accesses differs as intended by the planner. It is a question of serving the through traffic without interruption and providing access to the surroundings. As a far as development of a city is concerned, a balance of the two criteria will be compulsory. The development of the city will be limited when mobility is encouraged. Recreational centers, cafeterias, hotels, schools and market areas usually abandon high speed streets. On the other extreme, if access is to be fully provided, speed will highly be affected or reduced which induces traffic congestion. Therefore, as a far as development of a city is concerned, a balance between access and mobility criteria will be compulsory.

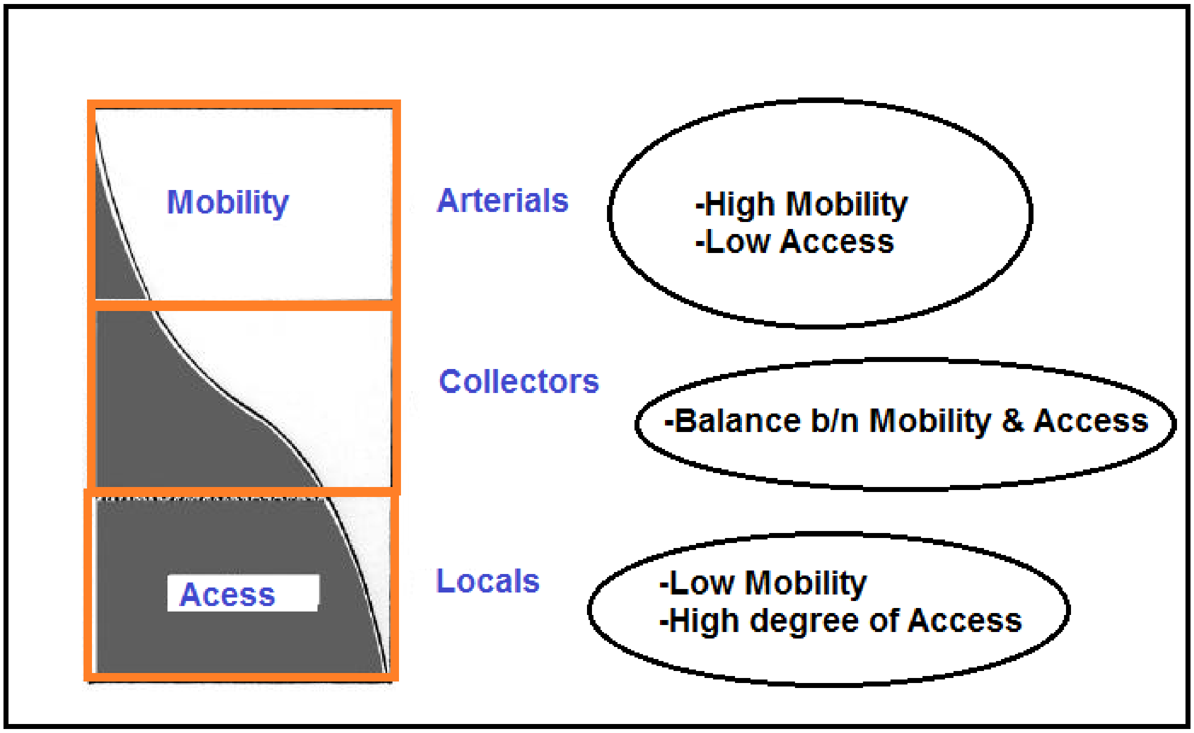


Figure 2-2: Access versus Mobility

Depending on the extent of access control, all streets and highways could be grouped into arterials, collectors and Local Streets. Furthermore, the four classifications of highway systems in urbanized areas as per AASHTO are:

- **Principal Arterial Streets (PAS):-**Provides for movement across and between large subareas of an urban region and serves predominantly through traffic with some degree of access control.

- **Minor Arterial Streets:-**Provides for movement within the larger subareas bound by principal arterials. A minor arterial may also serve through traffic but provides more direct access to adjoining land uses than does a principal arterial.

- **Collector Streets: -** Provides for movement within smaller areas which are often definable neighborhoods, and which may be bound by arterials with higher classifications. Collectors serve very little through traffic and serve a high proportion of local traffic requiring direct access to adjoining properties. Collector arterials provide the link between local neighborhood streets (non-arterials) and larger arterials.

- **Local Streets: -**Provides primarily direct access to land uses and connections to the arterial system.

2.8 Impact of an LRT System on Fuel Consumption by Street Vehicles

The LRT Light Rapid Transit System (LRT) is a mass transport system characterized by low-carbon emission since it uses electricity in place of fuel. As a result it provides support to the cities' environment and economy on sustainable development.

Different literatures revealed that electric rail transit and electric trolleybus modes provide substantially better carbon-based energy efficiency than motor vehicles, either motor bus or private car, and thus represent a very promising tool in the effort to reduce carbon emissions and thus to mitigate Global Warming.

A report from the American Public Transit Association (accessed via internet at www.apta.com on March 5, 2013) presents evidence that each person riding light rail versus driving an automobile for one year reduces hydrocarbon emissions by nine pounds, nitrogen oxide emissions by five pounds and carbon monoxide emissions by sixty three pounds. The report clearly shows that one electric light-rail train produces nearly 99 percent less carbon monoxide and hydrocarbon emissions per mile than one automobile does.

2.9 Integration of LRT System and Principal Arterial Streets

In principle the two different systems of transport, Light Rail Transit and Principal Arterial Streets, need to be harmonized with each other and with the surrounding environment for better development of a city. At grade intersection locations of the two systems, LRT Stations, access to and from the stations, parking provisions, aesthetics and safety are area of concern for the integrated planning and implementation of Light Rail Transit and Principal Arterial Streets.

2.9.1 Transport Cooperative Research Program Report 17"*Integration of LRT System and Principal Arterial Streets"*

A research was made by Korve Engineering, Inc. under Transport Cooperative Research Program (TCRP) in 1996 on 10 selected American Cities to know the Integration of Light Rail Transit into City Streets. In the study, an inventory of LRT alignments, traffic control devices, and accident experience were collected. The researchers identified the measures of effectiveness and developed methodologies for evaluating the effectiveness of traffic engineering treatments for LRT systems. It has been indicated in the study that LRT accident data were related to the alignment and the traffic control devices in use at the accident site. The study also identifies effective enforcement and public safety educational techniques that have been in use by different LRT operating agencies. Moreover, the following findings were indicated in the study:

- LRT system design should respect and adapt to the existing urban environment;
- LRT system design should comply with motorist and pedestrian expectations;
- Decisions by motorists and pedestrians who interact with the LRT should be kept as simple as possible;
- Traffic control devices related to LRT operations should clearly communicate the level of risk associated with the LRT system; and
- LRT system design should provide recovery opportunities for erratic motor vehicle and pedestrian movements.

However, the research failed to show the impacts of LRT system on traffic congestion with respect to harmonization of the LRT system with City Streets.

2.9.2 Light Rail Transit Service Guide Lines (Santa Clara Valley Transportation Authority-VTA 2007)

Light Rail Transit Service Guidelines (VTA- 2007) stated that all new LRT line segments shall undergo a system analysis to assess the operational impacts to the existing system, and identify the improvements needed to maintain system speed and operational flexibility. The manual further explains that LRT lines shall be integrated into the Community with pedestrian oriented and transit friendly developments. That is equivalently to say that LRT lines shall be well harmonized with the regional transit systems and have multiple transfer opportunities to local buses.

It is emphasized in the manual that new LRT extensions shall include the development of a parking management plan that will incorporate park and ride demand, shared parking opportunities, public-private partnership opportunities and security issues and measures including high-tech solutions such as video monitoring and smartcard control entry and exit systems.

The following recommendations are indicated in the manual regarding the transfer facilities and accessibility at LRT stations as far as harmonization of LRT in to city streets is concerned.

- Stations shall be physically harmonized with major transit facilities nearby in ordered to facilitate transfers.

- Stations shall possess appropriate facilities for at-station transfers to local mode of transportation as bus, where appropriate. This may include:
    - Appropriate signage and transfer information.

- Pedestrian crossings, transfer corridors, and walking paths.
- Passenger queuing areas.
- Loading/unloading curb space for buses.
- Layover bays.

➢ Stations shall be well integrated into the community with supporting land uses and densities, and pedestrian-oriented and transit-friendly developments around stations.

➢ Stations shall be provided with direct pedestrian access.

➢ Stations shall possess sufficient facilities to meet park and ride demand at suburban stations where there is available space or accommodations parking spaces and appropriate access roads.

➢ Suburban stations having physical constraints preventing implementation of parking shall provide appropriate walkways.

2.9.3 AACRA Geometric Design Manual (2002)

Addis Ababa City Roads Authority (AACRA) Geometric Design Manual (2002) explained that Arterial Streets at railway crossings is critical to the safety and comfort of the crossings. Apart from the effect of the alignment on visibility, the relationship of the alignments of the road and rail at the crossing determine the comfort of the crossing. If the crossing does not occur with minimal impact on the vehicle, safety will be compromised. Hence, highway and structural designers need to consider the design parameters of both highway and railway systems and provide the necessary design controls to harmonize the two systems with minimal impact and optimized efficiency.

It is indicated in the manual that the geometric design of railroad/highway grade crossings must be made in consideration of warning devices such as signs, pavement markings, light signals and automated gates.

The manual further explains that some of the considerations for evaluating the need for active warning devices at a grade crossing include the type of highway, volume of vehicular traffic, number of trains per day, number of mainline tracks, maximum speed of trains, speed of vehicular traffic, volume of pedestrian traffic, accident experience, sight distance, and geometrics. This principle work for light rail transit and arterial street highways at-grade crossings.

2.9.4 Addis Ababa E-W Light Rail Transit Project Study Report (China Railway Group Limited-2009)

The East-West and North-South corridors of Addis Ababa City are characterized by high transport demand and pass through highly populated areas, busiest commercial centers, and residential areas with high traffic flow. China Railway Group Limited (2009) has made a detailed study on these important lines in regard to introducing new LRT system into the existing street highways.

The following General Design Guide Lines and Principles to be followed for harmonization of rail transit and conventional public transportation system are indicated in the report:

- The formation of an efficient public transportation system can be realized by merging both railway and conventional transport systems. The public transport can be formed from the two systems and in order to guarantee their dominance in the city transportation system, good harmonization techniques shall be applied in the planning and design phase.

- The light rail transit and other transport systems should integrate and supplement to each other and with the surrounding land space. For instance, the railway transportation system can feed/receive passengers to/from surrounding stations which are operated by other transport systems. This enables the efficient use of public resources and the overall transportation infrastructure.

- The LRT system can be used as a backbone to harmonize the integration of different transportation systems in the city. The conventional bus yard, cross-section, public space, minibus transfer parking yard, taxi station, social vehicle station and other transport facilities can be shared by other transportation systems. Traffic flow can also be eased by distributing the surrounding systems within 50 meters from the LRT connection.

- The planning shall consider the transfer between LRT and conventional bus transport system. The bus stations shall be located near the exit and entrance of Light Rail Transit stations. In addition, LRT station should provide clear traffic guiding information. Taxi stations shall be located within a reasonable walk range near the entrance and exit of the LRT stations.

- While provision of the LRT stationing, it is important to consider good architectural forms and decorative items for aesthetical convenience of the users and the city. The exit and entrance of the station shall be equipped with ramps for the disabled people.

2.10 Effects of LRT Systems on Traffic Congestion

2.10.1 Defining Traffic Congestion

The European Conference of Ministers of Transport (ECMT-2007) explains that there is no single definition of traffic congestion. One of the principal reasons for this lack of consensus as indicated by the Transport Minister is that congestion is both a physical phenomenon relating to the manner in which vehicles impede each other for limited road space and a relative phenomenon relating to user expectations with regard to road system performance. However, according to Lomax (1997) traffic congestion is defined as travel time or delay in excess of the normally incurred or agreed magnitude in the normal circumstance.

William S. Vickrey (1969) classified congestion into two broad categories based on the nature of their occurrence as recurrent and non-recurrent. As per his classification, recurrent congestions are those happening regularly on a daily, weekly or annual cycle. And non-recurrent congestions are those traffic incidents such as accidents and disabled vehicles. Further, the economist identified six types of congestion which are described below:

- **Simple interaction on homogeneous roads**: when two vehicles travel close together.
- **Multiple interactions on homogeneous roads**: when several vehicles interact.
- **Bottlenecks:** when several vehicles compete to pass through narrowed lanes.
- **Trigger Neck Congestion**: when an initial narrowing generates a line of vehicles interfering with a flow of vehicles not seeking to follow the jammed route.
- **Network control congestion**: where traffic controls are programmed for peak-hour traffic.
- **Congestion due to network morphology:** where traffic congestion reflects the state of traffic on all routes and for all modes.

2.10.2 Level of Service (LOS) as traffic congestion indicator

The Highway Capacity Manual (2000) defines Level of service as "*a range of operating conditions which occur on a transportation facility when it is accommodating a range of traffic volumes. The descriptions of individual levels of service characterize these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience. Six levels of service are defined for each type of facility for which analysis procedures are available. The levels are given letter designations, from A to F, with level of service (LOS) A, representing the best operating conditions and LOS F the worst*".

As per the HCM, the LOS F indicates the worst state of flow and represents congested state. It is the most acceptable level of service which could represent congestion state. The Level of service D and E are sometimes taken as congestion indicators by some traffic Engineers.

The general operating conditions for Level of Service criteria of Highway Capacity Manual is as summarized below:

Table 2-1 Highway Level of Service Operation Conditions (Source: HCM 2000)

LOS	Description	Spacing	Density	Delay at Signalized Intersection	Delay at un-signalized Intersection
		(m)	(pc/km/ln)	(Sec/Veh.)	(Sec/Veh.)
A	Describes free flow conditions. The operation of vehicles is virtually unaffected by the presence of other vehicles and operations are constrained only by the geometric features of the highway and by driver preferences. Maneuverability within the traffic stream is good. Minor disruptions to flow are easily absorbed at this level without change in travel speed.	167	7	≤10	≤10
B	An indicative of free flow, although the presence of other vehicles begins to be noticeable. Average travel speeds are the same as in LOS A, but drivers have slightly less freedom of maneuver. Minor disruptions are still easily absorbed at this level, although localized deterioration in LOS will be more obvious.	100	12	10-20	10-15
C	Represents a range in which the influence of traffic density on operations becomes marked. The ability to maneuver within the traffic stream is affected by the presence of other vehicles. Travel speeds begin to show some reduction for multilane highways with free flow speeds over 80km/h. Minor disruptions may be expected to cause serious local deterioration in service and queues may form behind any significant traffic disruption.	67	17	20-35	15-25
D	Represents a range in which ability to maneuver is severely restricted because of traffic congestion. Travel speed begins to be reduced by increasing volumes. Only minor disruptions can be absorbed without the formation of extensive queues and the deterioration of service.	50	21	35-55	25-35
E	Represents operations at or near capacity and this level is quite unstable. The densities vary depending upon the free flow speed. Vehicles are operating with the minimum spacing at which uniform flow can be maintained. Disruptions cannot be damped or readily dissipated and most disruptions will cause queues to form and service to deteriorate to LOS F. For the majority of multilane highways with free flow speeds between 70 and 100 km/h but are highly variable and unpredictable within that range.	NA	NA	55-80	35-50
F	Represents forced or breakdown flow. It occurs either at a point where vehicles arrive at a rate greater than the rate at which they are discharged or at a point on a planned facility where forecast demand exceeds computed capacity. Although operations at such points will appear to be at capacity, queues will form behind these breakdowns. Operations within queues are highly unstable, with vehicles experiencing brief periods of movement followed by stoppages.	NA	NA	≥80	≥80

Table 2-2 Delay LOS Criteria (Source: HCM 2000)

Level of Service	Control Delay per vehicles (Seconds)		
	Signals	Roundabouts	Stop and Give way/Yield Signs
A	$d\leq10$	$d\leq10$	$d\leq10$
B	$10<d\leq20$	$10<d\leq20$	$10<d\leq15$
C	$20<d\leq35$	$20<d\leq35$	$15<d\leq25$
D	$35<d\leq55$	$35<d\leq50$	$25<d\leq35$
E	$55<d\leq80$	$50<d\leq70$	$35<d\leq50$
F	$80<d$	$70<d$	$50<d$

Note that "d" in the table above represents delay.

Table 2-3 Practical Degree of Saturation Limits (Source: HCM 2000)

Intersection Type	Maximum Practical Degree of Saturation
Signals	0.9
Roundabouts	0.85
Sign-controlled	0.8
Continuous Lanes	0.98

2.10.3 Effect of Introducing New LRT System into Existing Street Highways in terms of Congestion

It may seem reasonable to assume that the availability of comfortable transit system as LRT would decrease congestion by reducing the need to use car. However, different studies showed that introduction of LRT system into city streets increase in traffic congestion.

A research by Chad Chandler (May 2004) showed that there is a great possibility for vehicles to experience additional delays when there is interference by LRT operations, such as in the case of at-grade crossings or due to priority being given to LRT vehicles at signalized intersections at the expense of conflicting turning movements. The study examines the effects of light rail crossings on average delays experienced by vehicles by using the VISSIM 3.70 computer simulation model and considering different scenarios. He identified a set of factors that were good predictors of increased traffic congestion at LRT crossings: the number of vehicles crossing, the frequency of Light Rail car crossings, intersection geometry, signal preemption configurations, the presence of driveways or intersections near crossings, types of traffic (such as familiar drivers, and heavy trucks), and degrees of priority given to LRT. When LRT crossed very often with vehicles, the delays could be significant. For example, at the North Lynnhaven Road crossing (Virginia), the LRT crossing every 5 minutes could give an average additional delay for southbound traffic of 34.56 seconds per vehicle. However, that delay would reduce to 6.48 seconds per vehicle, if the LRT only crossed every 10 minutes, and would further reduce to 3.85 seconds per vehicle, if the LRT only crossed every 15 minutes. The results of the simulated test scenarios indicated that the average additional delays from light rail transit crossings increase with increasing light rail crossing frequencies and increasing traffic volumes up to the roadway's capacity. As the road enters an over saturated condition, the average total delays continue to increase, but the difference in total delays with and without light rail decreases from the unsaturated condition. Preemption of traffic signals near light rail crossings increases the total delay experienced by vehicles that are in conflict with the light rail crossing, but it tends to improve travel times for the non- conflicting movements due to the increased green time. Based on these results, it is determined that traffic volumes at crossings and the frequency of light rail crossings are important variables that affect the average additional delays experienced by vehicles. The research has indicated that during the initial planning for a light rail line, special consideration should be given to the traffic volumes at the proposed at-grade crossings as well as the proposed service frequency during the peak periods. If the level of service is expected to include five-minute crossing frequencies or if at-grade crossings are proposed for streets that are near capacity, measures such as widening roads at crossings, providing extra space for turning vehicles, or constructing a grade-separated crossing should be considered.

In recent studies (Patricia Ciorici and Yoshi Ludwig 2009), it has been shown that introduction of LRT lines into existing arterial streets are correlated with increased traffic and congestion. A possible explanation is that LRT system reduces available space in automobile traffic lanes. Another possibility is that residents do not necessarily increase their use of mass transit in response to the introduction of LRT. In the same study, it is well explained that in order to reduce traffic and congestion, LRT systems need to be integrated with future development and other forms of transportation.

To minimize the increase in traffic congestion, a strong recommendation that came repeatedly in studies was to integrate LRT construction and usage with other forms of mass transit. LRT stations connected with bike paths and pedestrian walkways, and parking areas around LRT stations, made LRT more appealing to the general public. The quality of urban transportation, a warm and welcoming design of LRT stations, and ring roads for cars also are factors that offset increases in traffic.

A Master of Science thesis by James Curtiss Cline, Jr., of Texas A&M University scrutinized the delays that could be attributed to LRT at-grade crossings in 1986. The researcher used the Network Simulator (NETSIM) model to test four scenarios with light rail crossings: an isolated crossing, an adjacent intersection crossing, a series of coordinated intersections with preemption, and a case study based on a corridor in Houston. The study found that the volume to capacity (v/c) ratio was the major factor in the delay experienced per vehicle at an isolated crossing. For a crossing near an adjacent intersection, the distance between the intersection and the crossing as well as the v/c ratio were major components of the delay, but traffic traveling parallel to the LRT line did not appear to be affected greatly. Locations of LRT crossings within a coordinated signal network did not appear to affect the traffic significantly. The results from the Houston case study showed that most of the effects were shown to be localized near crossings; there did not appear to be a network wide effect on delays.

It has been described by American Public Transportation Association that introduction of the LRT right-of-way will reduce the vehicular capacity but increase person carrying capacity.

2.11 LRT Station Locations and Interval

Station locations and Parking provision are important elements planners and designers need to give emphasis in regard to the Harmonization of Light Rail transit in to Principal Arterial Street Highways.

Good station location can help harmonize successfully light rail systems into city streets in ways that encourage transit-oriented development. Best Practices for Light Rail Design by Vancouver Working Group recommends that the LRT stations need to reflect the character and community standards of the City. Neighborhoods and downtown need to be well maintained and the light rail facilities should reflect a similar commitment. The stations should be constructed with high quality, durable materials; have good pedestrian connections into the adjacent neighborhoods; receive regular and frequent security and maintenance attention; and be designed to maximize positive effects and minimize negative effects on adjacent properties.

As far as LRT Stations are concerned, an associated issue is the connection or accessibility to the provided LRT Stations. In principle, planning and design of a light rail transit system should provide safe and convenient access to the users. The access to the station could be made on foot, by bicycle, in buses, in shuttles, carpools, or single-occupant vehicles. At the end of the access, sidewalks, paths, and street crossings will be provided to the pedestrians to make getting to the station safe and easy.

The Light Rail Transit Service Guideline of Santa Clara Valley Transportation Authority (VTA-2007) indicated that LRT Stations need to be attractive, well designed, and above all, well located and placed to provide convenient and easy access. In the guide line, recommendations of station placement are as listed below:

- In general, stations shall be located every 0.75 to 1.00 mile (1200-1600m). Specific station placement shall be based on planning studies that identify the location of key activity generators along the corridor and/or demand at particular locations along the corridor.

- Stations shall be located in close walking distance to, if not directly serving, major trip generators, such as civic and employment centers, downtown business districts, mixed-use districts and high density residential areas, colleges and universities, and shopping centers.
- Stations shall be placed at locations with potential for development and densification to encourage transit use.
- Station usage forecasts shall satisfy ridership standards for new stations.
- Specific station location shall depend on surrounding safety conditions and physical constraints.
- Where a station is to be located at an intersection with transit signal priority, the stops shall always be located at the far side.
- Stations shall be provided in locations with sufficient ROW for related facilities

In order to harmonize the Light Rail Transit in to the city ongoing development station location shall be designed within a walk able residential, commercial and neighborhood supporting land uses as cafeteria, recreational centers, schools, etc.

2.11.1 Housing (Residential) near LRT Stations

The Transit-Oriented Development Guidelines of San Francisco Bay Area Rapid Transit (BART) pointed out that stations help to stimulate ridership which helps development of a city. It is well indicated in the guideline that new development in a station area should allow a wide variety of choices for living ranging from apartments and studios to single-family homes, rental and owner ship all with the convenience of regional transit access next door. Furthermore it is suggested that residential density within a half-mile radius (500 acres) of transit station should be high enough to support healthy ridership. In general, the residential density of the station area should be higher than that of the surrounding jurisdiction. Usually, a minimum value of 80-100 residents per acre is recommended.

Pacheco-Raguz (2010) showed in his study that the tendency for residential land values decrease with distance from Light Rail Transit System.

2.11.2 Commercial and Office near LRT Stations

Commercial and office development contributes to both healthy ridership and quick transport oriented development of a city. For better harmonization, if a community seeks to develop a large office center, then it is advisable that work places with the highest concentration of jobs be located as close to the LRT station as possible. As per the Transit-Oriented Development Guidelines of San Francisco Bay Area Rapid Transit, the suggested target density for station area employment is a minimum of 10 jobs per gross acre.

2.12 Modes of Access "to" and "from" LRT Stations

Good connections to stations have a significant influence on transit use and it is essential to ridership by reducing community impacts .It is clearly mentioned in the Light Rail Design Report made by Vancouver Group as follows:

"Good connections to stations have a significant influence on transit use and reduce community impacts. For transit riders, travel to and from the light rail station is integral part of their overall trip. Therefore, the light rail system must be coordinated with pedestrian and bicycle facilities, bus transfers, drop-off areas, and parking. Research indicates that people are willing to walk approximately ten minutes to get to a light rail station. For this reason, the most successful transit systems have safe, comfortable walking environments within the ten-minute walking area and accommodate riders of all ages and abilities. Way finding signage near stations and on the platforms is critical to riders' understanding, comfort, and security. Pedestrians prefer direct walking routes with minimum delay and will cross illegally if designated routes are not direct. Bicycle riders also use light rail and will typically ride up to two miles to access a station."

Generally, residents of a city in every LRT Catchment areas will access to the LRT by several modes: feeder bus, park and ride, kiss and ride (auto passenger drop-off), walking and bicycle. In developing countries like in our case the main share will be walking, feeder bus and "taxi".

As per a research made in the city of Calgary in 1992 by John H., et al, access mode modal share for feeder bus is 60 to 65 percent; park and ride 15 to 20 percent; Kiss and Ride 15 percent and Walking and Others 5 percent.

2.12.1 Feeder Bus Access to and from LRT stations

John H., et al (1992) showed in their study that feeder buses are the primary mode of access to the city of Calgary LRT system. Provision of a high quality feeder bus service has to be taken into consideration in the planning and design phase of a new LRT system in order to maximize transit users and in order to ensure effective integration of transit service within the community. The researchers further emphasized that the overall goal of the feeder bus network shall be so as to provide transit service as direct as possible to the LRT and where possible, to accommodate community oriented travel(e.g. school trips, shopping trips) and cross town trips.

2.12.2 Private Auto and Taxi Access to and from LRT stations

The private auto users include both the park and ride, and auto passenger drop off (kiss and ride). The park and ride mode of access to the LRT Stations is highly dependent on provision of parking facilities (to be discussed in the parking facilities part).

Generally, users getting picked-up and dropped-off by taxi or other drivers usually seek to get the LRT Station as close as possible from the point of drop. Transit-Oriented Development Guidelines of San Francisco Bay Area Rapid Transit (BART) recommends that Taxi and pick up/drop off areas should be signed, well-lit, close to and visible from the station entrance.

Studies revealed that the provision of park and ride facilities affects the use of other station access modes thereby recommending that an appropriate balance be maintained between park and ride and other access modes to LRT Stations so as to sustainable e feeder bus system and to minimize traffic impacts in adjacent residential areas.

2.12.3 Bicycle Access to and from LRT stations

Enhancing the integration of cycling and Light Rail Transit Systems is a major task to not be overlooked by transport planners as cycling is an environmentally friendly and healthy mode of transport. Bicycle accesses to and from LRT Stations could be provided as a separate track or could be shared with vehicles. Although it is unsafe, using the existing infrastructure is usually a compulsory since the street system already exists in place since before the widespread use of the automobile. Many resources have been dedicated to creating this system. Often, creating a totally new infrastructure for bicyclists is not financially, physically or politically feasible. Effective bicycle networks are best achieved by modifying the existing roads, rather than trying to create a separate network because almost all destinations are located on a street and people bicycling need access to these same destinations. This could be very sound for the case of Addis Ababa of which many of the streets are constructed many years before without bicycle facilities.

2.12.4 Pedestrian (Walking) Access to and from LRT stations

Provision of good pedestrian facilities to and from transit stations or stops will make the LRT System more effective by generating many users. These facilities need to be safe and very pleasant so that the users will enjoy and feel comfortable while walking. It is well indicated in the Pedestrian and Streetscape Guide by Georgia Department of Transportation (September 2013) that the success of transit as a mode of transportation is highly dependent on pedestrian access.

Pedestrian access to the LRT Stations is accommodated through provision of sidewalks and facilities like special ramps, escalators and elevators for handicapped people. Acceptable walking distances will vary depending on geography, climate conditions, and land use patterns. The distance pedestrians will travel is also influenced by the weather, the time of day, demographics, the purpose of their trip, and many other factors. Most people will walk longer distances for recreational purposes, but prefer to walk shorter distances when they are commuting or in a hurry, such as from the bus stop or transit station to their office. However, as per Transit Friendly Design Guide (by Calgary City Council, December 1995), realistically most people will not walk more than 400 meters to use transit, and as a general rule, all dwellings should be within 400 meters walking distance of a transit stop. Pedestrians are discouraged by a long, indirect walk to transit - especially in inclement weather. They are more likely to use transit services if the beginning and the end of their trip is close to a transit stop or station. Efficient community design that addresses both walking distance and the need to minimize transit travel distance will reduce the costs associated with providing and operating transit service.

Anderson, J. E. (1978) and Stringham, M. G. (1994) showed at different times in San Francisco and Edmonton (Canada) that virtually nobody walked farther than 1750 m to reach a Light Rail Transit Station and that walking accounts for more than 50 percent of the access mode from distances up to approximately 900 m. Beyond this distance the bus becomes the dominant access mode. Another study by Cervero, R. (1994) found out that 32 percent of residents living within 457 m of a suburban LRT station take transit to work, compared with approximately 5 percent of residents living more than 457 m away.

The transit master plan of the Sacramento Regional Transit District recommends that development within 457 m of transit corridors or within 610 m of LRT stations provide or ensure direct pedestrian access to the transit system, and that pedestrian paths should be designed with adequate lighting, visibility, smooth and hazard-free walking surfaces and protection from weather in order to enhance the safety and attractiveness of walking to transit.

Best practices for Rail Design by Vancouver Working Group recommends a reasonable walking distance of up to one-half mile (800 meters). Similarly it is mentioned in the Cooperative Research Program report (TCRP-Report 153) that traditionally, ½ mile (800m) has been assumed as the reasonable maximum walking distance for pedestrian access to high-capacity transit, in which those passengers located less than 800 meters from the station will walk, and others will not. However, surveys of walk access trips show that the mean rapid transit walk access trip length is nearly 800 meters and that many pedestrians walk more than 800 meters to access rapid transit.

2.13 Accessibility of Elevated LRT Stations

In order to evaluate accessibility of a station by any mode of transport, the following criteria are set as per the study made by Anastasia Loukaitou-Sideris et al in March 2012.

- **Cumulative amenities**: the number of amenities or neighborhood-serving commercial and institutional establishments within ¼ mile e.g. grocery stores, parks, banks and other commercial establishments, etc.

- **Cumulative non-amenities:** the number of facilities within the ¼ mile area that were understood as having a negative effect on walking or the perception of pedestrian safety e.g. off-brand motels, liquor stores or adult entertainment establishments. This category included auto-oriented uses, such as gas stations, drive-through eateries or auto repair shops because of their lack of attraction for pedestrians and the barriers they pose to pedestrian accessibility.

- **Infrastructural barriers**: accessibility around elevated stations estimated as the ratio of surface land occupied by freeways and freeway ramps within the ¼ mile area.

- **Connectivity of the pedestrian network:** intersection density, the number of unbroken pedestrian paths perpendicular to the rail right-of-way, the horizontal distance from the platform to the nearest active nonresidential destination, number of station entry points, number of parking ingresses or egresses, mileage of marked bicycle lanes, availability of bicycle parking, and number of transit stops within 400m.

- **Visibility**: how visible a station is from its surrounding area and legibility Visibility of a station entrances and exits and the legibility of directional signage are important factors to evaluate accessibility.

- **Platform accessibility:** ease of accessing the station platform from the station entrance above the ground level, number of station entrances, number of escalators, number of directional changes from entrance to platform, and vertical and horizontal distance from the platform center to the nearest station entrance.

- **Environmental condition:** environmental factors in a station's vicinity that may enhance or decrease a rider's perception of station accessibility. This criteria indicates the presence or absence of positive environmental factors (street trees, public art, street lighting, well-maintained buildings); negative environmental factors (graffiti, litter, vacant lots, vacant buildings, poorly maintained buildings, billboards); and platform nuisances (noise, pollution, vibration).

The researchers selected 14 elevated stations along Los Angeles LRT network and evaluated their accessibility with respect to the above listed criteria. The analysis result demonstrates that integration of Elevated LRT Stations with the rest of the city presents significant challenges. The elevated nature of the stations and their location on freeway medians significantly decrease their accessibility and connectivity. Based on the result they have recommended four broad categories of design interventions namely architectural interventions, landscape interventions, mobile urbanism interventions and perceptual link in order to increase accessibility of elevated LRT Stations.

2.14 Provision of Pedestrian Crossing for the Non-Transistors

Pedestrian crossing for the non-transistors is an important aspect which needs to be considered in the planning stage of Light Rail Transit development. The crossing may be at grade or grade separated depending on the prevailing conditions and economy. At grade zebra crossing for pedestrians on Median LRT systems requires a due consideration from safety point of view.

In principle, the introduction of a new LRT system should not be a barrier on the left and right corridor of the streets. Convenient at grade crosses and interchanges should be provided to allow non-transistors to easily access the surrounding different land uses.

Pedestrian bridges need adequate right of way to accommodate accessible ramp approaches leading up to and off the structure. And they need to be provided where there is high demand of pedestrians like in areas of schools in order to protect them from motorists and high speed Light Rail Vehicles.

2.15 Vehicular Access to the nearby land use

As per the Highway Capacity Manual (HCM), vehicular accessibility is measured in terms of access point which includes an at-grade intersection, drive-way (a private road that enables to travel from public road to the entrance of a building such as house or hotel), or median opening. By allowing or prohibiting turning, entering, exiting and crossing traffic movements at these access points, the accessibility of the surrounding land use of principal arterial street corridors will be highly affected. Usually when the traffic volume is high and the intended purpose is to increase speed, prohibition of the access points will be applied. On the other hand, when the traffic volume is low and the interest is access, the access points are provided and permitted at every required location.

2.16 Parking at LRT Stations

Provision of parking at Light Rail Transit Stations for people who must drive to their stations because of distance or other concerns; who don't live near a feeder bus line, or are unable to walk or bike due to age, infirmity or just being out of shape is the best practice transit planners and designers need to follow.

Best Practices for Light Rail Design Report by Vancouver Working Group explains that Parking at light rail stations can take two forms: park-and-ride structures and on-street parking. Park-and-ride structures will be developed in connection with the light rail project. Design and location considerations include the ground floor character of the parking structures, traffic impacts, and distance from the platform. Parking issues include management of on-street parking in commercial areas and prevention of spillover parking in residential neighborhoods.

In the same report, it is shown that the park-and-ride structures will enhance ridership and reduce automobile commuting. As to the report, the size, location, and integration of parking facilities shall be carefully considered in the planning and design stage of Light Rail transits.

The Transit-Oriented Development Guidelines of San Francisco Bay Area Rapid Transit (BART) has put the following points regarding parking near Light Rail Transit Stations:

- Parking facilities should be sited so that the automobile traffic does not affect pedestrian circulation between the LRT station and the surrounding community.

- Parking facilities near LRT stations should be sized and located to enhance shared-use strategies for non-transistors.

- Parking facilities should feed pedestrians onto primary pedestrian routes and should be located to promote retail opportunities along the LRT Station locations.

Parking Facilities in Light Rail Transit Park and ride lots can be provided as free parking or reserved parking. Provision of Free parking service near LRT Stations is on a first-come, first-served basis. And reserved parking service is provision of parking service on the basis of reservation by the users.

2.17 Traffic controls in LRT and Urban Street Highway Combinations

At grade intersections induce many conflicts due to the competition of vehicles for the same space and this conflict is resolved by traffic control systems. Traffic control systems play an important role in the functionality of the intersection. Generally at-grade intersections can be signalized where traffic signals are applied or un-signalized where static signs of stop or yield (give-away) are applied depending on the method of design.

As it is indicated in the Traffic Engineering book by Roger P. Roess et al. (2004) there are three levels of traffic control systems applied in an at-intersection. These are:

Level I: Basic Rule of the road
Level II: Direct assignment of right-of-way using Yield or Stop Signs and
Level III: Traffic Signalizations

The introduction of new LRT systems will be harmonized with the existing city streets either by stop signs for the crossing vehicles or traffic signals giving priority to the LRT. When the LRT is grade separated, it will not be a problem and traffic controls are less significant.

Transit Corporative Research Program (TCRP-1996) Report 17 indicated that the use of traffic control devices provides information to facilitate the safe, orderly, and integrated movement of all traffic, including light rail, throughout the public highway system and to provide a ***harmonized*** transport system of in the transport network as far as LRT and Street Highways are concerned.

Engineers in Maryland State Highway Administration examined ways to reduce the delays of street traffic at the coordinated intersections without reducing the level of service of the light rail system. Some of the ideas pointed out by the researchers were:

- Allowing turning movements that were not in conflict with the LRT to proceed through the intersection while the LRT is crossing.
- Allowing the signal controller to select the phase that operates first after the LRT vehicle clears the intersection based on traffic demand.
- Testing with different signal sequences used to clear vehicles from the LRT tracks.
- Finding ways to reduce the disruption to the coordinated signals that results from frequent LRT preemption calls.
- Holding the transit vehicle at the intersection until there is a convenient moment in the cycle for it to clear the intersection and still allow for efficient traffic movement.

With the express buses, the Maryland Engineers found out that bus travel times are decreased by 14-18%, and automobiles sometimes also experience a decrease in travel time because of the additional green time given for the buses.

Koch, Chin, and Smith showed in their study how to optimize signal timings for the benefit of both LRT and street traffic along a transit mall with cross streets. Their study considers the total traffic delay and the total passenger delay together using real-time sensor data. The data was used to calculate a measure of effectiveness that determines how well the system is optimized; the results then affect how the signals operate. This concept has been tested using computer simulations of the Baltimore Central Business District area during the afternoon peak period. The Researchers found out that this method was effective in reducing the total delay for both modes; however, it resulted in greater delays for the LRT than there would have been if there was just preemption.

2.18 Safety in Light Rail Transit (LRT) and Principal Arterial Streets (PAS) Combinations

Safety is a major concern in Light Rail Transit (LRT) and Principal Arterial Streets (PAS) at grade crossings. Especially when new light rail transit system is introduced into existing principal streets it could be a confusing for street vehicle drivers. This has to be given a due attention for transport planners and designers. Many studies revealed that the most common accidents at median LRT grade crossings are left turn accidents.

Benjamin Coifman and Robert L. Bertini. (1997) showed four types of accident causal events and three types of counter measures in their study of accident causation and countermeasures for median Light Rail Transit.

2.18.1 Accident Causal Events at LRT and PAS Crossings

The following are as per the research paper by Benjamin Coifman and Robert L. Bertini. (1997) with little modifications:

- **Disobedience:** an inappropriately low perception of risk and expectations from conventional intersections contribute to driver disobedience. Drivers with undesirable behavior at crossings who tend not to accept that their actions are hazardous, and they believe that their actions are legal will contribute a lot to the occurrence of accidents

- **Failure to Perceive**: common critical event which occurs when the driver fails to perceive the traffic control device. This event is likely to arise from poor stimulus conspicuity. Sometimes, a stimulus that would normally be detected may be overlooked by a driver who is occupied with a great deal of other information. Factors leading to violation typically range from seeing the through-traffic signal turn green and the adjacent through-traffic move, to drivers anticipating the leading left turn phase only to discover that it had been skipped for transit priority. These errors are related to faulty expectations and cognitive limitations.

- **Misinterpretation:** Other accidents are related to expectation errors and drivers' cognitive limitations. For example, drivers may hear the Light Rail Vehicle horn behind them and assume it was another automobile urging them into the intersection. Most people make a mistake in the direction of over-estimating both the information given and their ability to use it. The phenomenon of over confidence as a result of poorly controlled information processing is available everywhere.

- **Drivers' Expectations:** From the driver's perspective, the LRT crossing can appear to be a normal intersection. In fact, when no Light Rail Vehicles are present, it operates as such. At a normal intersection, as soon as the through-traffic receives the green signal, a turning driver will complete as much of the left turn as possible without entering the oncoming flow of traffic. The driver tries to take advantage of the smallest gap in the oncoming traffic. The driver is not looking at the traffic signal and has already begun the turning maneuver. This disregard for traffic control devices undermines the effectiveness of existing countermeasures at LRT crossings. Overconfidence or inappropriate expectation of risk can lead a driver to disobey traffic control devices. For left turns, it is usually a habit to allow movement on yellow signals or fresh red signals.

  Through familiarity with a given intersection, some drivers come to associate the onset of red for the cross traffic with the beginning of the leading left turn phase. Transit priority at crossings can preempt leading left turn phases and make the intersection behave differently when an LRV approaches. From a driver's perspective, it is a relatively rare event to be in the left turn lane when the left turn phase is preempted. Only the first stopped driver has to make a decision based solely on the signals, all subsequent drivers can only move if the vehicle in front of them advances. Thus, the disassociation between the left turn arrow and other signals is only reinforced for the first turning driver and it only occurs when the left turn phase is skipped.

2.18.2 Countermeasures of Accidents at LRT and PAS Crossings

The normal trend is classifying accident counter measures at grade Light Rail Transit and Principal Arterial Street crossings as passive or active. However, Benjamin Coifman and Robert L. Bertini (1997) added a third classification of counter measure called reactive. As per the researchers approach the three categories of accident counter measures for LRT and PAS at grade crossings are as described below:

- **Passive***:* Static warning devices that warn the driver of a grade crossing or keep automobiles out of the track way whether or not an LRV is present, e.g., signs and delineations.
- **Active***:* Warning devices that change states and restrict movement when an LRV approaches, e.g., crossing gates and traffic signals. Although it is the common definition of active grade crossing protection, such systems are essentially proactive; they operate independent of driver’s actions or the presence of automobiles.

- **Reactive***:* Proposed warning devices that respond to illegal or unsafe automobile movements when a Light Rail Vehicle (LRV) approaches, e.g., automated encroachment alarms and other Intelligent Transportation Systems (ITS) devices. It is supported in many studies that audible alarms are effective for reducing accidents at conventional railroad grade crossings.

In other studies, Transit Corporative Research Program (TCRP-1996) Report 17 shows that motor vehicles that make illegal turns in front of approaching Light Rail Vehicles account for the greatest percentage of total collisions for most Light Rail Transit systems. Moreover, when such a collision occurs, the door of the motor vehicle is the only protection between the driver/passenger and the Light Rail Vehicle, which makes turning collisions one of the most severe types of collision between motor vehicles and Light Rail Vehicles. Thus, traffic control devices that regulate turns are critical to Light Rail Transit and general traffic safety. Where turning traffic crosses a non-gated, semi-exclusive Light Rail Transit alignment and is controlled by left- or right-turn arrow signal indications, the LRT agency should install an LRV activated, flashing, internally illuminated warning sign displaying the front view LRV symbol or the side View LRV symbol when the Light Rail Vehicle approaches.

2.19 Visual and Aesthetics Impacts of New LRT Systems on existing environment

It is well explained in the LRT DESIGN GUIDELINES of City of Edmonton (2005) that the installation of the LRT infrastructure which includes the track way, overhead Catenary wires and support masts, signal support poles, grade crossing control measures, fencing, stations, and other ancillary structures, including the LRT train moving through the community, may be considered by some community residents as being visually displeasing.

In an Environmental Assessment Study Made by DART-2007 (Dallas Area Rapid Transit), it is stated that Visual impacts occur as a result of a new bridge structure that would be constructed to accommodate LRT passage over the existing road. Potential visual impacts resulting from proposed aerial structures through a downtown of a City would be reduced by designing the structure to be consistent with the overall settings. In this manual it recommended that visual treatments shall be applied to the new bridge structures to create bridge designs that are aesthetically complementary to their surroundings.

In a separate Environmental Impact Report made by Honolulu Transit in January 2012, it is indicated that both above and below ground construction activities of LRT systems which includes installation of tracks and poles, station construction, and pedestrian and train portal construction would temporarily disrupt the visual character and views along the corridors. However, construction of the project would not noticeably reduce visual quality or alter viewing context. Therefore, temporary construction impacts would be less than significant.

Nevertheless, the report fails to incorporate the human perceptions towards the visual and aesthetics impacts of LRT Systems on the existing Streets Highways.

3.0 METHODOLOGY

3.1 Description of the Study Area

The study area is Addis Ababa, the Capital City of Ethiopia. Addis Ababa was founded by Minellik II and Empress Taitu in 1887. It has an expanded area of over 530 sq. km having more than 2.7 million number of population and is situated at an altitude of about 2500 meters above sea level. Addis Ababa city is the seat of African Union and it is the political and economic center of the country. The city is generally characterized by:

- Highly populated town
- Small number of cars compared to the population
- Large number of private taxis, pick-ups and mini buses
- Relatively less number of buses
- Negligible number of bicycles and motorcycles
- No traffic volume in rail transport
- Relatively high volume of pedestrians
- High degree of accident
- Absence of grid plan system and existence of rugged terrain
- Possess a highland climate zones.

3.1.1 Study Corridor: East –West of Addis Ababa

Addis Ababa city has four major corridors in the road network. These are the East-West, North – South, the Ring Road and the Central Business Districts. Currently, LRT ongoing project is found in the two corridors; the east-west and north-south corridors. However, the research considers only the East- West corridor due to time and budget constraint. As many studies revealed, the East-West corridor is one of the highly populated and congested area. It consists of the busiest commercial areas associated with high traffic flow.

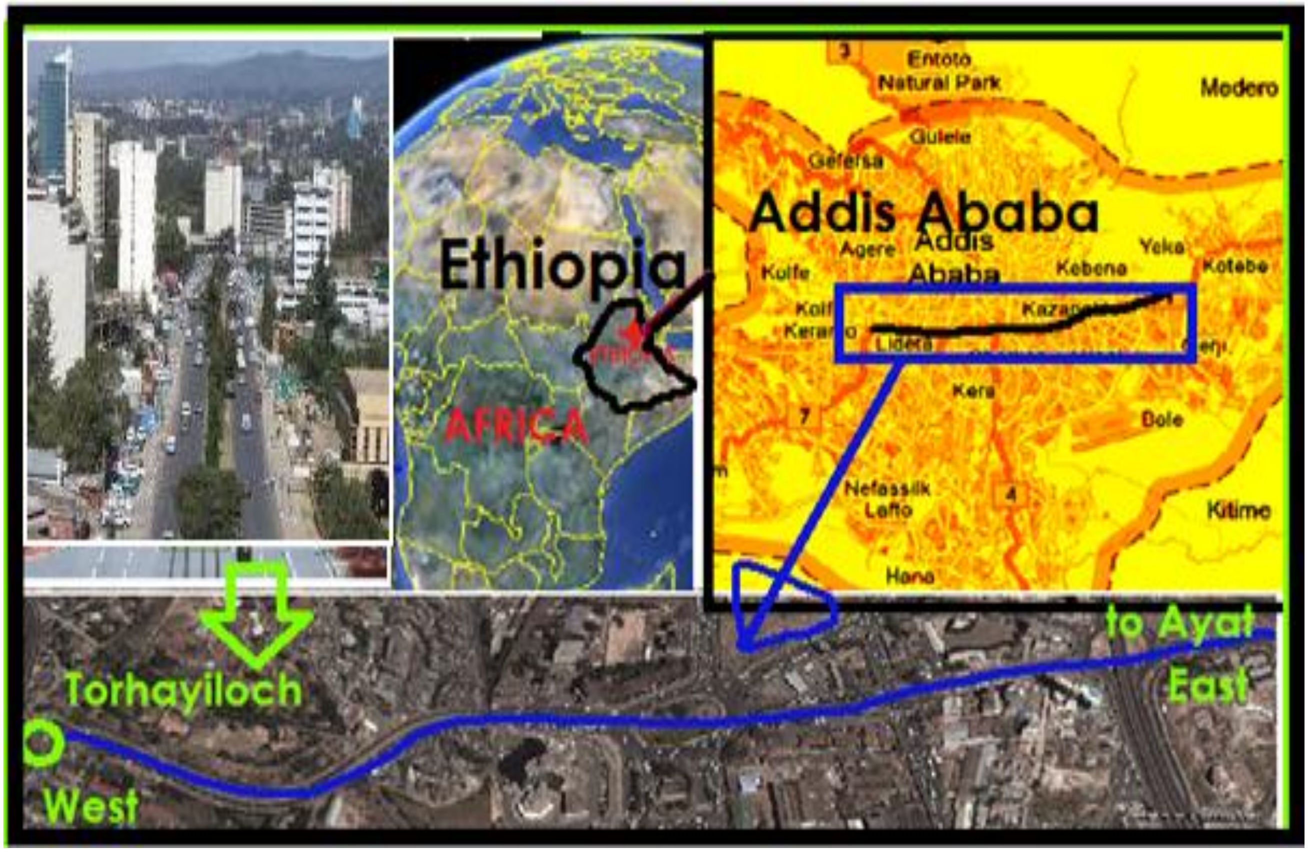


Figure 3-1 Location Map of Study Area (Source: Google Earth-2009)

3.1.2 Addis Ababa E-W LRT Project as a case Study

The electrified light rail System project of Addis Ababa City has a total length of 34.25 Km running from North-South (16.9 km) and East-West (17.35km) with a capacity of 80,000 passengers per hour. The system has a double truck for the whole route with a standard gauge of 1.435 m. The two systems have 2.7km common (overlapping) truck. Only the East-West LRT Line is taken as a case study. This line which stretches from Ayat to Torhayiloch round about via Megenagna-Hayahulet- Lagar-Mexico has 18 intersection points with the main street roads of the city in the East-West corridor. There are 22 (twenty two) LRT Stations and five of which are shared with North –South LRT route. Average interval between two adjacent stations is 815 meters.

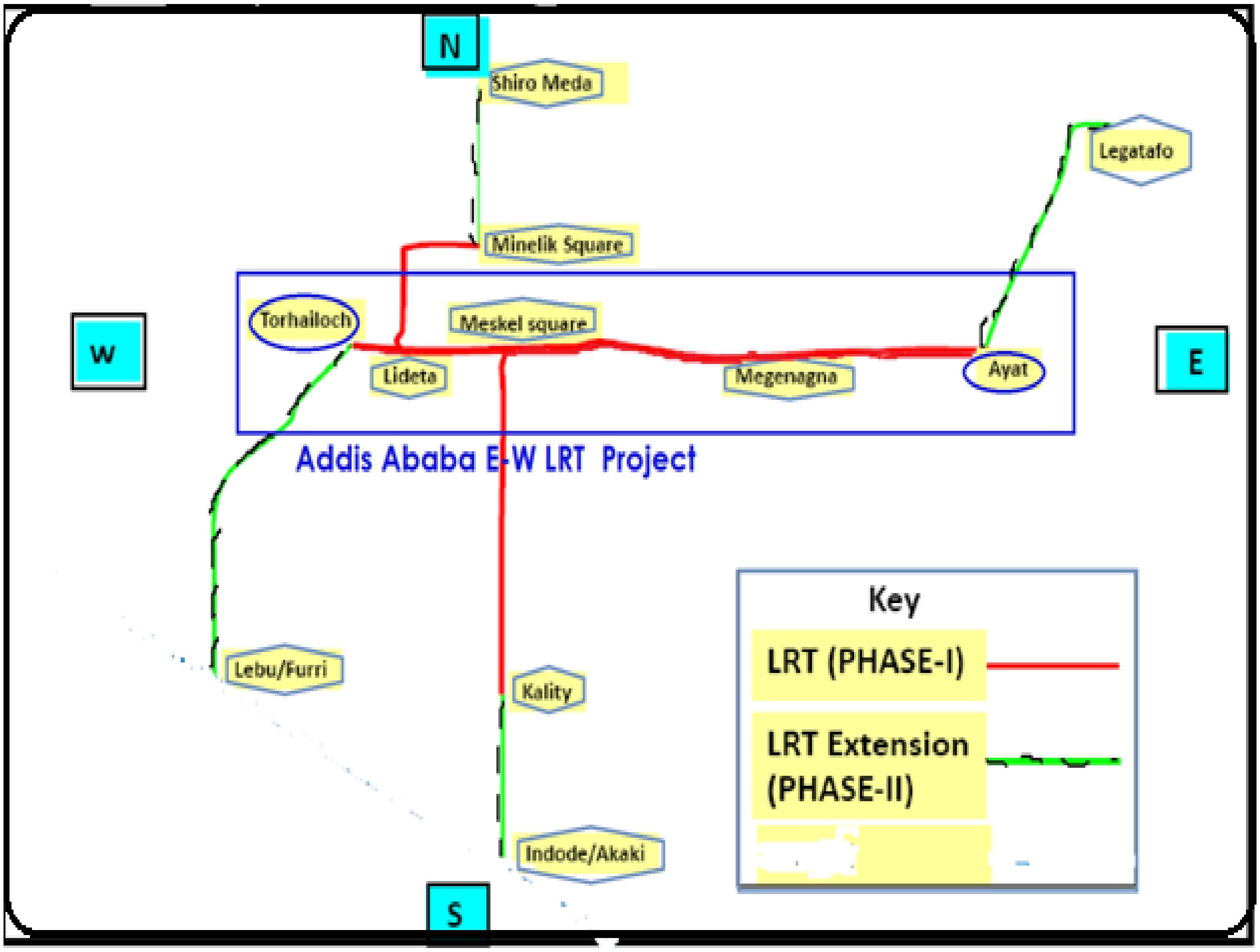


Figure 3-2 LRT System Locations in Addis Ababa (Source: *Ethiopian Rail ways Corporation*)

3.2 Description of the Research Design

Relevant literatures have been reviewed in regard to Integration of Light Rail Transit System and Arterial Street Roads in a city with an emphasis given to the likely challenges that may be faced due to the introduction of LRT system on the principal arterial streets and possible solutions for the problems.

As a case study, the Addis Ababa E-W Light Rail Transit System has been taken in regard to Harmonization with the existing arterial streets based on the basic scientific principles and best practices all over the world. Harmonization is a broad term to refer integration of the two different modes of transportation systems namely Light Rail Transit System and Principal Arterial Street System. Mainly the principle focuses on ***accessibility***, **safety** and **aesthetics**. Therefore, in the assessment of the new LRT project which is under implementation and expected to be functional in the coming couple of years the basic criteria taken are location of

LRT Stations, accessibility, provision of parking lots, safety and aesthetics from the scientific stand point of view and best practices all over the world which have been indicated in the literature review part of this paper. Accessibility by itself has two designations in this paper. The first one is mode of access to LRT stations and the second one is accessibility of non-transistors which do not use the light rail transit system.

In order to assess **impact on traffic congestion** (the possible additional delay to be induced) at Intersections after the introduction of new Light Rail Transit System into existing Principal Arterial Streets, primary data was collected at four selected junctions among E-W corridor where the LRT crosses at- grade with the existing principal street intersection. Peak hour traffic data was collected and geometric elements of the study junctions was measured.

The primary measure of effectiveness used in order to measure the impact of introducing LRT system into existing principal arterial streets at Intersections in this research is the Average Vehicular delay associated with the Level of Service using SIDRA INTERSECTION Software. Four at-grade sections are selected in the East-West LRT line of Addis Ababa City which runs from Ayat to Megenagna to Tor-Hayiloch. These are Bambis Intersection, Beshale Hotel Round About, CMC Round About and Ayat Round about Junctions. The capacity of each was analyzed as "before" and "after" the introduction of LRT under the same geometric condition and future projected traffic volume in the after scenario. The "after" scenario is created by changing the Yield Control type to Stop Control in order to represent the actual scenario.

Additional data was collected by interviewing the prospective users of the light rail transit. As observation, direct field measurements and secondary data were utilized. It could be said that the method applied is more of quantitative than qualitative approach.

The study method is designed in order to answer how to harmonize new LRT systems into city streets by analyzing the impact it has on at-grade intersections and visual aesthetical impacts when it is grade separated. The design starts by defining the study corridor and sampling intersections of LRT with Street Highways. The research design is as described in the diagram below:

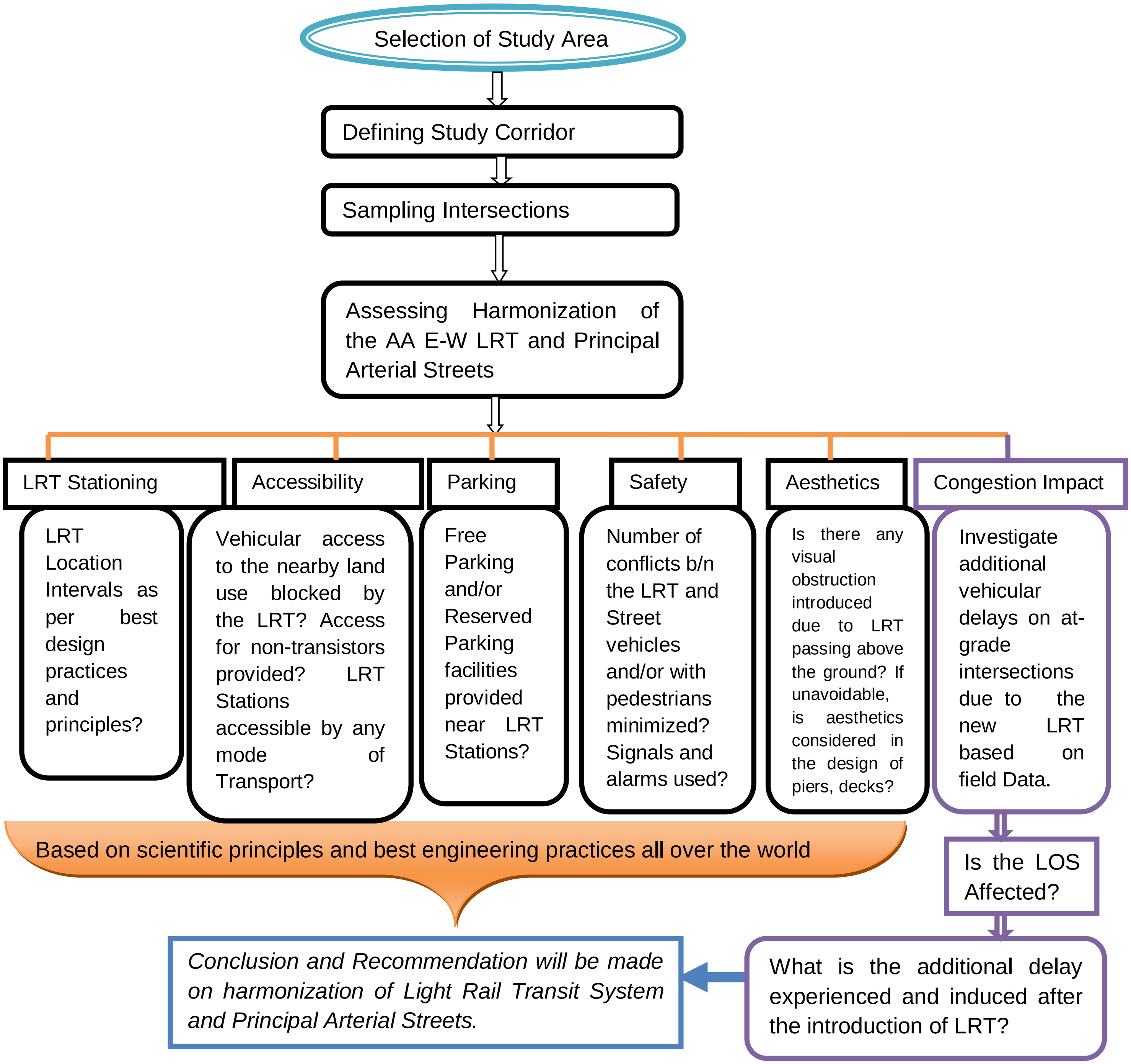


Figure 3-3 Chart showing description of Research Design

3.2.2 Data Collection and Analysis Techniques

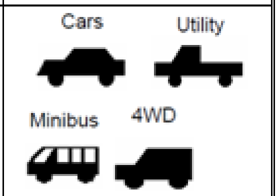
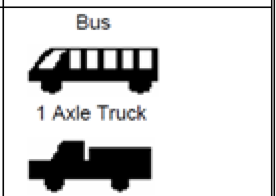
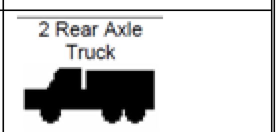
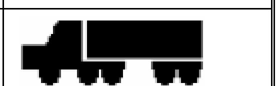
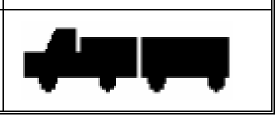
The required data for this research on assessing the congestion impact of the LRT on the existing street at-grade intersections is mainly the traffic volume and geometric features of junctions. Traffic data is collected using manual count and video recording with manual transcription at the selected intersections. The geometric features measured include carriageway width, number of entering and exit lanes, grade, median width, and central island diameter.

3.2.1.1 Traffic Data and Analysis

The input traffic volume to be used for the study of congestion impact of the LRT on the existing street at-grade intersections is based on the forecasted ADT volumes based on the manual count data at intersections.

An exhaustive classification vehicle is up to twenty classes. However, for simplification ERA Pavement Design Manual (2002) indicated five categories of classified count as shown in the table below:

Table 3-1 Vehicle Classification (Source: ERA Pavement Design Manual, 2002)

Class No.	Vehicle Type	Definition	Pictorial Sketch
1	Small Car	Passenger cars, minibuses (up to 24-passenger seats),taxis, pick-ups, and Land Cruisers, Land Rovers, etc.	
2	Light Truck &Bus	Medium and large size buses above 24 passenger seats and one axle (light) truck.	
3	Medium Truck	Medium sized trucks including tankers up to 7tons load (dual rare axle).	
4	Heavy Truck	Trucks above 7 tons load (four or five rear axle).	
5	Articulated Truck	Trucks with trailer or semi-trailer and Tanker Trailers.	

Accordingly, the count is done on the basis of the above classification at four at-grade junctions of the LRT project namely Bambis intersection, Beshale Hotel Round About, CMC roundabout and Ayat Round About junctions . A seven days video recording of traffic data for three hours is made at the four at-grade junctions of the East-West corridor. The time of recording is either 8:00 AM-9:00 AM, 12:00 AM-1:00 PM or 5:00 PM-6:00 PM which is determined from the general trend of Addis Ababa Traffic characteristics. The researcher has made an assessment of peak hours at the study junctions before commencement of traffic count. The data obtained from video recording is counted at office. The type of video used is a 16 GB internal memory Apple Mobile Video Camera by continuously charging with the Satellite A665 Toshiba Lap Top having an additional external battery which enables to use more than 8 hours without charging once it has been fully charged.

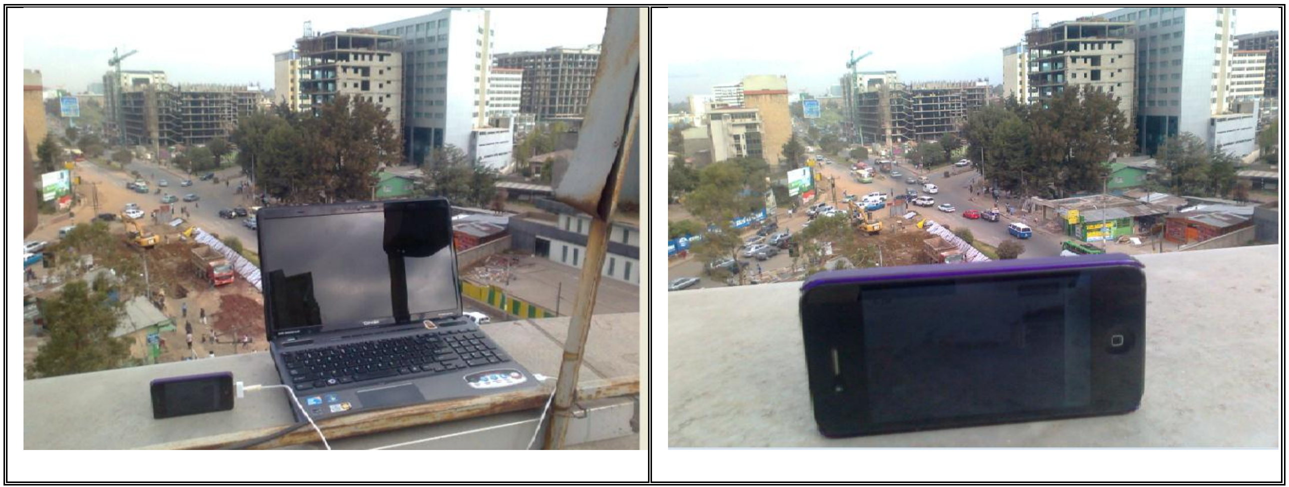


Figure 3-4: Video Recording under progress at the sixth floor of Haile Gabriel Building near Bambis Intersection (With Apple Mobile Video Camera)

The time of Video Recording on each study junctions are summarized in the table below:

Table 3-2 Date and Location of Traffic Count

Junction No.	Name of Junction	Date of Recording	Time of Recording	Video Camera Location
1	Bambis Intersection	20-05-2013 (Monday)	8:00 AM-9:00 AM	At the Sixth Floor of Haile Gebrail Building
			12:00 AM-1:00 PM	
			5:00 PM-6:00 PM	
2	Beshale Hotel Round About	21-05-2013 (Tuesday)	8:00 AM-9:00 AM	At the Sixth Floor of Beshale Hotel
			12:00 AM-1:00 PM	
		23-05-2013 (Thursday)	5:00 PM-6:00 PM	
3	CMC Round About	22-05-2013 (Wednesday)	8:00 AM-9:00 AM	At the fourth Floor of AtoTewodros Belay Building (under Construction)
		24-05-2013 (Friday)	12:00 AM-1:00 PM	
			5:00 PM-6:00 PM	
4	Ayat Round About	19-09-2013 (Thursday)	8:00 AM-9:00 AM	At the third floor of nearby building under construction on the way to Lagatafu (Right Hand Side of the Approach Road).
			12:00 AM-1:00 PM	
		20/09/2013 (Friday)	5:00 PM-6:00 PM	

It is not practical to treat each vehicle type separately during design and analysis. For this reason, trucks usually are converted to equivalent Passenger Car Units (PCUs). The number of

PCU's associated with a single truck is a measure of the impedance that it offers to the passenger cars in the traffic stream. The vehicle volume count is converted to passenger's car unit (PCU) to evaluate the capacity of junctions. The PCU conversion factor is as indicated in table below which is adopted from Highway Capacity Manual, 2000.

Table 3-3 Passenger - Car Equivalent Factors (Source: HCM 2000)

Vehicle Type	Definition	Pictorial Sketch	PCU Factor
Small Car	Passenger cars, minibuses (up to 24-passenger seats),taxis, pick-ups, and Land Cruisers, Land Rovers, etc.		1
Light Truck and Bus	Medium and large size buses above 24 passenger seats and single rear axle truck.		1.5*
Medium Truck	Small and medium sized trucks including tankers up to 7tons load(dual rear axle truck)		3
Heavy Truck	Trucks above 7 tons load (Four or Five rear axle truck)		3
Articulated Truck	Trucks with trailer or semi-trailer and Tanker Trailers		3

**Standard bus has an equivalent factor of 3. Actually it is treated as two normal buses while counting is made.*

Small car, bus and light truck (single rear axle truck) are considered as light vehicles and Medium truck, heavy truck and articulated truck are grouped under heavy vehicles in applying SIDRA INTERSECTION software. The volume of Light Vehicles and Heavy Vehicles is entered separately in the Volume dialogue box.

3.2.1.2 Traffic Analysis Period

As the East-West Line of Addis Ababa city is a major corridor where many Principal Arterial Streets exist, it is reasonable to project the current traffic volume by taking analysis period from the date of count to the required point of time. Accordingly, the traffic count was made in 2013 and the LRT system will be opened in 2015. The required point of time selected to know the effect in this research is in the year 2016; just one year after opening to Light Rail Vehicles. Hence, 3 years of traffic analysis period is taken in this study.

3.2.1.4 Traffic Growth Rates

The following traffic growth rates were taken from the Final Engineering Report of Megenagna-Torhayiloch Road Upgrading Project (April 2013) prepared by CORE Consulting Engineers PLC which is based on demand elasticity and GDP growth rate.

Table 3-4Traffic Growth Rates (Source: From Final Engineering Report of Torhayiloch-Megenagna Road Upgrading Project by CORE Consulting Engineers PLC- April 2013)

Period	Passenger Traffic			Freight Traffic		
	Cars/4WD	S/Bus	M & L Bus	S/Truck	L & M Truck	Truck & Trailer
2011 - 2015	8.4	7.7	7.0	7.7	8.4	9.8
2016 – 2020	7.8	7.2	6.5	7.2	7.8	9.1
2021 - 2035	7.2	6.6	6.0	6.0	6.6	7.8

For the pedestrian traffic, a growth rate of 3.8% will be taken which is the annual population growth factor as per the Ethiopian Statistics Agency.

3.2.1.5 Traffic Forecasting Formula

Considering three years of construction period, it is anticipated that that the road will be opened to traffic in 2015.

Traffic Volume $_{(n+1)}$ = [Traffic Volume (n)][(1+r)]

Where; Traffic Volume $_{(n+1)}$ = Traffic Volume in the next Year

Traffic Volume $_{(n)}$ = Traffic Volume in the base or reference (n^{th}) year

r = growth rate (fraction)

Moreover, in the after scenario it has been considered that private cars and taxi including medium buses will be reduced due to the modal shift to Light Rail Transit system. Based on different literatures 40% reduction of Small Vehicles has been assumed in the analysis of future traffic. (Particular to this figure, a reference can be made on the internet web site via http://www.lrtf.org.uk/library/factsheets/lrt-facts.html owned by Howard Johnston).

3.2.1.6 Geometric Data

The existing features of the selected junctions are measured using simple measurement tools. Regarding the geometric input data collected from field are as described in the table below.

Table 3-5 Geometric Features of the Existing Junctions (Source: SIDRA INTERSECTION User Guide, July 2009)

No.	Feature	Description
1	Number of legs and their orientation	Number of Intersection legs and approximate geographical orientations as :
		S = South (Northbound) **SE** = Southeast Bound
		E = East (Westbound) **NE** = Northeast Bound
		N = North (Southbound) **NW** = Northwest Bound
		W = West (Eastbound) **SW** = Southwest Bound
2	Number of lanes	
3	Lane Width	Lane width along a line perpendicular to the direction of traffic.
4	Median Width	
5	Lane Discipline	The lane discipline indicates the movements allocated to the lane as shared or exclusive. This includes Left, Through, Right or combination of them.
6	Grade	A percentage figure in the direction of travel. It is taken positive for uphill grade and negative values for downhill grade (and zero for level/flat intersection).However, Regardless of uphill or downhill the general rule considered is that grade data for approach and exit lanes on the same intersection leg should have opposite signs.
7	Central Island diameter	Diameter of the central island of the roundabout junction.
8	Circulating road width	The width of the road circumscribing the central island.
9	Number of entry lanes	
10	Entry lane width	

3.2.2 Use of Computer Aided Software

Use of Computer Aided Software is generally important to save time in regard to demonstrating a methodology for identifying effects of introducing light rail transit grade crossings into existing city streets that can be used during the planning process by designers and planners. SIDRA INTERSECTION software is selected to be the appropriate software for the evaluation of effects of LRT grade crossings into city streets in terms of Level of Service and delay as one of the basic performance measures. *The SIDRA INTERSECTION software (older versions known as SIDRA and aaSIDRA) as defined in the SIDRA User's Guide Manual is an advanced micro-analytical tool for evaluation of alternative intersection designs in terms 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*. *SIDRA (stands for): Signalized and un-signalized Intersection Design and Research Aid*.

The software is usually applied to model various scenarios for both existing and future intersections to determine their performance under a range of conditions. Default values of some insensitive input variables are taken. However, other variable as traffic volume, geometric features and lane discipline their actual value is used. Moreover, for some significant input variables as basic saturation flow and critical gap, other values are taken from manuals instead of the default value. Actually, these values are to be determined by collecting a series of data from field which requires a separate research. For the purpose of this study, the researcher referred the values from manuals as follows.

3.2.2.1 Approach and Exit Cruise Speed

It is recommended by SIDRA INTERSECTION Guideline that the approach cruise speed and exit cruise speed for existing intersections should reflect the present conditions. Accordingly, as per Addis Ababa City Roads Geometric Manual (2003), the proposed speed limit for arterial and sub arterial roads is 60KMPH. However, this speed is on the higher side when compared to the actual conditions. An approach and exit cruise speed of 40KMPH is therefore taken for the purpose of analysis.

3.2.2.2 Basic Saturation Flow

Saturation flow rate could be defined as the flow rate per lane at which vehicles can pass through a signalized intersection. Determination of the basic saturation flow is a complicated matter and needs a separate field study. A saturation flow rate of 1900 vehicles/hour/lane, which corresponds to saturation headway of about 1.9 seconds, is usually a common nominal value. Design manuals usually provide adjustment factors that take parameters such as lane-width, pedestrian traffic, and traffic composition into account. For the purpose of this research, a value of 1500 Veh/hour which corresponds to 2.4 seconds of headway is used as per SIDRA INTERSECTION GUIDE LINE adopted in 2010 by GLADSTONE REGIONAL COUNCIL (AUSTRALIA).

Table 3-6 Basic Saturation flow parameters for Urban Roads (Source: SIDRA INTERSECTION GUIDE LINE, 2010 by GLADSTONE REGIONAL COUNCIL)

Criterion			Basic Saturation flow (pcu/h)
Road	Arterial Road	Highway	1800
		Arterial	1800
		Arterial Main Street	1500
	Sub-arterial Road	Traffic Distributor	1500
		Controlled Distributor	1500
		Sub-arterial main street	900
Street	Collector Street	Major Collector	450
		Minor Collector	300
	Local Street	Access Street	120
		Access place	30

3.2.2.3 Gap Acceptance Parameters

The two gap acceptance parameters are critical gap and follow-up headway. Critical Gap, as defined by SIDRA INTERSECTION GUIDE, is the minimum time (headway) between successive vehicles in the opposing (major) traffic stream that is acceptable for entry by opposed (minor) stream vehicles. It is the minimum gap length in time which is acceptable by drivers. And Follow-up Headway is the average headway between successive opposed (minor) stream vehicles entering a gap available in the opposing (major) traffic stream.

Critical gap and follow-up headway values are determined from the table below adopted from SIDRA INTERSECTION GUIDE LINE for the purpose of this study. The researched recommends a separate research for determining the two crucial parameters to calibrate the software especially a research intended to study the capacity of intersections.

Table 3-7 Gap Acceptance parameters for Sign Controlled Intersections (Adopted from SIDRA INTERSECTION GUIDE LINE, 2010 by GLADSTONE REGIONAL COUNCIL)

Gap Acceptance Parameters for Sign Controlled Intersections

Type of Movement	Less than 70km/hr		71km/hr to 100km/hr		Greater than 100km/hr	
	Critical Gap (seconds)	Follow-up Headway (seconds)	Critical Gap (seconds)	Follow-up Headway (seconds)	Critical Gap (seconds)	Follow-up Headway (seconds)
Left turn						
1-lane opposing	4.5	3.0	6.5	4.5	8.0	5.5
2-lane (or more) opposing	5.0	3.0	7.0	4.5	9.0	5.5
Through movement crossing one-way road						
1-lane one -way	4.0	2.0	6.0	3.0	7.5	3.5
2-lane one-way	4.5	2.5	6.5	3.5	8.0	4.5
3-lane one-way	6.0	3.0	8.5	4.5	11.0	5.5
Through movement crossing two-way road						
2-lane two-way	5.0	3.0	7.0	4.5	9.0	5.5
3-lane two-way	6.5	4.0	9.0	6.0	11.5	7.5
4-lane two-way	8.0	5.0	11.5	7.0	14.5	9.0
Right turn from major road						
Across 1 lane	4.0	2.0	6.0	3.0	7.5	3.5
Across 2 lane	5.0	3.0	7.0	4.5	9.0	5.5
Right turn from minor road						
One-way	4.5	3	6.5	4.5	8.0	5.5
2-lane (two-way)	5.5	3.5	8.0	5.0	10.0	6.5
3-lane (two-way)	6.5	4.0	9.0	6.0	11.5	7.5
4-lane (two-way)	8.0	5.0	11.5	7.0	14.5	9.0
Merge from acceleration lane	3.0	2.0	3.0	2.0	3.0	2.0

The critical gap and follow up headway for Round About is calculated by the software.

3.3 Measure of Effectiveness

The primary measure of effectiveness used in this research is the Average Vehicular delay associated with the Level of Service. According to SIDRA INTERSECTION User Manual (2009), Delay to a vehicle is the difference between interrupted and uninterrupted travel times through the intersection which shows the delay experienced by a through vehicle stopping and starting at traffic signals.

SIDRA INTERSECTION predicts the average delay for all queued and un-queued vehicles. As per this definition, the total delay (vehicle-hours per hour) is the product of average delay and the total demand flow rate. The total delay for a movement (or lane group) is the aggregate of total delays for all lanes that are used by the movement (or belong to the lane group) allowing for the proportion of movement demand flow in each lane.

The four intersections are analyzed as “before” and “after” the introduction of LRT under the same geometric condition and future traffic volume in the “after” scenario. The “after” scenario is created by changing the Yield Control type to Stop Control and considering arrival of the Light Rail Vehicles every 6 minutes in order to represent the actual scenario. In this scenario, the output is based on the fact that the "Stop" Control will function for the full hour. However, in the actual condition, the LRT Vehicles will arrive every 6 minutes and the stop control is assumed to function for 30 seconds per each arrival. The LRT Vehicles could cross the intersection less than 30 seconds. Nevertheless, for safety and operational purpose, 30 seconds will be realistic. Hence, a total of 300 seconds phase duration per 1 hour (300 sec / 3600 Sec) correction factor is applied in the analysis.

The difference between the average total delay with LRT crossings and the baseline average total delay without LRT crossings is the average additional delay:

Average additional delay = average total delay with LRT crossings – average total delay without LRT. The performance of each lane is looked into "before" and "after" the introduction of Light Rail Transit to account for the left turns of all approaches and the through movements of opposed approaches (N-S) which are expected to be affected highly due to stoppage per every interval the LRT Vehicles pass.

3.4 Study Junctions

In order to determine the effects of light rail transit crossings on traffic delays, four at grade sections are selected in the East-West LRT proposed line of Addis Ababa City which runs from Ayat to Megenagna to Tor-Hayiloch. These are Bambis Intersection, Beshale Hotel Round About, CMC Round About and Ayat Round about junctions.

3.4.1 Bambis Intersection

Bambis Intersection is a flared type of intersection having a four leg approaches namely Kasanchis approach, Olympia Approach, Mesqel Square Approach and Hayahulet Approach.

Table 3-8 Description of Bambis Intersection

Name of the Junction: Bambis Intersection			
Leg	**Orientation**	**Approach**	**Geometric Data**
1	North Bound	to and from Kasanchis	Number of entry lanes=2; Lane width=3.5m; Grade=3%; Median width=1m
2	South- East Bound	to and from Olompiya	Number of entry and exit lanes=2; Lane width=3.5m;Grade=5%; Median Width=0.2m
3	East Bound	to and from Hayahulet	Number of entry and exit lanes =4; Lane width=3.0m; Grade=2%; Median Width=2m
4	West Bound	to and from Meskel Square	Number of entry and exit lanes=4; Lane width=3.0m; Grade=2%; Median Width=2m

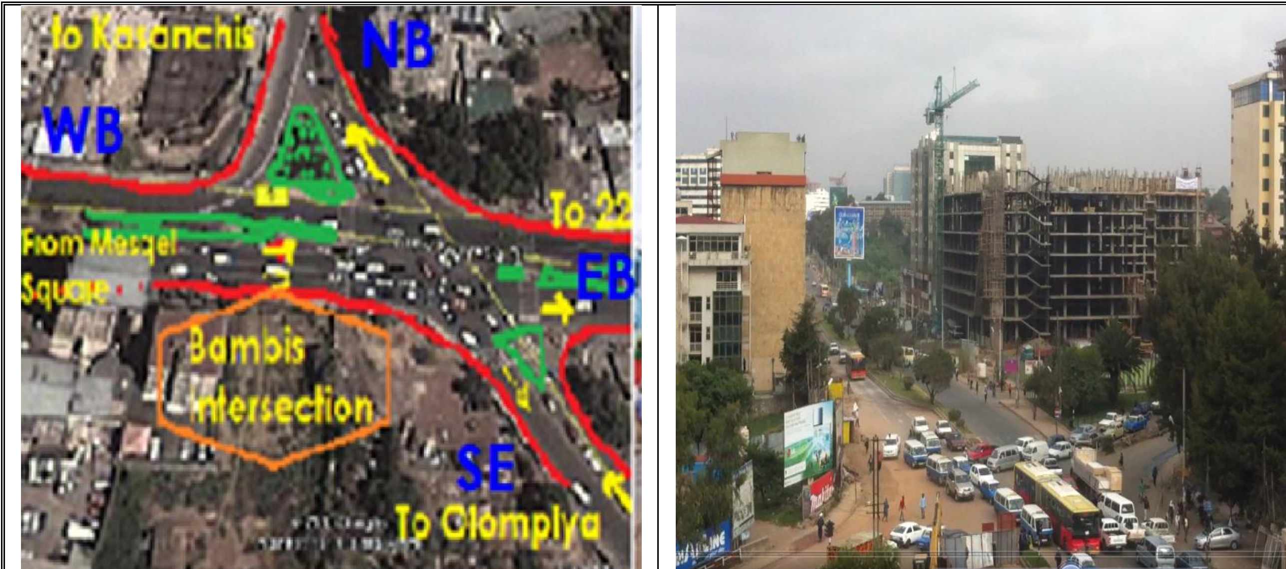


Figure 3-5 Bambis Intersection (Near Urael Junction)

3.4.2 Beshale Hotel Round About

The junction is a four leg round about found near to Beshale Hotel around St. Mary Church. The Roundabout has the following features as indicated in the table.

Table 3-9 Beshale Hotel Roundabout Features

Name of the Junction: Beshale Hotel Round About			
Leg	**Orientation**	**Approach**	**Geometric Data**
1	North Bound	to and from Kara	Number of entry and exit lanes=3; Entry lane width=3.7m; Grade= -4%
2	South Bound	to and from Mebrat Hail	Number of entry and exit lanes=3; Entry lane width=4.3m; Grade=7%
3	East Bound	to and from CMC	Number of entry and exit lanes=4; Entry lane width=3.5m; Grade =2%,Median width=11m
4	West Bound	to and from Megenagna side	Number of entry and exit lanes=4; Entry lane width=3.5m; Grade =2%; Median Width=11m
Central Island diameter=100m; Circulating road width =14m			

Figure 3-6 Beshale Hotel Round About

3.4.3 CMC Round About

CMC Round about is one of the major junctions found in the East-West corridor of Addis Ababa city characterized by four legs and having a central island diameter of 125m.

The Geometric Features of the roundabout junction are summarized in the table below:

Table 3-10 CMC Roundabout Feature

Name of the Junction: CMC Round About			
Leg	**Orientation**	**Approach**	**Geometric Data**
1	North Bound	to and from Sunshine Real Estate	Number of entry lanes=2; Entry lane width=3.5m; Grade=1.5%
2	South Bound	to and from Summit	Number of entry and exit lanes=2; Entry lane width=4m; Grade=3%
3	East Bound	to and from Ayat	Number of entry and exit lanes=4; Entry lane width=3.5m; Grade = 1.5%
4	West Bound	to and from Megenagna Side	Number of entry and exit lanes=4; Entry lane width=3.5m; Grade =1.5%
Central Island Diameter=125m; Circulating Road Width =14m			

Figure 3-7 CMC Round About

3.4.4 Ayat Round About

This round about junction is found in the Eastern part of the city to accommodate the traffic passing through and generated from Ayat and the surrounding locations. The end of the first phase of the Addis Ababa East-West LRT is at this intersection. It has four approaches namely the Lagatafu Approach in the North, Ayat Condominium Approach in the East, Summit Approach in the South and Megenagna Approach in the West Approach and having a central island diameter of 110m. The geometric features of the roundabout junction are as summarized in the table.

Table 3-11 Ayat Roundabout Geometric Features

Name of the Junction: Ayat Round About			
Leg	**Orientation**	**Approach**	**Geometric Data**
1	North- Bound	to and from Lagatafu	Number of entry lanes= 2; Entry lane width=4m; Grade=2.5%, Median=40m
2	South Bound	to and from Summit	Number of entry and exit lanes=2; Entry lane width=4m; Grade=4%; Median=40m
3	East Bound	to and from Ayat Condominium (Chefe)	Number of entry and exit lanes=2; Entry lane width=3.5m; Grade = 1.5%; Median =30m
4	West Bound	to and from Megenagna Side	Number of entry and exit lanes=4; Entry lane width=3.75m; Grade =1.5%;Median=11m
Central Island Diameter=110m; Circulating Road Width =16m			

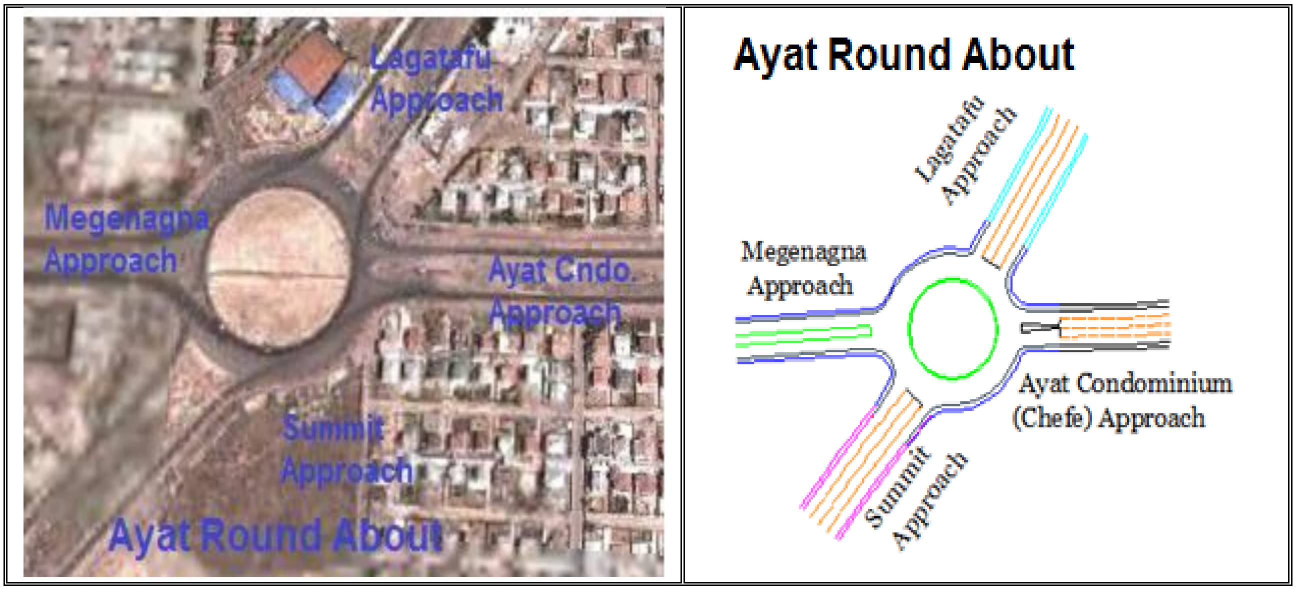


Figure 3-8 Ayat Round about Layout

3.5 Description of the Test Scenarios

In order to determine the effects of light rail transit crossings on traffic delays in regard to harmonization processes of rails and roads, two basic scenarios are established which includes capacity evaluation of the selected intersections “before” and “after “ the introduction of LRT crossing. The “Before” scenario represents the existing situation of the intersections and the “after” scenario characterizes the future condition when the LRT system come into service mixed with the existing junction condition.

3.5.1 “Before” LRT Scenario

The LOS of the four at-grade intersections namely Bambis Intersection, Beshale Hotel Round About, CMC Round and Ayat Roundabout junction is analyzed using SIDRA INTERSECTION software. The corresponding LOS of lanes and average vehicular delay are evaluated. The type of existing control of the four intersections is Yield Control based on which the analysis is made.

3.5.2 “After” LRT Scenario

In a similar manner, the LOS of the four at-grade intersections is analyzed using SIDRA INTERSECTION software by converting yield control system of the site to “Stop Control” by taking the E-W as Major road with which the LRT along with the through traffic will always pass uninterruptedly with the expense (stop) of the North-South through traffic and left turns of all approaches. The corresponding LOS of lanes and average vehicular delay is evaluated for this scenario.

Making the control type signalized complicates the evaluation and less suits the actual condition intended to be implemented after the LRT comes into service. Moreover, the software does not account the frequency of LRT vehicles at each signalized intersections. Using the prolonged cycle in the software would lead to unacceptable result. Instead, each arrival of the Light Rail vehicles can be considered to be given an always priority which is incorporated in the stop- way control system. This is possible because the Light Rail Vehicles will not be stopped with the signal. The purpose of the signal to be installed is to stop other conflicting vehicles by giving priority for the Light Rail Vehicles. This is the same as that in the stop way control system. Therefore, the "before" scenario will be treated by analyzing as "yield" control system and the "after" scenario will be analyzed by changing the "yield" control to "stop" control system by assuming 30 sec phase time per each arrival of Light Rail Vehicles. The Light Rail Vehicles could cross the Intersection less than 30 seconds. But for safety and operational purpose (entering, stopping, clearing and start up lost times), this value is assumed.

4.0 DATA ANALYSIS AND RESULT

4.1 Assessment of the Addis Ababa E-W LRT System in regard to Harmonization with the Existing Arterial Streets

Harmonization is a broad term to signify integration of the two different modes of transportation systems. Mainly the principle focuses on accessibility, safety and aesthetics. Therefore, in the assessment of the new LRT project which is under implementation and expected to be functional in the coming couple of years, the basic criteria taken are location of LRT Stations, accessibility, provision of parking lots, safety and aesthetics from the scientific stand point of view and best practices all over the world which have been indicated in the literature review part of this paper. Accessibility by itself has two broad designations in this paper. The first one is mode of access to LRT stations and the second one is accessibility of non-transistors which do not use the light rail transit system.

4.1.1 Addis Ababa E-W LRT Locations

The East –West LRT project of Addis Ababa City which runs from West to East direction stretching from Tor Hayiloch to Ayat Village passing through Megenagna, Legahar and Mexico has a total length of 17.35 km. In this stretch, there are 22 (twenty two) LRT Stations and five of which are shared with North –South LRT route. Average interval between two adjacent stations is 815 meters. The longest interval is 1,300 meters which is from Ayat 1 to Ayat Round About station and the shortest interval is 510 meters from Road Authority to Lagar LRT Station.

Generally, stations shall be located every 1200m to 1600m as per the LRT Service Guideline of Santa Clara Valley Transportation Authority (VTA-2007) even though specific station placement shall be based on planning studies that identify the location of key activity generators and/or demand at particular locations along the corridor. As per this guide line the station interval of Addis Ababa Light Rail Transit is acceptable the maximum being 1300m and the minimum 510m.

The Stations are listed under the table below as follows:

Table 4-1 Location of Addis Ababa East –West LRT Stations (Source: Ethiopian Railway Corporation)

Station	Station	Interval (Distance in meters from previous Station)	Remark
Tor Hayiloch	0+000 *	0	As per the general recommendation by Santa Clara Valley Transportation Authority (VTA-2007), the location of the stations is quite acceptable regarding the interval between each successive station.
Coca-Cola	0+845*	845	
Lideta	1+461*	616	
Mexico Square (Underground)	2+608*	1,147	
Road Authority	3+118*	510	
Lagare	3+663*	545	
Stadium MesqelSqaure 1	4+447	784	
EstifanosMesqelSqaure 2	5+147	700	
Yordanos Hotel (Kasanchis)	5+695*	548	
Urael Church (Under Ground)	6+286	591	
Chemical Corporation	7+015*	729	
Mazoria/Traffic Police HQ	7+675	660	
Lem Hotel	8+513	838	
Megenagna/Adwa Sq.	9+548	1,035	
Gurdshola	10+552	1,004	
Salitemihiret Church	11+474	922	
Civil Service College	12+380	906	
St.Michael Church	13+165	785	
CMC1	14+030	865	
CMC2 (Meri)	14+926	896	
Ayat 1	15+960	1,034	
Ayat 2	17+260	1,300	

[*Note that missing distances are measured from design drawings by the researcher.]

4.1.2 Accessibility in AA E-W LRT and Principal Arterial Streets

Although accessibility has broad definitions, related to transport, it can be defined as the ease or ability to access or reach and benefit from some system or location. When a location or a system is accessed by able or disabled people either directly or indirectly, then it is called accessible.

The associated issue called mobility is the efficient movement of traffic. When a highway is made accessible at every location, then mobility will highly be affected. The extreme result will be congested system of traffic which has a negative impact on the development of a city. An extreme focus given to mobility will result in a decrease in accessibility which limits surrounding land use development. Retailing centers, cafeterias, commercial centers deny road side corridors through which high speed traffic passes. This affects directly or indirectly development of the inter-urban centers. On one hand, planning of accessibility by compromising mobility can create benefits by expanding small-scale retail development in residential areas, thereby bringing shops within walking distance that could be accessed by circulator bus route that links residential areas to commercial areas. Therefore, a trade-off between accessibility and mobility shall come into play by transport planners and designers for better development of a city.

Accessibility can be seen from different perspectives. These are accessibility of LRT Stations, accessibility for non-transitory pedestrians and vehicular accessibility of surrounding land use as far as harmonization of Light Rail Transit and Principal Arterial Street Highways is concerned.

4.1.3 Accessibility of LRT Stations

Good connections to LRT stations have a significant role in the effectiveness of transit use and it is indispensable to ridership with regard to reducing community impacts .As clearly indicated in the literature review part of this paper, residents of a city in every LRT catchment areas access to the LRT by feeder bus, park and ride, kiss and ride (auto passenger drop-off), walking and bicycle.

In the city of Addis Ababa the main contributors will be taxi, walking and bus transit modes for most of the LRT Stations as far as the current trend is concerned. The other modes like park and ride and passenger drop off contribute the minimum as far as the current condition is concerned. However, the share is believed to be increased in the future as automobile ownership increases with increase in the city infrastructure or development.

The number of pedestrians in the city is increasing rapidly as the population grows quickly which calls for the provision of maintained and adequate walkways in the city. Most of the existing footpaths (walkways) are badly damaged and do not accommodate pedestrians efficiently due to width problem compared to the number of pedestrians. In the current scenario, the existing condition of walkways near the LRT stations from Tor Hay loch to Megenagna is poor. However, the specified stretch is currently under upgrading and after completion it will help improvement of Walkways near LRT Stations to make the LRT more effective.

Bicycles access mode is almost negligible in the city of Addis. Even though the rugged terrain nature of the city contributes a lot, there are no dedicated cycle tracks in the city streets. Consequently, people are discouraged to bicycle. Those few in number including the professionals are using the main carriage ways intended for the vehicular traffic which is unsafe.

As per the design practice of today, the average walking distance considered in the provision of LRT Stations as far as Pedestrians are concerned, is 400m. With respect to these criteria, most of the Stations are to be built in the main corridor of the City Streets. And hence, most people are believed to walk less than this from their settlement and/or other mode of transit.

4.1.4 Accessibility for non-transitory pedestrians

In principle, the introduction of a new LRT system should not be a barrier on the left and right corridor of the streets. Convenient at-grade crossings and interchanges should be provided to allow non-transistors to easily access the surrounding land uses. However, at-grade zebra crossing for pedestrians on median LRT systems requires a due consideration from safety point of view.

Pedestrian bridges need adequate right of way to accommodate accessible ramp approaches leading up to and off the structure. And they need to be provided where there is high demand of pedestrians like in areas of schools in order to protect them from motorists and high speed Light Rail Vehicles.

As to the researcher's knowledge, it is planned to provide pedestrian overcrossing bridges every 300m where the LRT is exclusively treated at-grade within the median in the first lot which stretches from Tor Hayiloch to Megenagna. The at-grade median exclusive LRT section in this lot is from Tor Hayiloch to Coca Cola and Estifanos to Urael. In the specified stretch the pedestrians will use the existing zebra crossings of the existing streets where the LRT crosses over the bridge. From Megenagna to Ayat, as per the current design, the pedestrians are intended to use the LRT stations. However, all stations in this lot are more than 400m over which walking is believed to be difficult and discouraging. However, as the information obtained from the LRT Project office found in Ayat, it is currently planned to provide few at-grade crossings in between stations where the interval and pedestrian traffic is high. If this plan is to be implemented, then accessibility will be enhanced. However, the zebra crossings shall be given emphasis regarding safety. The Zebra Crossings shall be changed into foot bridge crossings. In case zebra crossings are unavoidable, a signal with an alarm shall be used.

4.1.5 Vehicular Accessibility of Surrounding Land Use

As per the Highway Capacity Manual (HCM), vehicular accessibility is measured in terms of access point which comprises of an at-grade intersection, driveway, or median opening. Allowing or prohibiting turning, entering, exiting and crossing traffic movements at access points determines the accessibility of the surrounding land use of principal arterial street corridors. Usually when the traffic volume is high and the intension is to increase speed, prohibition of the access points is made. On the other hand, when the traffic volume is low and the interest is access, the access points are provided and permitted.

Where the access points are not provided or prohibited, the road side development will be limited. For the case of Addis Ababa East-West Corridor where the traffic volume is increasing beyond the capacity of the street highways, frequent provision and permission of access points (at-grade intersection and median openings) may result in traffic congestion. And on the other hand prohibition of access points for long stretch by overlooking important business district areas highly affects the growth of the city. Therefore, a balance or tradeoff principle between access and mobility shall be adopted.

In general, the first lot of Addis Ababa East-West corridor which stretches from Tor Hayiloch to Megenagna (9.458 km) has major intersection points with the principal arterial streets. From those, the major intersection points which provide access to the surrounding land uses and other destination points are Tor Hayiloch Round About, Coca Cola, Lideta (Fird bet) Intersection, Mexico Round About, Mesqel Square Intersection, Bambis, Urael Intersection,Wuha Limat, Hayahulet Mazoria, Lem Hotel and Megenagna Round About. In the second lot which stretches from Megenagna to Ayat Round About (7.712km) there are three major access points (Beshale Hotel Round About, CMC Round About and Ayat Round About) which are critically serving the eastern corridor of Addis Ababa city traffic.

The introduction the new LRT into the existing East-West arterial street highways is made grade separated from Coca-Cola to Estifanos, Urael Junction, at Wuhalimat, Hayahulet Mazoria, Lem Hotel and Megenagna intersections. Other than these locations the LRT is allowed to pass through the median at grade with the driveways by blocking many median openings. Especially in the second lot, as the LRT is not grade separated, many median openings are blocked which affects accessibility to the surrounding land uses of the road corridors.

4.1.6 Parking provision near LRT Stations of AA E-W LRT Project

In principle, provision of parking at Light Rail Transit Stations for people who drive to their stations because of distance or other concerns is best practice transit planners and designers need to follow in order to enhance transit ridership.

As per the researcher's knowledge, there is no free parking considered near LRT Stations in the Addis Ababa East-West LRT System. In fact, Parking in Addis Ababa is a serious problem. The demand exceeds by far the supply and it is usually made on the principal street highways of the city. Only few off-street parking is found in private government premises, fuel stations and under few high rising buildings. According to current studies, there is no parking strategy and responsible body assigned to claim for planning and development of off-street parking. Therefore, the city's transport authority or Addis Ababa City Roads Authority or Urban Land Administration of Addis Ababa shall be responsible not to overlook in the revision of the city master plan in order to introduce parking lots near the LRT Stations. Until then, the outer parking lane of the main carriage way of the Main Principal Arterial Street shall be allowed to the LRT users for temporary (for passenger drop off purpose) and permanent parking (park and ride purpose) in order to enhance transit ridership and reduce automobile commuting.

4.1.7 Safety Consideration of Addis Ababa East-West LRT and Principal Streets Crossings

The safety consideration of LRT median crossing with the street consists of the conflict between LRT Vehicles with the traditional vehicles, LRT vehicles with pedestrians. The Addis Ababa East –West LRT System is allowed to pass underground, on the ground and above the ground. Of which the on-ground passage take the maximum share. Due to this the LRT crosses street highways at many locations. At this locations safety is a major concern.

The East-West Line of the Addis Ababa LRT project could be seen in two lots as from Tor Hayiloch to Megenagna having a total length of 9.458 km and the second lot as Megenagna-to Ayat Round About having a total length of 7.712 Km.

The first lot from Tor Hayiloch to Megenagna has major intersection points with the principal arterial streets namely Coca Cola, Lideta (Fird bet) Intersection, Mexico Round About, Mesqel Square Intersection, Bambis, Urael Intersection, Wuha Limat, Hayahulet Mazoria, Lem Hotel and Megenagna Round About. At these major intersections where the number of conflicts was high, the LRT is made grade separated except at Bambis Intersection. At Bambis Intersection the LRT is exclusively separated with median by closing the south and north bound traffic and allowing them to make a “U” turn at URAEL Round about and Estifanos at which a clear grade separation is made. In doing so, the number of conflicts between the LRT vehicles and other street vehicles are minimized. Hence, safety is enhanced in this stretch.

Figure 4-1 LRT grade separated at Mexico and Urael Round-About (Source: CORE Consulting Engineers PLC).

In general the locations of Grade separations at major intersections from Tor Hayiloch to Megenagna (Lot I) are as summarized in table below:

Table 4-2 Summary of major Junctions where the AA E-W LRT is made Grade Separated in Lot I

(Source: CORE Consulting Engineers PLC)

No.	Intersection	LRT Grade Separation Type	Remark
1	Lideta (Fird bet)	Under	
2	Mexico	Over	
3	Mesqel Square	Over	
4	Bambis	At	North and South Junction Approaches are allowed to make an extended U-Turn by blocking with Median Curbstones.
5	Urael	Under	
6	Wuhalimat	Over	
7	22-Mazoria	Under	
8	Lem hotel	Over	
9	Megenagna	Under	

Even though the LRT Vehicles are not in conflict with the North and south approach street vehicles at Bambis Intersection, pedestrians are expected to cross with zebra crossing. Therefore, pedestrian over crossing should have been implemented at this location in order to separate the Pedestrians from the LRT vehicles and major road street vehicles too. If zebra crossing is an option, reactive counter measures as signals with alarm shall be implemented at this location. In fact there is One LRT station near to this intersection. The LRT Station shall be raised and be enough to accommodate all types of pedestrians including transistors and non-transistors instead of allowing a separate zebra crossing for the non-transitory pedestrians.

In the second lot which stretches from Megenagna to Ayat Round About (7.712km) there are three major round-about junctions which are critically serving the eastern corridor of Addis Ababa city traffic. At these major intersections, the LRT is made to cross at grade dividing the central islands in to two equal parts and to be managed with traffic signals. The LRT vehicles are in conflict with the street vehicles. Moreover pedestrians will use zebra crossings at many locations other than the LRT Stations. It can be said that safety is compromised in this lot. Grade separation should have been implemented at the three major roundabout junctions in order to harmonize the new LRT system into the existing principal arterial streets.

Figure 4-2 Top view of Beshale Hotel Round about Junction where the LRT crosses at-grade

In a similar fashion the other two major roundabout junctions are to be crossed at-grade and they will be equipped with traffic signals.

With this scenario, possible mitigation measures shall be adopted in order to minimize possible accident events at these locations. The counter measures are not exhaustive and are as per the recommendation by Benjamin Coifman and Robert L. Bertini (1997).

- **Static**: warning devices that warn the driver of a grade crossing or keep automobiles out of the track way whether or not an LRV is present, e.g., signs and delineation. This could be applied at Bambis Intersection in order to keep the Olympia and Kasanchis Approach traffic out of the median track way.

- **Active***:* Warning devices that change states and restrict movement when an LRV approaches, e.g., crossing gates and traffic signals. Although it is the common definition of active grade crossing protection, such systems are essentially proactive; they operate independent of driver's actions or the presence of automobiles. This shall be adopted in the at-grade crossing locations namely Beshale Hotel Round About, CMC Round About , Ayat Round About and/or other locations having zebra crossings for pedestrians where the LRT Vehicles are kept away from other traffic.

- **Reactive***:* Proposed warning devices that respond to illegal or unsafe automobile movements when a Light Rail Vehicle (LRV) approaches, e.g., automated encroachment alarms and other Intelligent Transportation Systems (ITS) devices. It is supported in many studies that audible alarms are effective for reducing accidents at conventional railroad grade crossings. Therefore, this devices need to be implemented in the above said locations in order to minimize accident.

4.1.8 Aesthetics Consideration of Addis Ababa East –West LRT

For better harmonization of the new Light Rail Transit System with the city environment, aesthetics is one factor to be considered in the planning stage. In different literatures, it is indicated that the installation of the LRT infrastructure which includes the track way, overhead Catenary wires and support masts, signal support poles, grade crossing control measures, fencing, stations, and other ancillary structures, including the LRT train moving through the community, may be considered by some community residents as being visually displeasing.

As aesthetics could be measured in terms of user's perception, the researcher made preliminary assessment on the field whether the prospective users would like the LRT line to pass above the ground using piers, on the ground or below the ground. In line with this, interview of concerned bodies involved in Urban Planning was made. The primary finding showed two different opposing ideas from professionalism point of view and outside the context by the users. It is more of exposure, knowledge about the impact and experience than simple perception. Hence, the researcher preferred to assess the aesthetics impact based on literatures and scientific stand point of view.

Visual perceptions differ among individuals. Since it is a new technology for most of the city residents, some individuals may prefer the LRT pass above the ground on important locations. In the same city, the concerned individuals which incorporates Civil Engineers, Architects and Urban planners most of them may prefer the LRT pass underground in order to minimize the visual aesthetical impacts.

The E-W LRT project of Addis Ababa passes on scenery places like Mexico, Legahar and Mesqel Square which have pleasant urban views. However, the LRT passing through these important locations is above the ground which obstructs aesthetical views and brings noise to people gathering at places like Mesqel Square.

Unless economic problem or other factors like drainage and geologic conditions prohibit, at the above specified locations where most of the city's scenery places concentrate, would have been made below the ground.

4.1.9 Congestion Impact of Addis Ababa East-West LRT at Intersections of Principal Arterial Streets

The assessment of the Addis Ababa East-West LRT Project includes the congestion impact by taking average vehicular delay as a measure of effectiveness. As per the analysis result, there is a significant increase in average vehicular delay for the through traffic of opposed approaches (N-S Approaches) and left turns of all approaches at all the junctions.

Moreover, as to the researcher's knowledge the existing central islands of the three roundabouts will be left as it is after the LRT comes into function. On the other hand, the LRT Vehicle is expected to cross the junction every six (6) minutes. This will increase clearing time of vehicles before and after red light signal system. This will induce additional delay to the traffic. Therefore, they shall be demolished to allow more evacuating space for the through and left turn vehicles while red light is about to turn into green and vice versa in which case the type of intersection is changed into signalized intersection. Beshale hotel round about having 100m diameter of traffic island, the shortest distance for the through traffic will be reduced from 146m to 99m (by 47m) upon demolishing. Similarly, for CMC roundabout having 125m diameter, a reduction of 61m and at Ayat Roundabout with 110m island diameter, a reduction of 52m will be obtained after demolishing.

Detail data analysis and result with discussion is separately presented in Section 4.2.

4.2 Data Analysis and Result of LRT Impact on Traffic Congestion

After collection of the required data, SIDRA INTERSECTION 5.1 software is used for the analysis. The level of service and average delays for the four selected at-grade intersections are evaluated using SIDRA INTERSECTION 5.1 based on HCM 2000 criteria. Four at grade intersections found in the Addis Ababa East-West LRT corridor are evaluated as “before” and “after” the introduction of LRT. As described in the methodology, the base case is analyzed as Give Way/Yield Control and the “after” scenario is created by changing the Yield control site to Stop Control type with consideration of arrival of the LRT every 6 minutes and 30 seconds of phase time to the stop control in order to represent the actual condition.

4.2.1 LOS Analysis of Intersections

The Level of Service (LOS) of the selected at-grade junctions is evaluated using SIDRA Intersection software for both the “before” and “after” LRT scenario. The intersections along the study corridor selected for analysis are:

1. Bambis Intersection,
2. Behsale Hotel Roundabout
3. CMC Round About
4. Ayat Round About

These junctions are selected for they are at-grade with the LRT system and the LRT vehicles are in conflict with the street vehicles except at the Bambis Intersection. At Bambis intersection, though not grade separated, the LRT vehicles are kept away from conflicting with the south-East and north approaching vehicles with median curbstone. The through and left turn vehicles are allowed to make a right turn with the normal right turn vehicles and will use Urael Round about. Similarly, for Kasanchis approach the through and left turn vehicles will make a right turn with the normal right turns and make a U-turn at Estifanos where the LRT is grade separated.

4.2.1.1 Average Delay and LOS Analysis of Intersections “Before” LRT

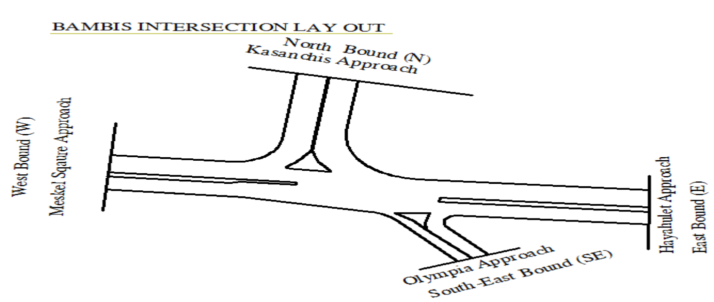
A. Average Delay and LOS Analysis of Bambis Intersection before LRT

The input data used for the analysis are traffic and geometric data as tabulated in table below. The traffic data is forecasted using traffic growth rates by considering 20 years of analysis period as the East-West Line of the city is Major corridor where many Principal Arterial Streets exists. Traffic growth rates were taken from Final Engineering Report of Megenagna-Torhayiloch Road Upgrading Project (April 2013) prepared by CORE Consulting Engineers PLC which is based on demand elasticity and GDP growth rate as described in detail in the methodology of this paper.

Other features like lane discipline are also entered into the program. However, recommended values associated with default values of the software are also used for the analysis. For example, for the purpose of this research a value of 1500 Veh/hour which corresponds to 2.4 seconds of headway is used as per SIDRA INTERSECTION GUIDE LINE adopted in 2010 by GLADSTONE REGIONAL COUNCIL (AUSTRALIA). Minimum Follow-up head way and critical gap values are also taken from this manual.

Table 4-3 Summary of traffic count and geometric data of Bambis Intersection

TRAFFIC AND GEOMETRIC DATA													
1. BAMBIS INTERSECTION													
LEG 1:MESKEL SQUARE APPROACH													
Time of Count: 8:00AM-9:00 AM	**Survey Location: BAMBIS INTERSECTION**						**Date: 20/05/2013**				**Geometry Data**		
	Light Vehicles		**Heavy Vehicles**										
Direction	**Small Car**	**Small Truck**	**Bus**	**Medium Truck (Dual Rear Axle Truck)**	**Heavy Truck (4/5 R.Axle Trucks)**	**Truck & Trailor (Large Truck)**	**Total LV Veh/hr**	**Total HV Veh/hr**	**Total Veh/hr**	**Peds**	**No.of Entry Lanes**	**Lane Width (m)**	**Median Width (m)**
Through Traffic (TH)	363	8	41	1	1	0	371	43	414	**233**	**4.00**	**3.50**	**1.00**
Right Turn Traffic (RT)	47	0	1	0	0	0	47	1	48				
Left Turn Traffic (LT)	95	7	3	3	0	0	102	6	108				
Total	**505**	**15**	**45**	**4**	**1**	**0**	**520**	**50**	**570**				
LEG 2: OLYMPIA APPROACH													
Through Traffic (TH)	209	5	3	2	0	0	214	5	219	**280**	**2.00**	**3.50**	**NA**
Right Turn Traffic (RT)	197	2	1	2	0	0	199	3	202				
Left Turn Traffic (LT)	52	2	0	1	0	0	54	1	55				
Total	**458**	**9**	**4**	**5**	**0**	**0**	**467**	**9**	**476**				
LEG 3: HAYAHULET APPROACH													
Through Traffic (TH)	520	11	45	2	0	0	531	47	578	**431**	**4.00**	**3.00**	**2.00**
Right Turn Traffic (RT)	32	0	0	0	0	0	32	0	32				
Left Turn Traffic (LT)	101	0	0	1	0	0	101	1	102				
Total	**653**	**11**	**45**	**3**	**0**	**0**	**664**	**48**	**712**				
LEG 4: KASANCHIS APPROACH													
Through Traffic (TH)	280	0	0	1	0	0	280	1	281	**312**	**2.00**	**3.00**	**2.00**
Right Turn Traffic (RT)	204	5	0	1	0	0	209	1	210				
Left Turn Traffic (LT)	15	1	0	1	0	0	16	1	17				
Total	**499**	**6**	**0**	**3**	**0**	**0**	**505**	**3**	**508**				



The summary of forecasted traffic volume used as an input for the software in the capacity analysis is as shown in the table below:

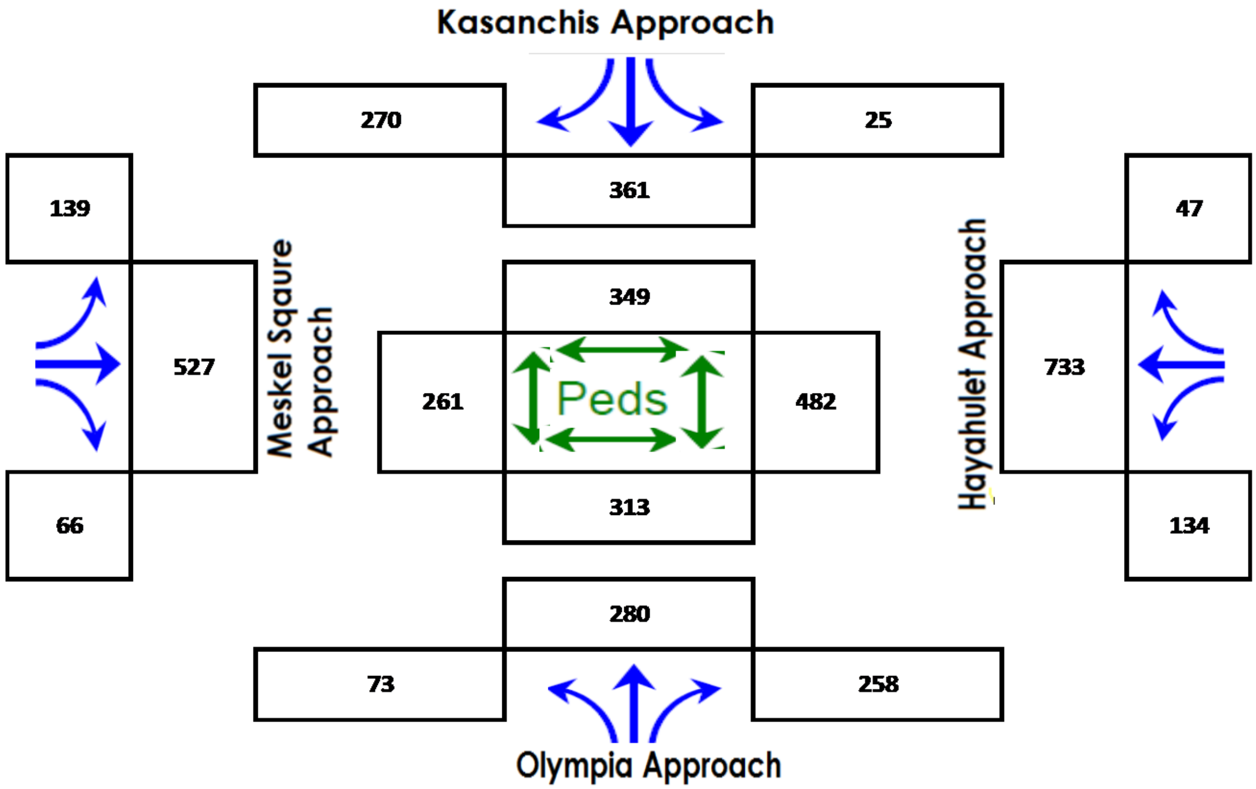
Table 4-4 Summary of Traffic Analysis Result for Bambis Intersection

1. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR BAMBIS INTERSECTION												
LEG 1:MESKEL SQUARE APPROACH												
Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	363	8	41	1	1	0	371	43	414	233	261
	2016	460	10	51	4	1	1	470	58	527		
Right Turn Traffic (RT)	2013	47	0	1	0	0	0	47	1	48		
	2016	60	1	1	1	1	1	61	5	66		
Left Turn Traffic (LT)	2013	95	7	3	3	0	0	102	6	108		
	2016	120	9	4	4	1	1	129	10	139		
Total	**2013**	**505**	**15**	**45**	**4**	**1**	**0**	**520**	**50**	**570**		
	2016	**640**	**20**	**56**	**9**	**4**	**4**	**659**	**73**	**732**		
LEG 2: OLYMPIA APPROACH												
Through Traffic (TH)	2013	209	5	3	2	0	0	214	5	219	280	313
	2016	265	6	4	3	1	1	271	9	280		
Right Turn Traffic (RT)	2013	197	2	1	2	0	0	199	3	202		
	2016	250	2	1	3	1	1	252	6	258		
Left Turn Traffic (LT)	2013	52	2	0	1	0	0	54	1	55		
	2016	66	2	1	1	1	1	68	5	73		
Total	**2013**	**458**	**9**	**4**	**5**	**0**	**0**	**467**	**9**	**476**		
	2016	**580**	**11**	**6**	**6**	**4**	**4**	**591**	**20**	**612**		
LEG 3: HAYAHULET APPROACH												
Through Traffic (TH)	2013	520	11	45	2	0	0	531	47	578	431	482
	2016	659	14	56	3	1	1	672	61	733		
Right Turn Traffic (RT)	2013	32	0	0	0	0	0	32	0	32		
	2016	41	1	1	1	1	1	42	5	47		
Left Turn Traffic (LT)	2013	101	0	0	1	0	0	101	1	102		
	2016	128	1	1	1	1	1	129	5	134		
Total	**2013**	**653**	**11**	**45**	**3**	**0**	**0**	**664**	**48**	**712**		
	2016	**827**	**16**	**58**	**5**	**4**	**4**	**843**	**71**	**914**		
LEG 4: KASANCHIS APPROACH												
Through Traffic (TH)	2013	280	0	0	1	0	0	280	1	281	312	349
	2016	355	1	1	1	1	1	356	5	361		
Right Turn Traffic (RT)	2013	204	5	0	1	0	0	209	1	210		
	2016	258	6	1	1	1	1	265	5	270		
Left Turn Traffic (LT)	2013	15	1	0	1	0	0	16	1	17		
	2016	19	1	1	1	1	1	20	5	25		
Total	**2013**	**499**	**6**	**0**	**3**	**0**	**0**	**505**	**3**	**508**		
	2016	**632**	**9**	**4**	**4**	**4**	**4**	**641**	**15**	**656**		

Diagrammatical Summary of Input Data of SIDRA INTERSECTION SOFTWARE

Name of Intersection: BAMBIS INTERSECTION

Type of Input Data: Projected Demand Traffic Volume



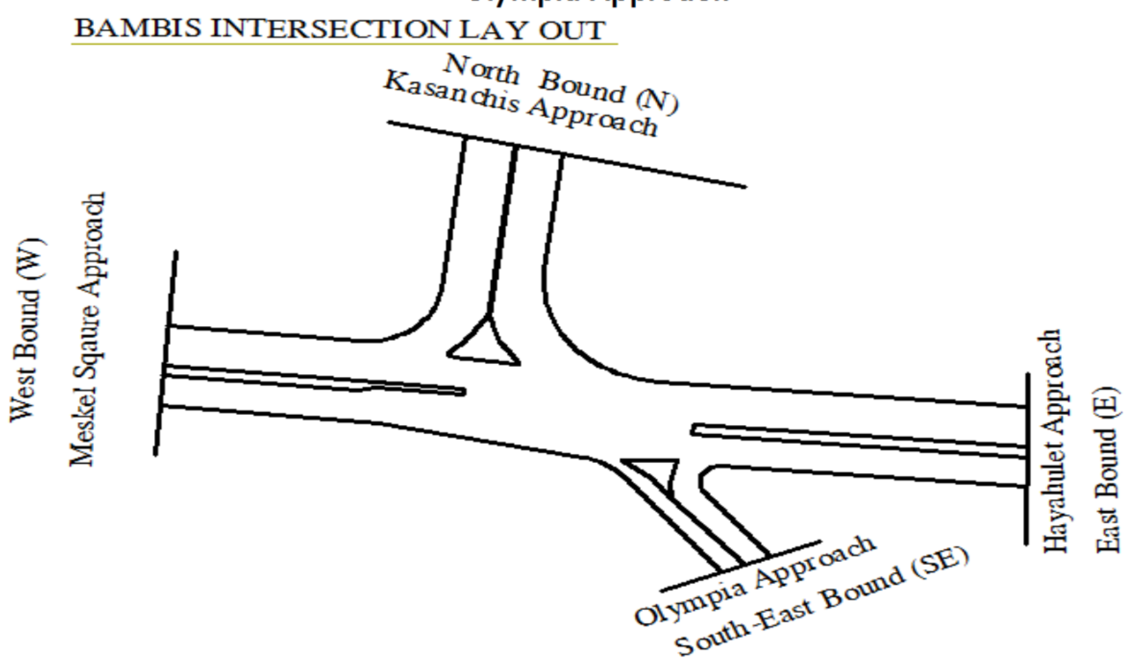


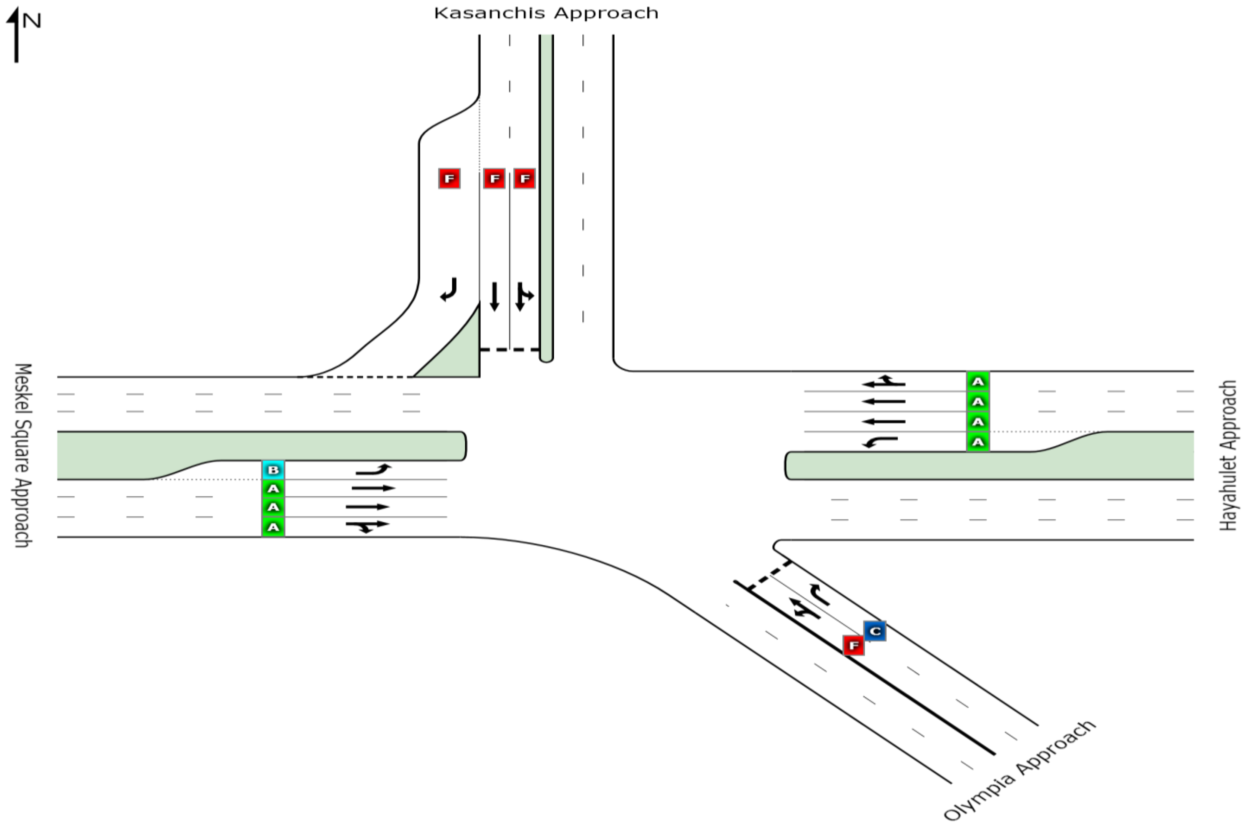
Figure 4-3 Diagrammatical sketch for input traffic data of Bambis Intersection

Moreover, as it is explained in the methodology part of this study, approach and exit cruise speed of 40 KMPH is used based on the speed limit recommended by Addis Ababa City Roads Authority Design Manual (2003) with some amendment in order to consider the actual conditions.

The SIDRA INTERSECTION Software output of Bambis Intersection is as summarized below:

Table 4-5 Average Delay and LOS Analysis output using SIDRA INTERSECTION for Bambis Junction before the LRT

Movement Performance – Vehicles before the LRT						
Movement ID	**Turn**	**Demand Flow**	**HV**	**Degree of Saturation**	**Average Delay**	**Level of Service**
		Veh/h	%	V/c	Sec	
South East: Olympia Approach						
1	L	79	6.8	3.144	1040.7	LOS F
2	T	304	3.2	3.144	1040.7	LOS F
3	R	280	2.3	0.575	19.8	LOS C
Approach		664	3.3	3.144	609.6	LOS F
East: Hayahulet Approach						
4	L	146	3.7	0.259	7.9	LOS A
5	T	797	8.3	0.206	0.0	LOS A
6	R	51	10.6	0.206	0.0	LOS A
Approach		993	7.8	0.259	1.2	NA
North: Kasanchis Approach						
7	L	27	20.0	1.659	397.6	LOS F
8	T	392	1.4	1.659	389.2	LOS F
9	R	293	1.9	0.924	69.6	LOS F
Approach		713	2.3	1.659	258	LOS F
West: Meskel Square Approach						
10	L	151	7.2	0.362	11.6	LOS B
11	T	574	11.0	0.161	0.0	LOS A
12	R	72	7.6	0.161	0.0	LOS A
Approach		797	10.0	0.362	2.2	NA
All Vehicles		3167	6.1	3.144	186.8	NA



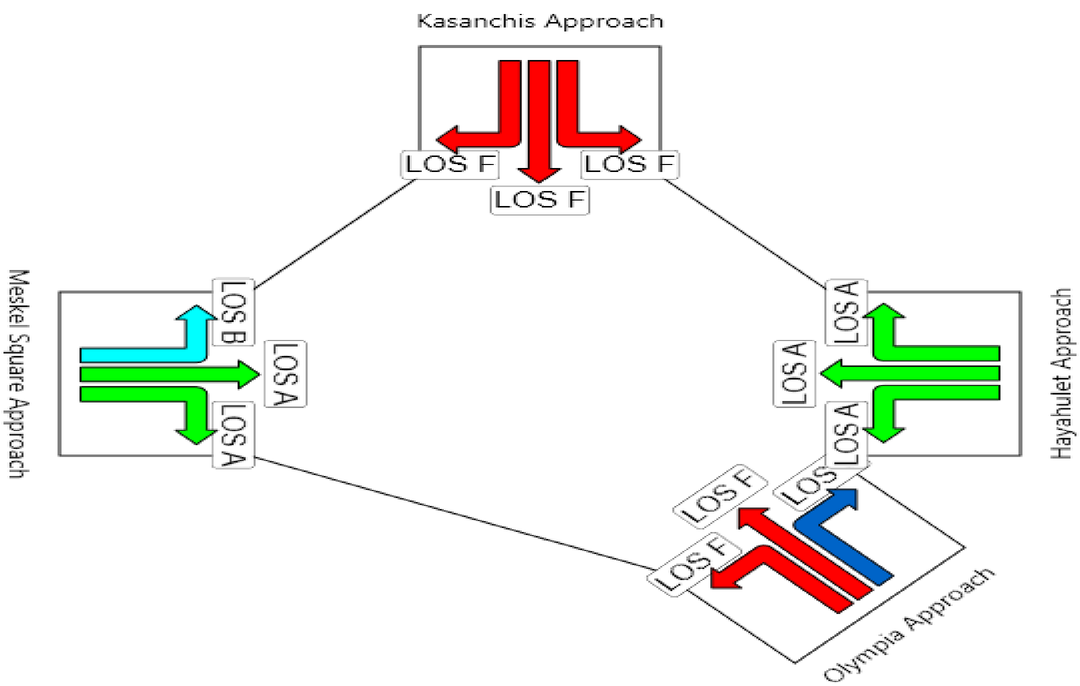


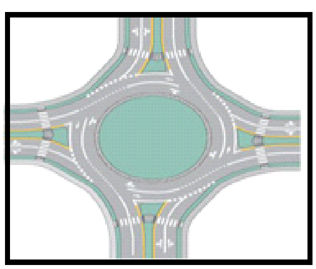
Figure 4-4 LOS Analysis output Display of Bambis Intersection before LRT

B. Average Delay and LOS Analysis of Beshale Hotel Round about Before LRT

Summary of the input data for the analysis of Beshale Hotel Round About is as indicated in the table below. As discussed earlier, the input data gathered from field are traffic volume, geometric data and lane discipline. Regarding traffic volume, the peak hour data is used.

Table 4-6 Summary of traffic count and geometric data of Beshale Hotel Round About

2. BESHALE HOTEL ROUND ABOUT													
LEG 1: CMC APPROACH													
Time of Count: 8:00AM-9:00 AM	Survey Location: BESHALE HOTEL ROUND ABOUT						Date: 21/05/2013				Geometric Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
Through Traffic (TH)	637	8	62	15	0	0	645	77	722	474	4	3.5	11
Right Turn Traffic (RT)	65	0	1	2	0	0	65	3	68				
Left Turn Traffic (LT)	448	11	3	24	0	2	459	29	488				
Total	**1,150**	**19**	**66**	**41**	**0**	**2**	**1,169**	**109**	**1,278**				
LEG 2: KARA APPROACH													
Through Traffic (TH)	193	8	2	17	1	1	201	21	222	180	3	3.7	NA
Right Turn Traffic (RT)	220	7	4	5	0	0	227	9	236				
Left Turn Traffic (LT)	96	0	2	0	0	0	96	2	98				
Total	**509**	**15**	**8**	**22**	**1**	**1**	**524**	**32**	**556**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	479	13	48	31	0	1	492	80	572	524	4	3.5	11
Right Turn Traffic (RT)	96	7	4	3	0	0	103	7	110				
Left Turn Traffic (LT)	411	9	19	14	0	0	420	33	453				
Total	**986**	**29**	**71**	**48**	**0**	**1**	**1,015**	**120**	**1,135**				
LEG 4: MEBRAT HAIL APPROACH													
Through Traffic (TH)	191	4	11	9	0	0	195	20	215	207	3	4.3	NA
Right Turn Traffic (RT)	189	13	7	23	0	0	202	30	232				
Left Turn Traffic (LT)	74	1	3	2	0	0	75	5	80				
Total	**454**	**18**	**21**	**34**	**0**	**0**	**472**	**55**	**527**				



Junction Layout

Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -100m
5-Incribed diameter-128m

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

The summary of forecasted traffic volume used as an input for the software in the capacity analysis is as shown in the table below:

Table 4-7 Summary of Traffic Analysis Result for Bambis Intersection

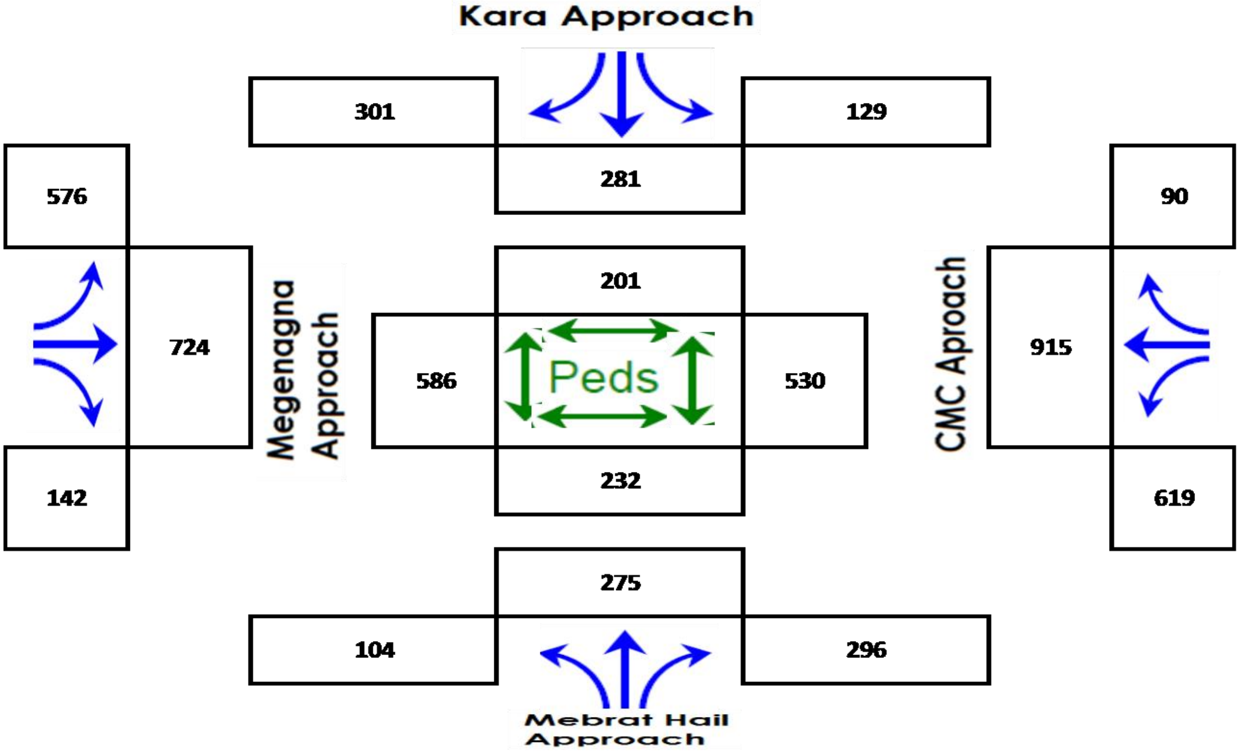
2.SUMMARY OF TRAFFIC ANALYSIS RESULT FOR BESHALE HOTEL ROUNDABOUT												
LEG 1: CMC APPROACH												
Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	637	8	62	15	0	0	645	77	722	474	530
	2016	807	10	77	19	1	1	817	99	915		
Right Turn Traffic (RT)	2013	65	0	1	2	0	0	65	3	68		
	2016	82	1	1	3	1	1	84	6	90		
Left Turn Traffic (LT)	2013	448	11	3	24	0	2	459	29	488		
	2016	567	14	4	30	1	3	581	38	619		
Total	2013	**1150**	**19**	**66**	**41**	**0**	**2**	**1169**	**109**	**1278**		
	2016	**1457**	**25**	**82**	**52**	**4**	**5**	**1481**	**143**	**1624**		
LEG 2: KARA APPROACH												
Through Traffic (TH)	2013	193	8	2	17	1	1	201	21	222	180	201
	2016	244	10	2	22	1	1	254	27	281		
Right Turn Traffic (RT)	2013	220	7	4	5	0	0	227	9	236		
	2016	279	9	5	6	1	1	287	14	301		
Left Turn Traffic (LT)	2013	96	0	2	0	0	0	96	2	98		
	2016	122	1	2	1	1	1	123	6	129		
Total	2013	**509**	**15**	**8**	**22**	**1**	**1**	**524**	**32**	**556**		
	2016	**645**	**20**	**10**	**29**	**4**	**4**	**665**	**47**	**711**		
LEG 3: MEGENAGNA APPROACH												
Through Traffic (TH)	2013	479	13	48	31	0	1	492	80	572	524	586
	2016	607	16	60	39	1	1	623	102	724		
Right Turn Traffic (RT)	2013	96	7	4	3	0	0	103	7	110		
	2016	122	9	5	4	1	1	130	11	142		
Left Turn Traffic (LT)	2013	411	9	19	14	0	0	420	33	453		
	2016	521	11	24	18	1	1	532	44	576		
Total	2013	**986**	**29**	**71**	**48**	**0**	**1**	**1015**	**120**	**1135**		
	2016	**1249**	**36**	**88**	**61**	**4**	**4**	**1285**	**157**	**1442**		
LEG 4: MEBRAT HAIL APPROACH												
Through Traffic (TH)	2013	191	4	11	9	0	0	195	20	215	207	232
	2016	242	5	14	11	1	1	247	28	275		
Right Turn Traffic (RT)	2013	189	13	7	23	0	0	202	30	232		
	2016	239	16	9	29	1	1	255	40	296		
Left Turn Traffic (LT)	2013	74	1	3	2	0	0	75	5	80		
	2016	94	1	4	3	1	1	95	9	104		
Total	2013	**454**	**18**	**21**	**34**	**0**	**0**	**472**	**55**	**527**		
	2016	**575**	**22**	**26**	**43**	**4**	**4**	**597**	**77**	**674**		

The Summary of input data including projected traffic volume is as shown in the following diagram.

Diagrammatical Representation of Input Data for SIDRAINTERSECTION SOFTWARE

Name of Intersection: Beshale Hotel Roundabout

Type of Input Data: Demand Traffic Volume



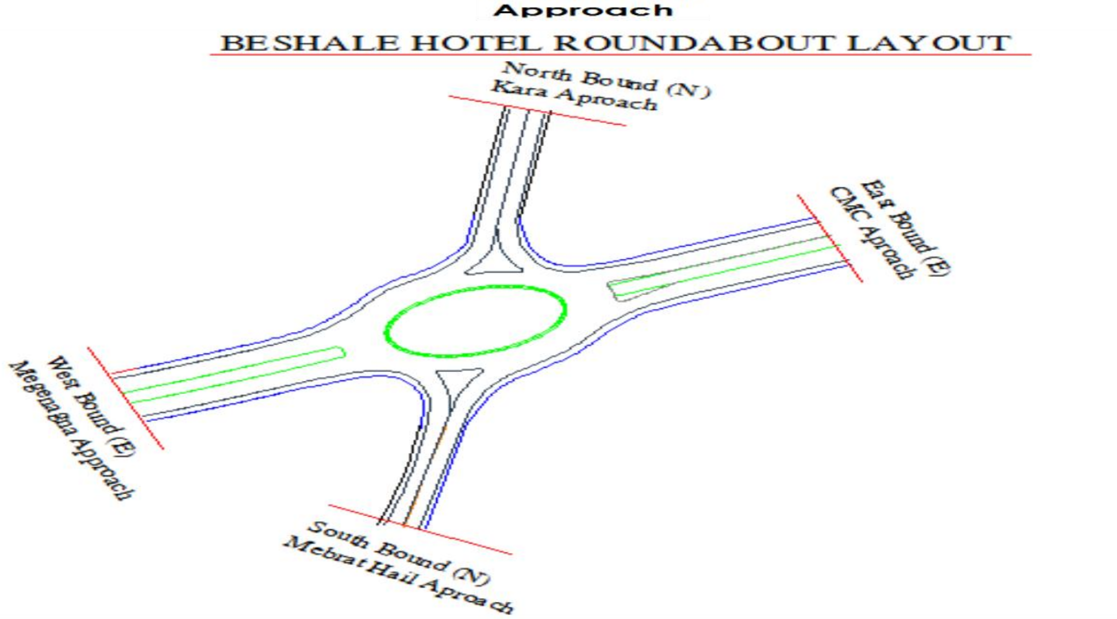


Figure 4-5 Diagrammatical sketch for input traffic data of Beshale Hotel Roundabout

The average delay and LOS Analysis result is as depicted in the table below:

Table 4-8 Average Delay and LOS Analysis output using SIDRA INTERSECTION for Beshale Hotel Roundabout before the LRT

Movement Performance – Vehicles Before LRT						
Movement ID	**Turn**	**Demand Flow**	**HV**	**Degree of Saturation**	**Average Delay**	**Level of Service**
		veh/h	**%**	**v/c**	**sec**	
South: MEBRAT HAIL						
3	L	113	8.7	0.702	35.1	LOS E
8	T	299	10.2	0.702	34.2	LOS D
18	R	321	13.6	0.702	35.5	LOS E
Approach		733	11.4	0.702	34.9	LOS D
East: CMC APPROACH						
1	L	673	6.1	1.347	198.3	LOS F
6	T	996	10.8	1.347	198.9	LOS F
16	R	98	6.7	0.236	12.5	LOS B
Approach		1766	8.8	1.347	188.4	LOS F
North: KARA APPROACH						
7	L	140	4.7	0.715	35.8	LOS E
4	T	305	9.6	0.715	34.7	LOS D
14	R	327	4.7	0.715	34.9	LOS D
Approach		1376	6.6	0.715	35.0	LOS D
West: MEGENAGNA APPROACH						
10	L	626	7.6	1.198	141.2	LOS F
11	T	788	14.1	1.198	141.4	LOS F
12	R	153	7.8	0.384	16.5	LOS C
Approach		1567	10.9	1.198	129.6	LOS F
All Vehicles		4839	9.5	1.347	121.6	LOS F

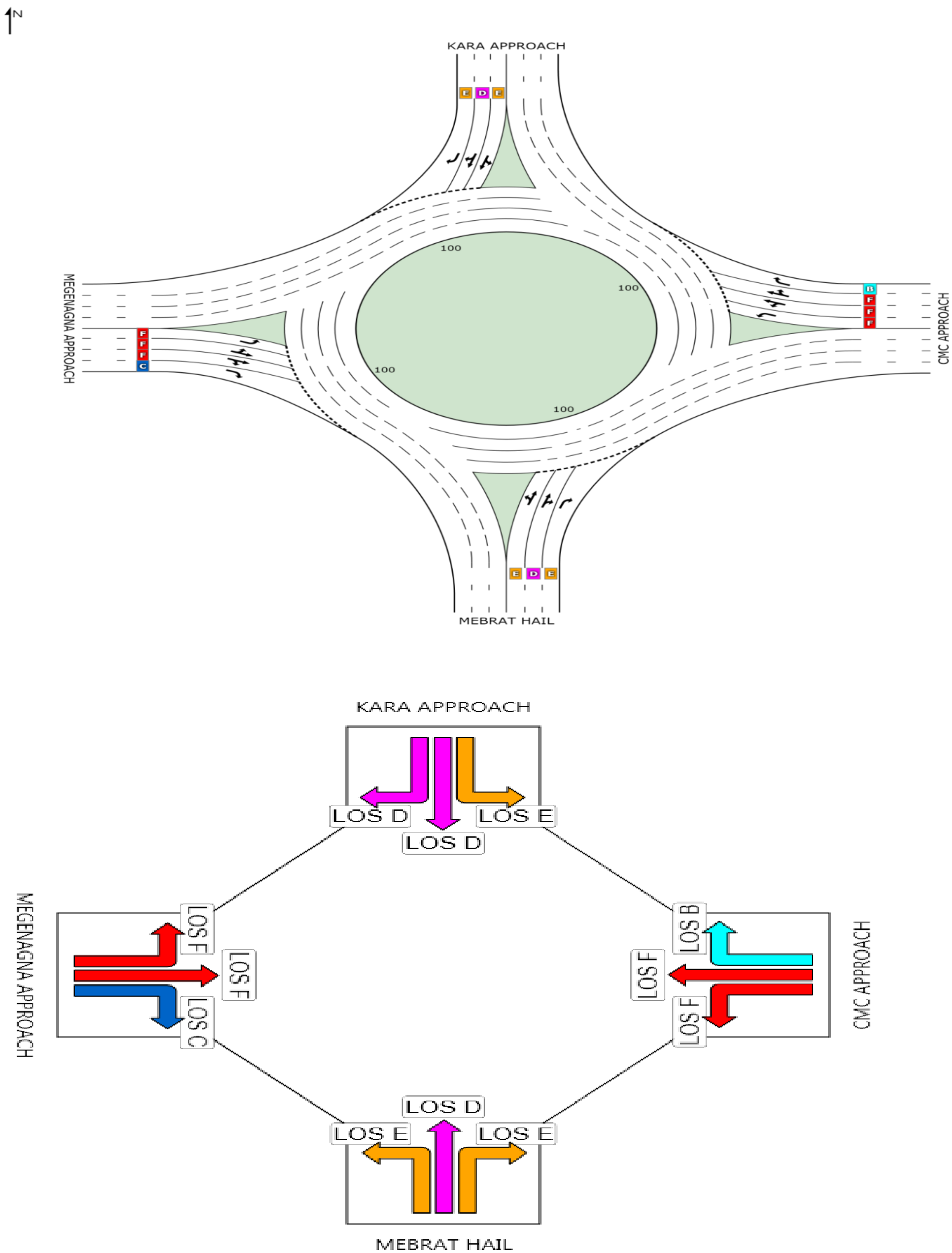


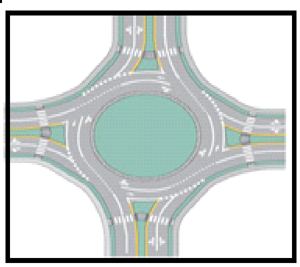
Figure 4-6 Average Delay and LOS Analysis output Display of Beshale Hotel Roundabout before the LRT

C. Average Delay and LOS Analysis of CMC Round about Before LRT

For the LOS analysis of this site, the geometric and directional hourly traffic volume data are prepared as an input for SIDRA INTERSECTION Software as indicated in table below:

Table 4-9 Summaries of Traffic Count and Geometric Data for CMC Round About

3. CMC ROUND ABOUT													
Time of Count: 8:00AM-9:00 AM	Survey Location: CMC ROUND ABOUT						Date: 22/05/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
LEG 1: SUMMIT APPROACH													
Through Traffic (TH)	51	4	3	1	2	1	55	7	62	127	2	4	25
Right Turn Traffic (RT)	65	5	6	12	1	0	70	19	89				
Left Turn Traffic (LT)	255	5	12	5	0	0	260	17	277				
Total	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**				
LEG 2: AYAT APPROACH													
Through Traffic (TH)	693	12	45	14	2	1	705	62	767	401	4	3.5	11
Right Turn Traffic (RT)	71	8	2	1	1	1	79	5	84				
Left Turn Traffic (LT)	199	5	8	16	0	1	204	25	229				
Total	**963**	**25**	**55**	**31**	**3**	**3**	**988**	**92**	**1,080**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	367	18	45	27	0	0	385	72	457	35	4	3.5	11
Right Turn Traffic (RT)	294	7	25	14	0	1	301	40	341				
Left Turn Traffic (LT)	55	3	3	1	2	1	58	7	65				
Total	**716**	**28**	**73**	**42**	**2**	**2**	**744**	**119**	**863**				
LEG 4: SUNSHINE REAL ESTATE (Generated Traffic)													
Through Traffic (TH)	51	4	3	1	2	1	0	7	7	42	2	3.5	25
Right Turn Traffic (RT)	249	5	9	12	1	0	254	22	276				
Left Turn Traffic (LT)	65	5	6	12	1	0	70	19	89				
Total	**365**	**14**	**18**	**25**	**4**	**1**	**0**	**48**	**48**				



Junction Lay out

Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -125m
5-Incribed diameter-153m

Notes:-

-The inscribed diameter includes twice the circulatory road width plus central island diameter.

-Generated traffic is considered in the Sunshine Realstate Approach by assumming similar socio-economic factor to that of the Summit Approach.

Table 4-10 Summary of Traffic Input Data for CMC Round About

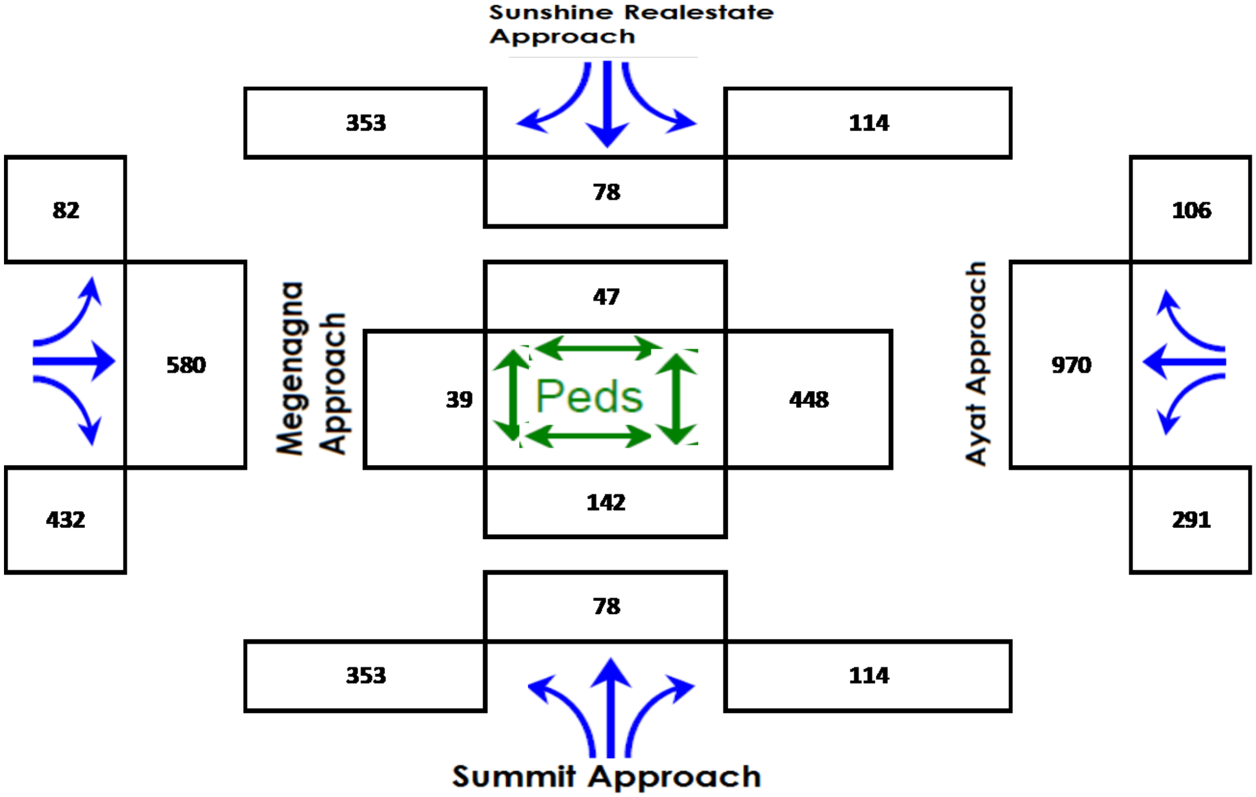
3. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR CMC ROUNDABOUT												
LEG 1:SUMMIT APPROACH												
Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	51	4	3	1	2	1	55	7	62	127	142
	2016	65	5	4	1	3	1	70	9	78		
Right Turn Traffic (RT)	2013	65	5	6	12	1	0	70	19	89		
	2016	82	6	7	15	1	1	89	25	114		
Left Turn Traffic (LT)	2013	255	5	12	5	0	0	260	17	277		
	2016	323	6	15	6	1	1	329	24	353		
Total	**2013**	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**		
	2016	**470**	**17**	**26**	**23**	**5**	**4**	**487**	**58**	**545**		
LEG 2: AYAT APPROACH												
Through Traffic (TH)	2013	693	12	45	14	2	1	705	62	767	401	448
	2016	878	15	56	18	3	1	893	78	970		
Right Turn Traffic (RT)	2013	71	8	2	1	1	1	79	5	84		
	2016	90	10	2	1	1	1	100	6	106		
Left Turn Traffic (LT)	2013	199	5	8	16	0	1	204	25	229		
	2016	252	6	10	20	1	1	258	33	291		
Total	**2013**	**963**	**25**	**55**	**31**	**3**	**3**	**988**	**92**	**1080**		
	2016	**1220**	**31**	**68**	**39**	**5**	**4**	**1251**	**117**	**1367**		
LEG 3: MEGENAGNA APPROACH												
Through Traffic (TH)	2013	367	18	45	27	0	0	385	72	457	35	39
	2016	465	22	56	34	1	1	487	93	580		
Right Turn Traffic (RT)	2013	294	7	25	14	0	1	301	40	341		
	2016	372	9	31	18	1	1	381	51	432		
Left Turn Traffic (LT)	2013	55	3	3	1	2	1	58	7	65		
	2016	70	4	4	1	3	1	73	9	82		
Total	**2013**	**716**	**28**	**73**	**42**	**2**	**2**	**744**	**119**	**863**		
	2016	**907**	**35**	**91**	**53**	**5**	**4**	**942**	**153**	**1095**		
LEG 4: SUNSHINE REAL ESTATE (GENERATED TRAFFIC)												
Through Traffic (TH)	2013	51	4	3	1	2	1	55	7	62	42	47
	2016	65	5	4	1	3	1	70	9	78		
Right Turn Traffic (RT)	2013	255	5	12	5	0	0	260	17	277		
	2016	323	6	15	6	1	1	329	24	353		
Left Turn Traffic (LT)	2013	65	5	6	12	1	0	70	19	89		
	2016	82	6	7	15	1	1	89	25	114		
Total	**2013**	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**		
	2016	**470**	**17**	**26**	**23**	**5**	**4**	**487**	**58**	**545**		

Digramattically the projected traffic data is shown in the table below:

<u>Diagrammatical Representation of Input Data for SIDRAINTERSECTION SOFTWARE</u>

Name of Intersection:<u>CMC ROUND ABOUT</u>

Type of Input Data: <u>Demand Traffic Volume</u>



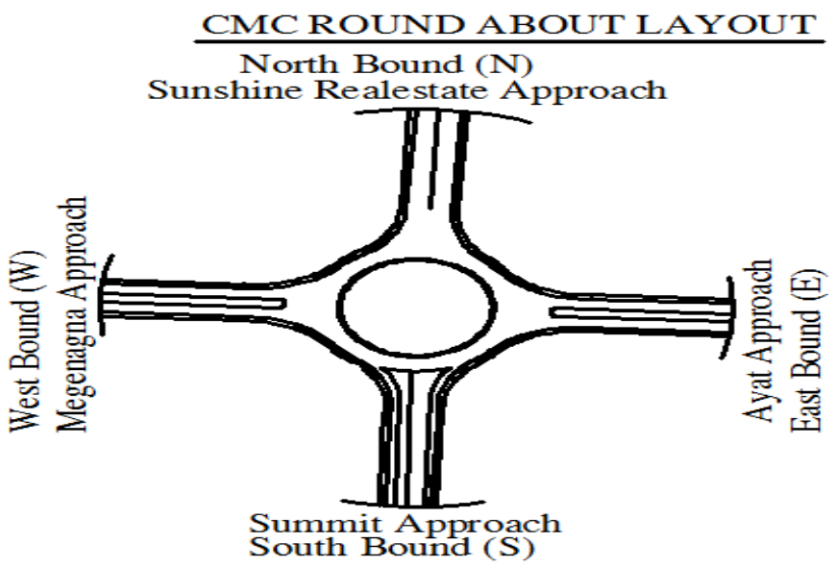
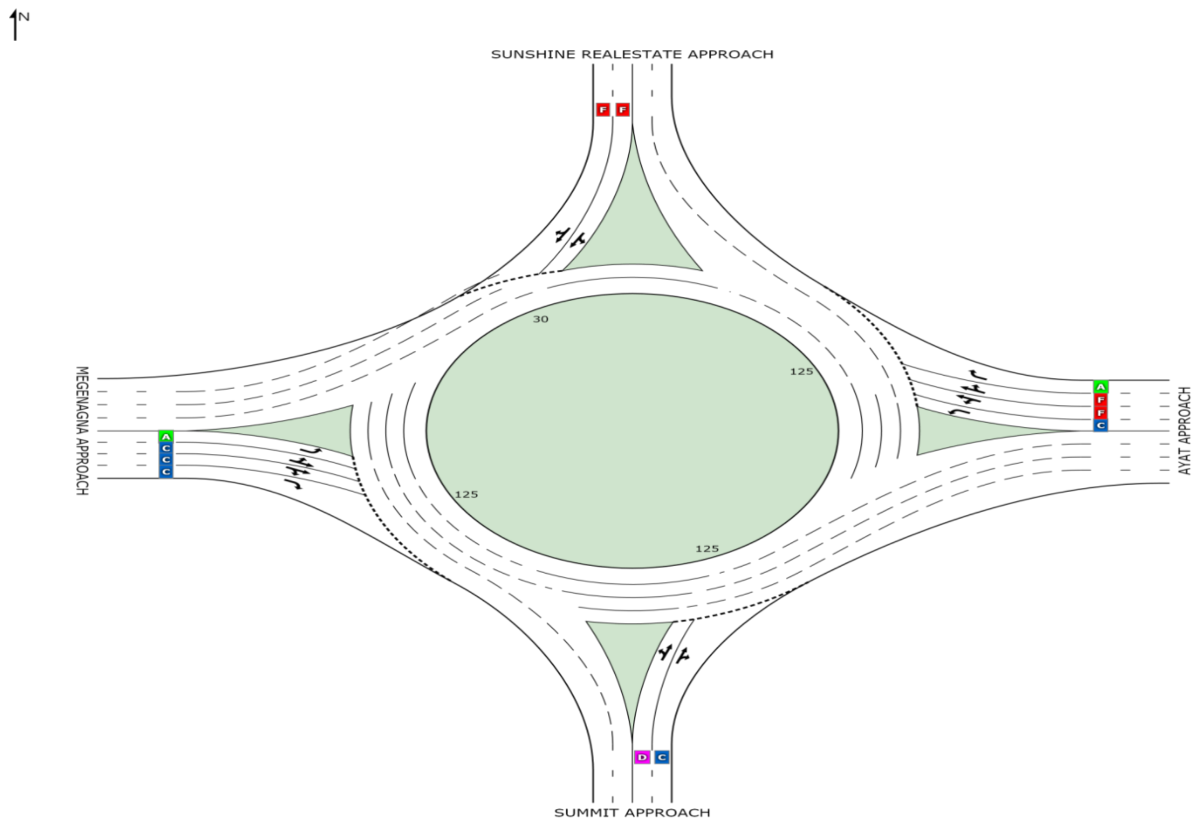


Figure 4-7 Diagrammatical sketch for input traffic data of CMC Roundabout

Table 4-11 Average Delay and LOS Analysis output using SIDRA INTERSECTION for CMC Roundabout before the LRT

Movement Performance – Vehicles before the LRT						
Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South: SUMMIT APPROACH						
1	L	384	6.8	0.724	26.2	LOS D
8	T	86	11.4	0.458	16.6	LOS C
2	R	124	21.9	0.458	16.6	LOS C
Approach		593	10.6	0.724	22.8	LOS C
East: AYAT APPROACH						
3	L	316	11.3	0.59	18.9	LOS C
4	T	1055	8.0	0.941	51.6	LOS F
16	R	115	5.7	0.204	9.0	LOS A
Approach		2645	8.6	0.941	41.4	LOS E
North: SUNSHINE REALESTATE APPROACH						
7	L	124	21.9	0.909	82.2	LOS F
4	T	86	11.4	0.909	82.2	LOS F
14	R	384	6.8	1.373	224.4	LOS F
Approach		593	10.6	1.373	174.1	LOS F
West: MEGENAGNA APPROACH						
5	L	89	11.0	0.140	7.3	LOS A
5	T	630	16.0	0.586	16.8	LOS C
6	R	470	11.8	0.586	16.1	LOS C
Approach		1189	14.0	0.586	15.8	LOS C
All Vehicles		6877	10.9	1.373	51.1	LOS F



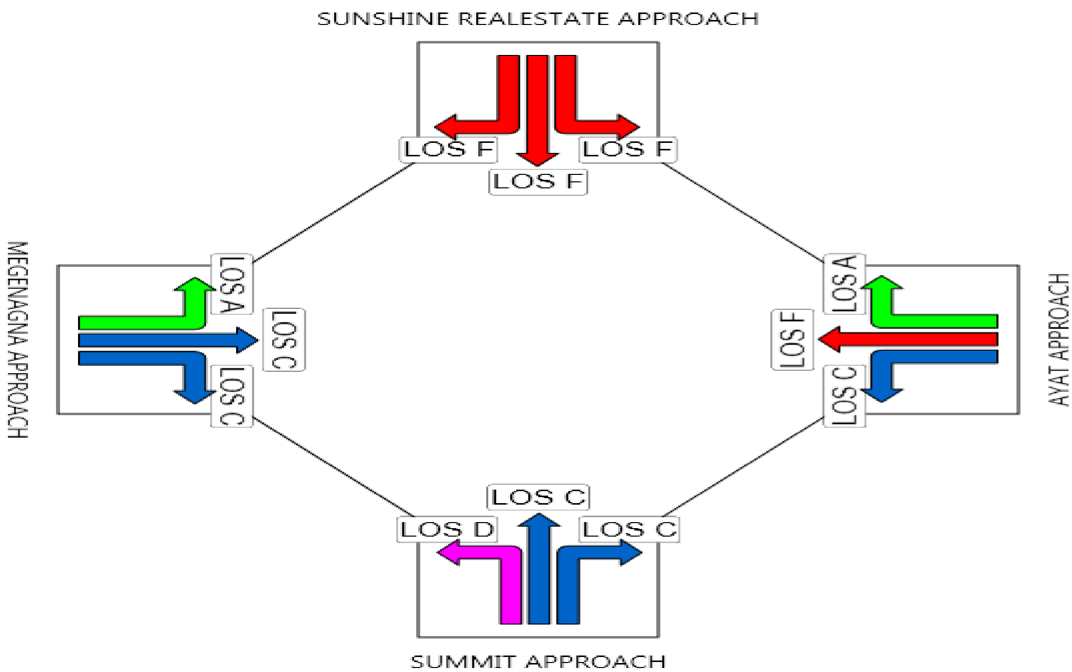


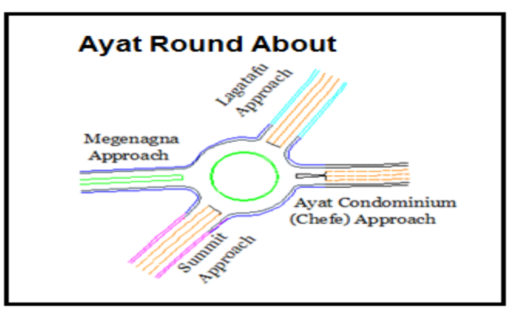
Figure 4-8 LOS Analysis output Display of CMC Roundabout before the LRT

D. Average Delay and LOS Analysis of Ayat Round about Before LRT

The geometric and directional hourly traffic volume data of Ayat Round About are summarized in the table below:

Table 4-12 Summary of Traffic Count and Geometric Data for Ayat Round About

TRAFFIC AND GEOMETRIC DATA													
4. AYAT ROUND ABOUT JUNCTION													
LEG 1:MEGENAGNA APPROACH													
Time of Count: 8:00AM-9:00 AM	Survey Location: AYAT ROUNDABOUT						Date: 19/09/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Lane Width (m)	Median Width (m)
Through Traffic (TH)	370	11	30	1	1	1	381	33	414	189	4.00	3.75	11.00
Right Turn Traffic (RT)	252	0	1	0	0	1	252	2	254				
Left Turn Traffic (LT)	324	5	4	1	0	0	329	5	334				
Total	**946**	**16**	**35**	**2**	**1**	**2**	**962**	**40**	**1002**				
LEG 2: SUMMIT APPROACH													
Through Traffic (TH)	193	6	3	3	1	0	199	7	206	217	2.00	4.00	40.00
Right Turn Traffic (RT)	61	1	2	1	0	1	62	4	66				
Left Turn Traffic (LT)	200	1	0	1	1	0	201	2	203				
Total	**454**	**8**	**5**	**5**	**2**	**1**	**462**	**13**	**475**				
LEG 3: AYAT CONDOMINIUM APPROACH													
Through Traffic (TH)	519	9	39	1	1	1	528	42	570	198	2.00	3.50	29.00
Right Turn Traffic (RT)	32	5	0	1	0	0	37	1	38				
Left Turn Traffic (LT)	159	2	2	1	0	0	161	3	164				
Total	**710**	**16**	**41**	**3**	**1**	**1**	**726**	**46**	**772**				
LEG 4: LAGATAFU APPROACH													
Through Traffic (TH)	175	0	2	1	0	1	175	4	179	240	2.00	4.00	40.00
Right Turn Traffic (RT)	208	5	0	1	0	0	213	1	214				
Left Turn Traffic (LT)	76	3	1	1	1	0	79	3	82				
Total	**459**	**8**	**3**	**3**	**1**	**1**	**467**	**8**	**475**				



Additional Roundabout Geometric Data
1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 16m
4- Central island diameter -110m
5-Incribed diameter-142m

The following table depicts summary of the projected hourly traffic volume used as an input data for SIDRA Intersection software.

Table 4-13 Summary of Traffic Input Data for Ayat Round About

4. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR AYAT ROUNDABOUT												
LEG 1:MEGENAGNA APPROACH												
Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	370	11	30	1	1	1	381	33	414	189	211
	2016	469	14	37	1	1	2	482	42	524		
Right Turn Traffic (RT)	2013	252	0	1	0	0	1	252	2	254		
	2016	319	1	1	1	1	5	320	9	329		
Left Turn Traffic (LT)	2013	324	5	4	1	0	0	329	5	334		
	2016	410	6	5	1	1	2	417	10	426		
Total	**2013**	**946**	**16**	**35**	**2**	**1**	**2**	**962**	**40**	**1002**		
	2016	**1198**	**21**	**44**	**4**	**4**	**10**	**1219**	**61**	**1280**		
LEG 2: SUMMIT APPROACH												
Through Traffic (TH)	2013	193	6	3	3	1	0	199	7	206	217	243
	2016	244	7	4	4	1	2	252	11	263		
Right Turn Traffic (RT)	2013	61	1	2	1	0	1	62	4	66		
	2016	77	1	2	1	1	1	79	6	85		
Left Turn Traffic (LT)	2013	200	1	0	1	1	0	201	2	203		
	2016	253	1	0	1	1	1	255	4	258		
Total	**2013**	**454**	**8**	**5**	**5**	**2**	**1**	**462**	**13**	**475**		
	2016	**575**	**10**	**6**	**6**	**4**	**5**	**585**	**21**	**606**		
LEG 3: AYAT CONDOMINIUM APPROACH												
Through Traffic (TH)	2013	519	9	39	1	1	1	528	42	570	198	221
	2016	657	11	48	1	1	1	669	52	721		
Right Turn Traffic (RT)	2013	32	5	0	1	0	0	37	1	38		
	2016	41	6	0	1	1	1	47	4	51		
Left Turn Traffic (LT)	2013	159	2	2	1	0	0	161	3	164		
	2016	201	2	2	1	1	1	204	6	210		
Total	**2013**	**710**	**16**	**41**	**3**	**1**	**1**	**726**	**46**	**772**		
	2016	**899**	**20**	**51**	**4**	**4**	**4**	**919**	**63**	**982**		
LEG 4: LAGATAFU APPROACH												
Through Traffic (TH)	2013	175	0	2	1	0	1	175	4	179	240	268
	2016	222	1	2	1	1	1	223	6	229		
Right Turn Traffic (RT)	2013	208	5	0	1	0	0	213	1	214		
	2016	263	6	1	1	1	1	270	5	275		
Left Turn Traffic (LT)	2013	76	3	1	1	1	0	79	3	82		
	2016	96	4	1	1	1	1	100	5	105		
Total	**2013**	**459**	**8**	**3**	**3**	**1**	**1**	**467**	**8**	**475**		
	2016	**581**	**11**	**5**	**4**	**4**	**4**	**593**	**17**	**609**		

Diagrammatically, the final input data used in the capacity analysis of Ayat Round About is shown as follows:

Diagrammatical Representation of Input Data for SIDRAINTERSECTION SOFTWARE
Name of Intersection:AYAT ROUND ABOUT
Type of Input Data: Demand Traffic Volume

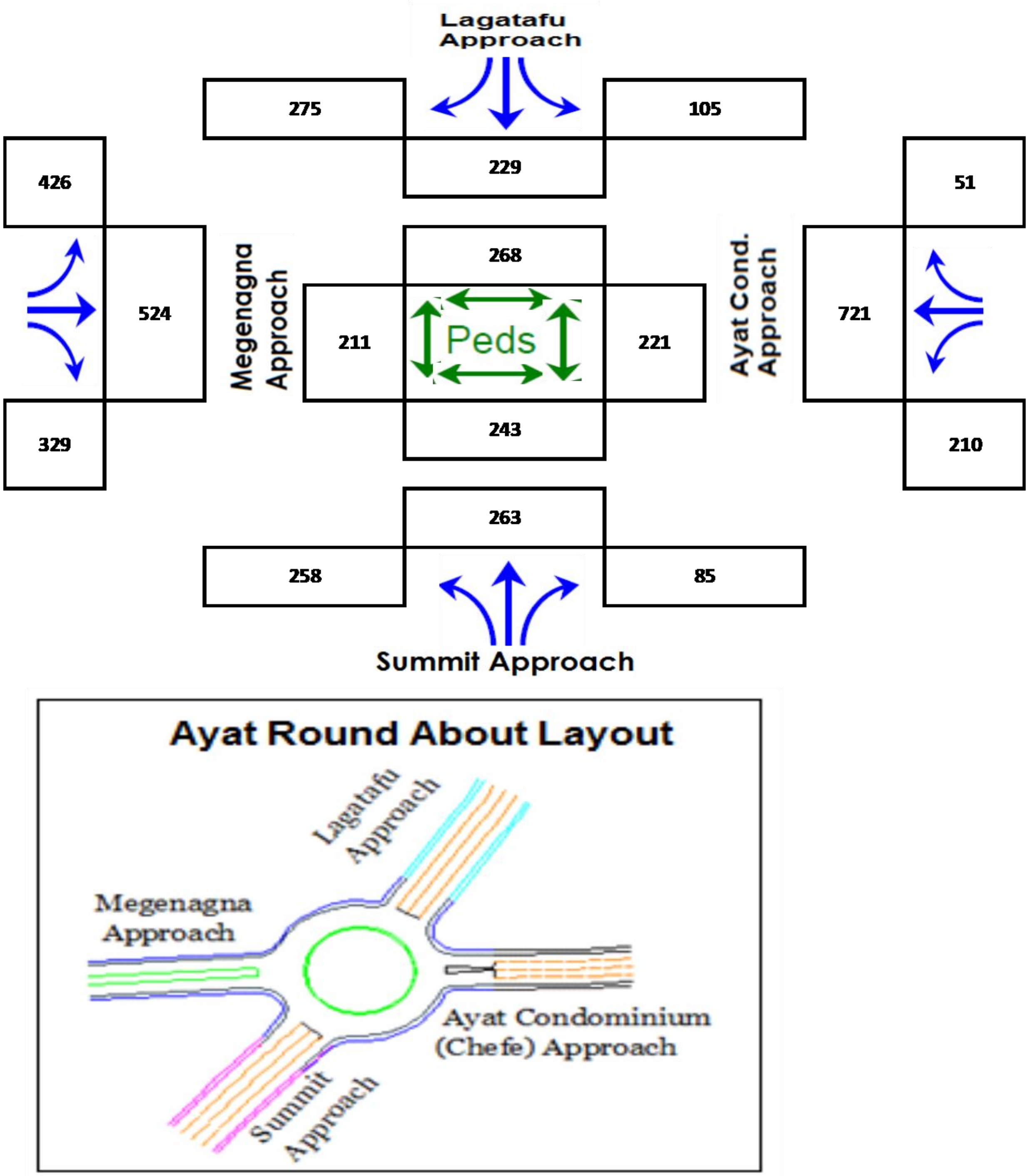


Figure 4-9 Diagrammatical Representation of input data for Ayat Round About

Table 4-14 Average Delay and LOS Analysis Ayat Roundabout using SIDRA INTERSECTION before the LRT

Movement Performance – Vehicles Before the LRT						
Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South: SUMMIT APPROACH						
1	L	282	1.5	0.738	31.6	LOS D
8	T	286	4.2	0.738	31.0	LOS D
2	R	92	7.1	0.738	30.9	LOS D
Approach		660	3.5	0.738	31.2	LOS D
East: AYAT COND. APPROACH						
3	L	228	2.9	1.121	107.8	LOS F
4	T	784	7.3	1.121	107.0	LOS F
16	R	55	7.8	1.121	106.6	LOS F
Approach		1067	6.3	1.121	107.2	LOS F
North: LAGATAFU APPROACH						
7	L	114	4.8	0.758	34.7	LOS D
4	T	249	2.6	0.758	34.3	LOS D
14	R	299	1.8	0.758	32.6	LOS D
Approach		662	2.6	0.758	33.6	LOS D
West: MEGENAGNA APPROACH						
5	L	464	2.3	0.817	29.3	LOS D
5	T	570	8.0	0.817	30.8	LOS D
6	R	358	2.7	0.559	15.3	LOS C
Approach		1391	4.8	0.817	26.3	LOS D
All Vehicles		3780	4.6	1.121	51.3	LOS F

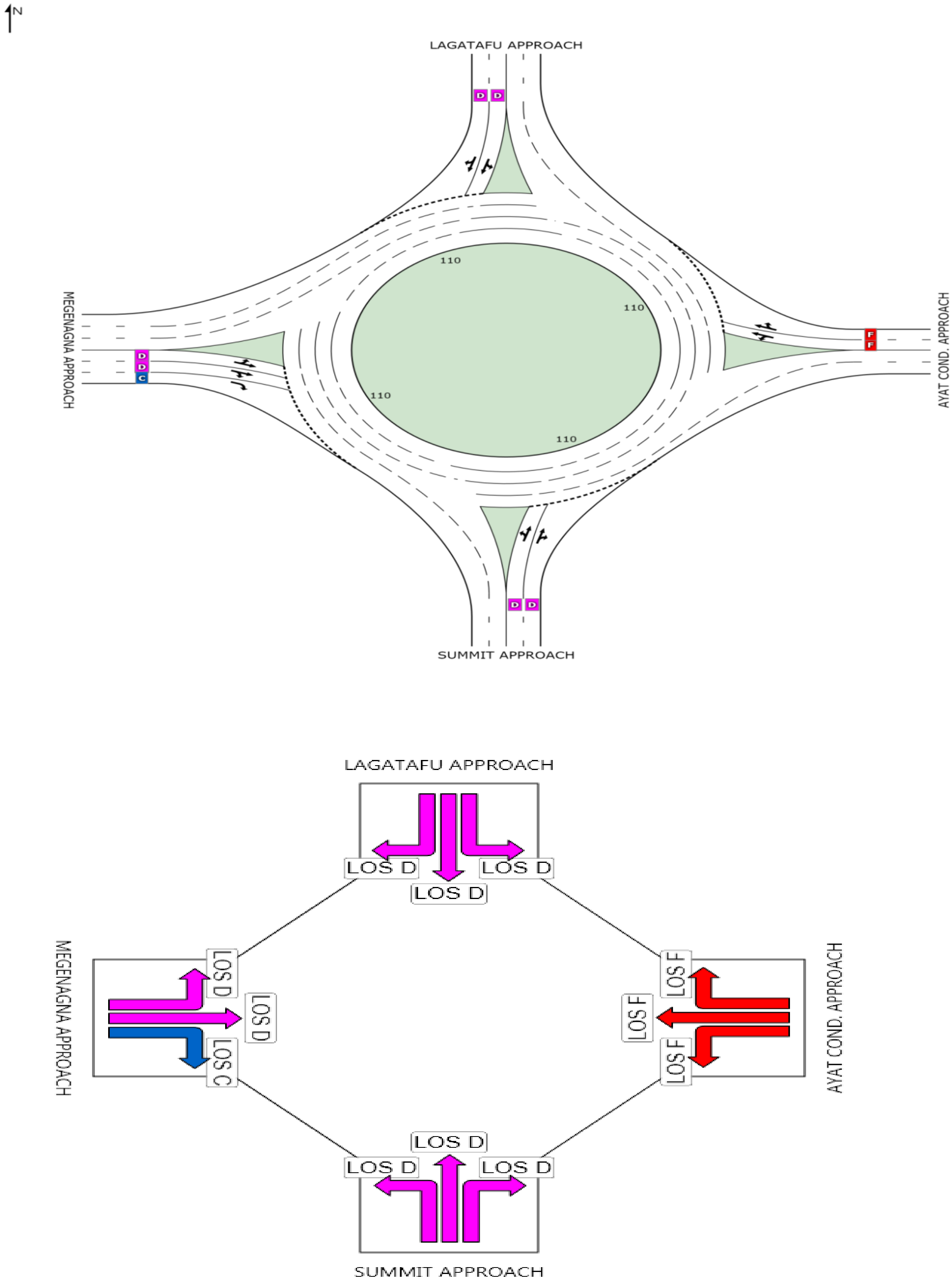


Figure 4-10 LOS Analysis output Display of Ayat Roundabout before the LRT

4.2.1.2 Average Delay and LOS Analysis of Intersections "After" LRT

As it is indicated in the methodology, the LOS of the four at-grade intersections is analyzed using SIDRA INTERSECTION software by converting Give way/yield control system of the site to "Stop Control" by taking the E-W as Major road with which the LRT and the through traffic will always pass uninterruptedly. Making the control type signalized complicates the evaluation and less suits the actual condition intended to be implemented after the LRT comes into service. Moreover, the software does not account the frequency of LRT vehicles at each signalized intersections. Using the prolonged cycle in the software would lead to in unacceptable result. Instead, each arrival of the Light Rail vehicles can be considered to be given an always priority which is incorporated in the stop way control system. This is possible because the Light Rail Vehicles will not be stopped with the signal. The purpose of the signal is to stop other conflicting vehicles by giving priority for the Light Rail Vehicles. This is the same as that in the stop way control system. Therefore, the "before" scenario will be treated by analyzing as "yield" control system and the "after" scenario will be analyzed by changing the "yield" control to "stop" control system.

The input traffic and geometric data is the same as the first scenario except the control type. Conversion of the sites to as top control is made using the program. After converting the yield control to a two way stop control with the E-W as major, proper assigning of priorities has been done for each approach.

(i) Average Delay and LOS Analysis of BAMBIS Intersection "After" LRT

In the "after scenario" it has been considered that private cars and taxi including medium buses will be reduced due to the modal shift to Light Rail Transit system. Based on different literatures 40% reduction of small vehicles has been assumed in the analysis. This applies to the other three junctions in the study.

Furthermore, in the "after" Scenario the output is based on the fact that the "Stop" Control will function for the full hour. However, in the actual condition, the LRT Vehicles will arrive every 6 minutes of time and the stop control is assumed to exist for 30 seconds per each arrival. The LRT Vehicles could cross the intersection less than 30 seconds. However, for safety and operational purpose, 30 seconds will be realistic. Hence, a total of 300 sec phase duration per 1 hour (3600 Sec) correction factor will be applied to the additional delay which is the difference of the after and before scenarios.

The average delay and LOS analysis result for Bambis Intersection after the introduction of LRT System is as indicated in table.

Table 4-15 Average Delay and LOS Analysis output of BAMBIS INTERSECTION (After LRT) using SIDRA INTERSECTION

Movement Performance - Vehicles after LRT						
Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South East: Olympia Approach						
3	R	412	5.3	0.213	9.7	LOS A
Approach		412	5.3	0.213	9.7	LOS A
East: Hayahulet Approach						
5	T	601	11.9	0.220	4.8	LOS A
6	R	34	16.1	0.220	4.8	LOS A
Approach		635	12.2	0.220	4.8	NA
North: Kasanchis Approach						
9	R	438	3.7	0.167	9.9	LOS A
Approach		438	3.7	0.167	9.9	LOS A
West: Meskel Square Approach						
11	T	473	15.8	0.183	4.7	LOS A
12	R	46	11.9	0.183	4.6	LOS A
Approach		518	15.6	0.183	4.7	NA
All Vehicles		2003	10.0	0.220	6.9	NA

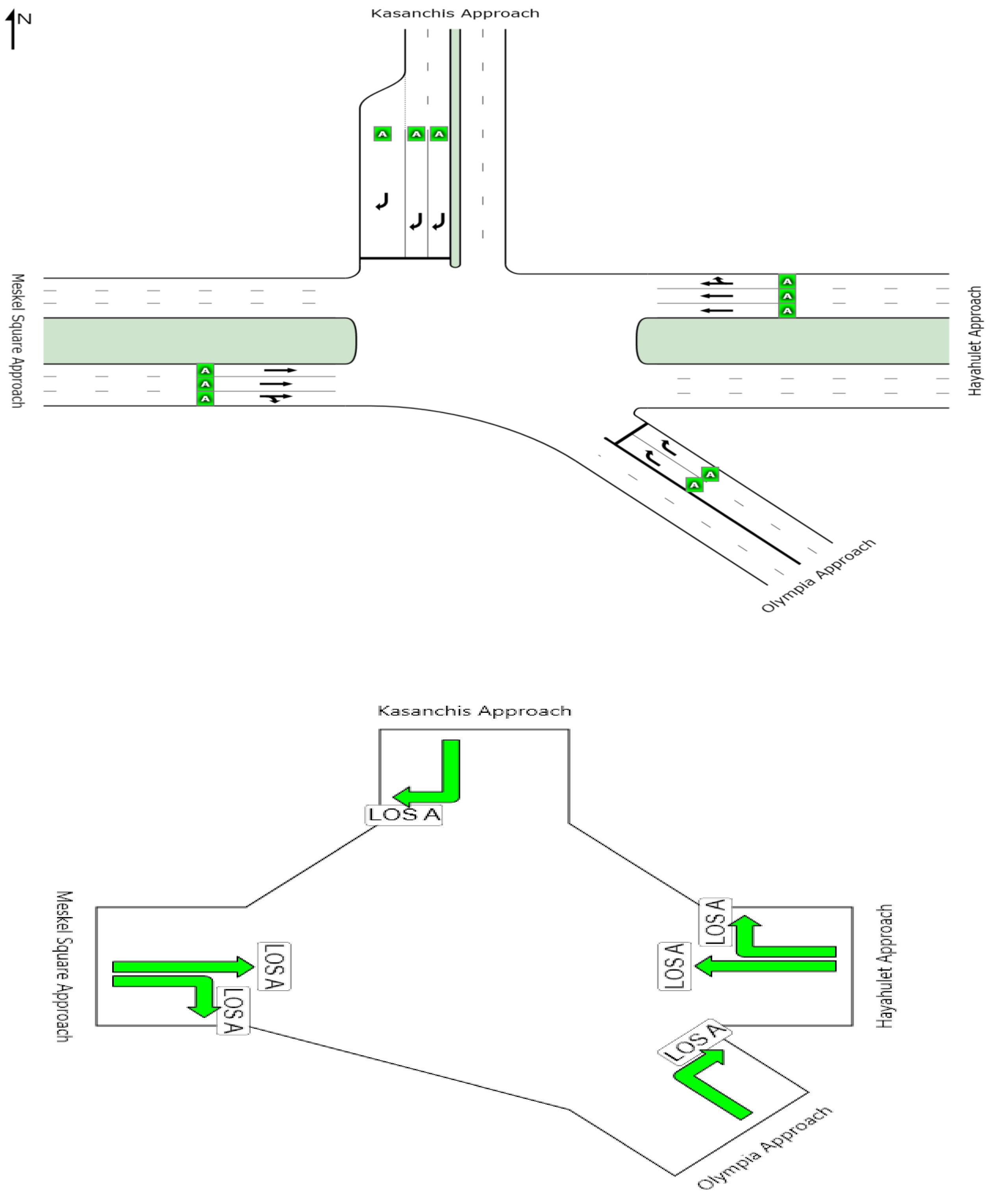


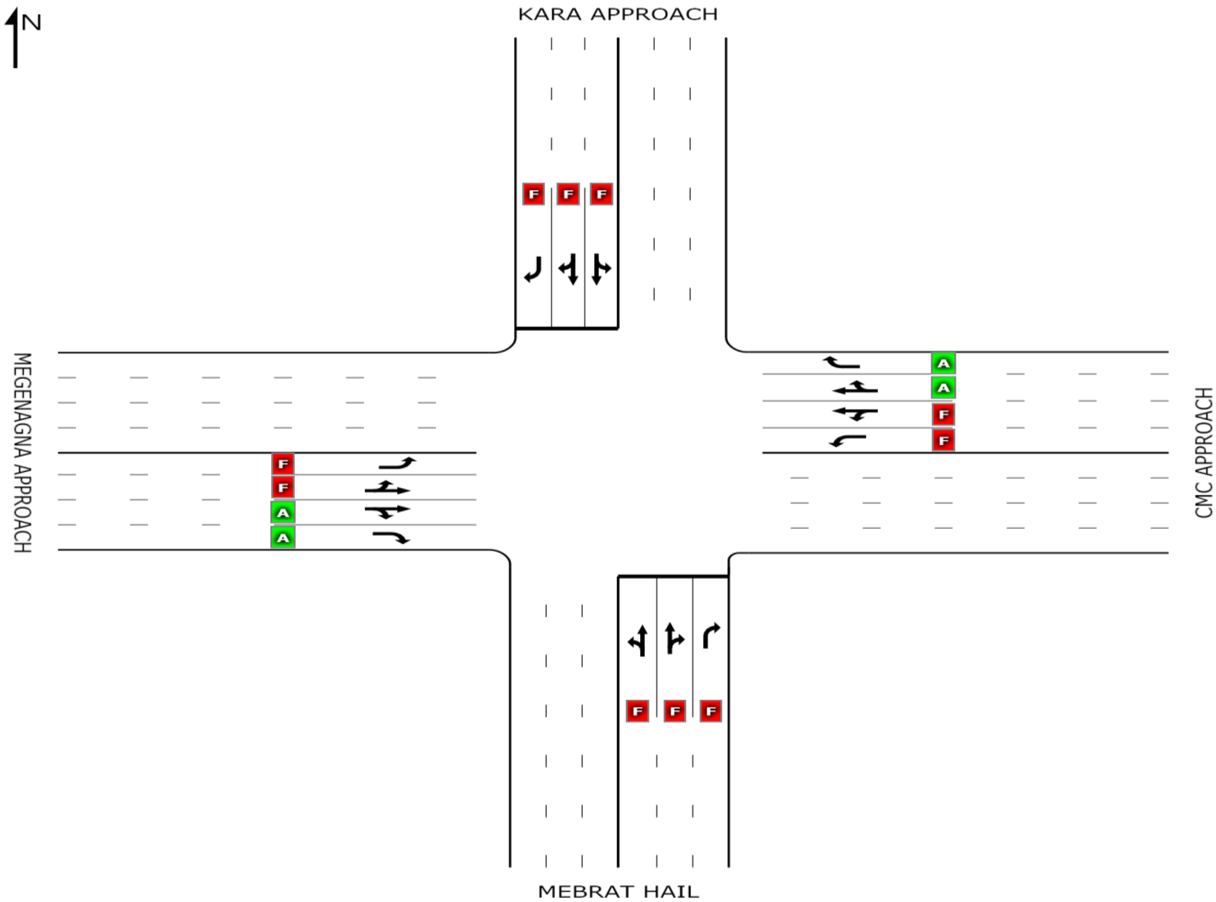
Figure 4-11 LOS Analysis output Display of BAMBIS Intersection (after LRT)

(ii) Average Delay and LOS Analysis of Beshale Hotel Roundabout “After” LRT

After converting the give way/yield control types to a stop control type, a different analysis result than the “before” scenario is obtained the summary of which is depicted below:

Table 4-16 Average Delay and LOS Analysis output using SIDRA INTERSECTION for Beshale Hotel Roundabout (After LRT)

Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South: MEBRAT HAIL						
1	L	72	13.6	2.210	703.1	LOS F
8	T	193	15.7	2.210	703.1	LOS F
2	R	217	20.0	0.924	84.7	LOS F
Approach		483	17.3	2.210	424.5	LOS F
East: CMC APPROACH						
3	L	426	9.7	2.309	669.2	LOS F
4	T	645	16.7	0.571	7.0	LOS A
16	R	62	10.5	0.060	3.8	LOS A
Approach		1133	13.7	2.309	256.0	NA
North: KARA APPROACH						
7	L	87	7.5	1.449	388.2	LOS F
4	T	354	14.7	3.333	1194.7	LOS F
14	R	367	7.4	0.798	57.5	LOS F
Approach		877	10.4	3.333	576.6	LOS F
West: MEGENAGNA APPROACH						
5	L	399	12.0	2.719	867.1	LOS F
5	T	524	21.2	0.506	6.8	LOS A
6	R	101	11.8	0.104	4.2	LOS A
Approach		1024	16.7	2.719	341.7	NA
All Vehicles		3133	14.7	3.333	360.5	NA



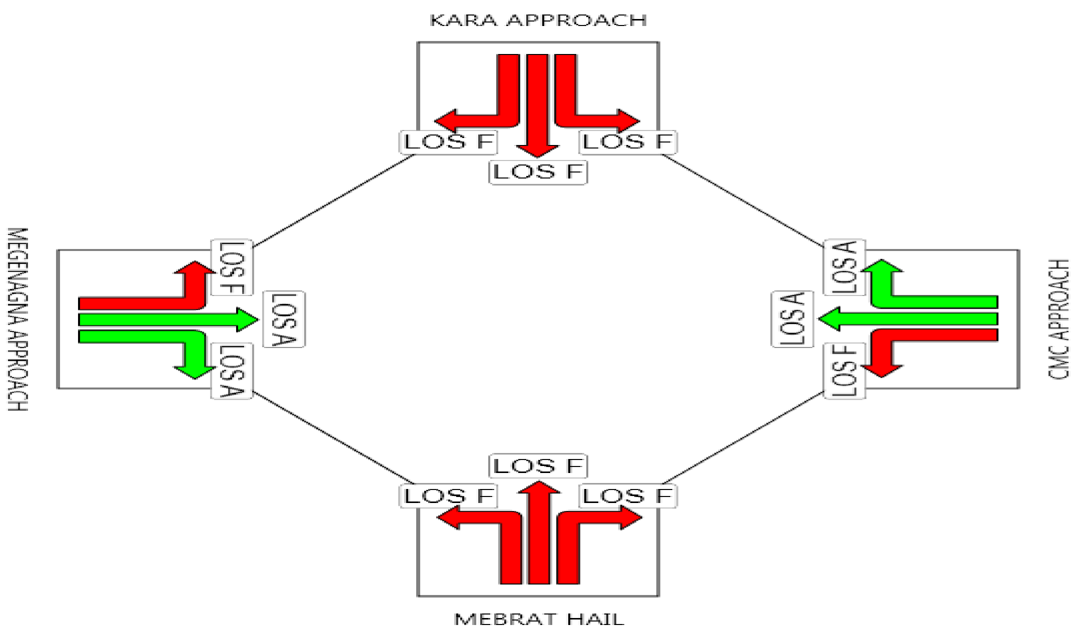


Figure 4-12 LOS Analysis output Display of Beshale Hotel Round About (after LRT)

(iii) Average Delay and LOS Analysis of CMC Roundabout "After" LRT

When the yield control system is converted into the stop control while the LRT passes, the roundabout could be assumed to act as cross intersection with the E-W as major direction getting priority with a stoppage of North-South traffic. With this assumption the analysis result is as indicated below:

Table 4-17 Average Delay and LOS Analysis output using SIDRA INTERSECTION for CMC Roundabout (After LRT)

Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South: SUMMIT APPROACH						
1	L	243	10.7	4.058	1516.6	LOS F
8	T	58	17.0	1.494	346.1	LOS F
2	R	88	30.9	1.494	346.1	LOS F
Approach		389	16.2	4.058	1078.5	LOS F
East: AYAT APPROACH						
3	L	207	17.4	1.053	171.3	LOS F
4	T	674	12.6	0.598	7.5	LOS A
16	R	76	8.6	0.057	3.0	LOS A
Approach		957	13.3	1.053	42.5	NA
North: SUNSHINE REALESTATE APPROACH						
7	L	88	30.9	1.699	488.0	LOS F
4	T	58	17.0	1.699	410.7	LOS F
14	R	243	10.7	1.699	386.1	LOS F
Approach		389	16.2	1.699	412.8	LOS F
West: MEGENAGNA APPROACH						
5	L	60	16.4	0.368	65.2	LOS F
5	T	428	23.6	0.364	4.9	LOS A
6	R	308	18.0	0.298	5.0	LOS A
Approach		796	20.9	0.368	9.5	NA
All Vehicles		2530	16.6	4.058	248.4	NA

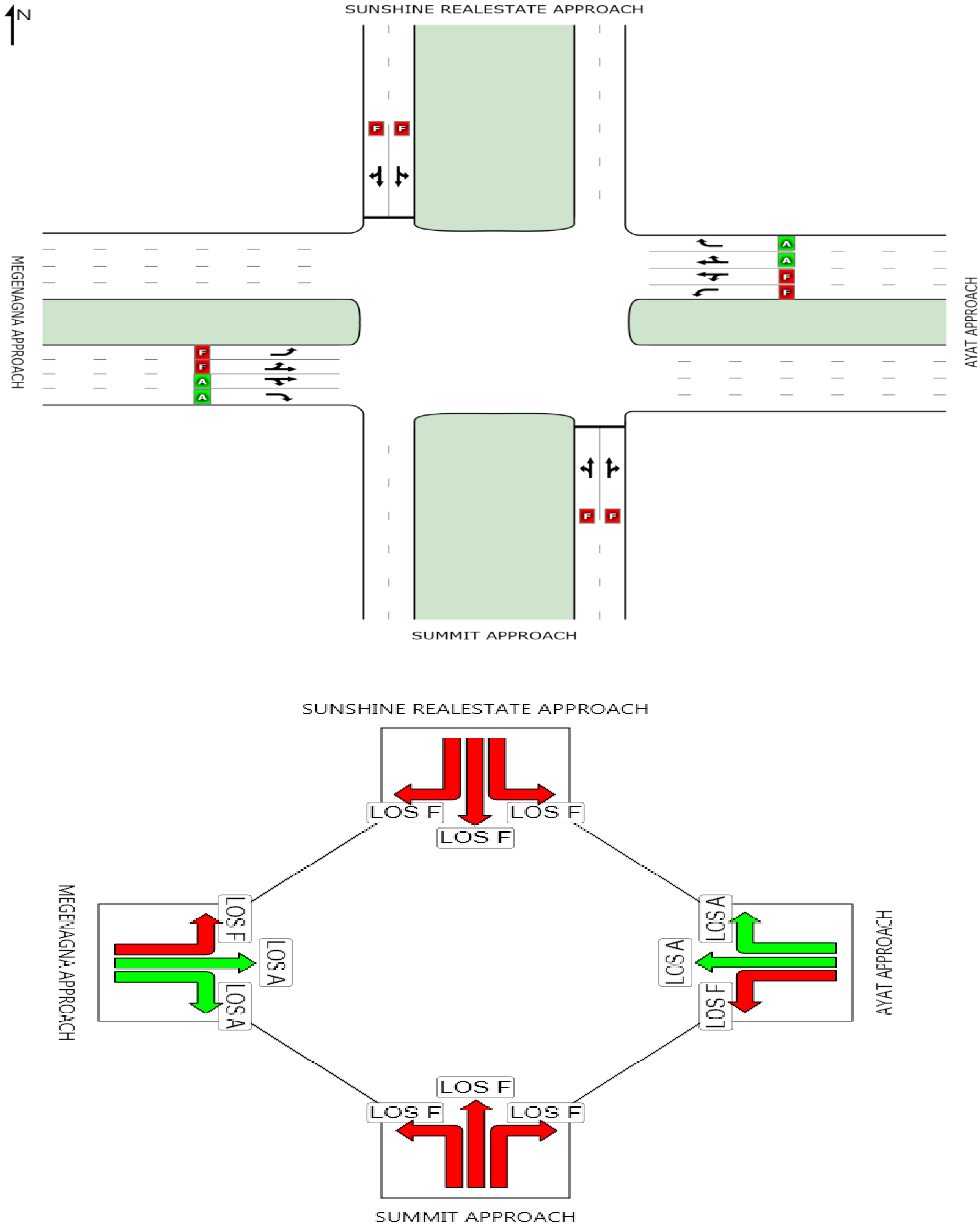


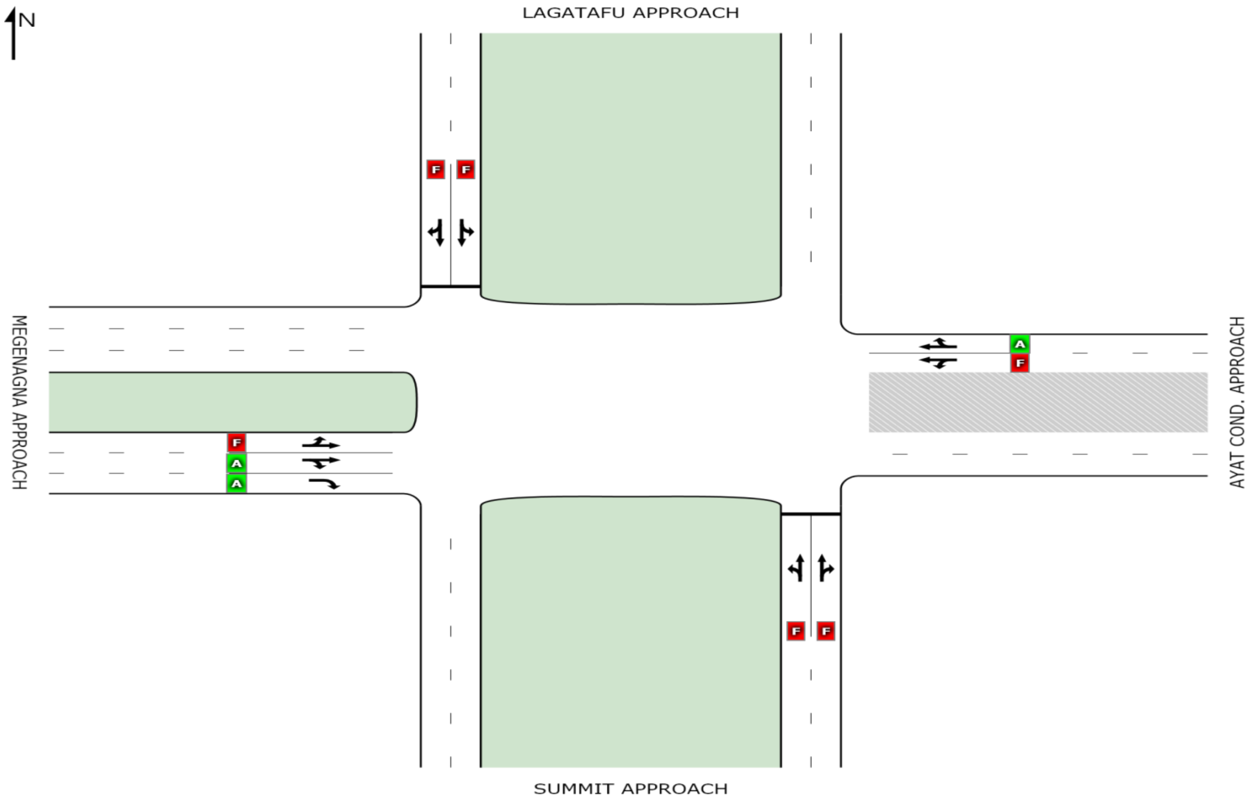
Figure 4-13 LOS Analysis output Display of CMC Round About (after LRT)

(iv) Average Delay and LOS Analysis of AYAT Roundabout "After" LRT

The yield control system before the introduction of LRT is converted into a two way stop control after the introduction of LRT by taking the East –West approaches as major. The analysis result is as indicated below:

Table 4-18 Average Delay and LOS Analysis of Ayat Round about using SIDRA INTERSECTION after LRT

Movement Performance - Vehicles After the LRT						
Movement ID	Turn	Demand Flow	HV	Degree of Saturation	Average Delay	Level of Service
		veh/h	%	v/c	sec	
South: SUMMIT APPROACH						
1	L	171	2.5	2.844	978.9	LOS F
8	T	179	6.7	2.110	591.2	LOS F
2	R	59	11.1	2.110	591.2	LOS F
Approach		409	5.6	2.844	753.1	LOS F
East: AYAT COND. APPROACH						
3	L	140	4.7	1.046	141.9	LOS F
4	T	498	11.4	0.434	5.1	LOS A
16	R	37	11.8	0.434	5.1	LOS A
Approach		675	10.0	1.046	33.5	NA
North: LAGATAFU APPROACH						
7	L	72	7.6	1.962	592.2	LOS F
4	T	152	4.3	1.962	536.3	LOS F
14	R	184	3.0	1.962	508.5	LOS F
Approach		408	4.3	1.962	533.6	LOS F
West: MEGENAGNA APPROACH						
5	L	285	3.8	1.511	289.2	LOS F
5	T	366	12.5	0.268	4.0	LOS A
6	R	220	4.5	0.161	3.4	LOS A
Approach		871	7.6	1.511	97.1	NA
All Vehicles		2362	7.4	2.844	267.8	NA



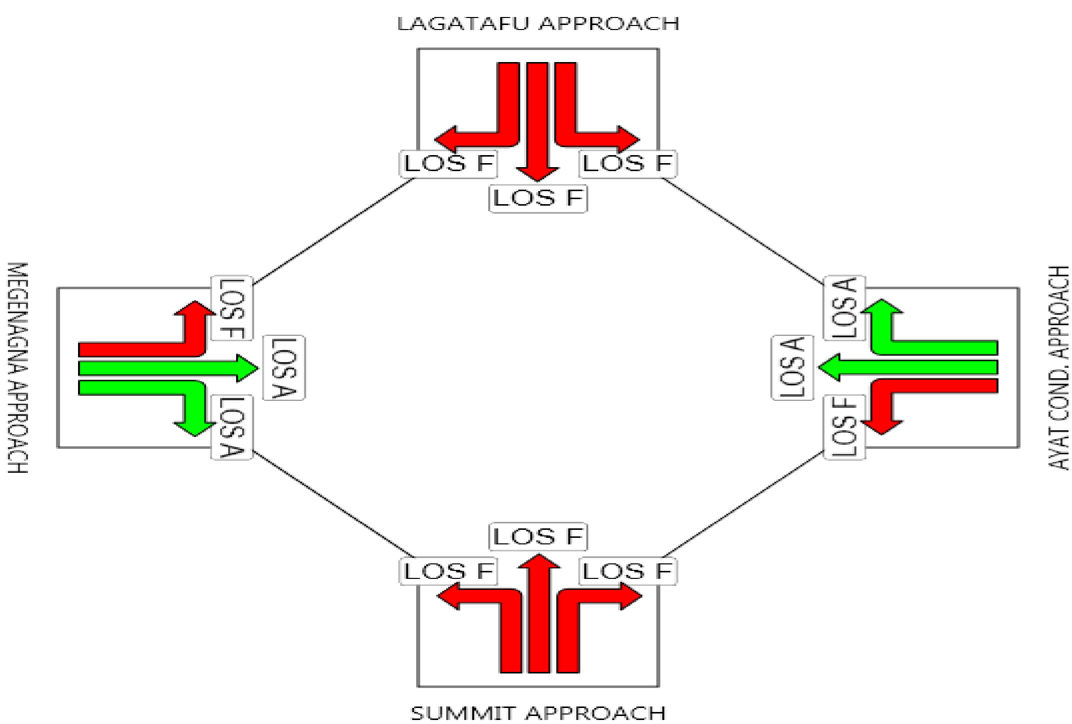


Figure 4-14 LOS Analysis output Display of AYAT Round About (after LRT)

4.2.2 Comparison of “Before” and “After” Scenarios with respect to Average Delay and LOS

As it is clearly shown in the methodology part of this research**,** the four intersections are analyzed as “before” and “after” the introduction of LRT. The “after” scenario is created by changing the Yield Control type to a two way Stop Control with East –West Approaches as major in order to represent the actual scenario.

The difference between the average total delay with LRT crossings and the baseline average total delay without LRT crossings is the *average additional delay*:

Average additional delay = average total delay with LRT crossings – average total delay without LRT.

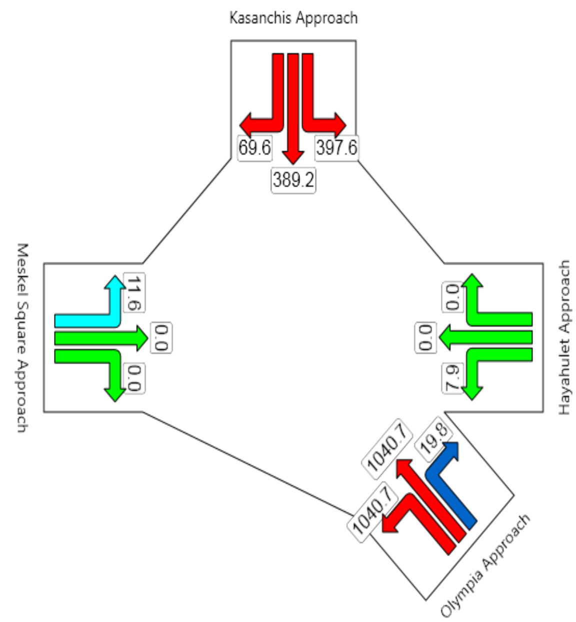
The major measure of effectiveness is taken to be the Average vehicular delay.

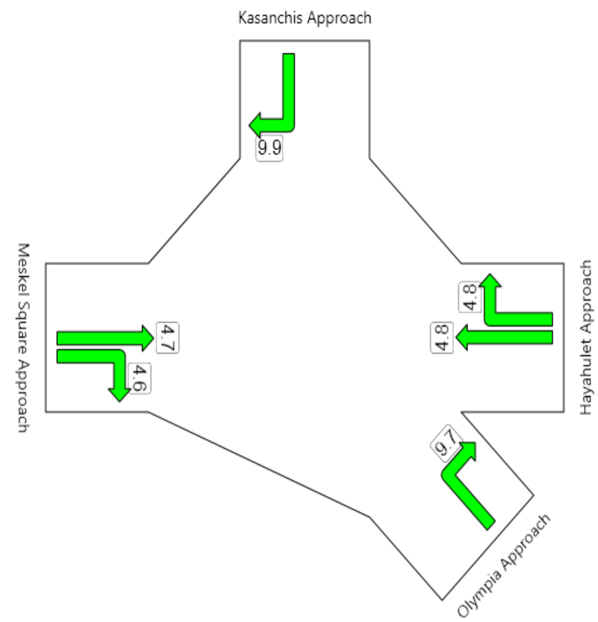
The performance of each lane is looked into before and after the introduction of Light Rail Transit to account for the left turns of all approaches and the through movement of opposed (N-S) approaches which are expected to be affected highly due to stoppage per every interval the LRT Vehicles pass.

Table 4-19 Comparison of Performance Measures for Bambis Intersection

Summary of Additional Delays at Bambis Intersection										
Movement ID	Turn Before	Turn After	Demand Flow Before veh/h	Demand Flow After veh/h	Level of Service Before	Level of Service After	Average Delay (s) Before	Average Delay (s) After	Difference	Corrected Value for Arrival of LRV every 6mins & 30 sec Phase Duration (x300/3600)
South East: Olympia Approach										
3	L		79		LOS F		1040.7			
8	T		304		LOS F		1040.7			
18	R	R	280	412	LOS C	LOS A	19.8	9.7	-10.1	-0.84
Approach			664	412	LOS F	LOS A	609.6	9.7	-599.9	-49.99
East: Hayahulet Approach										
1	L		146		LOS A		7.9			
6	T	T	197	601	LOS A	LOS A	0.0	4.8	4.8	0.40
16	R	R	51	34	LOS A	LOS A	0.0	4.8	4.8	0.40
Approach			993	635	NA	NA	1.2	4.8	3.6	0.30
North: Kasanchis Approach										
7	L		27		LOS F		397.6			
4	T		392		LOS F		389.2			
14	R	R	293	438	LOS F	LOS A	69.6	9.9	-59.7	-4.98
Approach			713	438	LOS F	LOS A	258.0	9.9	-248.1	-20.68
West: Meskel Square Approach										
10	L		151		LOS B		11.6			
11	T	T	574	473	LOS A	LOS A	0.0	4.7	4.7	0.39
12	R	R	72	46	LOS A	LOS A	0.0	4.6	4.6	0.38
Approach			797	518	NA	NA	2.2	4.7	2.5	0.21
All Vehicles			3167	2003	NA	NA	186.8	6.9	-179.9	-14.99

The result shows that the capacity of Bambis intersection is improved in the after scenario. With the upgrading of the main road, the LRT system will be separated with median delineation (curbstone) and the number of conflicts with the north and south approach traffic including left turns of the East and West traffic is avoided.





Average control delay per vehicle before LRT within an hour	**Average control delay per vehicle within an hour After LRT**

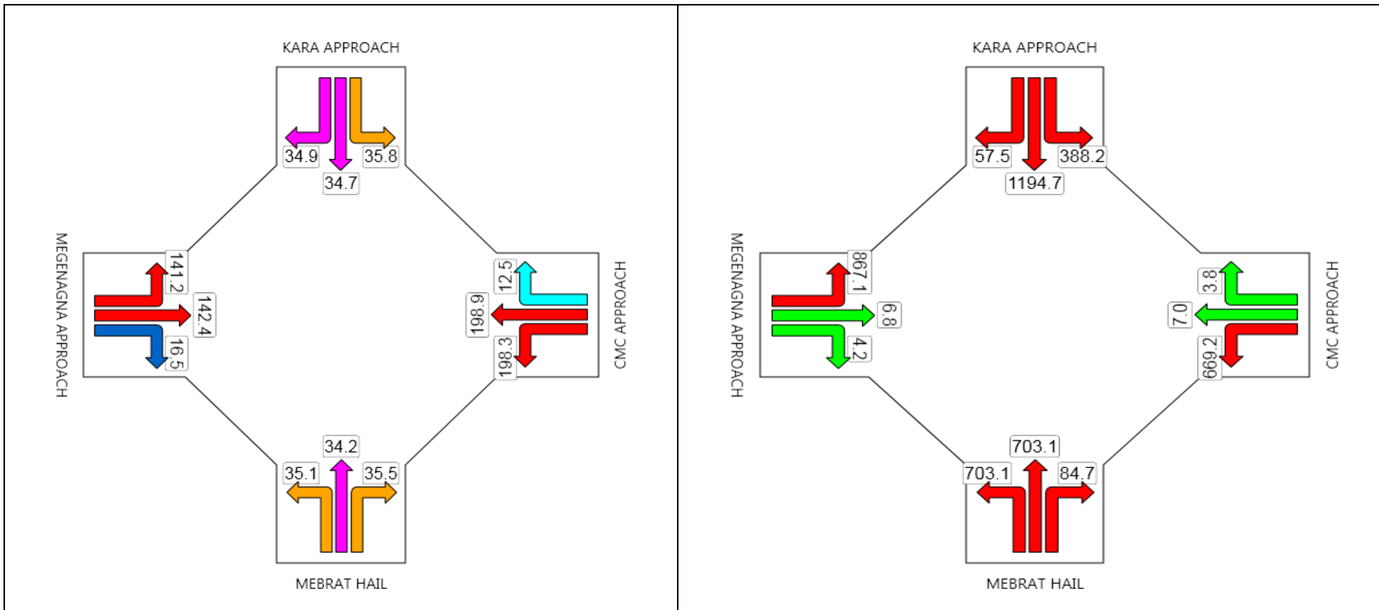
Figure 4-15 Comparison display of Average control delay for Bambis Intersection

In a similar technique, the comparison of performance measures for Beshale Hotel Round about before and after the introduction of LRT is as shown in the following table:

Table 4-20 Comparison of Performance Measures for Beshale Hotel Roundabout

Summary of Additional Delays at Beshale Hotel Round About										
Movement ID	Turn Before	Turn After	Demand Flow Before veh/h	Demand Flow After veh/h	Level of Service Before	Level of Service After	Average Delay (s) Before	Average Delay (s) After	Difference	Corrected Value for Arrival of LRV every 6mins & 30 sec Phase Duration
South: Mebrathail Approach										
3	L	L	113	72	LOS E	LOS F	35.1	703.1	668	55.67
8	T	T	299	193	LOS D	LOS F	34.2	703.1	668.9	55.74
18	R	R	321	217	LOS E	LOS F	35.5	84.7	49.2	4.10
Approach			733	483	LOS D	LOS F	34.9	424.5	389.6	32.47
East: CMC Approach										
1	L	L	673	426	LOS F	LOS F	198.3	669.2	470.9	39.24
6	T	T	996	645	LOS F	LOS A	198.9	7.0	-191.9	-15.99
16	R	R	98	62	LOS B	LOS A	12.5	3.8	-8.7	-0.73
Approach			1766	1133	LOS F	NA	188.4	256.0	67.6	5.63
North: Kara Approach										
7	L	L	140	87	LOS E	LOS F	150.9	388.2	237.3	19.78
4	T	T	305	200	LOS D	LOS F	149.5	1194.7	1045.2	87.10
14	R	R	327	207	LOS D	LOS F	149.8	57.5	-92.3	-7.69
Approach			773	493	LOS D	LOS F	149.9	576.6	426.7	35.56
West: Megenagna Approach										
10	L	L	626	399	LOS F	LOS F	141.2	867.1	725.9	60.49
11	T	T	788	524	LOS F	LOS A	142.4	6.8	-135.6	-11.30
12	R	R	153	101	LOS C	LOS A	16.5	4.2	-12.3	-1.03
Approach			1567	1024	LOS F	NA	129.6	341.7	212.1	17.68
All Vehicles			4839	3133	LOS F	NA	121.6	360.5	238.9	19.91

An additional control delay of the left turns of all approaches and the through traffic of North-South is observed.



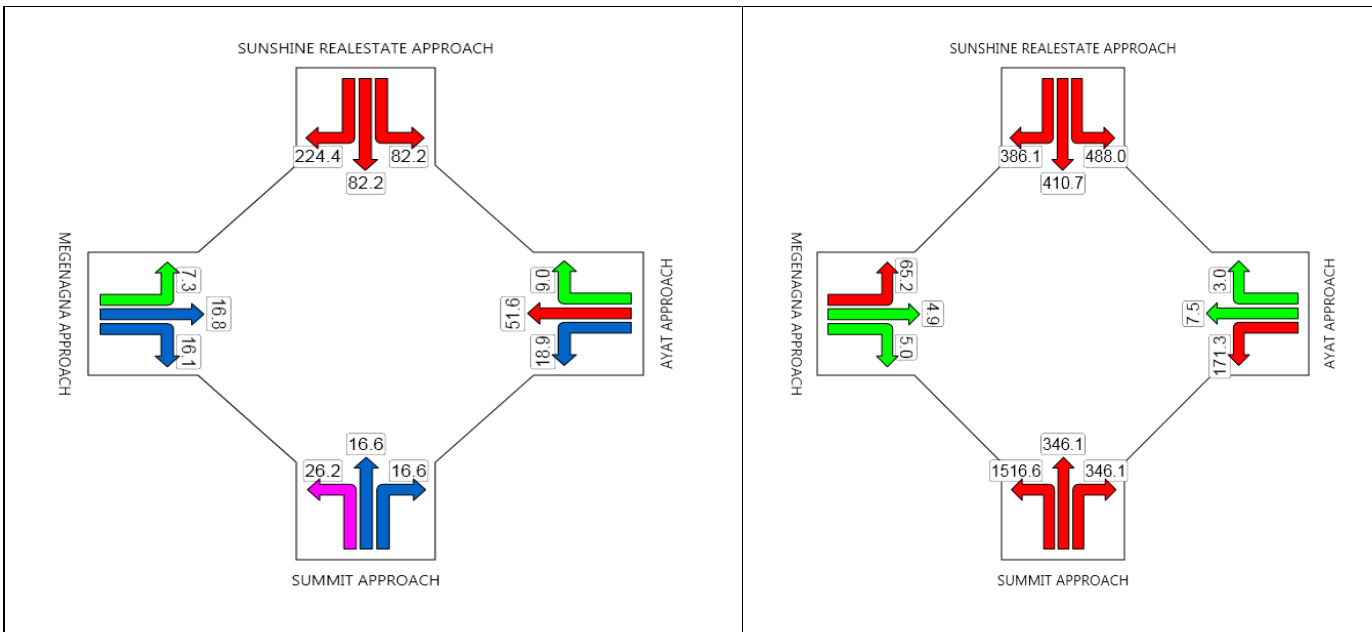
Average control delay per vehicle before LRT	Average control delay per vehicle After LRT

Figure 4-16 Comparison display of Average control delay for Beshale Hotel Round About

The following table depicts the comparison of performance measures at the CMC Round About before and after scenarios.

Table 4-21 Comparison of Performance Measures for CMC Roundabout

Summary of Additional Delays at CMC Round About										
Movement ID	Turn Before	Turn After	Demand Flow Before veh/h	Demand Flow After veh/h	Level of Service Before	Level of Service After	Average Delay (s) Before	Average Delay (s) After	Difference	Corrected Value for Arrival of LRV every 6mins & 30 sec Phase Duration
South: Summit Approach										
3	L	L	384	234	LOS D	LOS F	26.2	1516.6	1490.4	124.20
8	T	T	86	58	LOS C	LOS F	16.6	346.1	329.5	27.46
18	R	R	124	88	LOS C	LOS F	16.6	346.1	329.5	27.46
Approach			593	389	LOS C	LOS F	22.8	1078.5	1055.7	87.98
East: Ayat Approach										
1	L	L	316	207	LOS C	LOS F	18.9	171.3	152.4	12.70
6	T	T	1055	674	LOS F	LOS A	51.6	7.5	-44.1	-3.68
16	R	R	115	76	LOS A	LOS A	9.0	3.0	-6	-0.50
Approach			1487	957	LOS E	NA	41.4	42.5	1.1	0.09
North: Sunshine Realestate Approach										
7	L	L	124	88	LOS F	LOS F	82.2	488.0	405.8	33.82
4	T	T	86	58	LOS F	LOS F	82.2	410.7	328.5	27.38
14	R	R	384	243	LOS F	LOS F	224.4	386.1	161.7	13.48
Approach			593	389	LOS F	LOS F	174.1	412.8	238.7	19.89
West: Megenagna Approach										
10	L	L	89	60	LOS A	LOS F	7.3	65.2	57.9	4.83
11	T	T	630	428	LOS C	LOS A	16.8	4.9	-11.9	-0.99
12	R	R	470	308	LOS C	LOS A	16.1	5.0	-11.1	-0.93
Approach			1189	796	LOS C	NA	15.8	9.5	-6.3	-0.53
All Vehicles			3863	2530	LOS F	NA	51.1	248.4	197.3	16.44



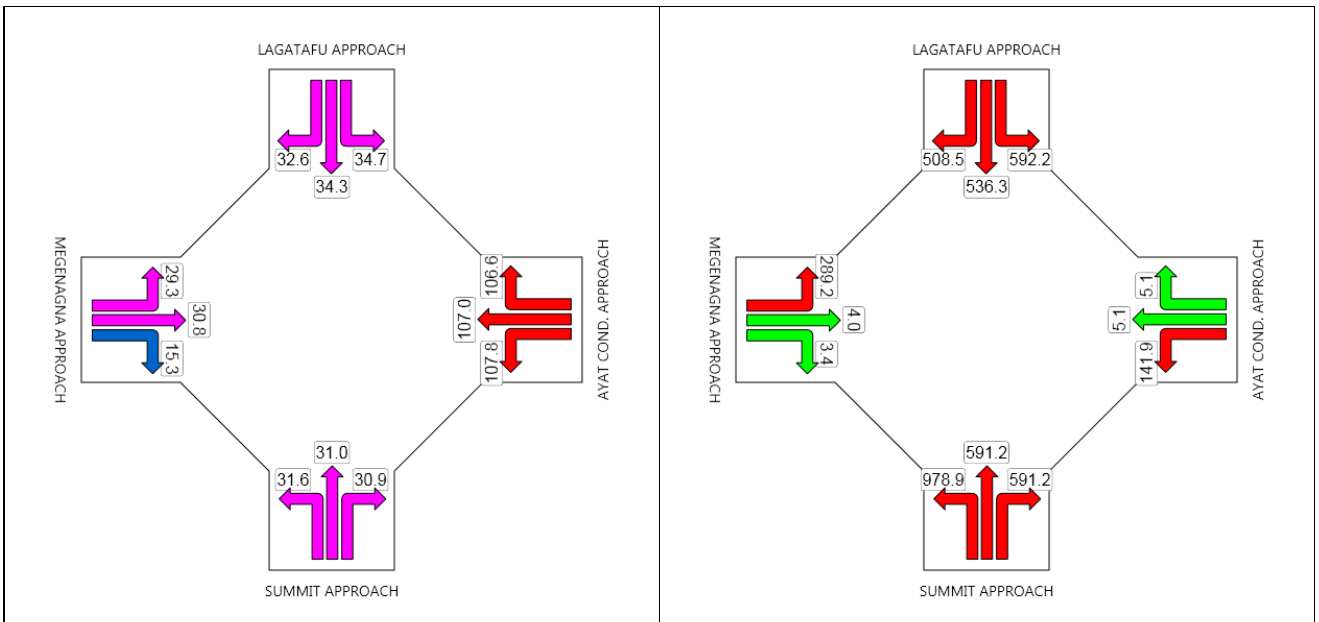
Average control delay per vehicle before LRT	Average control delay per vehicle After LRT

Figure 4-17 Comparison display of Average control delay for CMC Round About

As it can be seen from the table and the display diagram, the capacity of the left turns from Summit and Sunshine real-estate approaches is highly compromised due to the frequent priority given to the LRT vehicles along with the through traffic of E-W. The following table shows the comparison of performance measures at the CMC Round About before and after scenarios.

Table 4-22 Comparison of Performance Measures for Ayat Roundabout

Summary of Additional Delays at Ayat Round About										
Movement ID	Turn Before	Turn After	Demand Flow Before veh/h	Demand Flow After veh/h	Level of Service Before	Level of Service After	Average Delay (s) Before	Average Delay (s) After	Difference	Corrected Value for Arrival of LRV every 6mins & 30 sec Phase Duration
South: Summit Approach										
3	L	L	282	171	LOS D	LOS F	31.6	978.9	947.3	78.94
8	T	T	286	179	LOS D	LOS F	31.0	591.2	560.2	46.68
18	R	R	92	59	LOS D	LOS F	30.9	591.2	560.3	46.69
Approach			660	409	LOS D	LOS F	31.2	753.1	721.9	60.16
East: Ayat Cond. Approach										
1	L	L	228	140	LOS F	LOS F	107.8	141.9	34.1	2.84
6	T	T	784	498	LOS F	LOS A	107.0	5.1	-101.9	-8.49
16	R	R	55	37	LOS F	LOS A	106.6	5.1	-101.5	-8.46
Approach			1067	675	LOS F	NA	107.2	33.5	-73.7	-6.14
North: Lagatafu Approach										
7	L	L	114	72	LOS D	LOS F	34.7	592.2	557.5	46.46
4	T	T	249	152	LOS D	LOS F	34.3	536.3	502	41.83
14	R	R	299	184	LOS D	LOS F	32.6	508.5	475.9	39.66
Approach			662	408	LOS D	LOS F	33.6	533.6	500	41.67
West: Megenagna Approach										
10	L	L	464	285	LOS D	LOS F	29.3	289.2	259.9	21.66
11	T	T	570	366	LOS D	LOS A	30.8	4.0	-26.8	-2.23
12	R	R	358	220	LOS C	LOS A	15.3	3.4	-11.9	-0.99
Approach			1391	871	LOS D	NA	26.3	97.1	70.8	5.90
All Vehicles			3780	2362	LOS F	NA	51.3	267.8	216.5	18.04



Average control delay per vehicle before LRT	Average control delay per vehicle After LRT

Figure 4-18 Comparison display of Average control delay for Ayat Round About

As can be seen from the table and the display diagram, the capacity of the left turns from Summit and Lagatafu Approach is highly compromised due to the frequent priority given to the LRT vehicles along with the through traffic of E-W.

4.2.3 Additional Delays of Left Turn Movements and Through Movement of North-South Direction

The Light Rail Transit along with the through traffic of East –West will always be given a priority and on the other hand the left turn movements of all approaches and through movements of the North-South approach will frequently stop every 6 minutes. This operation will take place 30 seconds of duration of time per each arrival. Within an hour the LRT Vehicles will cross 10 times and hence the stop control will function for about 300 seconds per one hour (3600 seconds). An additional delay than expected will be incurred as a result.

Summary of Additional Delays for Left Turn Movement of all approaches and through movement of the North-South direction are summarized in table 4.23. It can be noted that Bambis Intersection is excluded in the comparison chart as the LRT is not in conflict with the Left turns of East-West and through traffic of the North-South crossing. The LRT line in the median is closed with curbstone delineation though it passes at grade in this intersection.

Table 4-23 Summary of Additional Delays for the Left Turn Movements of All Approaches and Through Traffic of North-South Direction

Summary of Congestion Impact Analysis Result of At-grade Intersections								
Name of Intersection	Approach	Turn	Demand Flow (Veh/h)		Average Delay (Sec)	Average Delay (Sec)	Difference	Additional Delay (sec)…With a Correction Fctor of 300sec/3600 sec
			Before	After	Before	After		
Beshale Hotel Roundabout	South: MEBRAT HAIL	LT	113	72	35.1	703.1	668.0	55.7
	East: CMC	LT	673	426	198.3	669.2	470.9	39.2
	North: KARA	LT	140	87	150.9	388.2	237.3	19.8
	West: MEGENAGNA	LT	626	399	141.2	867.1	725.9	60.5
CMCRoundabout	South: SUMMIT	LT	384	234	26.2	1516.6	1490.4	124.2
	East: AYAT	LT	316	207	18.9	171.3	152.4	12.7
	North:SUNSHINEREALESTATE	LT	124	88	82.2	488.0	405.8	33.8
	West: MEGENAGNA	LT	89	60	7.3	65.2	57.9	4.8
AYAT Round About	South: SUMMIT	LT	282	171	31.6	978.9	947.3	78.9
	East: AYAT COND.	LT	228	140	107.8	141.9	34.1	2.8
	North:LAGATAFU	LT	114	72	34.7	592.2	557.5	46.5
	West: MEGENAGNA	LT	464	285	29.3	289.2	259.9	21.7
Average								**41.7**
Summary of Additional Delays for the Through Traffic of North -South Direction								
Beshale Hotel Roundabout	South: MEBRAT HAIL	T	299	193	34.2	703.1	668.9	55.7
	North: KARA	T	305	200	149.5	1194.7	1045.2	87.1
CMCRoundabout	South: SUMMIT	T	86	58	16.6	346.1	329.5	27.5
	North: SUNSHINE REALEST.	T	86	58	82.2	410.7	328.5	27.4
AYAT Round About	South: SUMMIT	T	286	179	31	591.2	560.2	46.7
	North: LAGATAFU	T	249	152	34.3	536.3	502.0	41.8
Average								**47.7**

NB: In the "after" Scenario the out put is based on the fact that the "Stop" Contol will function for the full hour. However, in the actual condition, the LRT Vehicles will arrive every 6 min and the stop control is assumed to function for 30 sec per each arrival. The LRT Vehicles could cross the intersection less than 30 seconds. However, for safety and operational purpose, 30 sec will be realistic.Hence, a total of 300 sec phase duration per 1 hr (3600 Sec) correction factor is assumed in the analysis.

As it can be seen from the table, after the introduction of Light Rail Transit, in 2016 the left turn movement will face about **41.7 sec/vehicle** of additional average delay. On the other hand the through traffic of North-South direction will experience more additional delays of about **47.7 sec/vehicle** on average.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The introduction of New Rail Transit Systems into a city has proven to bring positive effects on property values and it contributes an important role to the development of a city by taking a greater share of Public Transport Demand. For the case of Addis Ababa, where the public transport is growing at a rapid rate due to the continued rise in population, the new LRT system which is under construction will contribute a lot to the transformation of the city. The new system is believed to attract more new investment, promotes economic activity and enhances healthy living. However, these benefits will be achieved if and only if the new LRT system is properly harmonized with the Existing Street Highways.

Harmonization, in this paper, is used to denote the integration of the two different modes of transportation systems namely the new Light Rail Transit and the existing Principal Arterial Street highways. The basic criteria considered in the process of evaluation with respect to harmonization of the two systems are **accessibility**, **safety, aesthetics** and **congestion impact**. Therefore, in the assessment of the new LRT project which is under implementation and expected to be functional in the coming couple of years the basic criteria taken are location of LRT Stations, accessibility, provision of parking lots, safety and aesthetics from the scientific stand point of view and best practices all over the world which have been indicated in the literature review part of this paper. Furthermore, assessing the effect of introducing new LRT system into the existing principal arterial streets at grade crossings was the main concern of the paper. This effect is analyzed for selected at grade intersections based on collected field data.

Accessibility can be seen from different perspectives. These are accessibility of LRT Stations, accessibility for non-transitory pedestrians and vehicular accessibility of surrounding land use as far as harmonization of Light Rail Transit and Principal Arterial Street Highways is concerned. Good access to LRT stations has a significant role in the effectiveness of transit use and it is indispensable to ridership with regard to reducing community impacts. As indicated in the literature review part of this paper, residents of a city in every LRT catchment area, access to the LRT Stations by different modes of transport. This includes feeder bus, park and ride, kiss and ride (auto passenger drop-off), walking and bicycle. In the city of Addis Ababa the main contributors will be taxi, walking and bus transit modes for most of the LRT Stations as far as the current trend is concerned. The other modes like park and ride and passenger drop off contribute the minimum. However, the share is believed to be increased in the future as automobile ownership increases with increase in the city infrastructure or development.

The number of pedestrians in the city is increasing rapidly as the population grows quickly which calls for the provision of maintained and adequate walkways in the city. Most of the existing footpaths (walkways) are badly damaged and do not accommodate pedestrians efficiently due to width problem compared to the number of pedestrians. In the current scenario, the existing condition of walkways near the LRT stations from Tor Hayloch to Megenagna is poor. However, after the specified stretch is under upgrading which opens a great opportunity for improvement of Walkways near LRT Stations to make the LRT more effective. Bicycles access mode is almost negligible in the city of Addis. Even though the rugged terrain nature of the city contributes a lot, there are no dedicated cycle tracks in the city streets. Consequently, people are discouraged to bicycle. Those few in number including the professionals are using the main carriage ways intended for the vehicular traffic which is unsafe. As per the design practice of today, the average walking distance considered in the provision of LRT Stations as far as Pedestrians are concerned, is 400m. With respect to these criteria, most of the Stations are to be built in the main corridor of the City Streets. And hence, most people are believed to walk less than this from their settlement and/or other mode of transit.

As per the Highway Capacity Manual (HCM), vehicular accessibility is measured in terms of access point which comprises of at-grade intersection, driveway, or median opening. Allowing or prohibiting turning, entering, exiting and crossing traffic movements at access points determines the accessibility of the surrounding land use of principal arterial street corridors. Where the access points are not provided or prohibited, the road side development will be limited. For the case of Addis Ababa East-West Corridor where the traffic volume is increasing beyond the capacity of the street highways, frequent provision and permission of access points (at-grade intersection and median openings) may result in traffic congestion. And on the other hand prohibition of access points for long stretch by overlooking important business district areas highly affects the growth of the city. Therefore, a tradeoff principle between access and mobility shall be adopted. In general, the first lot of Addis Ababa East-West corridor which stretches from Tor Hayiloch to Megenagna (9.458 km) has major intersection points with the principal arterial streets. From those, the major intersection points which provide access to the surrounding land uses and other destination points are Tor Hayiloch Round About, Coca Cola, Lideta (Fird bet) Intersection, Mexico Round About, Mesqel Square Intersection, Bambis, Urael Intersection, Hayahulet Mazoria and Megenagna Round About. In the second lot which stretches from Megenagna to Ayat Round About (7.712km) there are three major access points (Beshale Hotel Round About, CMC Round About and Ayat Round About) which are critically serving the eastern corridor of Addis Ababa city traffic. The introduction of the new LRT into the existing East-West arterial street highways is made grade separated from Coca-Cola to Estifanos and at Wuhalimat, Hayahulet Mazoria, and Lem Hotel and Megenagna intersections. Other than these locations the LRT is allowed to pass through the median being at-grade with the driveways by blocking many median openings. Especially in the second lot, as the LRT is not grade separated, many median openings are blocked which affects accessibility to the surrounding land uses of the road corridors.

As to the researcher's knowledge, it is planned to provide pedestrian overcrossing bridges every 300m where the LRT is exclusively treated at-grade within the median in the first lot which stretches from Tor Hayiloch to Megenagna. The at-grade median exclusive LRT section in this lot is from Tor Hayiloch to Coca Cola and Estifanos to Urael. In the specified stretch the pedestrians will use the existing zebra crossings of the existing streets where the LRT crosses over the bridge. From Megenagna to Ayat, as per the current design, the pedestrians are intended to use the LRT stations. However, all stations in this lot are more than 400m over which walking is believed to be difficult and discouraging. However, as the information obtained from the LRT Project office found in Ayat, it is currently planned to provide few at grade crossings in between stations where the interval and pedestrian traffic is high. If this plan is to be implemented, then accessibility will be enhanced. However, the zebra crossings shall be given emphasis regarding safety. The Zebra Crossings shall be changed into foot bridge crossings. In case zebra crossings are unavoidable, a signal with an alarm shall be used.

As **Aesthetics** could be measured in terms of user's perception, the researcher made preliminary assessment on the field whether the prospective users would like the LRT line to pass above the ground using piers, on the ground or below the ground. In line with this, interview of concerned bodies involved in Urban Planning was made. The primary finding showed two different opposing ideas from professionalism point of view and outside the context by the users. As to the preliminary result, it is found to be more of exposure, knowledge about the impact and experience than simple perception. Hence, the researcher preferred to assess the aesthetics impact based on literatures and scientific stand point of view. The E-W LRT project of Addis Ababa passes on scenery places like Mexico, Legahar and Mesqel Square which have pleasant urban views. However, the LRT passing through these important locations is above the ground which **obstructs aesthetical views** and brings **noise** to people gathering at places like Mesqel Square. Unless economic problem or other factors like drainage and geologic factors prohibit, at the above specified locations where most of the city's scenery places concentrate, would have been made below the ground.

The last assessment made was traffic congestion impact of introduction of LRT System into the existing Principal Arterial Streets based on field data. According to the analysis result, additional delay to the normal is observed at the three junctions (Beshale Hotel Round About, CMC Round About and Ayat Round about) under consideration where the LRT crosses at grade.

Generally, the findings of this research are as listed below:

- As per the best design practice, LRT **station**s shall be located every 1200m to 1600m even though specific station placement shall be based on planning studies that identify the location of key activity generators and/or demand at particular locations along the corridor. Accordingly, the station interval of Addis Ababa Light Rail Transit is acceptable the maximum being 1300m and minimum being 521m.

- The introduction of the new LRT into the existing East-West arterial street highways is made grade separated from Coca-Cola to Estifanos and at Wuhalimat, Hayahulet Mazoria, Lem Hotel and Megenagna intersections. Other than these locations the LRT is allowed to pass through the median at grade with the driveways by blocking many median openings. Especially in the second lot from Megenagna to Ayat Round About, as the LRT is not grade separated, many median openings are blocked which affects accessibility to the surrounding land uses of the road corridors.

- Residents of a city in every LRT catchment areas access to the LRT by feeder bus, park and ride, kiss and ride (auto passenger drop-off), walking and bicycle. In the Addis Ababa East-West corridor, the main contributors will be taxi, walking and bus transit modes for most of the LRT Stations as far as the current trend is concerned. The other modes like park and ride and passenger drop off contribute the minimum as far as the current condition is concerned. However, the share is believed to be increased in the future as automobile ownership increases with increase in the city infrastructure or development.

- As per the researcher's knowledge, there is no free parking provided near LRT Stations in the Addis Ababa East-West LRT Stations. In fact, Parking in Addis Ababa is a serious problem. The demand exceeds by far the supply and it is usually made on the principal street highways of the city. Only few off-street parking is found in private government premises, fuel stations and under few high rising buildings. According to current studies, there is no parking strategy and responsible body assigned to claim for planning and development of off-street parking. Therefore, the city's transport authority or Addis Ababa City Roads Authority or Urban Land Administration of Addis Ababa shall be responsible not to overlook in the revision of the city master plan in order to introduce parking lots near the LRT Stations. Until then, the outer parking lane of the main carriage way of the Main Principal Arterial Street shall be allowed to the LRT users for temporary (for passenger drop off purpose) and permanent parking (park and ride purpose) in order to enhance transit ridership and reduce automobile commuting.

- The **safety** consideration of LRT median crossing with the street consists of the conflict between LRT Vehicles with the traditional vehicles and LRT vehicles with pedestrians. The Addis Ababa East –West LRT System is allowed to pass underground, on the ground and above the ground. Of which the on-ground passage take the maximum share. Due to this the LRT crosses street highways at many locations. At this locations safety is a major concern. In general, the first lot from Tor Hayiloch to Megenagna has major intersection points with the principal arterial streets namely Coca Cola, Lideta (Fird bet) Intersection, Mexico Round About, Mesqel Square Intersection, Bambis, Urael Intersection, Hayahulet Mazoria and Megenagna Round About. At these major intersections where the number of conflicts was high, the LRT is made grade separated except at Bambis Intersection. At Bambis Intersection the LRT is exclusively separated with median by closing the south and north bound traffic and allowing them to make a U turn at URAEL Round about and Estifanos at which a clear grade separation is made. In doing so, the number of conflicts between the LRT vehicles and other street vehicles are minimized. In the second lot which stretches from Megenagna to Ayat Round About (7.712km), there are three major round-about junctions currently accommodating the traffic of the eastern corridor. At these major intersections, the LRT is made to cross at grade dividing the central islands in to two equal parts and to be managed with traffic signals. The LRT vehicles are frequently in conflict with the street vehicles. Moreover, pedestrians will use zebra crossings at many locations other than the LRT Stations. It can be said that safety is compromised in this lot. On the other hand, Even though the LRT Vehicles are not in conflict with the North and south approach street vehicles at Bambis Intersection, pedestrians are at high risk while crossing this intersection.

- As **aesthetics** could be measured in terms of perception by the users the researcher made preliminary assessment on the field whether the prospective users would like the LRT line to pass above the ground using piers, on the ground or below the ground. In line with this, interview of concerned bodies involved in Urban Planning was made. The primary finding showed two different opposing ideas from professionalism point of view and outside the context by the users. It is more of exposure, knowledge about the impact and experience than simple perception. Hence, the researcher preferred to assess the aesthetics impact based on literatures and scientific stand point of view. Visual perceptions differ among individuals. Since it is a new technology for most of the city residents, some individuals may prefer the LRT pass above the ground on important locations. In the same city, the concerned individuals which incorporates Civil Engineers, Architects and Urban planners most of them may prefer the LRT pass underground in order to minimize the visual aesthetical impacts. The E-W LRT project of Addis Ababa passes on scenery places like Mexico, Legahar and Mesqel Square which have pleasant urban views. However, the LRT passing through these important locations is above the ground which obstructs aesthetical views and brings noise to people gathering at places like Mesqel Square.

- **Additional delay** to the normal is observed at the three junctions (Beshale Hotel Round About, CMC Round About and Ayat Round about) under consideration where the LRT crosses at grade. With the existing geometric condition and future projected traffic, in 2016 the left turn movements will experience about 41.7 sec/vehicle of additional average delay after the introduction of Light Rail transit. On the other hand, the through traffic of North-South direction at these locations will experience more additional delays of about 47.7 sec/veh on average. At Bambis Intersection, since the LRT is separated from the city street traffic with median curb stone, additional delays are not observed. Instead, the through traffic of East-West direction at this junction will experience less control delay than before due to the decrease in conflicts of North and South crossing traffic. Moreover, as to the researcher's knowledge the existing central islands of the three roundabouts will be left as it is after the LRT comes into service. However, this will increase clearing time of vehicles before and after red light signal system. This will induce additional delay to the traffic.

5.2 Recommendations

- Integration of parking facilities shall be carefully considered in the planning and design stage of Light Rail transits. As per the researcher's knowledge, there is no free parking provided near LRT Stations in the Addis Ababa East-West LRT Stations. Therefore, the Addis Ababa City Transport Authority, Addis Ababa City Roads Authority and Urban Land Administration of Addis Ababa shall cooperate and take the responsibility in joint venture in order to introduce provision of free parking lots near LRT Stations in the revision of the city's master plan which is proposed to be revised in order to incorporate different things including off-street parking on major street highways. Until then, the outer parking lane of the main carriage way of the Main Principal Arterial Street shall be allowed to the LRT users for temporary (for passenger drop off purpose) and permanent parking (park and ride purpose) in order to enhance transit ridership and reduce automobile commuting.

- The E-W LRT project of Addis Ababa passes on scenery places like Mexico, Legahar and Mesqel Square which have pleasant urban views. However, the LRT passing through these important locations is above the ground which obstructs aesthetical views and brings noise to people gathering at locations like Mesqel Square. Unless economic problem or other factors like drainage and geologic factors prohibit, at the above specified locations where most of the city's scenery places concentrate, passage of the LRT would have been made below the ground. In general, Light Rail Transit System shall be constructed below the ground on important view areas to avoid visual obstruction. If above ground construction option is selected, attention has to be given on the architecture of piers in the design and planning stage so that the LRT will be aesthetically pleasing, and gives a strong positive image to the city.

- The zebra crossings on at-grade crossings of LRT system and Principal Arterial Streets shall be given emphasis regarding safety. The Zebra Crossings shall be changed into foot bridge crossings. In case zebra crossings are unavoidable, reactive counter measures like traffic signal with an alarm shall be used. Furthermore, possible mitigation measures shall be adopted in the planning and design phase of LRT system in order to minimize possible accident events at grade crossing locations of the LRT and Principal arterial street highways. The measures can be but not limited to:

  - **Static**: warning devices that warn the driver of a grade crossing or keep automobiles out of the track way whether or not an LRV is present, e.g., signs and delineation. The case of Bambis Intersection could be an appropriate location as an example.

  - **Active***:* warning devices that change states and restrict movement when Light Rail Vehicle approaches, e.g., crossing gates and traffic signals. This shall be adopted in the at grade crossing locations namely Beshale Hotel Round About, CMC Round

About , Ayat Round About and/or other locations having zebra crossings for pedestrians where the LRT Vehicles are kept away from other traffic.

- **Reactive**: Proposed warning devices that respond to illegal or unsafe automobile movements when a Light Rail Vehicle approaches, e.g., automated encroachment alarms and other Intelligent Transportation Systems devices. It is supported in many studies that audible alarms are effective for reducing accidents at conventional railroad grade crossings. Therefore, this devices need to be implemented in the above said locations in order to minimize accident.

- Light Rail Transit System shall be grade separated on major junctions whose capacity is in the worse scenario as far as future traffic is concerned. Specific to the case study, at the three-at grade major junctions namely the Beshale Hotel Round About, CMC Round About and Ayat Round About, the LRT should have been planned and designed to pass either below or above the ground whichever is the better option. This is because the capacity of these junctions is in the worse scenario based on future projected traffic as per the Highway Capacity Manual (2000). Allowing frequent, at grade LRT crossing made the junctions even worst. And therefore, considering the current decision and forecasted future conditions, it shall be noted by the transport planners of the city that the street principal arterial streets need to be grade separated in the future at the above specified locations.

- Since the existing central islands of the roundabouts after LRT will increase clearing time of vehicles before and after red light signal system and induce additional delay to the traffic, they shall be demolished to allow more evacuating space for the through and left turn vehicles while red light is about to turn into green and vice versa. In doing so, the roundabout intersections will be changed into signalized intersection and accordingly at Beshale hotel round about having 100m diameter of traffic island, the shortest distance for the through traffic will be reduced from 146m to 99m (by 47m) upon demolishing. Similarly, for CMC roundabout having 125m diameter of Central Island, a reduction of 61m and at Ayat Roundabout with 110m island diameter, 52m tangent will be obtained after demolishing.

- Further research to include other variables as frequency of LRT crossing shall be made in order to assess the effect of LRT system on Congestion.

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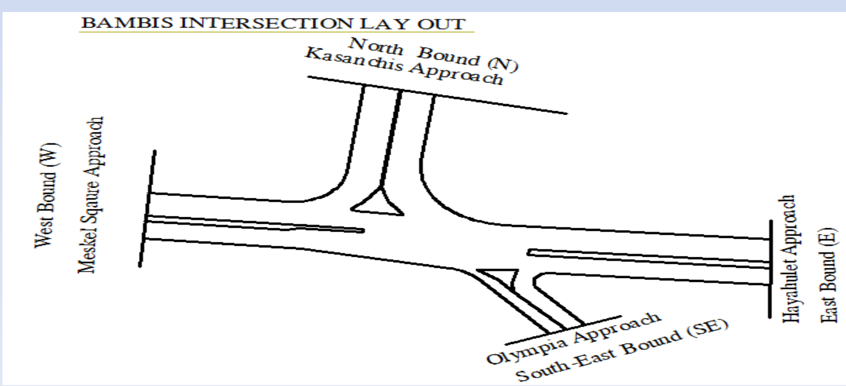
APPENDIXES

APPENDIX A: TRAFFIC VOLUME AND GEOMETRIC DATA (INPUT DATA)

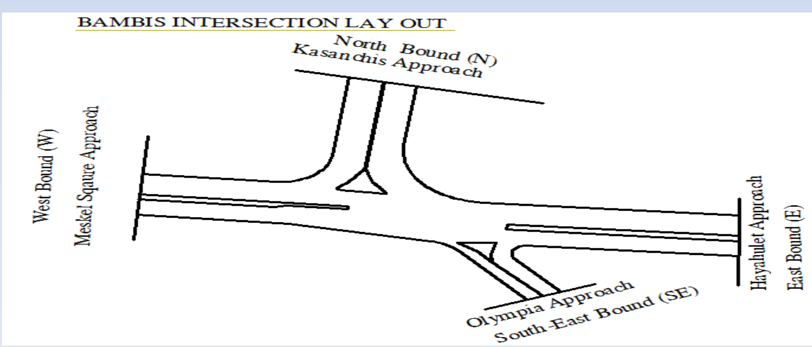
TRAFFIC AND GEOMETRIC DATA													
1. BAMBIS INTERSECTION													
LEG 1:MESKEL SQUARE APPROACH													
Time of Count: 8:00AM-9:00 AM	Survey Location: BAMBIS INTERSECTION						Date: 20/05/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Lane Width (m)	Median Width (m)
Through Traffic (TH)	363	8	41	1	1	0	371	43	414	233	4.00	3.50	1.00
Right Turn Traffic (RT)	47	0	1	0	0	0	47	1	48				
Left Turn Traffic (LT)	95	7	3	3	0	0	102	6	108				
Total	**505**	**15**	**45**	**4**	**1**	**0**	**520**	**50**	**570**				
LEG 2: OLYMPIA APPROACH													
Through Traffic (TH)	209	5	3	2	0	0	214	5	219	280	2.00	3.50	NA
Right Turn Traffic (RT)	197	2	1	2	0	0	199	3	202				
Left Turn Traffic (LT)	52	2	0	1	0	0	54	1	55				
Total	**458**	**9**	**4**	**5**	**0**	**0**	**467**	**9**	**476**				
LEG 3: HAYAHULET APPROACH													
Through Traffic (TH)	520	11	45	2	0	0	531	47	578	431	4.00	3.00	2.00
Right Turn Traffic (RT)	32	0	0	0	0	0	32	0	32				
Left Turn Traffic (LT)	101	0	0	1	0	0	101	1	102				
Total	**653**	**11**	**45**	**3**	**0**	**0**	**664**	**48**	**712**				
LEG 4: KASANCHIS APPROACH													
Through Traffic (TH)	280	0	0	1	0	0	280	1	281	312	2.00	3.00	2.00
Right Turn Traffic (RT)	204	5	0	1	0	0	209	1	210				
Left Turn Traffic (LT)	15	1	0	1	0	0	16	1	17				
Total	**499**	**6**	**0**	**3**	**0**	**0**	**505**	**3**	**508**				



TRAFFIC AND GEOMETRIC DATA

1. BAMBIS INTERSECTION

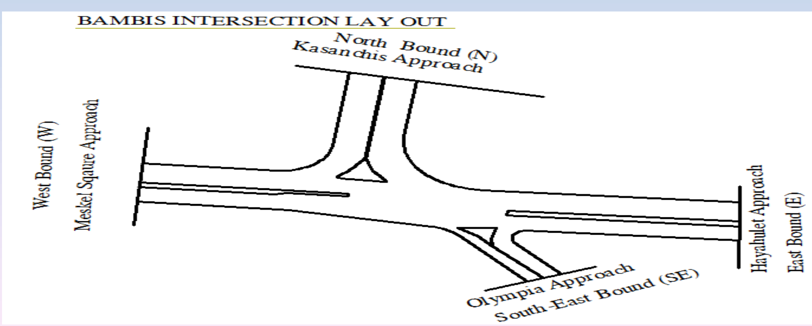
Time of Count: 12:00AM-1:00 PM	Survey Location: BAMBIS INTERSECTION						Date: 20/05/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Lane Width (m)	Median Width (m)
LEG 1:MESKEL SQUARE APPROACH													
Through Traffic (TH)	218	5	36	1	0	0	223	37	260	194	4	3.5	1
Right Turn Traffic (RT)	38	0	1	0	0	0	38	1	39				
Left Turn Traffic (LT)	81	4	2	1	0	0	85	3	88				
Total	337	9	39	2	0	0	346	41	387				
LEG 2: OLYMPIA APPROACH													
Through Traffic (TH)	186	3	3	1	0	0	189	4	193	243	2	3.5	NA
Right Turn Traffic (RT)	174	2	1	0	0	0	176	1	177				
Left Turn Traffic (LT)	47	1	0	1	0	0	48	1	49				
Total	407	6	4	2	0	0	413	6	419				
LEG 3: HAYAHULET APPROACH													
Through Traffic (TH)	457	7	32	1	0	0	464	33	497	340	4	3	2
Right Turn Traffic (RT)	23	0	0	0	0	0	23	0	23				
Left Turn Traffic (LT)	82	0	0	0	0	0	82	0	82				
Total	562	7	32	1	0	0	569	33	602				
LEG 4: KASANCHIS APPROACH													
Through Traffic (TH)	249	0	0	2	0	0	249	2	251	245	2	3	2
Right Turn Traffic (RT)	178	3	0	1	0	0	181	1	182				
Left Turn Traffic (LT)	11	0	0	1	0	0	11	1	12				
Total	438	3	0	4	0	0	441	4	445				



TRAFFIC AND GEOMETRIC DATA

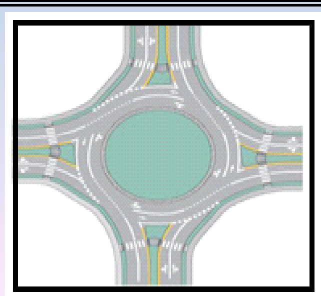
1. BAMBIS INTERSECTION

LEG 1:MESKEL SQUARE APPROACH													
Time of Count: 5:00 PM-6:00 PM	Survey Location: BAMBIS INTERSECTION						Date: 23/05/2013				Geometric Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Lane Width (m)	Median Width (m)
Through Traffic (TH)	335	10	43	1	0	0	345	44	389	198	4	3.5	1
Right Turn Traffic (RT)	39	0	0	1	1	0	39	2	41				
Left Turn Traffic (LT)	87	6	2	2	0	0	93	4	97				
Total	**461**	**16**	**45**	**4**	**1**	**0**	**477**	**50**	**527**				
LEG 2: OLYMPIA APPROACH													
Through Traffic (TH)	173	8	2	1	0	0	181	3	184	251	2	3.5	NA
Right Turn Traffic (RT)	201	1	0	2	0	0	202	2	204				
Left Turn Traffic (LT)	40	0	1	0	0	0	40	1	41				
Total	**414**	**9**	**3**	**3**	**0**	**0**	**423**	**6**	**429**				
LEG 3: HAYAHULET APPROACH													
Through Traffic (TH)	498	8	35	1	0	0	506	36	542	382	4	3	2
Right Turn Traffic (RT)	28	1	0	1	0	0	29	1	30				
Left Turn Traffic (LT)	90	0	0	0	0	0	90	0	90				
Total	**616**	**9**	**35**	**2**	**0**	**0**	**625**	**37**	**662**				
LEG 4: KASANCHIS APPROACH													
Through Traffic (TH)	258	0	0	1	0	0	258	1	259	260	2	3	2
Right Turn Traffic (RT)	177	4	0	0	0	0	181	0	181				
Left Turn Traffic (LT)	19	2	0	1	0	0	21	1	22				
Total	**454**	**6**	**0**	**2**	**0**	**0**	**460**	**2**	**462**				



2. BESHALE HOTEL ROUND ABOUT

Time of Count: 8:00AM-9:00 AM	Survey Location: BESHALE HOTEL ROUND ABOUT						Date: 21/05/2013				Geometric Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
LEG 1: CMC APPROACH													
Through Traffic (TH)	637	8	62	15	0	0	645	77	722	474	4	3.5	11
Right Turn Traffic (RT)	65	0	1	2	0	0	65	3	68				
Left Turn Traffic (LT)	448	11	3	24	0	2	459	29	488				
Total	**1,150**	**19**	**66**	**41**	**0**	**2**	**1,169**	**109**	**1,278**				
LEG 2: KARA APPROACH													
Through Traffic (TH)	193	8	2	17	1	1	201	21	222	180	3	3.7	NA
Right Turn Traffic (RT)	220	7	4	5	0	0	227	9	236				
Left Turn Traffic (LT)	96	0	2	0	0	0	96	2	98				
Total	**509**	**15**	**8**	**22**	**1**	**1**	**524**	**32**	**556**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	479	13	48	31	0	1	492	80	572	524	4	3.5	11
Right Turn Traffic (RT)	96	7	4	3	0	0	103	7	110				
Left Turn Traffic (LT)	411	9	19	14	0	0	420	33	453				
Total	**986**	**29**	**71**	**48**	**0**	**1**	**1,015**	**120**	**1,135**				
LEG 4: MEBRAT HAIL APPROACH													
Through Traffic (TH)	191	4	11	9	0	0	195	20	215	207	3	4.3	NA
Right Turn Traffic (RT)	189	13	7	23	0	0	202	30	232				
Left Turn Traffic (LT)	74	1	3	2	0	0	75	5	80				
Total	**454**	**18**	**21**	**34**	**0**	**0**	**472**	**55**	**527**				



Junction Layout

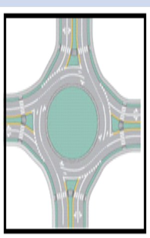
Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -100m
5-Incribed diameter-128m

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

2. BESHALE HOTEL ROUND ABOUT

LEG 1: CMC APPROACH													
Time of Count: 12:00AM-1:00 PM	Survey Location: BESHALE HOTEL ROUND ABOUT						Date: 21/05/2013				Geometric Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
Through Traffic (TH)	586	5	50	12	0	0	591	62	653	285	4	3.5	11
Right Turn Traffic (RT)	57	1	0	0	0	0	58	0	58				
Left Turn Traffic (LT)	401	13	1	18	0	2	414	21	435				
Total	**1,044**	**19**	**51**	**30**	**0**	**2**	**1,063**	**83**	**1,146**				
LEG 2: KARA APPROACH													
Through Traffic (TH)	193	8	2	17	1	1	201	21	222	112	3	3.7	NA
Right Turn Traffic (RT)	220	7	4	5	0	0	227	9	236				
Left Turn Traffic (LT)	96	0	2	0	0	0	96	2	98				
Total	**509**	**15**	**8**	**22**	**1**	**1**	**524**	**32**	**556**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	479	13	48	31	0	1	492	80	572	420	4	3.5	11
Right Turn Traffic (RT)	96	7	4	3	0	0	103	7	110				
Left Turn Traffic (LT)	411	9	19	14	0	0	420	33	453				
Total	**986**	**29**	**71**	**48**	**0**	**1**	**1,015**	**120**	**1,135**				
LEG 4: MEBRAT HAIL APPROACH													
Through Traffic (TH)	191	4	11	9	0	0	195	20	215	179	3	4.3	NA
Right Turn Traffic (RT)	189	13	7	23	0	0	202	30	232				
Left Turn Traffic (LT)	74	1	3	2	0	0	75	5	80				
Total	**454**	**18**	**21**	**34**	**0**	**0**	**472**	**55**	**527**				



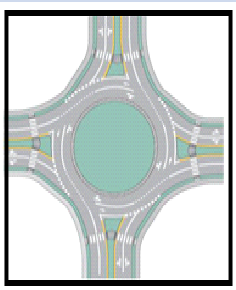
RA Lay out

Additional Roundabout Geometric Data
1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -100m
5-Incribed diameter-128m
6-Entry radius-
7-Entry Angle-

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

2. BESHALE HOTEL ROUND ABOUT

Time of Count: 5:00 PM-6:00 PM	Survey Location: BESHALE HOTEL ROUND ABOUT						Date: 23/05/2013				Geometric Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
LEG 1: CMC APPROACH													
Through Traffic (TH)	592	11	52	12	0	1	603	65	668	442	4	3.5	11
Right Turn Traffic (RT)	53	0	0	3	0	0	53	3	56				
Left Turn Traffic (LT)	406	7	4	19	0	0	413	23	436				
Total	**1,051**	**18**	**56**	**34**	**0**	**1**	**1,069**	**91**	**1,160**				
LEG 2: KARA APPROACH													
Through Traffic (TH)	160	6	2	11	0	2	166	15	181	162	3	3.7	NA
Right Turn Traffic (RT)	203	8	1	2	0	0	211	3	214				
Left Turn Traffic (LT)	80	1	3	0	0	0	81	3	84				
Total	**443**	**15**	**6**	**13**	**0**	**2**	**458**	**21**	**479**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	410	11	44	33	0	1	421	78	499	436	4	3.5	11
Right Turn Traffic (RT)	77	7	5	1	0	0	84	6	90				
Left Turn Traffic (LT)	359	5	13	8	0	0	364	21	385				
Total	**846**	**23**	**62**	**42**	**0**	**1**	**869**	**105**	**974**				
LEG 4: MEBRAT HAIL APPROACH													
Through Traffic (TH)	170	1	7	4	1	0	171	12	183	164	3	4.3	NA
Right Turn Traffic (RT)	136	9	9	21	0	0	145	30	175				
Left Turn Traffic (LT)	82	3	1	0	0	0	85	1	86				
Total	**388**	**13**	**17**	**25**	**1**	**0**	**401**	**43**	**444**				



RA Lay out

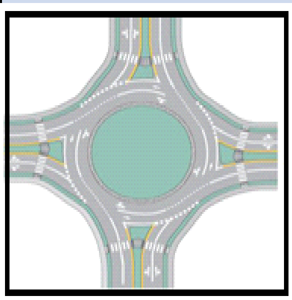
Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -100m
5-Incribed diameter-128m
6-Entry radius-
7-Entry Angle-

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

3. CMC ROUND ABOUT

Time of Count: 8:00AM-9:00 AM	Survey Location: CMC ROUND ABOUT						Date: 22/05/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
LEG 1: SUMMIT APPROACH													
Through Traffic (TH)	51	4	3	1	2	1	55	7	62	127	**2**	**4**	**25**
Right Turn Traffic (RT)	65	5	6	12	1	0	70	19	89				
Left Turn Traffic (LT)	255	5	12	5	0	0	260	17	277				
Total	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**				
LEG 2: AYAT APPROACH													
Through Traffic (TH)	693	12	45	14	2	1	705	62	767	401	**4**	**3.5**	**11**
Right Turn Traffic (RT)	71	8	2	1	1	1	79	5	84				
Left Turn Traffic (LT)	199	5	8	16	0	1	204	25	229				
Total	**963**	**25**	**55**	**31**	**3**	**3**	**988**	**92**	**1,080**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	367	18	45	27	0	0	385	72	457	35	**4**	**3.5**	**11**
Right Turn Traffic (RT)	294	7	25	14	0	1	301	40	341				
Left Turn Traffic (LT)	55	3	3	1	2	1	58	7	65				
Total	**716**	**28**	**73**	**42**	**2**	**2**	**744**	**119**	**863**				
LEG 4: SUNSHINE REAL ESTATE (Generated Traffic)													
Through Traffic (TH)	51	4	3	1	2	1	0	7	7	42	**2**	**3.5**	**25**
Right Turn Traffic (RT)	249	5	9	12	1	0	254	22	276				
Left Turn Traffic (LT)	65	5	6	12	1	0	70	19	89				
Total	**365**	**14**	**18**	**25**	**4**	**1**	**0**	**48**	**48**				



Junction Lay out

Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -125m
5-Incribed diameter-153m

Notes:-

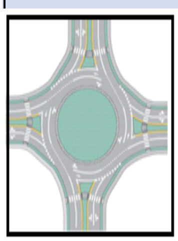
-The inscribed diameter includes twice the circulatory road width plus central island diameter.

-Generated traffic is considered in the Sunshine Realstate Approach by assumming similar socio-economic factor to that of the Summit Approach.

3. CMC ROUND ABOUT

LEG 1:SUMMIT APPROACH

Time of Count: 12:00AM-1:00 PM	Survey Location: CMC ROUND ABOUT						Date: 22/05/2013				Geometry Data		
	Light Vehicles	Heavy Vehicles											
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
Through Traffic (TH)	0	0	0	0	0	1	0	1	1	98	2	4	25
Right Turn Traffic (RT)	57	6	2	16	0	0	63	18	81				
Left Turn Traffic (LT)	202	2	8	1	0	0	204	9	213				
Total	**259**	**8**	**10**	**17**	**0**	**1**	**267**	**28**	**295**				
LEG 2: AYAT APPROACH													
Through Traffic (TH)	498	10	39	10	1	0	508	50	558	376	4	3.5	11
Right Turn Traffic (RT)	0	0	0	0	0	0	0	0	0				
Left Turn Traffic (LT)	171	5	9	13	0	0	176	22	198				
Total	**669**	**15**	**48**	**23**	**1**	**0**	**684**	**72**	**756**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	323	13	42	20	0	0	336	62	398	27	4	3.5	11
Right Turn Traffic (RT)	235	5	26	16	0	1	240	43	283				
Left Turn Traffic (LT)	0	0	0	0	0	0	0	0	0				
Total	**558**	**18**	**68**	**36**	**0**	**1**	**576**	**105**	**681**				
LEG 4: SUNSHINE REAL ESTATE													
Through Traffic (TH)	This leg is not functional at the time of traffic count for it is under construction						0	0	0	30	2	3.5	25
Right Turn Traffic (RT)							0	0	0				
Left Turn Traffic (LT)							0	0	0				
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**				



RA Lay out

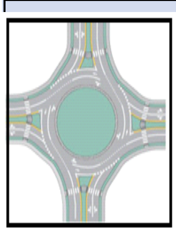
Additional Roundabout Geometric Data
1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -125m
5-Incribed diameter-153m

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

3. CMC ROUND ABOUT

LEG 1:SUMMIT APPROACH

Time of Count: 5:00PM-6:00 PM	Survey Location: CMC ROUND ABOUT						Date: 24/05/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck(Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Pedestrian	No.of Entry Lanes	Entry Lane Width (m)	Median Width (m)
Through Traffic (TH)	0	0	0	0	0	0	0	0	0	110	2	4	25
Right Turn Traffic (RT)	50	6	3	10	0	0	56	13	69				
Left Turn Traffic (LT)	267	2	12	8	0	0	269	20	289				
Total	**317**	**8**	**15**	**18**	**0**	**0**	**325**	**33**	**358**				
LEG 2: AYAT APPROACH													
Through Traffic (TH)	675	9	40	13	0	0	684	53	737	387	4	3.5	11
Right Turn Traffic (RT)	0	0	0	0	0	0	0	0	0				
Left Turn Traffic (LT)	181	7	9	12	0	0	188	21	209				
Total	**856**	**16**	**49**	**25**	**0**	**0**	**872**	**74**	**946**				
LEG 3: MEGENAGNA APPROACH													
Through Traffic (TH)	330	13	39	21	1	0	343	61	404	38	4	3.5	11
Right Turn Traffic (RT)	270	8	28	14	0	0	278	42	320				
Left Turn Traffic (LT)	0	0	0	0	0	0	0	0	0				
Total	**600**	**21**	**67**	**35**	**1**	**0**	**621**	**103**	**724**				
LEG 4: SUNSHINE REAL ESTATE													
Through Traffic (TH)	This leg is not functional at the time of traffic count for it is under construction						0	0	0	29	2	3.5	25
Right Turn Traffic (RT)							0	0	0				
Left Turn Traffic (LT)							0	0	0				
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**				

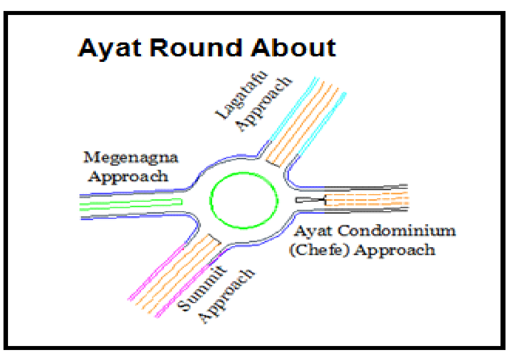


RA Lay out

Additional Roundabout Geometric Data
1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 14m
4- Central island diameter -125m
5-Incribed diameter-153m

Note:-
The inscribed diameter includes twice the circulatory road width plus central island diameter.

TRAFFIC AND GEOMETRIC DATA													
4. AYAT ROUND ABOUT JUNCTION													
LEG 1:MEGENAGNA APPROACH													
Time of Count: 8:00AM-9:00 AM	Survey Location: AYAT ROUNDABOUT						Date: 19/09/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Lane Width (m)	Median Width (m)
Through Traffic (TH)	370	11	30	1	1	1	381	33	414	189	4.00	3.75	11.00
Right Turn Traffic (RT)	252	0	1	0	0	1	252	2	254				
Left Turn Traffic (LT)	324	5	4	1	0	0	329	5	334				
Total	**946**	**16**	**35**	**2**	**1**	**2**	**962**	**40**	**1002**				
LEG 2: SUMMIT APPROACH													
Through Traffic (TH)	193	6	3	3	1	0	199	7	206	217	2.00	4.00	40.00
Right Turn Traffic (RT)	61	1	2	1	0	1	62	4	66				
Left Turn Traffic (LT)	200	1	0	1	1	0	201	2	203				
Total	**454**	**8**	**5**	**5**	**2**	**1**	**462**	**13**	**475**				
LEG 3: AYAT CONDOMINIUM APPROACH													
Through Traffic (TH)	519	9	39	1	1	1	528	42	570	198	2.00	3.50	29.00
Right Turn Traffic (RT)	32	5	0	1	0	0	37	1	38				
Left Turn Traffic (LT)	159	2	2	1	0	0	161	3	164				
Total	**710**	**16**	**41**	**3**	**1**	**1**	**726**	**46**	**772**				
LEG 4: LAGATAFU APPROACH													
Through Traffic (TH)	175	0	2	1	0	1	175	4	179	240	2.00	4.00	40.00
Right Turn Traffic (RT)	208	5	0	1	0	0	213	1	214				
Left Turn Traffic (LT)	76	3	1	1	1	0	79	3	82				
Total	**459**	**8**	**3**	**3**	**1**	**1**	**467**	**8**	**475**				



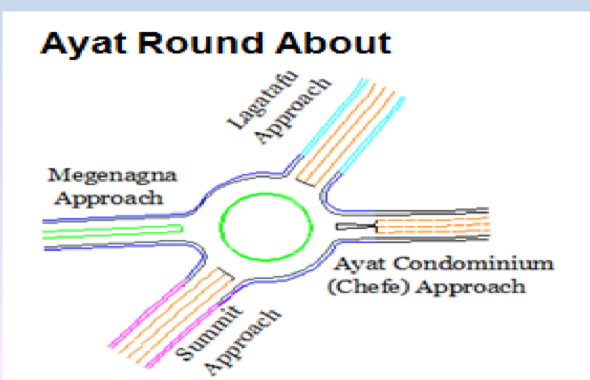
Additional Roundabout Geometric Data

1- Number of approaches or legs - 4
2- Number of circulating lanes - 4
3- Circulating Road Width - 16m
4- Central island diameter -110m
5-Incribed diameter-142m

TRAFFIC AND GEOMETRIC DATA

4. AYAT ROUND ABOUT JUNCTION

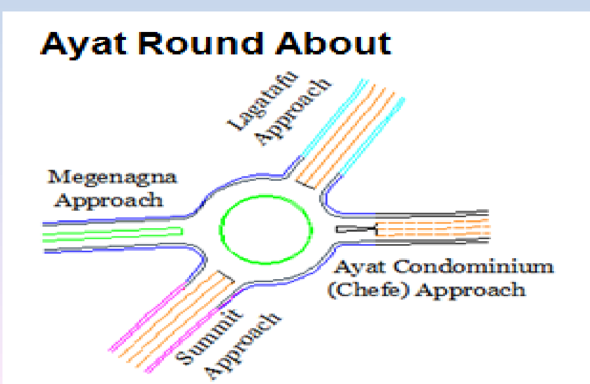
Time of Count: 12:00AM-1:00 PM	Survey Location: AYAT ROUNDABOUT						Date: 19/09/2013				Geometry Data		
	Light Vehicles		Heavy Vehicles										
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Lane Width (m)	Median Width (m)
LEG 1: MEGENAGNA APPROACH													
Through Traffic (TH)	304	9	21	0	1	0	313	22	335	**172**	**4.00**	**3.75**	**11.00**
Right Turn Traffic (RT)	39	0	1	0	0	1	39	2	41				
Left Turn Traffic (LT)	76	3	4	1	0	0	79	5	84				
Total	**419**	**12**	**26**	**1**	**1**	**1**	**431**	**29**	**460**				
LEG 2: SUMMIT APPROACH													
Through Traffic (TH)	180	4	1	2	0	0	184	3	187	**199**	**2.00**	**4.00**	**40.00**
Right Turn Traffic (RT)	148	1	1	0	0	1	149	2	151				
Left Turn Traffic (LT)	18	1	0	1	0	0	19	1	20				
Total	**346**	**6**	**2**	**3**	**0**	**1**	**352**	**6**	**358**				
LEG 3: AYAT CONDOMINIUM APPROACH													
Through Traffic (TH)	483	9	39	1	1	1	492	42	534	**190**	**2.00**	**3.50**	**29.00**
Right Turn Traffic (RT)	32	5	0	1	0	0	37	1	38				
Left Turn Traffic (LT)	94	2	2	1	0	0	96	3	99				
Total	**609**	**16**	**41**	**3**	**1**	**1**	**625**	**46**	**671**				
LEG 4: LAGATAFU APPROACH													
Through Traffic (TH)	160	0	2	1	0	1	160	4	164	**213**	**2.00**	**4.00**	**40.00**
Right Turn Traffic (RT)	197	5	0	1	0	0	202	1	203				
Left Turn Traffic (LT)	26	1	1	1	1	1	27	4	31				
Total	**383**	**6**	**3**	**3**	**1**	**2**	**389**	**9**	**398**				



TRAFFIC AND GEOMETRIC DATA

4. AYAT ROUND ABOUT JUNCTION

LEG 1:MEGENAGNA APPROACH													
Time of Count: 5:00PM-6:00 PM	Survey Location: AYAT ROUNDABOUT						Date: 20/09/2013				Geometry Data		
	Light Vehicles	Heavy Vehicles											
Direction	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds	No.of Entry Lanes	Lane Width (m)	Median Width (m)
Through Traffic (TH)	311	12	18	0	1	0	323	19	342	**179**	**4.00**	**3.75**	**11.00**
Right Turn Traffic (RT)	35	0	1	0	0	1	35	2	37				
Left Turn Traffic (LT)	81	2	2	1	0	0	83	3	86				
Total	**427**	**14**	**21**	**1**	**1**	**1**	**441**	**24**	**465**				
LEG 2: SUMMIT APPROACH													
Through Traffic (TH)	192	5	0	1	0	0	197	1	198	**203**	**2.00**	**4.00**	**40.00**
Right Turn Traffic (RT)	155	2	1	1	0	1	157	3	160				
Left Turn Traffic (LT)	23	1	0	1	0	0	24	1	25				
Total	**370**	**8**	**1**	**3**	**0**	**1**	**378**	**5**	**383**				
LEG 3: AYAT CONDOMINIUM APPROACH													
Through Traffic (TH)	490	12	42	1	1	1	502	45	547	**198**	**2.00**	**3.50**	**29.00**
Right Turn Traffic (RT)	38	7	0	1	0	0	45	1	46				
Left Turn Traffic (LT)	98	1	1	1	0	0	99	2	101				
Total	**626**	**20**	**43**	**3**	**1**	**1**	**646**	**48**	**694**				
LEG 4: LAGATAFU APPROACH													
Through Traffic (TH)	154	1	1	1	0	1	155	3	158	**221**	**2.00**	**4.00**	**40.00**
Right Turn Traffic (RT)	142	3	0	2	0	0	145	2	147				
Left Turn Traffic (LT)	31	2	1	1	1	1	33	4	37				
Total	**327**	**6**	**2**	**4**	**1**	**2**	**333**	**9**	**342**				



1. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR BAMBIS INTERSECTION

Direction	Year	Light Vehicles: Small Car	Light Vehicles: Small Truck	Heavy Vehicles: Bus	Heavy Vehicles: Medium Truck (Dual Rear Axle Truck)	Heavy Vehicles: Heavy Truck (4/5 R.Axle Trucks)	Heavy Vehicles: Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
LEG 1:MESKEL SQUARE APPROACH												
Through Traffic (TH)	**2013**	363	8	41	1	1	0	371	43	414	**233**	**261**
	2016	460	10	51	4	1	1	470	58	527		
Right Turn Traffic (RT)	**2013**	47	0	1	0	0	0	47	1	48		
	2016	60	1	1	1	1	1	**61**	**5**	**66**		
Left Turn Traffic (LT)	**2013**	95	7	3	3	0	0	102	6	108		
	2016	120	9	4	4	1	1	**129**	**10**	**139**		
Total	**2013**	**505**	**15**	**45**	**4**	**1**	**0**	**520**	**50**	**570**		
	2016	**640**	**20**	**56**	**9**	**4**	**4**	**659**	**73**	**732**		
LEG 2: OLYMPIA APPROACH												
Through Traffic (TH)	**2013**	209	5	3	2	0	0	214	5	219	**280**	**313**
	2016	265	6	4	3	1	1	**271**	**9**	**280**		
Right Turn Traffic (RT)	**2013**	197	2	1	2	0	0	199	3	202		
	2016	250	2	1	3	1	1	**252**	**6**	**258**		
Left Turn Traffic (LT)	**2013**	52	2	0	1	0	0	54	1	55		
	2016	66	2	1	1	1	1	**68**	**5**	**73**		
Total	**2013**	**458**	**9**	**4**	**5**	**0**	**0**	**467**	**9**	**476**		
	2016	**580**	**11**	**6**	**6**	**4**	**4**	**591**	**20**	**612**		
LEG 3: HAYAHULET APPROACH												
Through Traffic (TH)	**2013**	520	11	45	2	0	0	531	47	578	**431**	**482**
	2016	659	14	56	3	1	1	**672**	**61**	**733**		
Right Turn Traffic (RT)	**2013**	32	0	0	0	0	0	32	0	32		
	2016	41	1	1	1	1	1	**42**	**5**	**47**		
Left Turn Traffic (LT)	**2013**	101	0	0	1	0	0	101	1	102		
	2016	128	1	1	1	1	1	**129**	**5**	**134**		
Total	**2013**	**653**	**11**	**45**	**3**	**0**	**0**	**664**	**48**	**712**		
	2016	**827**	**16**	**58**	**5**	**4**	**4**	**843**	**71**	**914**		
LEG 4: KASANCHIS APPROACH												
Through Traffic (TH)	**2013**	280	0	0	1	0	0	280	1	281	**312**	**349**
	2016	355	1	1	1	1	1	**356**	**5**	**361**		
Right Turn Traffic (RT)	**2013**	204	5	0	1	0	0	209	1	210		
	2016	258	6	1	1	1	1	**265**	**5**	**270**		
Left Turn Traffic (LT)	**2013**	15	1	0	1	0	0	16	1	17		
	2016	19	1	1	1	1	1	**20**	**5**	**25**		
Total	**2013**	**499**	**6**	**0**	**3**	**0**	**0**	**505**	**3**	**508**		
	2016	**632**	**9**	**4**	**4**	**4**	**4**	**641**	**15**	**656**		

2.SUMMARY OF TRAFFIC ANALYSIS RESULT FOR BESHALE HOTEL ROUNDABOUT

LEG 1: CMC APPROACH

Direction	Year	Light Vehicles: Small Car	Light Vehicles: Small Truck	Heavy Vehicles: Bus	Heavy Vehicles: Medium Truck (Dual Rear Axle Truck)	Heavy Vehicles: Heavy Truck (4/5 R.Axle Trucks)	Heavy Vehicles: Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
Through Traffic (TH)	2013	637	8	62	15	0	0	645	77	722	474	530
	2016	807	10	77	19	1	1	817	99	915		
Right Turn Traffic (RT)	2013	65	0	1	2	0	0	65	3	68		
	2016	82	1	1	3	1	1	84	6	90		
Left Turn Traffic (LT)	2013	448	11	3	24	0	2	459	29	488		
	2016	567	14	4	30	1	3	581	38	619		
Total	**2013**	**1150**	**19**	**66**	**41**	**0**	**2**	**1169**	**109**	**1278**		
	2016	**1457**	**25**	**82**	**52**	**4**	**5**	**1481**	**143**	**1624**		

LEG 2: KARA APPROACH

Direction	Year	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
Through Traffic (TH)	2013	193	8	2	17	1	1	201	21	222	180	201
	2016	244	10	2	22	1	1	254	27	281		
Right Turn Traffic (RT)	2013	220	7	4	5	0	0	227	9	236		
	2016	279	9	5	6	1	1	287	14	301		
Left Turn Traffic (LT)	2013	96	0	2	0	0	0	96	2	98		
	2016	122	1	2	1	1	1	123	6	129		
Total	**2013**	**509**	**15**	**8**	**22**	**1**	**1**	**524**	**32**	**556**		
	2016	**645**	**20**	**10**	**29**	**4**	**4**	**665**	**47**	**711**		

LEG 3: MEGENAGNA APPROACH

Direction	Year	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
Through Traffic (TH)	2013	479	13	48	31	0	1	492	80	572	524	586
	2016	607	16	60	39	1	1	623	102	724		
Right Turn Traffic (RT)	2013	96	7	4	3	0	0	103	7	110		
	2016	122	9	5	4	1	1	130	11	142		
Left Turn Traffic (LT)	2013	411	9	19	14	0	0	420	33	453		
	2016	521	11	24	18	1	1	532	44	576		
Total	**2013**	**986**	**29**	**71**	**48**	**0**	**1**	**1015**	**120**	**1135**		
	2016	**1249**	**36**	**88**	**61**	**4**	**4**	**1285**	**157**	**1442**		

LEG 4: MEBRAT HAIL APPROACH

Direction	Year	Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)	Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
Through Traffic (TH)	2013	191	4	11	9	0	0	195	20	215	207	232
	2016	242	5	14	11	1	1	247	28	275		
Right Turn Traffic (RT)	2013	189	13	7	23	0	0	202	30	232		
	2016	239	16	9	29	1	1	255	40	296		
Left Turn Traffic (LT)	2013	74	1	3	2	0	0	75	5	80		
	2016	94	1	4	3	1	1	95	9	104		
Total	**2013**	**454**	**18**	**21**	**34**	**0**	**0**	**472**	**55**	**527**		
	2016	**575**	**22**	**26**	**43**	**4**	**4**	**597**	**77**	**674**		

3. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR CMC ROUNDABOUT												
LEG 1:SUMMIT APPROACH												
Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	51	4	3	1	2	1	55	7	62	127	142
	2016	65	5	4	1	3	1	70	9	78		
Right Turn Traffic (RT)	2013	65	5	6	12	1	0	70	19	89		
	2016	82	6	7	15	1	1	89	25	114		
Left Turn Traffic (LT)	2013	255	5	12	5	0	0	260	17	277		
	2016	323	6	15	6	1	1	329	24	353		
Total	**2013**	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**		
	2016	**470**	**17**	**26**	**23**	**5**	**4**	**487**	**58**	**545**		
LEG 2: AYAT APPROACH												
Through Traffic (TH)	2013	693	12	45	14	2	1	705	62	767	401	448
	2016	878	15	56	18	3	1	893	78	970		
Right Turn Traffic (RT)	2013	71	8	2	1	1	1	79	5	84		
	2016	90	10	2	1	1	1	100	6	106		
Left Turn Traffic (LT)	2013	199	5	8	16	0	1	204	25	229		
	2016	252	6	10	20	1	1	258	33	291		
Total	**2013**	**963**	**25**	**55**	**31**	**3**	**3**	**988**	**92**	**1080**		
	2016	**1220**	**31**	**68**	**39**	**5**	**4**	**1251**	**117**	**1367**		
LEG 3: MEGENAGNA APPROACH												
Through Traffic (TH)	2013	367	18	45	27	0	0	385	72	457	35	39
	2016	465	22	56	34	1	1	487	93	580		
Right Turn Traffic (RT)	2013	294	7	25	14	0	1	301	40	341		
	2016	372	9	31	18	1	1	381	51	432		
Left Turn Traffic (LT)	2013	55	3	3	1	2	1	58	7	65		
	2016	70	4	4	1	3	1	73	9	82		
Total	**2013**	**716**	**28**	**73**	**42**	**2**	**2**	**744**	**119**	**863**		
	2016	**907**	**35**	**91**	**53**	**5**	**4**	**942**	**153**	**1095**		
LEG 4: SUNSHINE REAL ESTATE (GENERATED TRAFFIC)												
Through Traffic (TH)	2013	51	4	3	1	2	1	55	7	62	42	47
	2016	65	5	4	1	3	1	70	9	78		
Right Turn Traffic (RT)	2013	255	5	12	5	0	0	260	17	277		
	2016	323	6	15	6	1	1	329	24	353		
Left Turn Traffic (LT)	2013	65	5	6	12	1	0	70	19	89		
	2016	82	6	7	15	1	1	89	25	114		
Total	**2013**	**371**	**14**	**21**	**18**	**3**	**1**	**385**	**43**	**428**		
	2016	**470**	**17**	**26**	**23**	**5**	**4**	**487**	**58**	**545**		

4. SUMMARY OF TRAFFIC ANALYSIS RESULT FOR AYAT ROUNDABOUT

LEG 1:MEGENAGNA APPROACH

Direction	Year	Light Vehicles		Heavy Vehicles				Total LV Veh/hr	Total HV Veh/hr	Total Veh/hr	Peds, 2013	Peds, 2016
		Small Car	Small Truck	Bus	Medium Truck (Dual Rear Axle Truck)	Heavy Truck (4/5 R.Axle Trucks)	Truck & Trailor (Large Truck)					
Through Traffic (TH)	2013	370	11	30	1	1	1	381	33	414	189	211
	2016	469	14	37	1	1	2	482	42	524		
Right Turn Traffic (RT)	2013	252	0	1	0	0	1	252	2	254		
	2016	319	1	1	1	1	5	320	9	329		
Left Turn Traffic (LT)	2013	324	5	4	1	0	0	329	5	334		
	2016	410	6	5	1	1	2	417	10	426		
Total	**2013**	**946**	**16**	**35**	**2**	**1**	**2**	**962**	**40**	**1002**		
	2016	**1198**	**21**	**44**	**4**	**4**	**10**	**1219**	**61**	**1280**		
LEG 2: SUMMIT APPROACH												
Through Traffic (TH)	2013	193	6	3	3	1	0	199	7	206	217	243
	2016	244	7	4	4	1	2	252	11	263		
Right Turn Traffic (RT)	2013	61	1	2	1	0	1	62	4	66		
	2016	77	1	2	1	1	1	79	6	85		
Left Turn Traffic (LT)	2013	200	1	0	1	1	0	201	2	203		
	2016	253	1	0	1	1	1	255	4	258		
Total	**2013**	**454**	**8**	**5**	**5**	**2**	**1**	**462**	**13**	**475**		
	2016	**575**	**10**	**6**	**6**	**4**	**5**	**585**	**21**	**606**		
LEG 3: AYAT CONDOMINIUM APPROACH												
Through Traffic (TH)	2013	519	9	39	1	1	1	528	42	570	198	221
	2016	657	11	48	1	1	1	669	52	721		
Right Turn Traffic (RT)	2013	32	5	0	1	0	0	37	1	38		
	2016	41	6	0	1	1	1	47	4	51		
Left Turn Traffic (LT)	2013	159	2	2	1	0	0	161	3	164		
	2016	201	2	2	1	1	1	204	6	210		
Total	**2013**	**710**	**16**	**41**	**3**	**1**	**1**	**726**	**46**	**772**		
	2016	**899**	**20**	**51**	**4**	**4**	**4**	**919**	**63**	**982**		
LEG 4: LAGATAFU APPROACH												
Through Traffic (TH)	2013	175	0	2	1	0	1	175	4	179	240	268
	2016	222	1	2	1	1	1	223	6	229		
Right Turn Traffic (RT)	2013	208	5	0	1	0	0	213	1	214		
	2016	263	6	1	1	1	1	270	5	275		
Left Turn Traffic (LT)	2013	76	3	1	1	1	0	79	3	82		
	2016	96	4	1	1	1	1	100	5	105		
Total	**2013**	**459**	**8**	**3**	**3**	**1**	**1**	**467**	**8**	**475**		
	2016	**581**	**11**	**5**	**4**	**4**	**4**	**593**	**17**	**609**		

APPENDIX B: SIDRA INTERSECTIONOUTPUT DATA

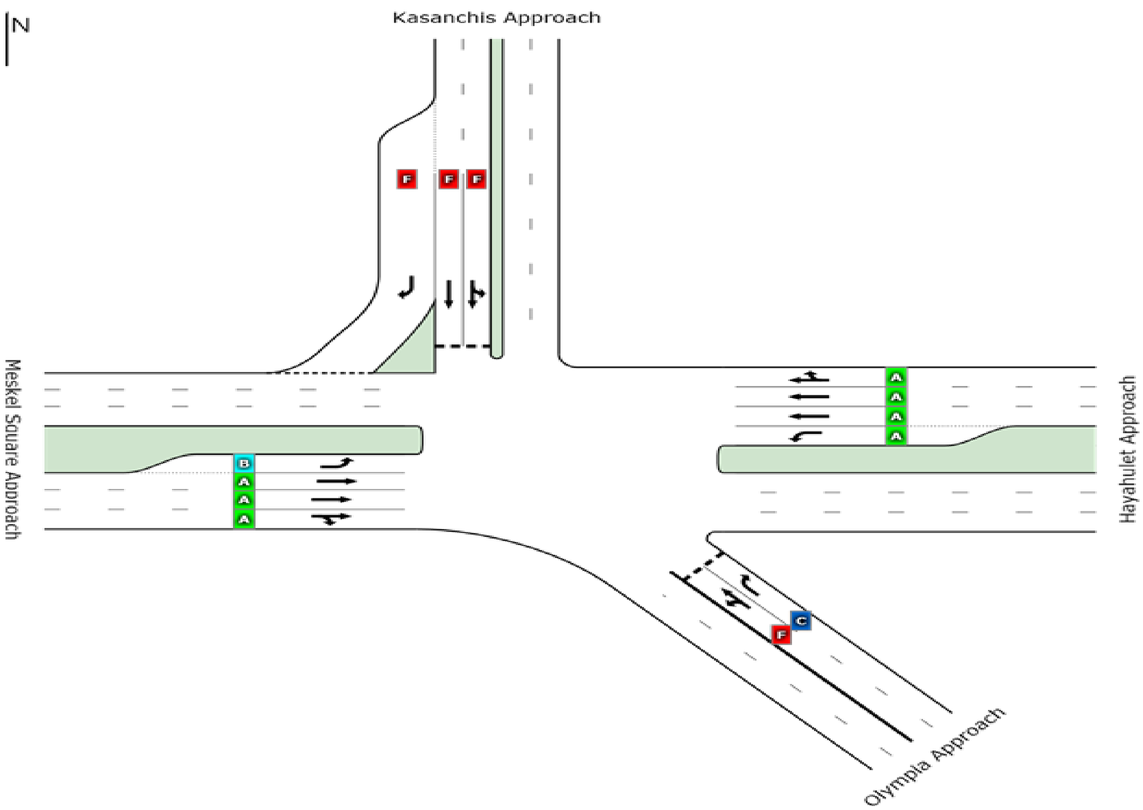
MOVEMENT SUMMARY

Site: BAMBIS INTESECTION BEFORE LRT

BAMBIS INTERSECTION
Giveway / Yield (Two-Way)

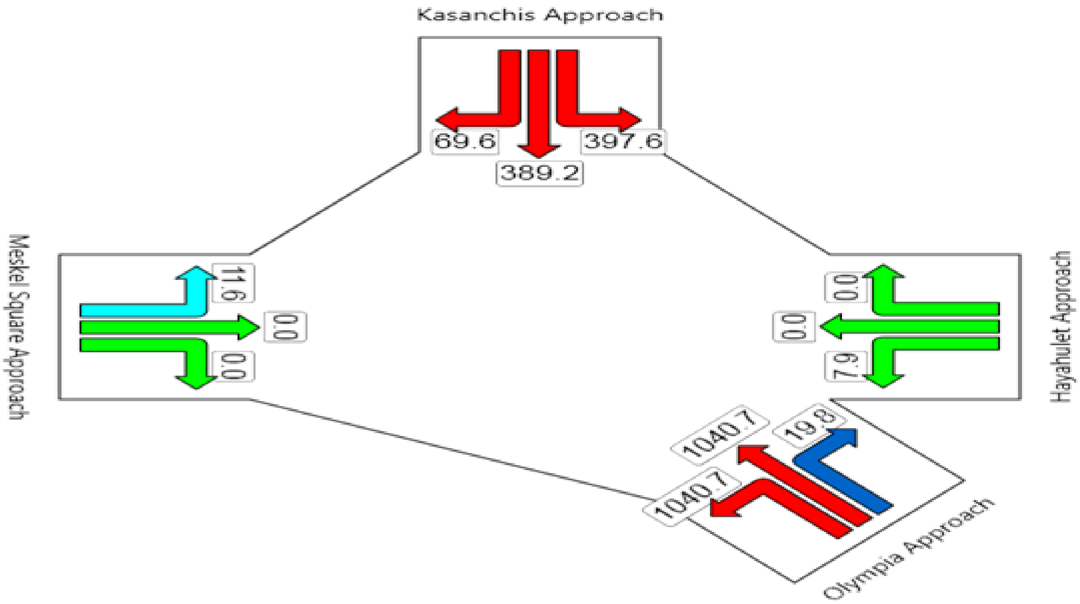
Movement Performance - Vehicles

Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South East: Olympia Approach											
1	L	79	6.8	3.144	1040.7	LOS F	92	722.4	1	4.28	0.5
2	T	304	3.2	3.144	1040.7	LOS F	92	722.4	1	4.53	0.5
3	R	280	2.3	0.575	19.8	LOS C	3.4	26.1	0.71	1.08	14.6
Approach		664	3.3	3.144	609.6	LOS F	92	722.4	0.88	3.04	0.9
East: Hayahulet Approach											
4	L	146	3.7	0.259	7.9	LOS A	1	8	0.59	0.87	20.5
5	T	797	8.3	0.206	0	LOS A	0	0	0	0	40
6	R	51	10.6	0.206	0	LOS A	0	0	0	0.66	30.1
Approach		993	7.8	0.259	1.2	NA	1	8	0.09	0.16	34.2
North: Kasanchis Approach											
7	L	27	20	1.659	397.6	LOS F	29.7	233.6	1	2.93	1.4
8	T	392	1.4	1.659	389.2	LOS F	34.7	266.6	1	3.21	1.3
9	R	293	1.9	0.924	69.6	LOS F	9	69.5	0.97	1.84	6.6
Approach		713	2.3	1.659	258	LOS F	34.7	266.6	0.99	2.64	2
West: Meskel Square Approach											
10	L	151	7.2	0.362	11.6	LOS B	1.6	12.6	0.72	0.93	19.4
11	T	574	11	0.161	0	LOS A	0	0	0	0	40
12	R	72	7.6	0.161	0	LOS A	0	0	0	0.32	34
Approach		797	10	0.362	2.2	NA	1.6	12.6	0.14	0.2	32.5
All Vehicles		3167	6.1	3.144	186.8	NA	92	722.4	0.47	1.33	2.7



DELAY (AVERAGE)

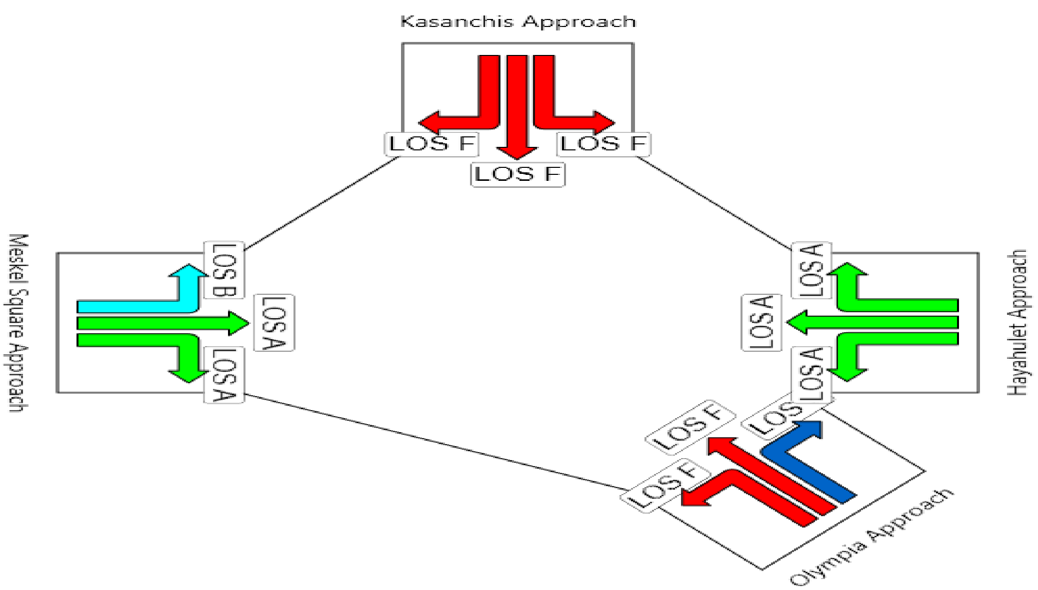
Site: BAMBIS INTESECTION
BEFORE LRT



	Southeast	East	North	West	Intersection
Delay (Average)	609.6	1.2	258.0	2.2	186.8
LOS	F	NA	F	NA	NA

LEVEL OF SERVICE

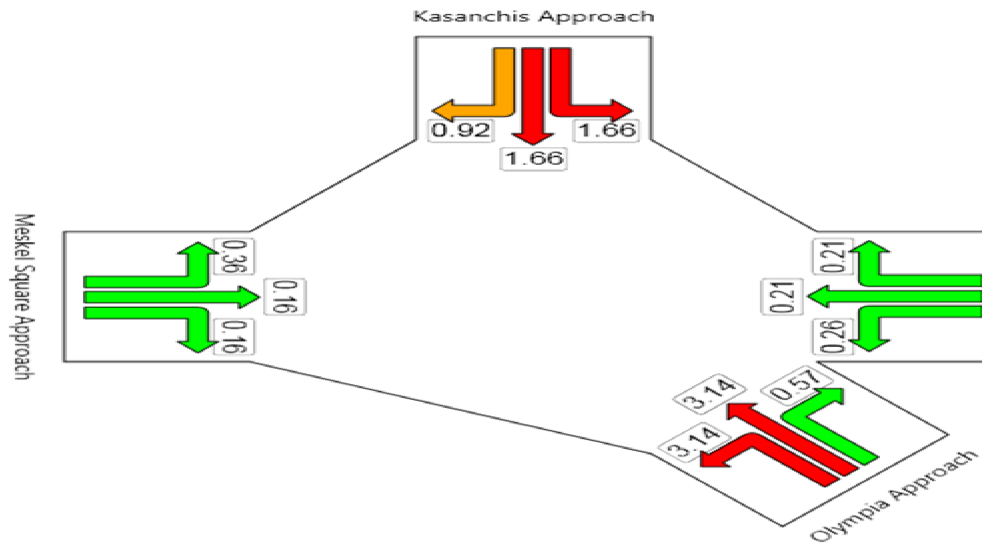
Site: BAMBIS INTESECTION
BEFORE LRT



	Southeast	East	North	West	Intersection
LOS	F	NA	F	NA	NA

DEGREE OF SATURATION

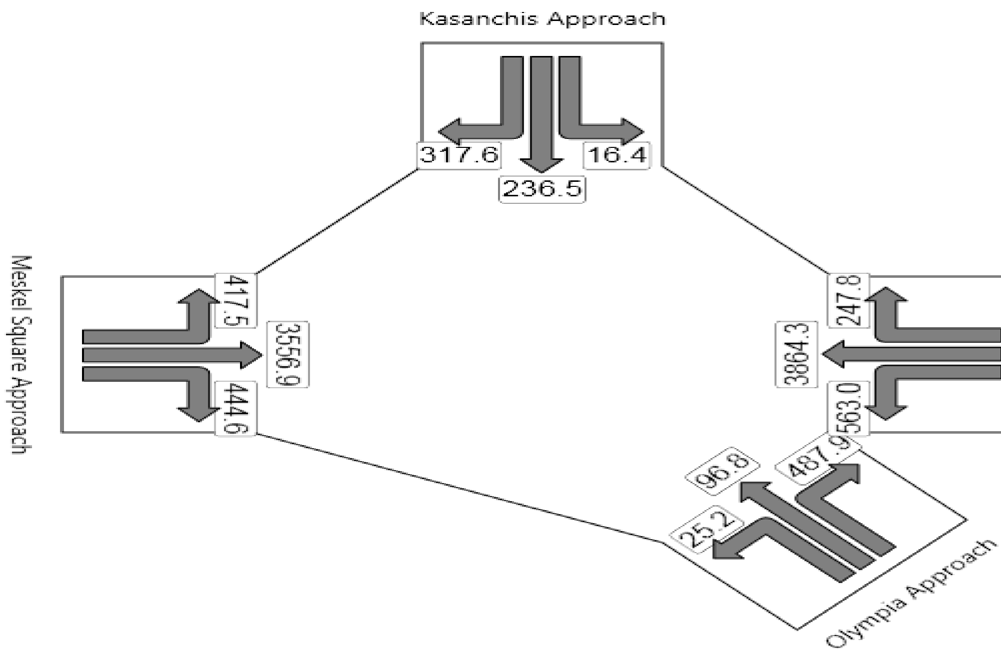
Site: BAMBIS INTESECTION
BEFORE LRT



	Southeast	East	North	West	Intersection
Degree of Saturation	3.14	0.26	1.66	0.36	3.14

CAPACITY

Site: BAMBIS INTESECTION
BEFORE LRT



MOVEMENT SUMMARY

Site: BAMBIS INTESECTION AFTER LRT

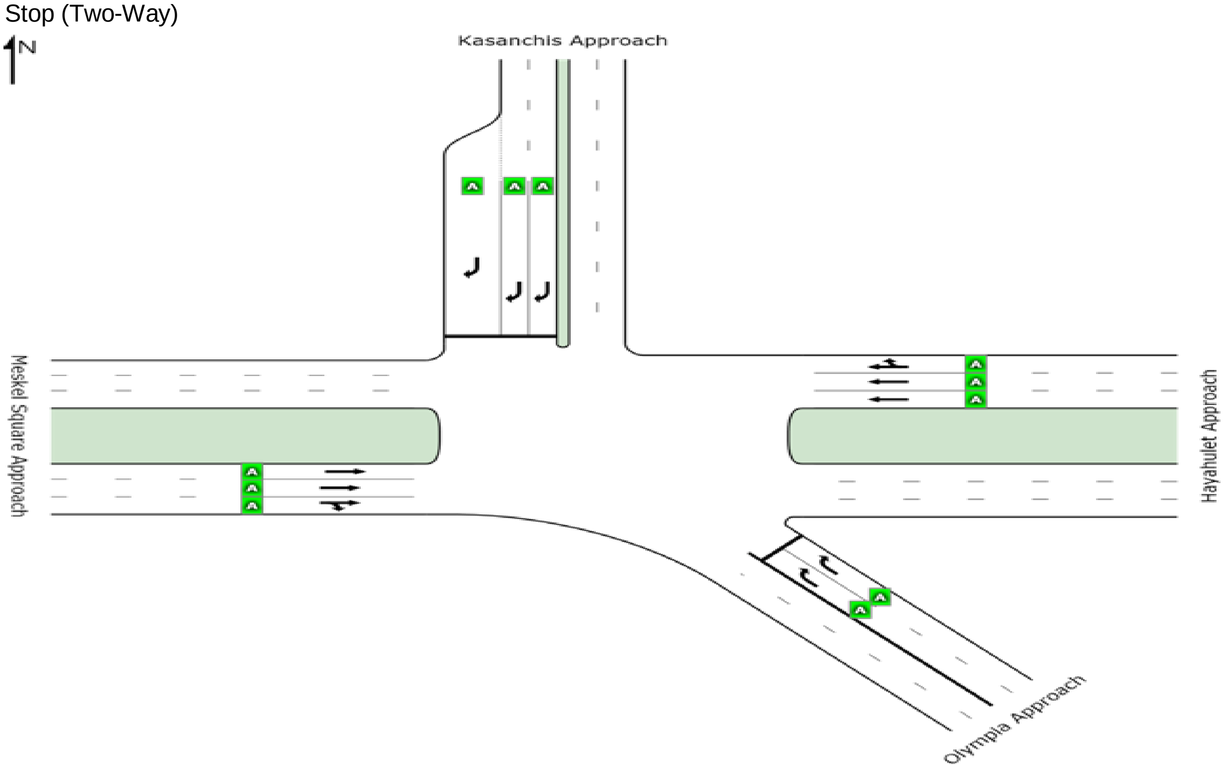
BAMBIS INTERSECTION
Stop (Two-Way)

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South East: Olympia Approach											
3	R	412	5.3	0.213	9.7	LOS A	0.9	7.3	0.53	0.93	18.6
Approach		412	5.3	0.213	9.7	LOS A	0.9	7.3	0.53	0.93	18.6
East: Hayahulet Approach											
5	T	601	11.9	0.22	4.8	LOS A	1	8.7	0.51	0.46	27
6	R	34	16.1	0.22	4.8	LOS A	1	8.7	0.51	0.32	24.6
Approach		635	12.2	0.22	4.8	NA	1	8.7	0.51	0.45	26.8
North: Kasanchis Approach											
9	R	438	3.7	0.167	9.9	LOS A	0.7	5.4	0.56	0.95	18.6
Approach		438	3.7	0.167	9.9	LOS A	0.7	5.4	0.56	0.95	18.6
West: Meskel Square Approach											
11	T	473	15.6	0.183	4.7	LOS A	0.9	7.4	0.5	0.44	27.3
12	R	46	11.9	0.183	4.6	LOS A	0.9	7.4	0.49	0.16	26.4
Approach		518	15.3	0.183	4.7	NA	0.9	7.4	0.5	0.41	27.2
All Vehicles		2003	9.7	0.22	6.9	NA	1	8.7	0.52	0.65	22.6

LEVEL OF SERVICE SUMMARY

Site: BAMBIS INTESECTION AFTER LRT

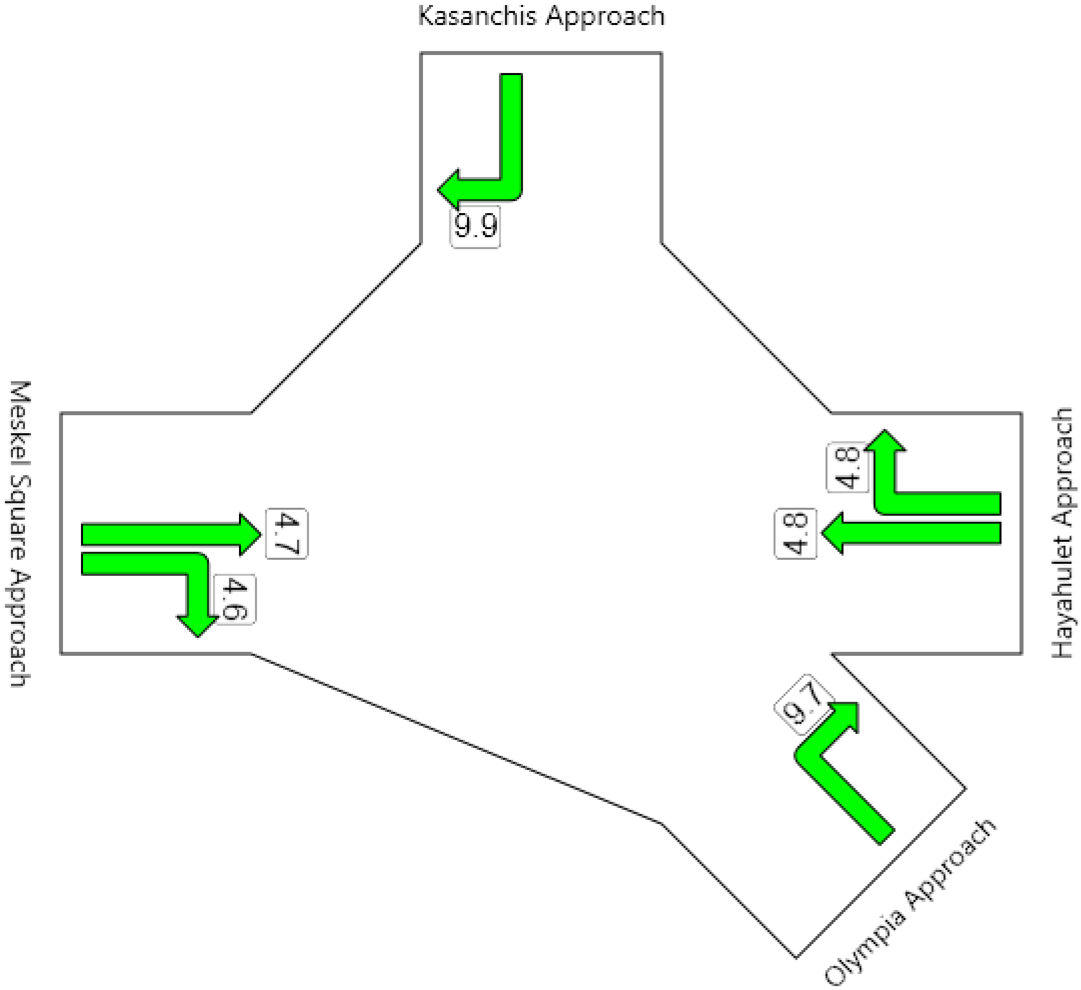
BAMBIS INTERSECTION
Stop (Two-Way)



	Southeast	East	North	West	Intersection
LOS	A	NA	A	NA	NA

DELAY (AVERAGE)

Site: BAMBIS INTESECTION
AFTER LRT



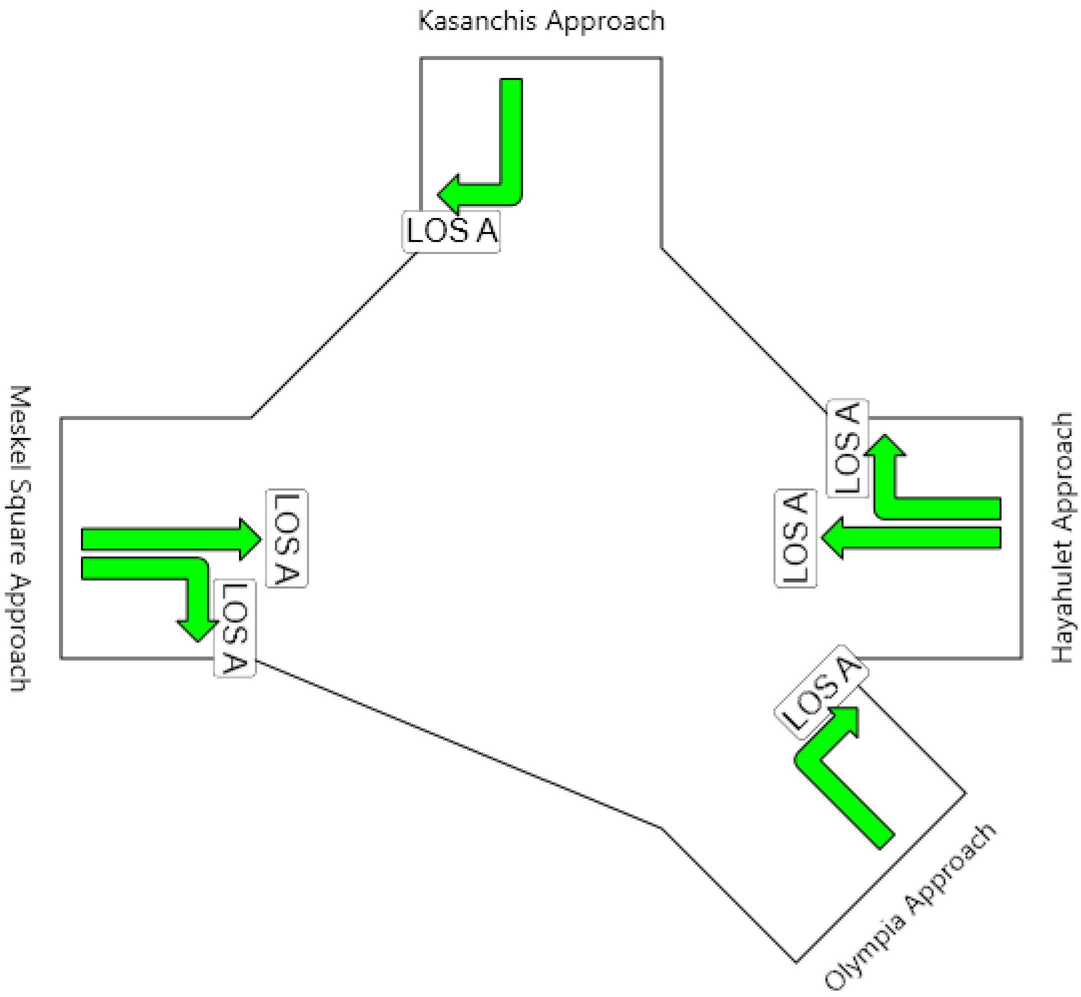
	Southeast	East	North	West	Intersection
Delay (Average)	9.7	4.8	9.9	4.7	6.9
LOS	A	NA	A	NA	NA

LEVEL OF SERVICE

Site: BAMBIS INTESECTION
AFTER LRT

Level of Service Method: Delay (HCM 2000)

BAMBIS INTERSECTION
Stop (Two-Way)

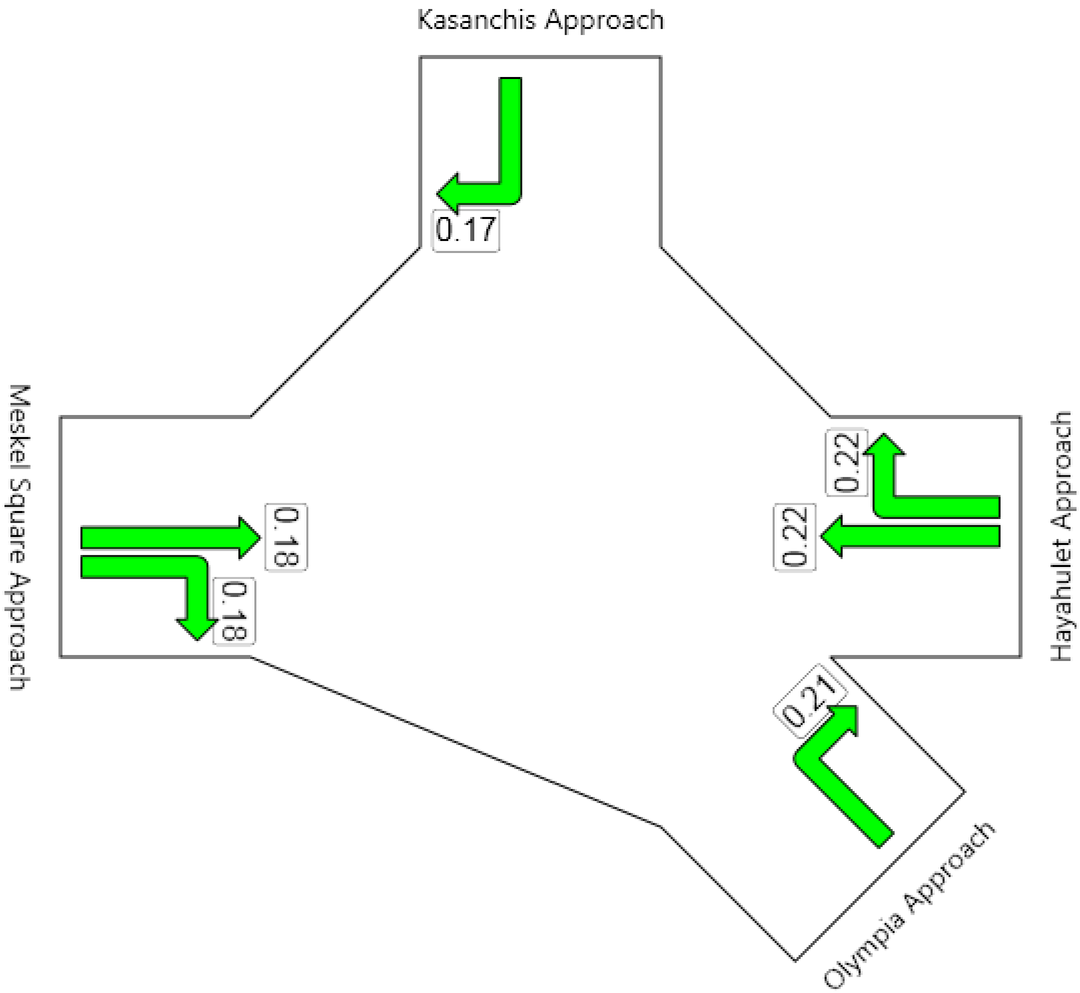


	Southeast	East	North	West	Intersection
LOS	A	NA	A	NA	NA

DEGREE OF SATURATION

Site: BAMBIS INTESECTION
AFTER LRT

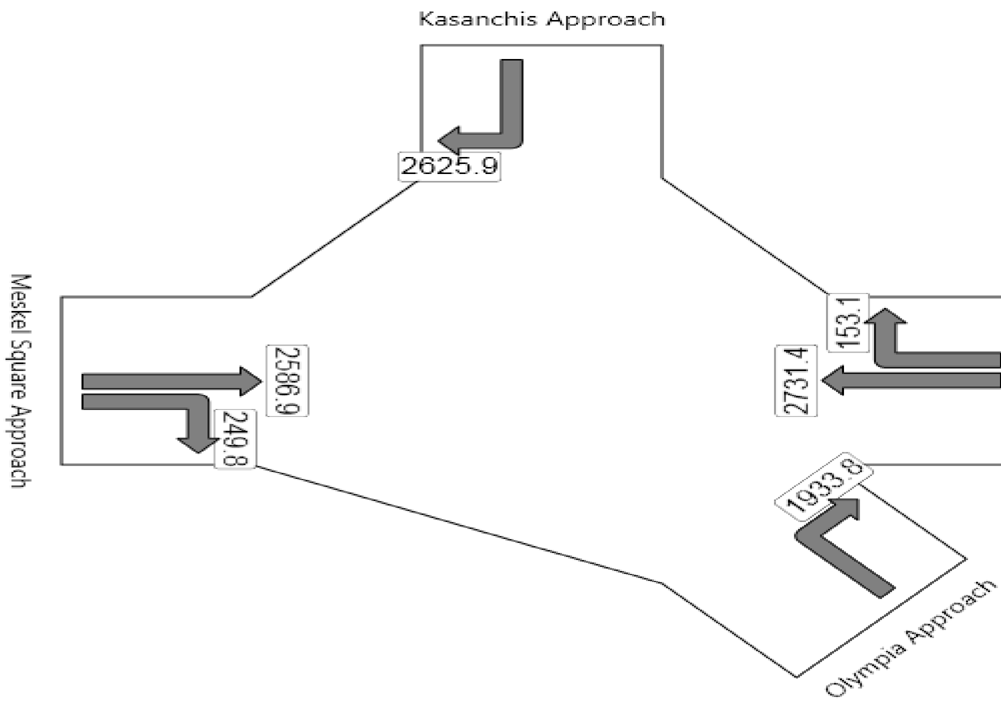
BAMBIS INTERSECTION
Stop (Two-Way)



	Southeast	East	North	West	Intersection
Degree of Saturation	0.21	0.22	0.17	0.18	0.22

CAPACITY

Site: BAMBIS INTESECTION AFTER LRT



MOVEMENT SUMMARY

Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT

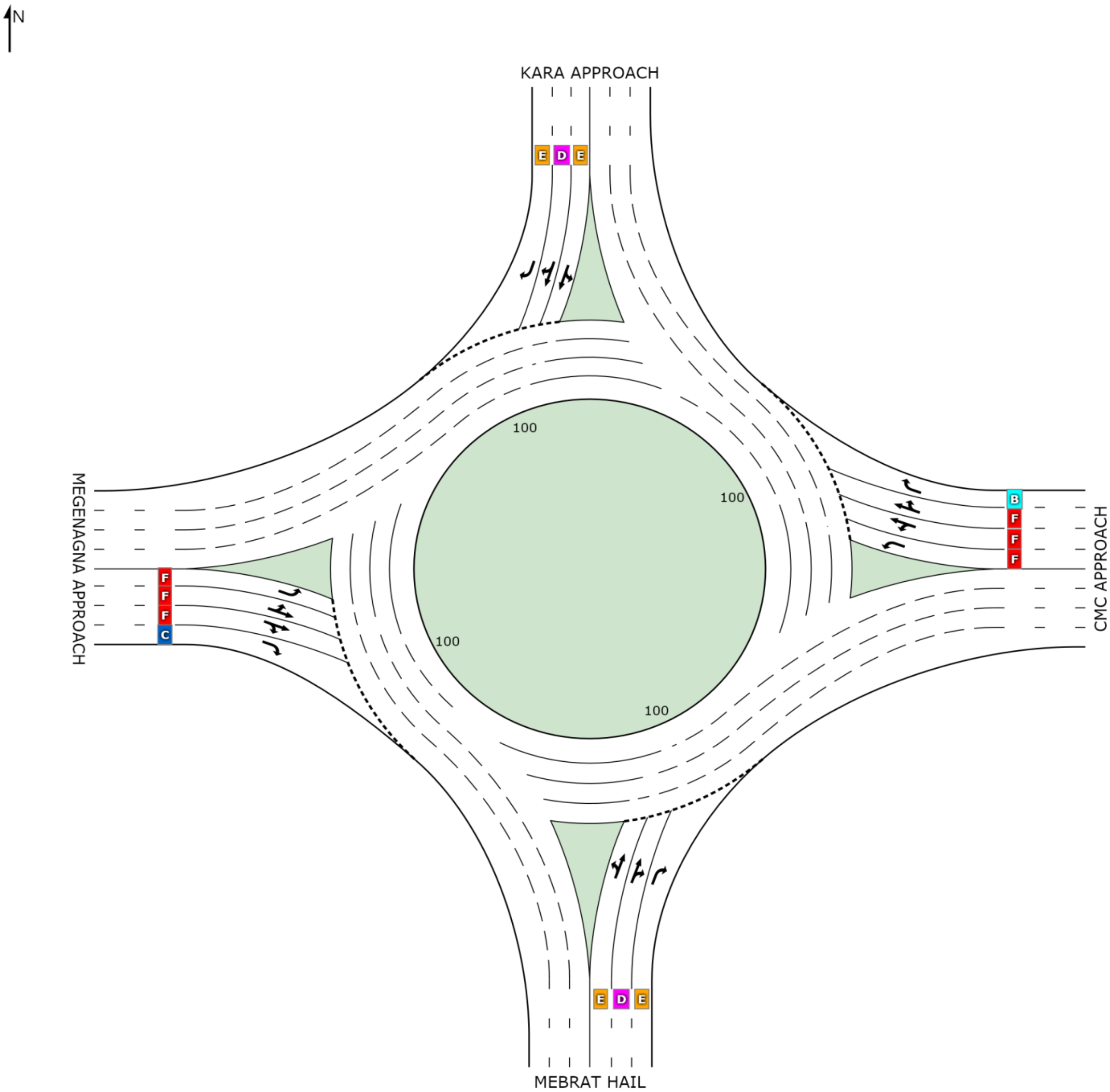
BESHALE HOTEL ROUND ABOUT
Roundabout

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: MEBRAT HAIL											
3	L	113	8.7	0.702	35.1	LOS E	2.7	22.1	0.85	1.07	17.9
8	T	299	10.2	0.702	34.2	LOS D	2.7	22.1	0.84	1.03	12.6
18	R	321	13.6	0.702	35.5	LOS E	2.6	21.8	0.84	1.04	11
Approach		733	11.4	0.702	34.9	LOS D	2.7	22.1	0.84	1.04	13
East: CMC APPROACH											
1	L	673	6.1	1.347	198.3	LOS F	52.1	429	1	5.57	5.1
6	T	996	10.8	1.347	198.9	LOS F	52.1	429	1	5.69	2.9
16	R	98	6.7	0.236	12.5	LOS B	0.5	4.2	0.58	0.58	20.7
Approach		1766	8.8	1.347	188.4	LOS F	52.1	429	0.98	5.36	4
North: KARA APPROACH											
7	L	140	4.7	0.715	35.8	LOS E	2.9	23.1	0.86	1.08	17.7
4	T	305	9.6	0.715	34.7	LOS D	2.9	23.1	0.85	1.05	12.5
14	R	327	4.7	0.715	34.9	LOS D	3	23.3	0.86	1.06	11.1
Approach		773	6.6	0.715	35	LOS D	3	23.3	0.85	1.06	13.2
West: MEGENAGNA APPROACH											
10	L	626	7.6	1.198	141.2	LOS F	31.1	259.4	1	4.14	6.8
11	T	788	14.1	1.198	142.4	LOS F	31	259.4	1	4.21	4
12	R	153	7.8	0.384	16.5	LOS C	0.9	7.5	0.62	0.67	18
Approach		1567	10.9	1.198	129.6	LOS F	31.1	259.4	0.96	3.84	5.5
All Vehicles		4839	9.5	1.347	121.6	LOS F	52.1	429	0.93	3.53	5.5

LEVEL OF SERVICE SUMMARY

Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT

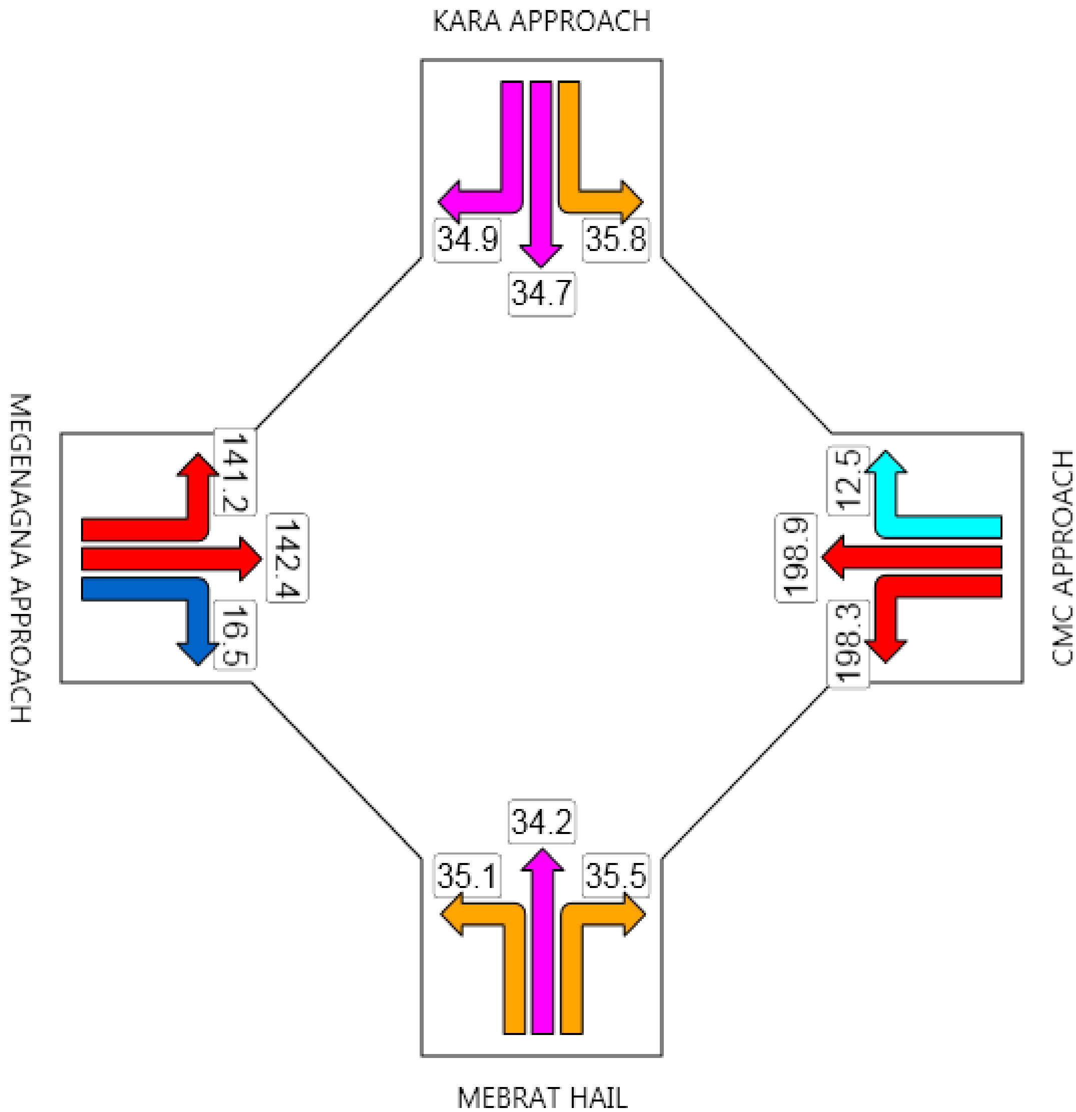
BESHALE HOTEL ROUND ABOUT
Roundabout



	South	East	North	West	Intersection
LOS	D	F	D	F	F

DELAY (AVERAGE)

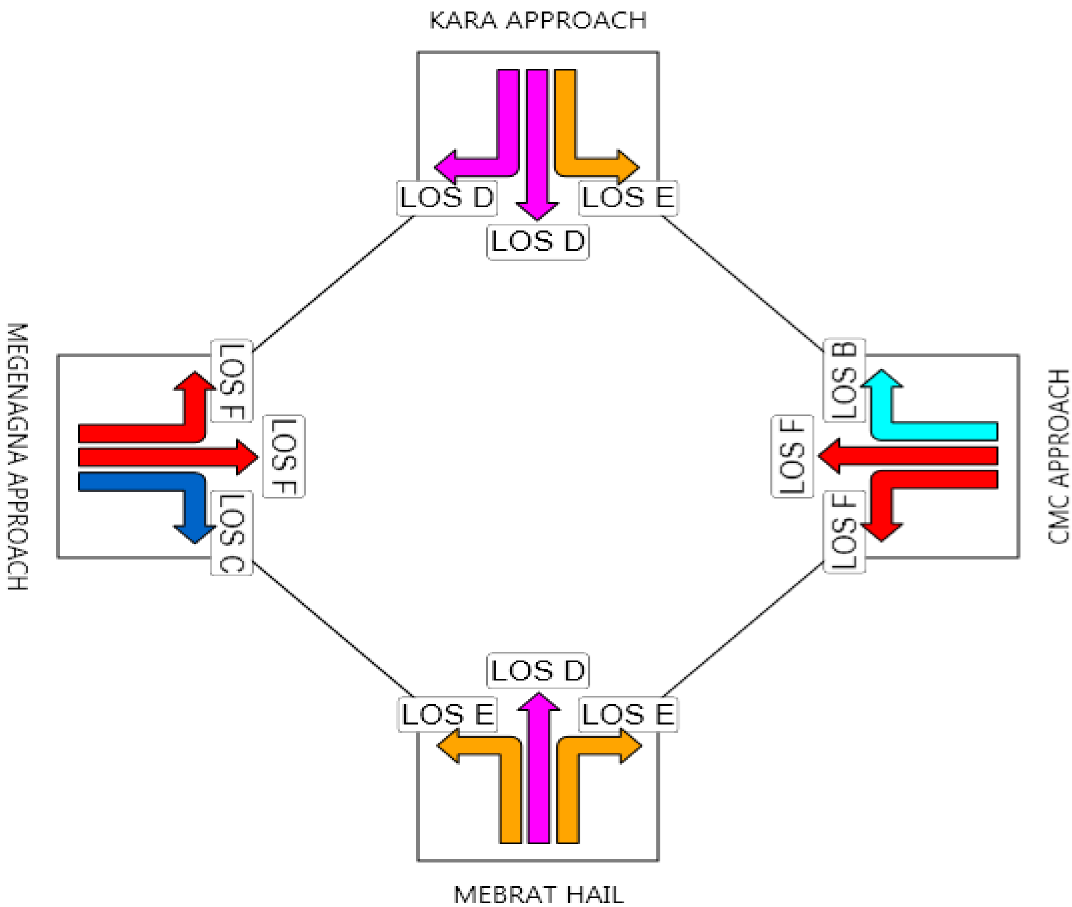
Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT



	South	East	North	West	Intersection
Delay (Average)	34.9	188.4	35.0	129.6	121.6
LOS	D	F	D	F	F

LEVEL OF SERVICE

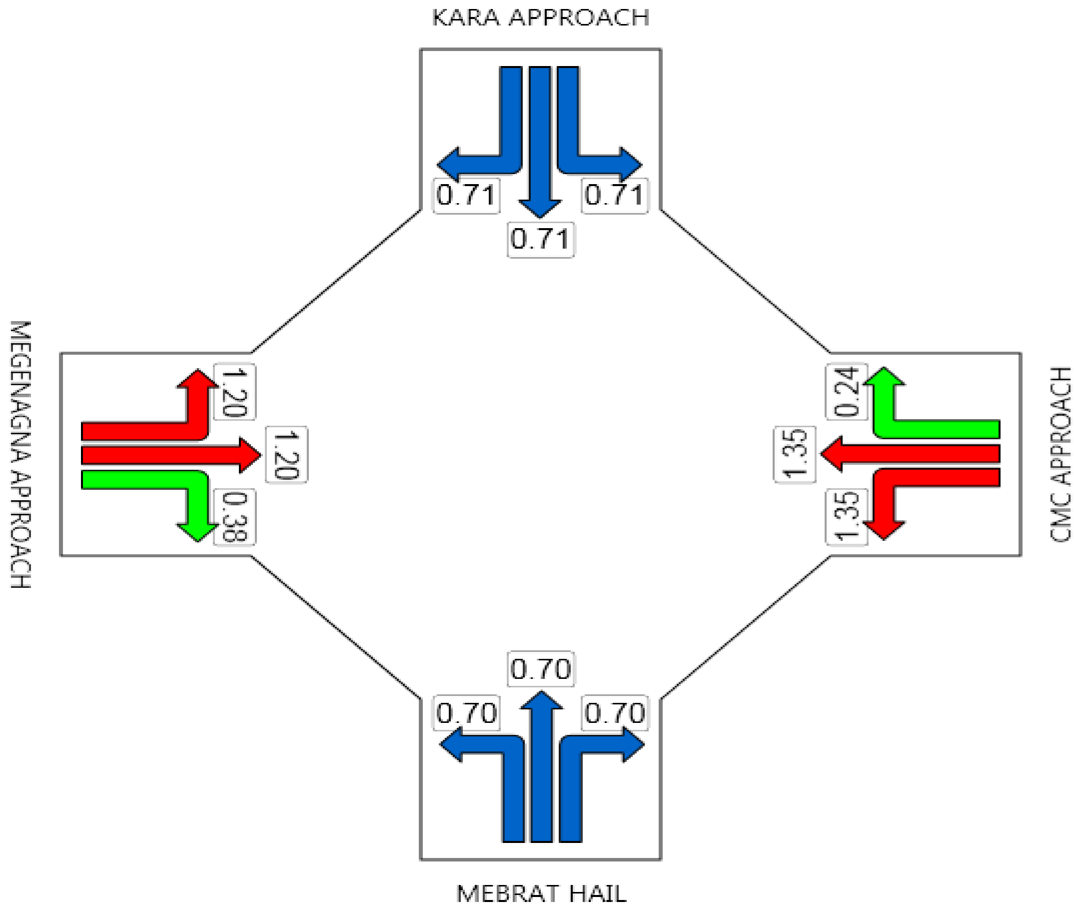
Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT



	South	East	North	West	Intersection
LOS	D	F	D	F	F

DEGREE OF SATURATION

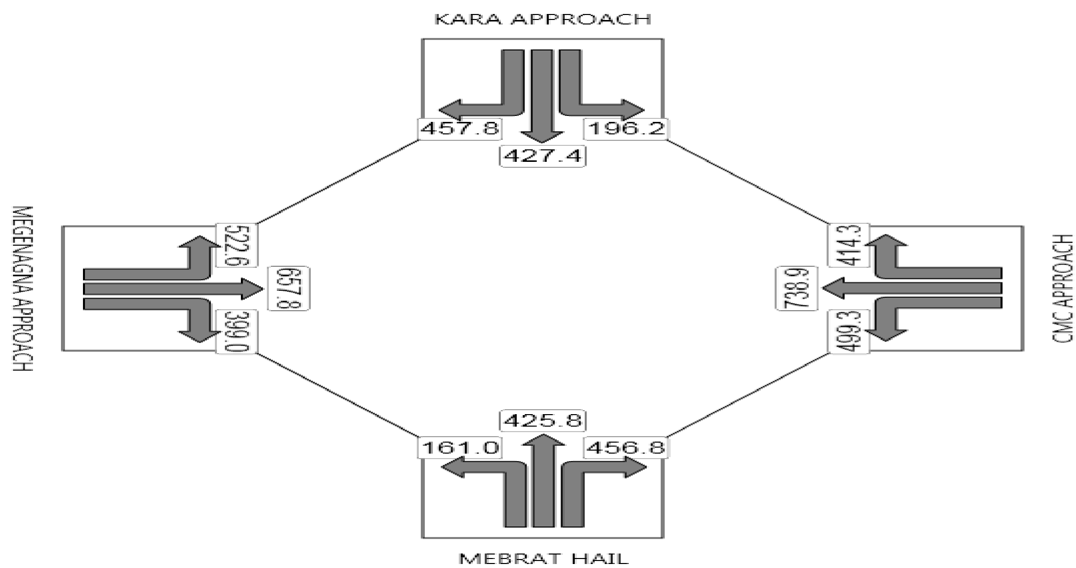
Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT



	South	East	North	West	Intersection
Degree of Saturation	0.70	1.35	0.71	1.20	1.35

CAPACITY

Site: BESHALE HOTEL ROUNDABOUT BEFORE LRT



MOVEMENT SUMMARY

Site: BESHALE HOTEL ROUNDABOUT AFTER LRT

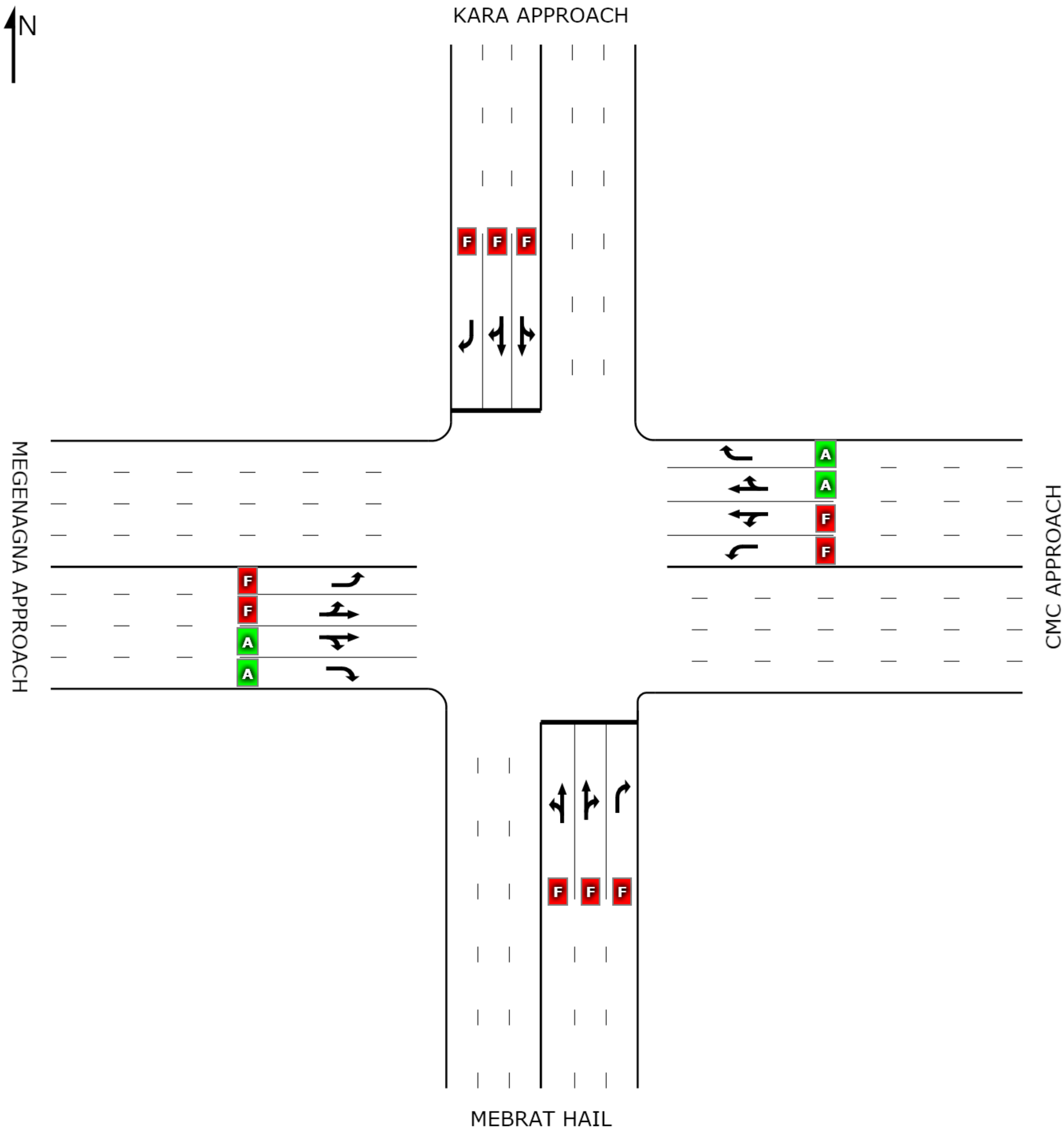
BESHALE HOTEL ROUND ABOUT
Stop (Two-Way)

Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: MEBRAT HAIL											
3	L	72	13.6	2.21	703.1	LOS F	28.4	242	1	2.65	0.8
8	T	193	15.7	2.21	703.1	LOS F	28.4	243.7	1	2.66	0.9
18	R	217	20	0.924	84.7	LOS F	10.7	94.8	0.97	1.91	5.3
Approach		483	17.3	2.21	424.5	LOS F	28.4	243.7	0.99	2.32	1.3
East: CMC APPROACH											
1	L	426	9.7	2.309	669.2	LOS F	48	394.8	1	3.01	0.8
6	T	645	16.7	0.571	7	LOS A	6.1	53	0.58	0.53	24.4
16	R	62	10.5	0.06	3.8	LOS A	0.2	2	0.43	0.6	24.9
Approach		1133	13.7	2.309	256	NA	48	394.8	0.73	1.47	2
North: KARA APPROACH											
7	L	87	7.5	1.449	388.2	LOS F	12.5	101.3	1	1.99	1.4
4	T	200	14.7	3.333	1194.7	LOS F	52	443.7	1	3.07	0.5
14	R	207	7.4	0.798	57.5	LOS F	6.9	55.5	0.94	1.56	7.1
Approach		493	10.4	3.333	576.6	LOS F	52	443.7	0.97	2.25	1
West: MEGENAGNA APPROACH											
10	L	399	12	2.719	867.1	LOS F	50.6	423.3	1	2.82	0.6
11	T	524	21.2	0.506	6.8	LOS A	4.4	39.4	0.57	0.53	24.8
12	R	101	11.8	0.104	4.2	LOS A	0.4	3.6	0.46	0.63	24.5
Approach		1024	16.7	2.719	341.7	NA	50.6	423.3	0.73	1.43	1.5
All Vehicles		3133	14.7	3.333	360.5	NA	52	443.7	0.81	1.71	1.5

LEVEL OF SERVICE SUMMARY

Site: BESHALE HOTEL ROUNDABOUT AFTER LRT

BESHALE HOTEL ROUND ABOUT
Stop (Two-Way)

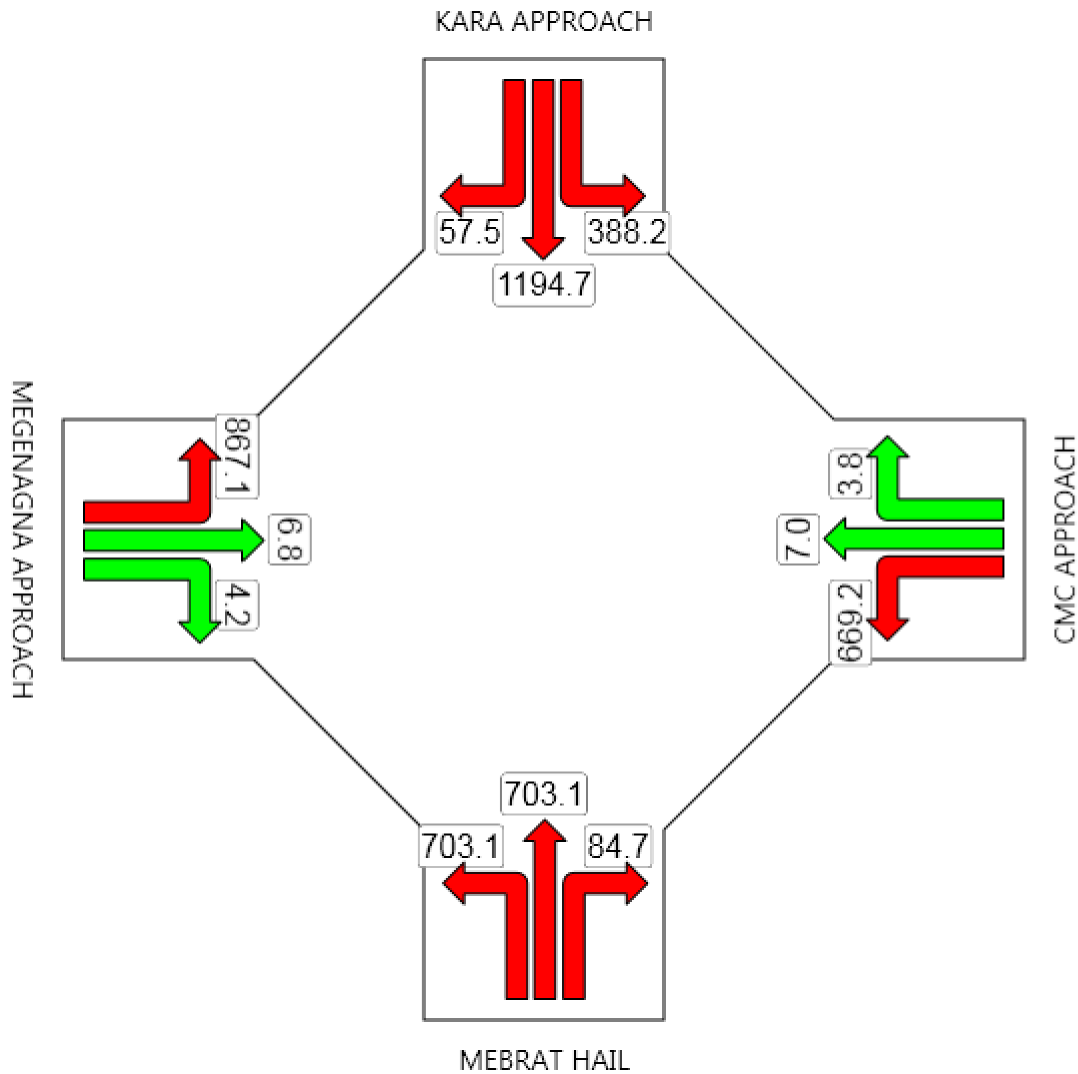


	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

Level of Service (LOS) Method: Delay (HCM 2000).
Lane LOS values are based on average delay per lane.
Minor Road Approach LOS values are based on average delay for all lanes.
NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road lanes.
HCM Delay Model used. Geometric Delay not included.

DELAY (AVERAGE)

Site: BESHALE HOTEL ROUNDABOUT AFTER LRT



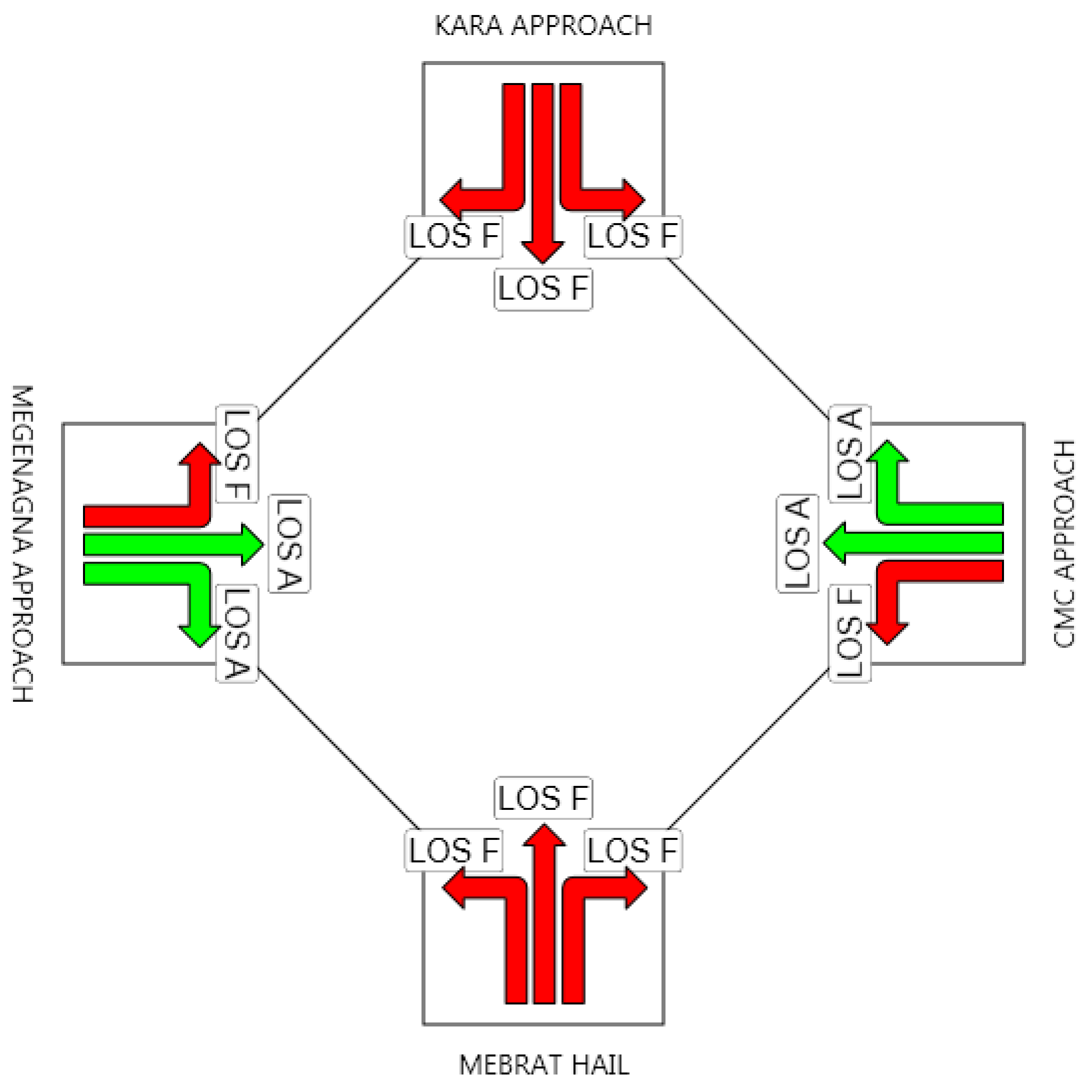
	South	East	North	West	Intersection
Delay (Average)	424.5	256.0	576.6	341.7	360.5
LOS	F	NA	F	NA	NA

Site: BESHALE HOTEL ROUNDABOUT AFTER LRT

LEVEL OF SERVICE

Level of Service Method: Delay (HCM 2000)

BESHALE HOTEL ROUND ABOUT
Stop (Two-Way)



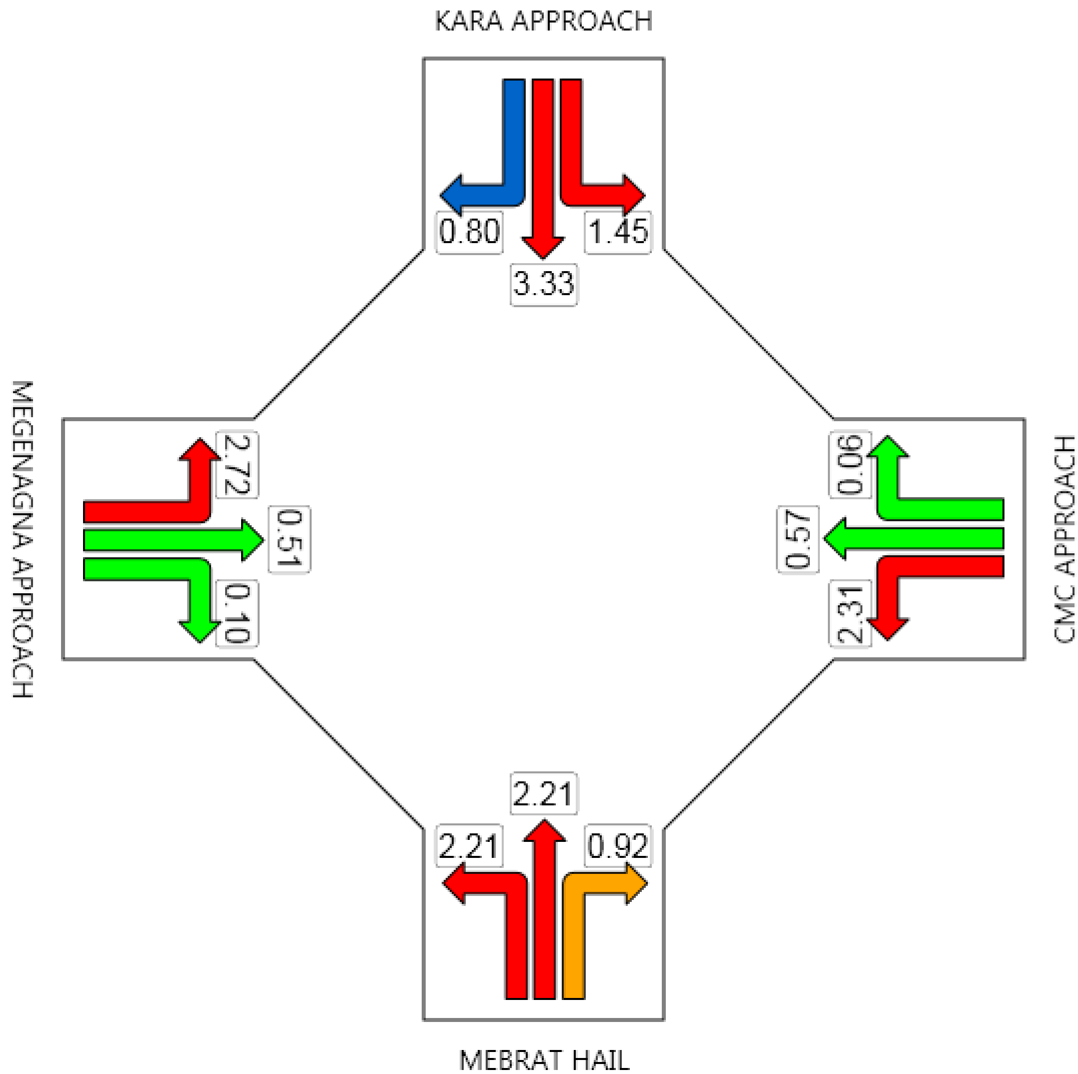
	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

DEGREE OF SATURATION

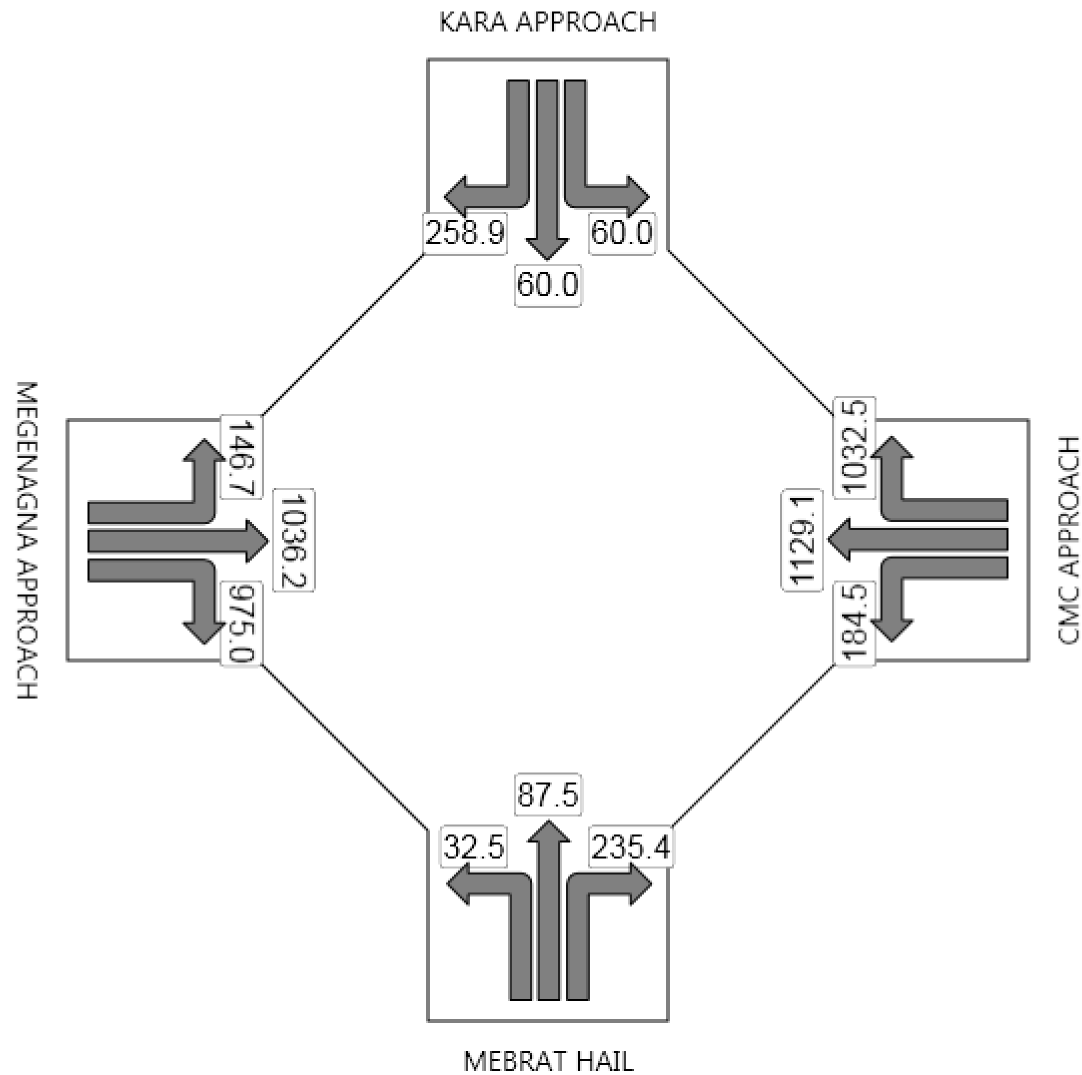
Site: BESHALE HOTEL ROUNDABOUT AFTER LRT

Ratio of Demand Volume to Capacity (v/c ratio)

BESHALE HOTEL ROUND ABOUT
Stop (Two-Way)



	South	East	North	West	Intersection
Degree of Saturation	2.21	2.31	3.33	2.72	3.33



KARA APPROACH
258.9
60.0
60.0
MEGENAGNA APPROACH
146.7
1036.2
975.0
CMC APPROACH
1032.5
1129.1
184.5
MEBRAT HAIL
87.5
32.5
235.4

MOVEMENT SUMMARY

Site: CMC ROUND ABOUT BEFORE LRT

CMC ROUND ABOUT
Roundabout

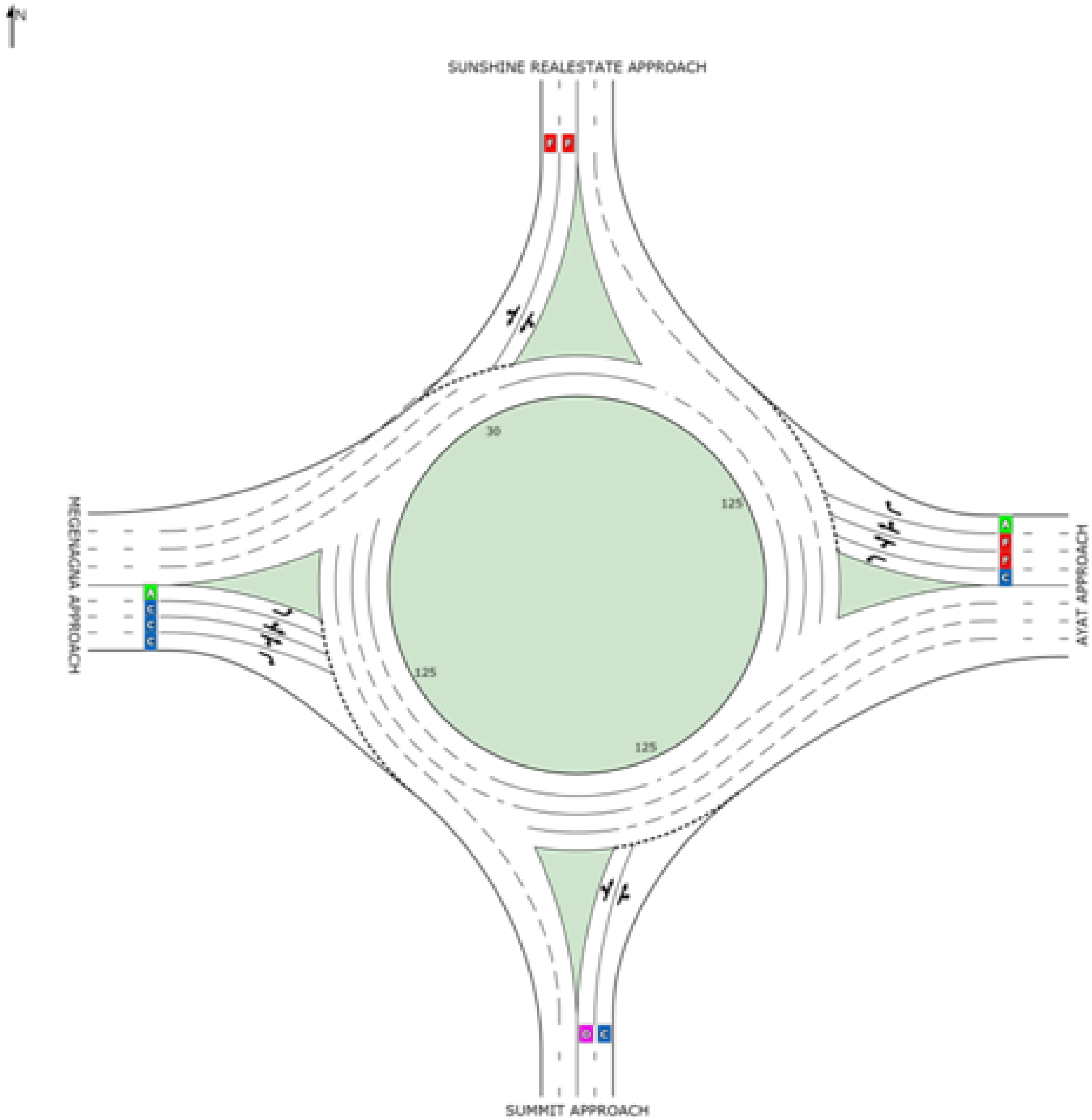
Movement Performance - Vehicles

Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: SUMMIT APPROACH											
1	L	384	6.8	0.724	26.2	LOS D	3.4	27.2	0.75	0.97	20.1
8	T	86	11.4	0.458	16.6	LOS C	1.4	12	0.64	0.71	30.2
2	R	124	21.9	0.458	16.6	LOS C	1.4	12	0.64	0.71	18.5
Approach		593	10.6	0.724	22.8	LOS C	3.4	27.2	0.71	0.88	21.8
East: AYAT APPROACH											
3	L	316	11.3	0.59	18.9	LOS C	1.9	15.9	0.56	0.72	23.2
4	T	1055	8	0.941	51.6	LOS F	8	64.9	0.73	1.28	9.9
16	R	115	5.7	0.204	9	LOS A	0.5	3.7	0.45	0.45	33.9
Approach		1487	8.6	0.941	41.4	LOS E	8	64.9	0.67	1.09	13.8
North: SUNSHINE REALESTATE APPROACH											
7	L	124	21.9	0.909	82.2	LOS F	4.2	37	0.93	1.48	17.4
4	T	86	11.4	0.909	82.2	LOS F	4.2	37	0.93	1.47	15.6
14	R	384	6.8	1.373	224.4	LOS F	37.8	304.1	1	4.41	7.2
Approach		593	10.6	1.373	174.1	LOS F	37.8	304.1	0.98	3.37	9.3
West: MEGENAGNA APPROACH											
5	L	89	11	0.14	7.3	LOS A	0.3	2.9	0.43	0.43	36.2
5	T	630	16	0.586	16.8	LOS C	2.3	19.6	0.59	0.67	18.8
6	R	470	11.8	0.586	16.1	LOS C	2.3	19.6	0.57	0.65	18.8
Approach		1189	14	0.586	15.8	LOS C	2.3	19.6	0.57	0.65	21.7
All Vehicles		3863	10.9	1.373	51.1	LOS F	37.8	304.1	0.69	1.27	13.6

LEVEL OF SERVICE SUMMARY

Site: CMC ROUND ABOUT
BEFORE LRT

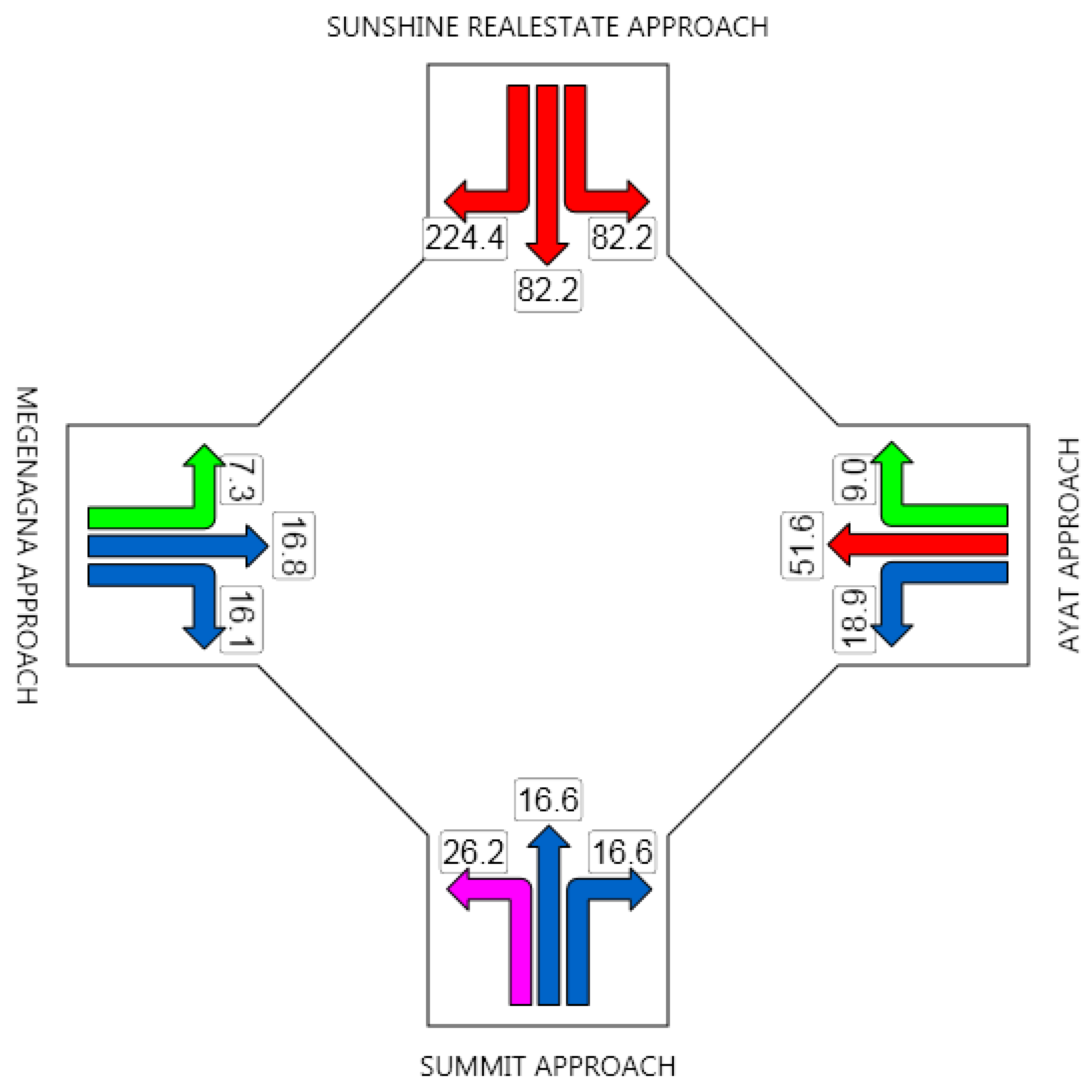
CMC ROUND ABOUT
Roundabout



	South	East	North	West	Intersection
LOS	C	E	F	C	F

DELAY (AVERAGE)

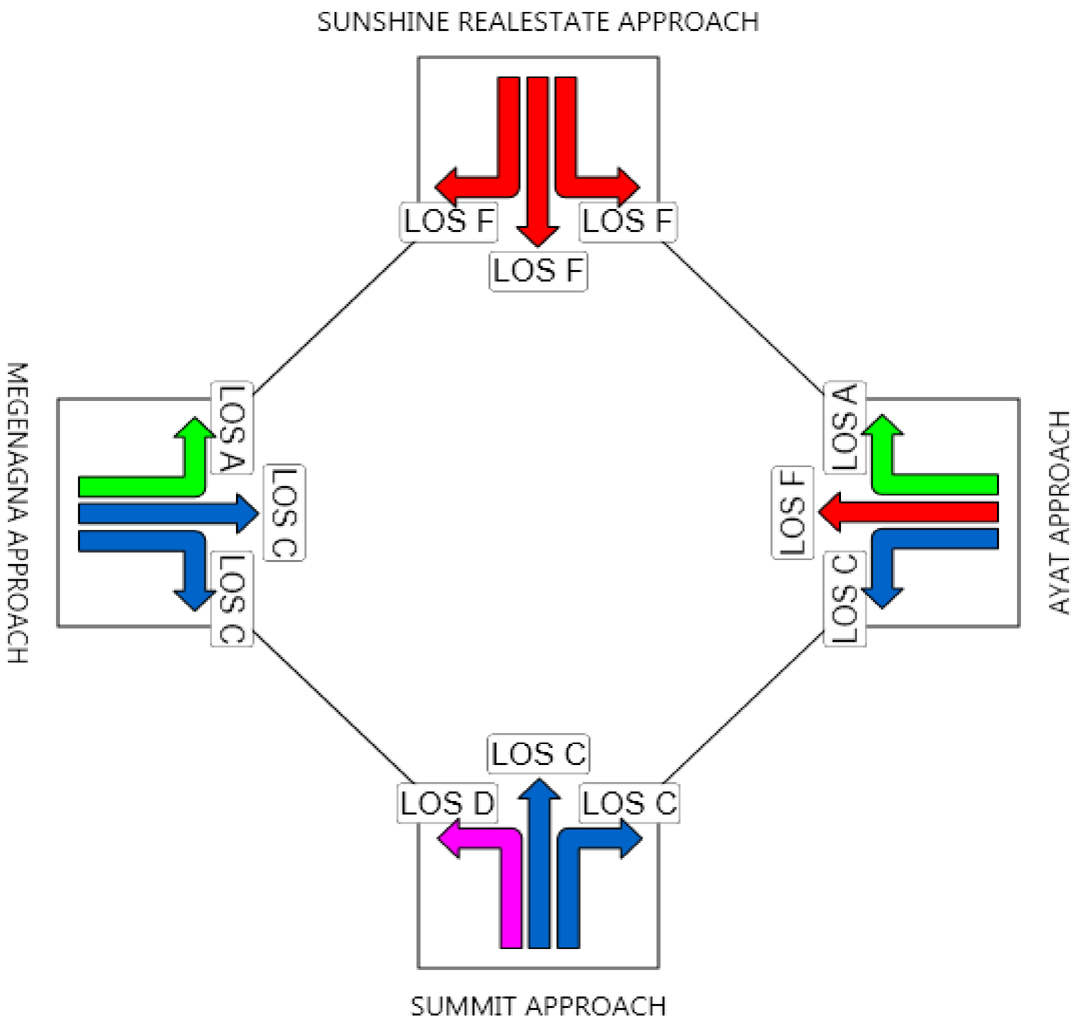
Site: CMC ROUND ABOUT BEFORE LRT



	South	East	North	West	Intersection
Delay (Average)	22.8	41.4	174.1	15.8	51.1
LOS	C	E	F	C	F

LEVEL OF SERVICE

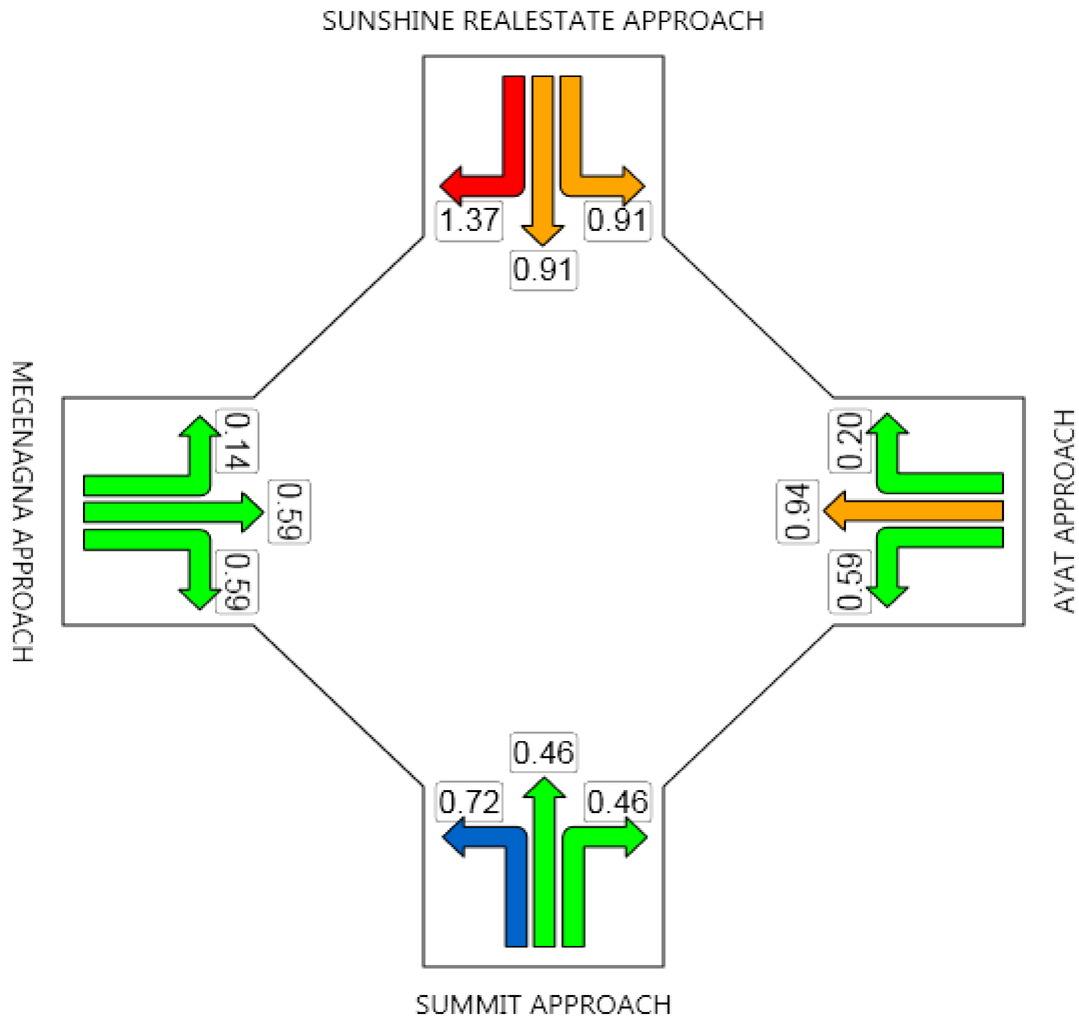
Site: CMC ROUND ABOUT BEFORE LRT



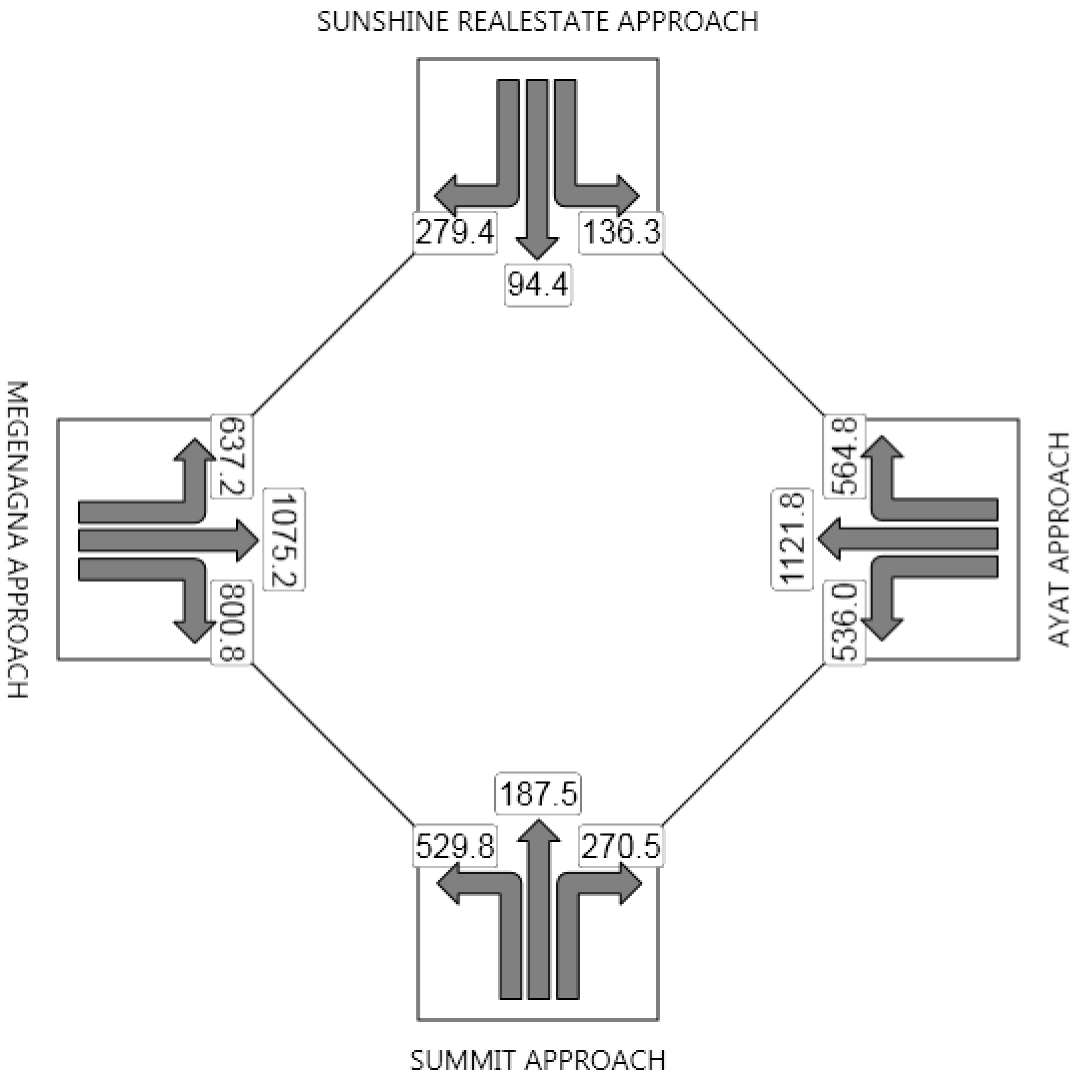
	South	East	North	West	Intersection
LOS	C	E	F	C	F

DEGREE OF SATURATION

Site: CMC ROUND ABOUT BEFORE LRT



	South	East	North	West	Intersection
Degree of Saturation	0.72	0.94	1.37	0.59	1.37



SUNSHINE REALESTATE APPROACH
279.4
136.3
94.4
MEGENAGNA APPROACH
637.2
1075.2
800.8
AYAT APPROACH
564.8
1121.8
536.0
187.5
529.8
270.5
SUMMIT APPROACH

MOVEMENT SUMMARY

Site: CMC ROUND ABOUT AFTER LRT

CMC ROUND ABOUT
Stop (Two-Way)

Movement Performance - Vehicles

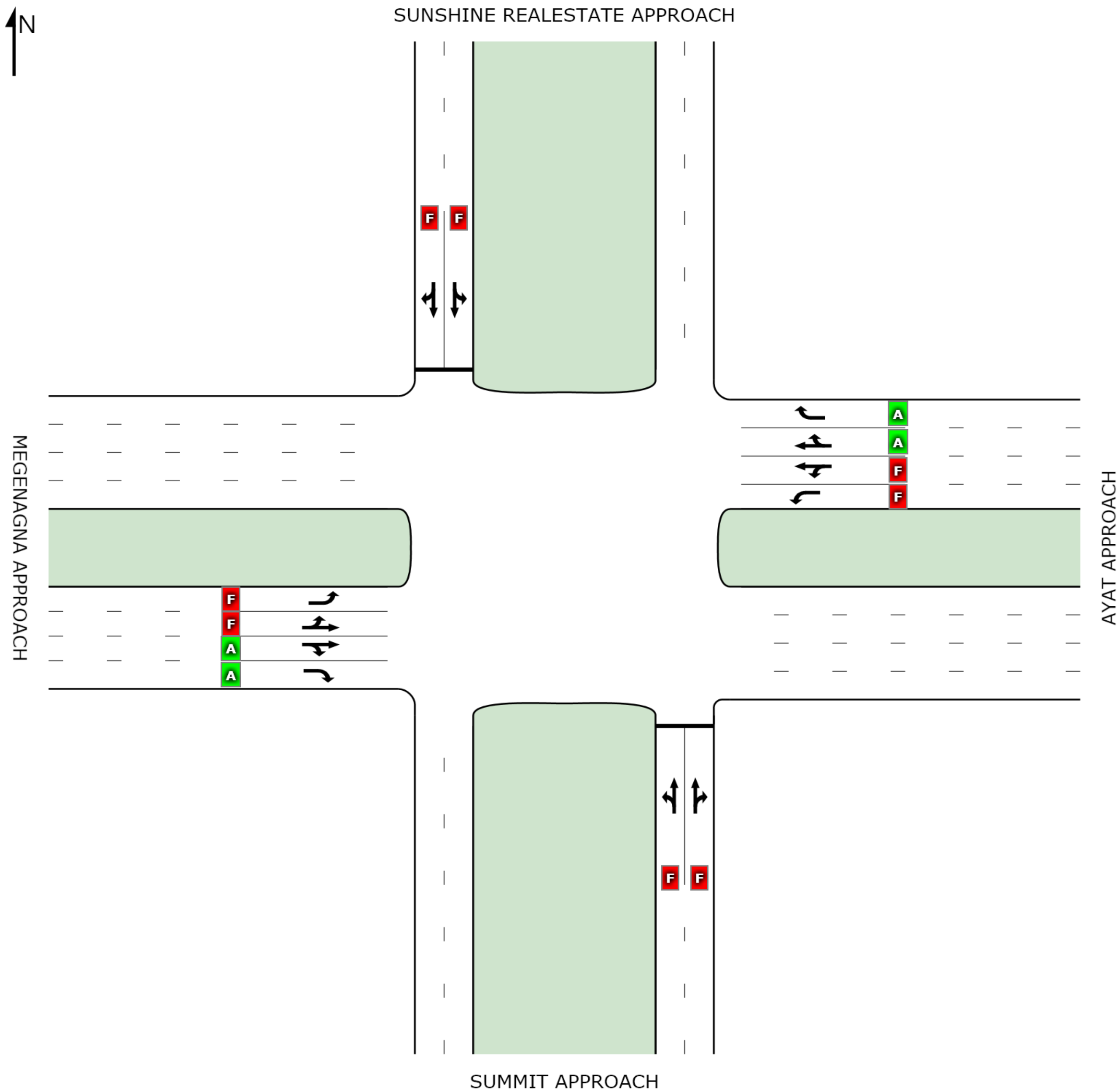
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: SUMMIT APPROACH											
1	L	243	10.7	4.058	1516.6	LOS F	68.6	568.8	1	3.05	0.4
8	T	58	17	1.494	346.1	LOS F	21.4	197.4	1	2.44	5.2
2	R	88	30.9	1.494	346.1	LOS F	21.4	197.4	1	2.83	1.5
Approach		389	16.2	4.058	1078.5	LOS F	68.6	568.8	1	2.91	0.7
East: AYAT APPROACH											
3	L	207	17.4	1.053	171.3	LOS F	10.2	88.9	1	1.73	3.3
4	T	674	12.6	0.598	7.5	LOS A	6.9	57.7	0.64	0.65	23.8
16	R	76	8.6	0.057	3	LOS A	0.2	2	0.25	0.51	34.8
Approach		957	13.3	1.053	42.5	NA	10.2	88.9	0.69	0.87	10.9
North: SUNSHINE REALESTATE APPROACH											
7	L	88	30.9	1.699	488	LOS F	20.3	191.6	1	1.95	3.8
4	T	58	17	1.699	410.7	LOS F	46.1	384.8	1	2.89	4.5
14	R	243	10.7	1.699	386.1	LOS F	46.1	384.8	1	3.95	4.5
Approach		389	16.2	1.699	412.8	LOS F	46.1	384.8	1	3.34	4.3
West: MEGENAGNA APPROACH											
5	L	60	16.4	0.368	65.2	LOS F	1.6	13.9	0.96	1.04	17.3
5	T	428	23.6	0.364	4.9	LOS A	2.2	19.7	0.34	0.19	28
6	R	308	18	0.298	5	LOS A	1.5	13.2	0.47	0.63	23.6
Approach		796	20.9	0.368	9.5	NA	2.2	19.7	0.44	0.42	23.2
All Vehicles		2530	16.6	4.058	248.4	NA	68.6	568.8	0.7	1.42	3.3

Level of Service (LOS) Method: Delay (HCM 2000).
Vehicle movement LOS values are based on average delay per movement
Minor Road Approach LOS values are based on average delay for all vehicle movements.
NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road movements.
HCM Delay Model used. Geometric Delay not included.

LEVEL OF SERVICE SUMMARY

Site: CMC ROUND ABOUT AFTER LRT

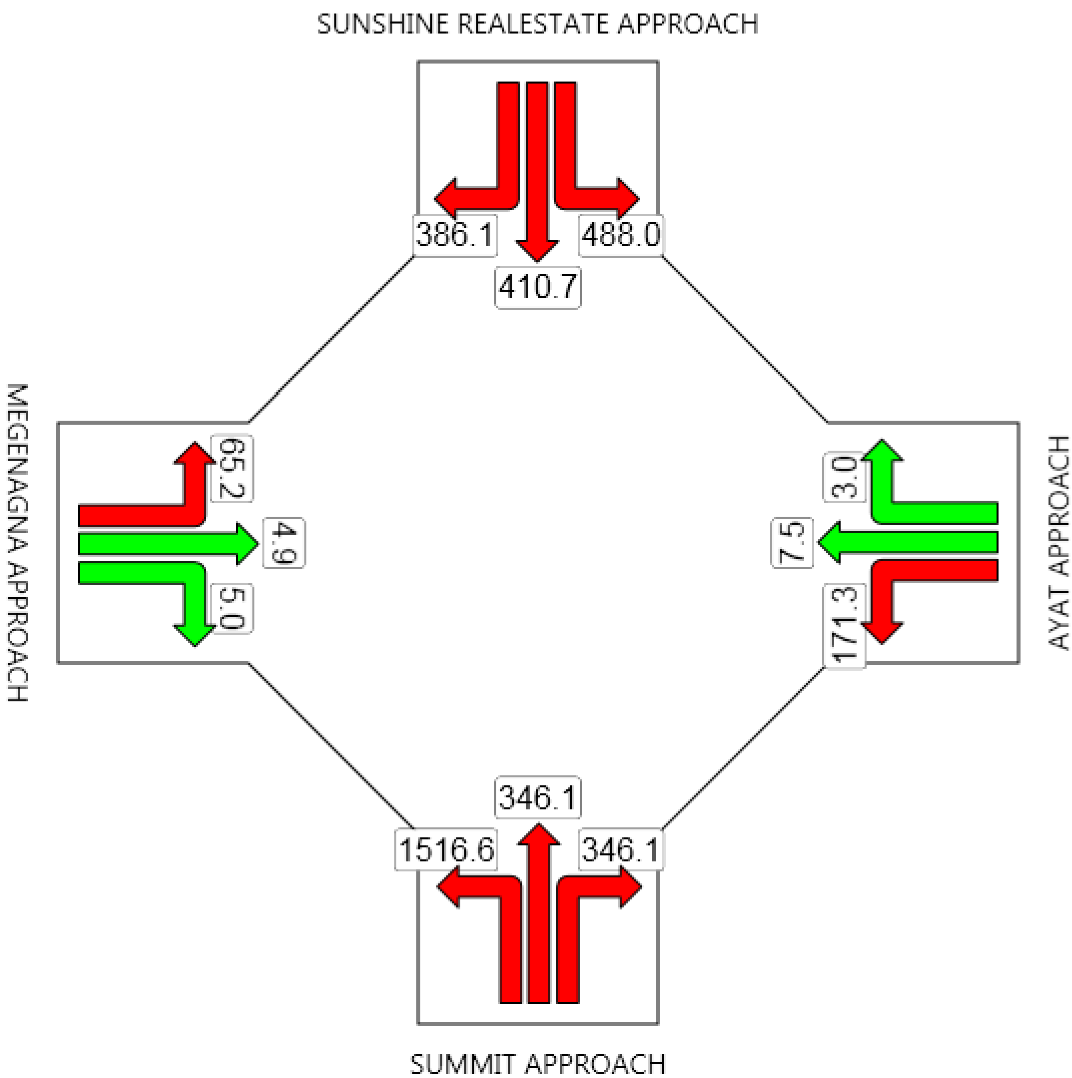
CMC ROUND ABOUT
Stop (Two-Way)



	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

DELAY (AVERAGE)

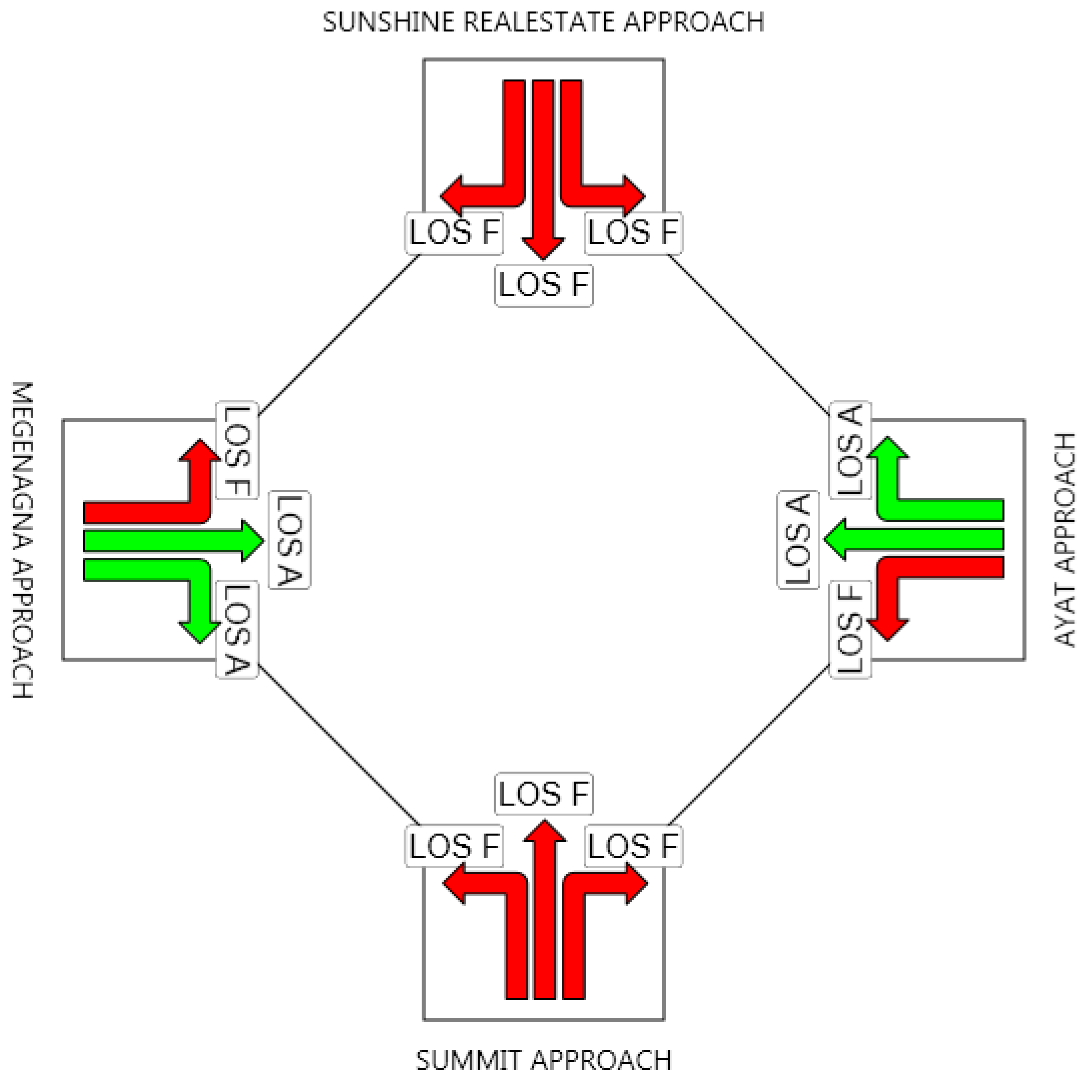
Site: CMC ROUND ABOUT AFTER LRT



	South	East	North	West	Intersection
Delay (Average)	1078.5	42.5	412.8	9.5	248.4
LOS	F	NA	F	NA	NA

LEVEL OF SERVICE

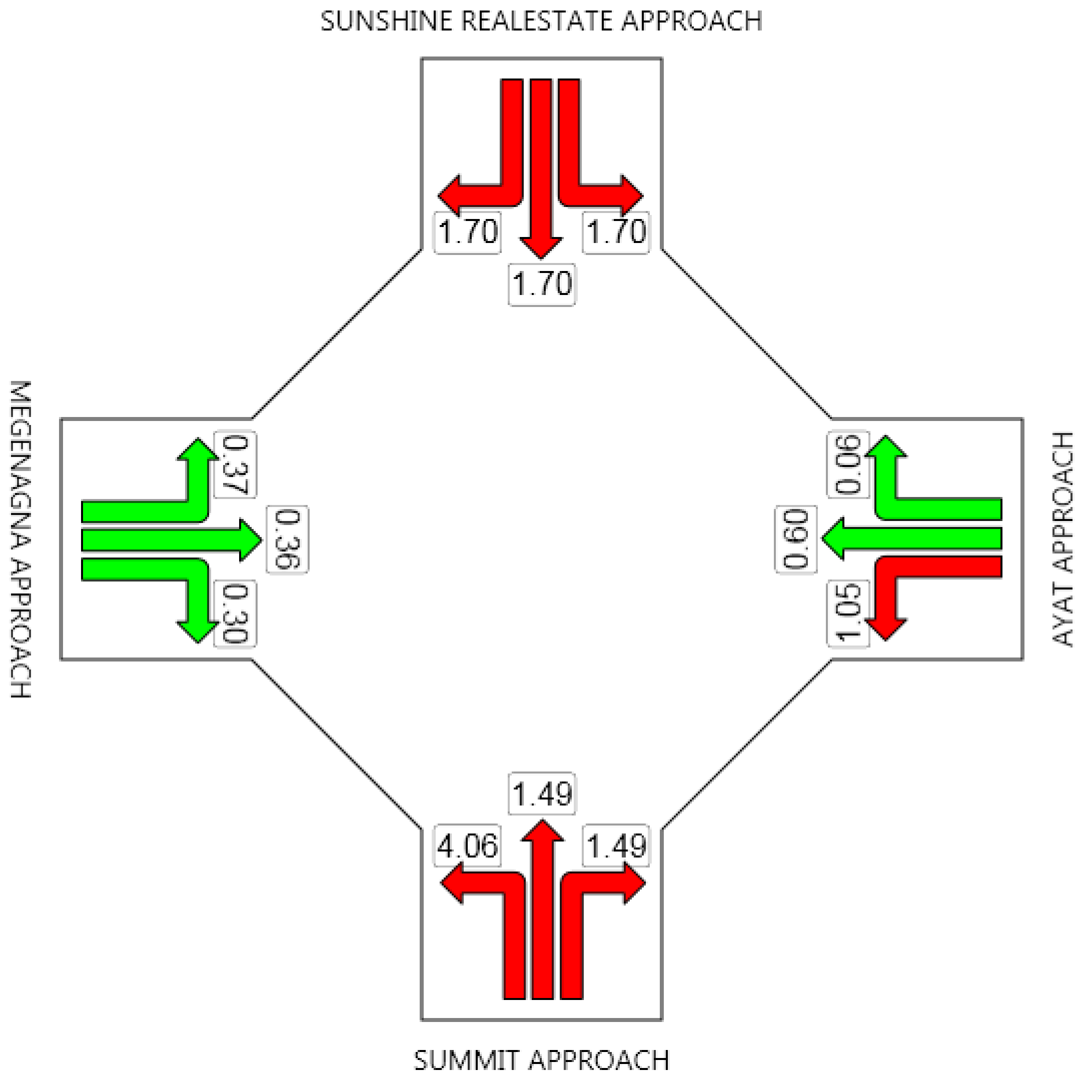
Site: CMC ROUND ABOUT
AFTER LRT



	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

DEGREE OF SATURATION

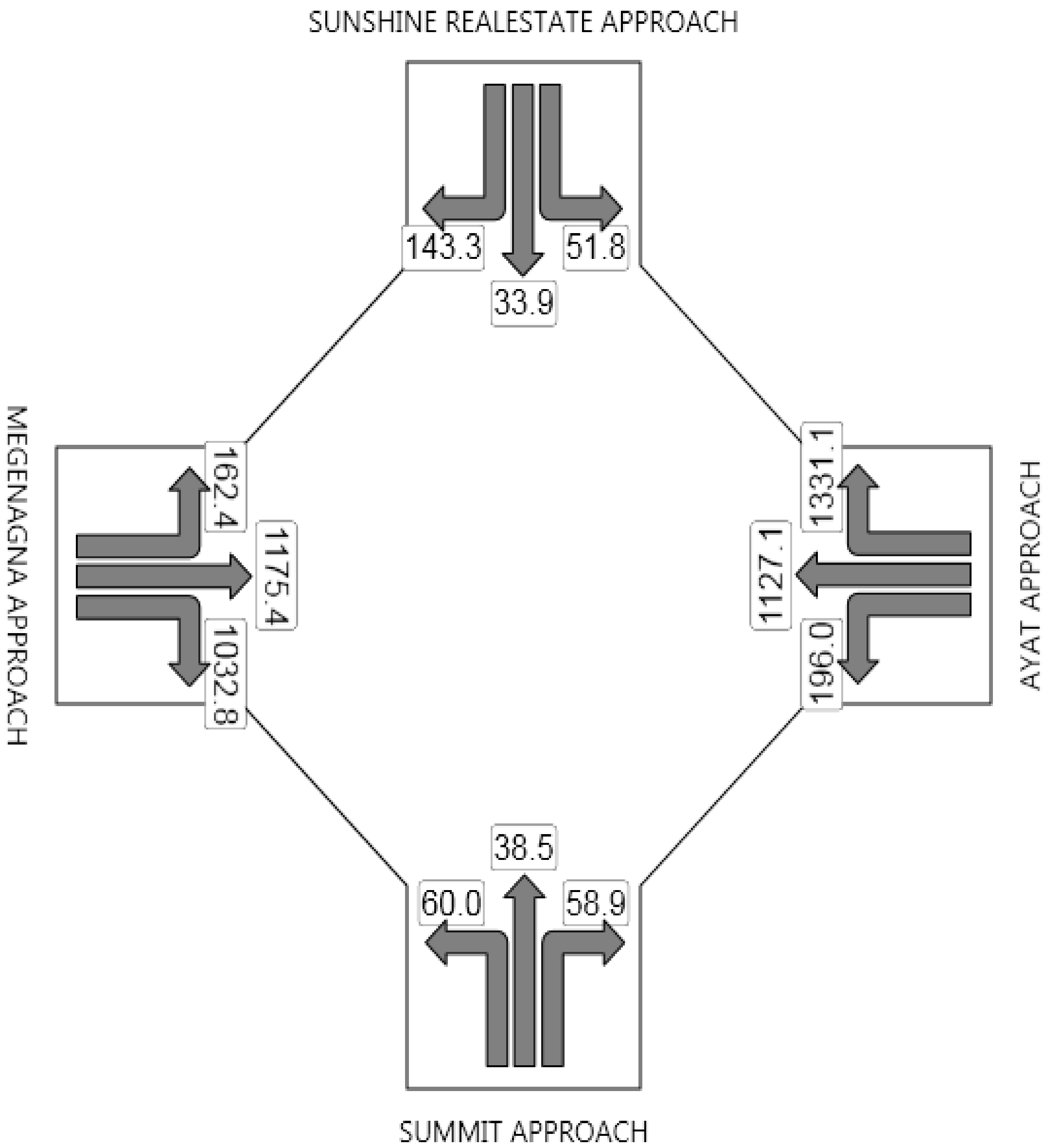
Site: CMC ROUND ABOUT AFTER LRT



	South	East	North	West	Intersection
Degree of Saturation	4.06	1.05	1.70	0.37	4.06

CAPACITY

Site: CMC ROUND ABOUT
AFTER LRT



MOVEMENT SUMMARY

Site: AYAT ROUND ABOUT BEFORE LRT

AYAT ROUND ABOUT
Roundabout

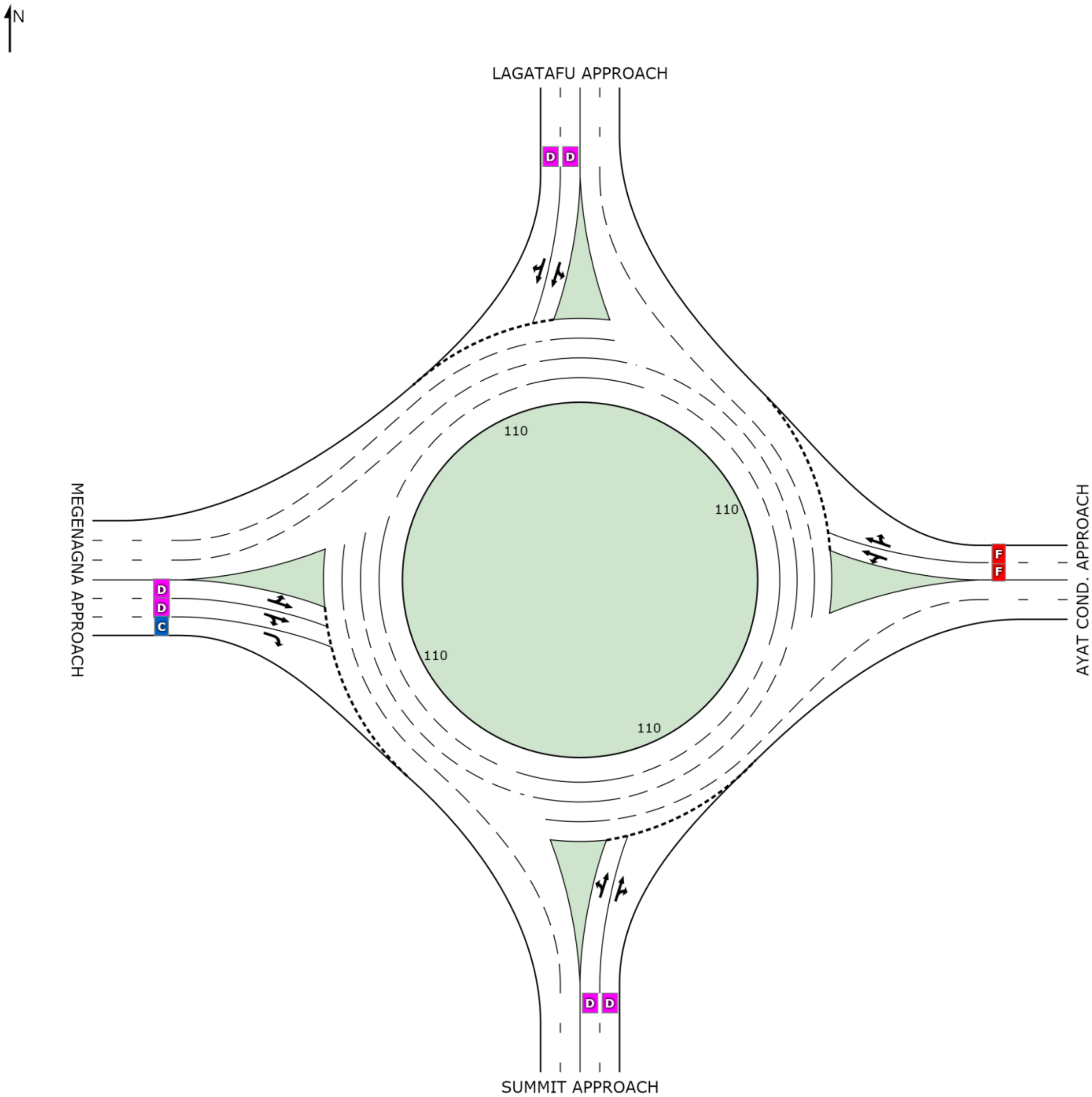
Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: SUMMIT APPROACH											
1	L	282	1.5	0.738	31.6	LOS D	3.5	27	0.84	1.05	19.7
8	T	286	4.2	0.738	31	LOS D	3.5	27	0.82	1.02	25
2	R	92	7.1	0.738	30.9	LOS D	3.3	25.9	0.81	1.01	12.5
Approach		660	3.5	0.738	31.2	LOS D	3.5	27	0.82	1.03	21.8
East: AYAT COND. APPROACH											
3	L	228	2.9	1.121	107.8	LOS F	26	206.3	1	3.21	8.9
4	T	784	7.2	1.121	107	LOS F	26.3	212.1	1	3.27	5
16	R	55	7.8	1.121	106.6	LOS F	26.3	212.1	1	3.3	12.8
Approach		1067	6.3	1.121	107.2	LOS F	26.3	212.1	1	3.26	6.4
North: LAGATAFU APPROACH											
7	L	114	4.8	0.758	34.7	LOS D	3.6	27.9	0.84	1.08	26.3
4	T	249	2.6	0.758	34.3	LOS D	3.6	27.9	0.84	1.08	24
14	R	299	1.8	0.758	32.6	LOS D	3.6	27.5	0.84	1.06	24.2
Approach		662	2.6	0.758	33.6	LOS D	3.6	27.9	0.84	1.07	24.5
West: MEGENAGNA APPROACH											
5	L	464	2.3	0.817	29.3	LOS D	5.1	39.4	0.71	0.92	27.8
5	T	570	8	0.817	30.8	LOS D	5.1	39.6	0.71	0.94	13.3
6	R	358	2.7	0.559	15.3	LOS C	2.2	17.1	0.58	0.65	19.1
Approach		1391	4.8	0.817	26.3	LOS D	5.1	39.6	0.68	0.86	22
All Vehicles		3780	4.6	1.121	51.3	LOS F	26.3	212.1	0.82	1.6	15.8

Level of Service (LOS) Method: Delay (HCM 2000).
Roundabout LOS Method: Same as Sign Control.
Vehicle movement LOS values are based on average delay per movement
Intersection and Approach LOS values are based on average delay for all vehicle movements.
Roundabout Capacity Model: US HCM 2010.
HCM Delay Model used. Geometric Delay not included.

LEVEL OF SERVICE SUMMARY

Site: AYAT ROUND ABOUT BEFORE LRT

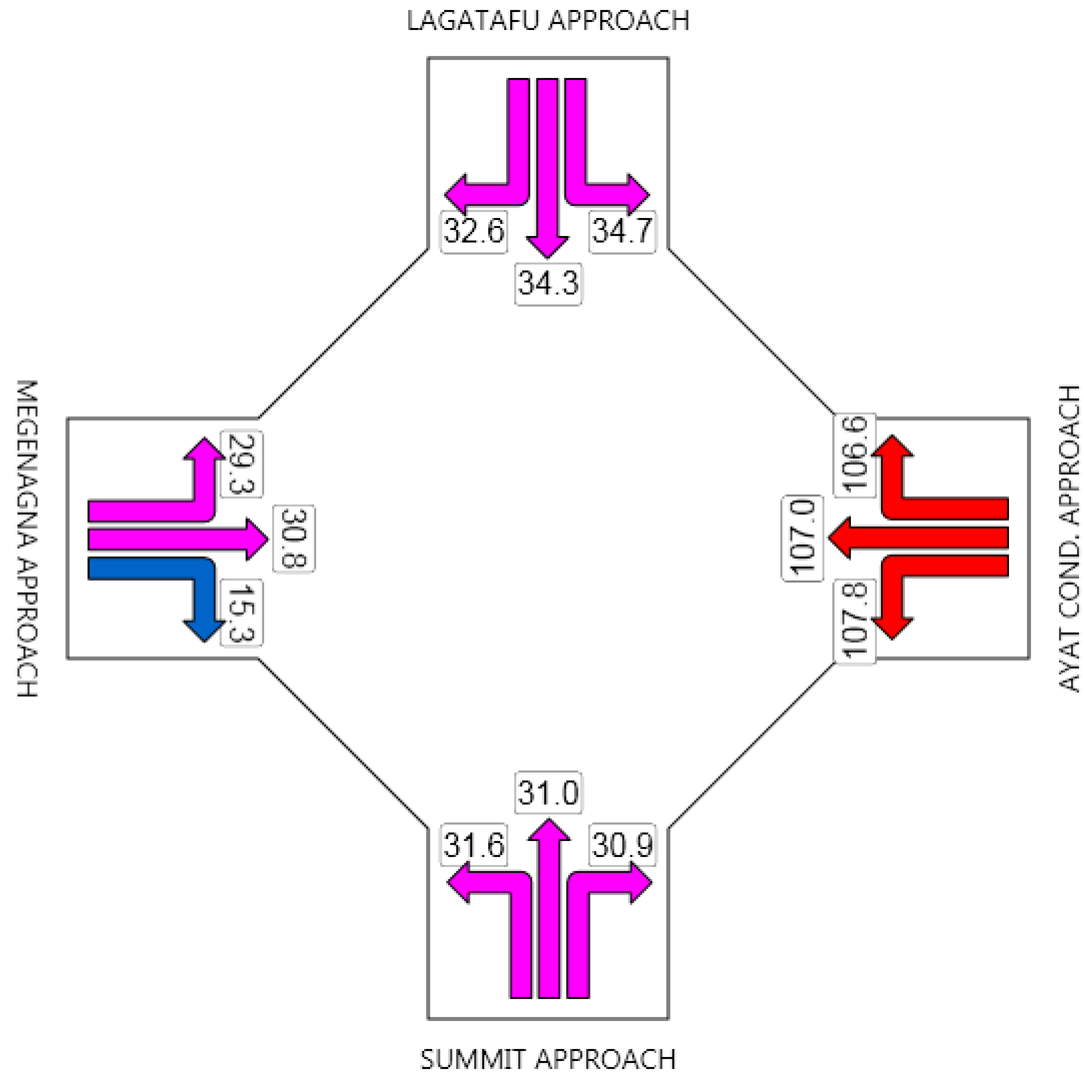
AYAT ROUND ABOUT
Roundabout



	South	East	North	West	Intersection
LOS	D	F	D	D	F

DELAY (AVERAGE)

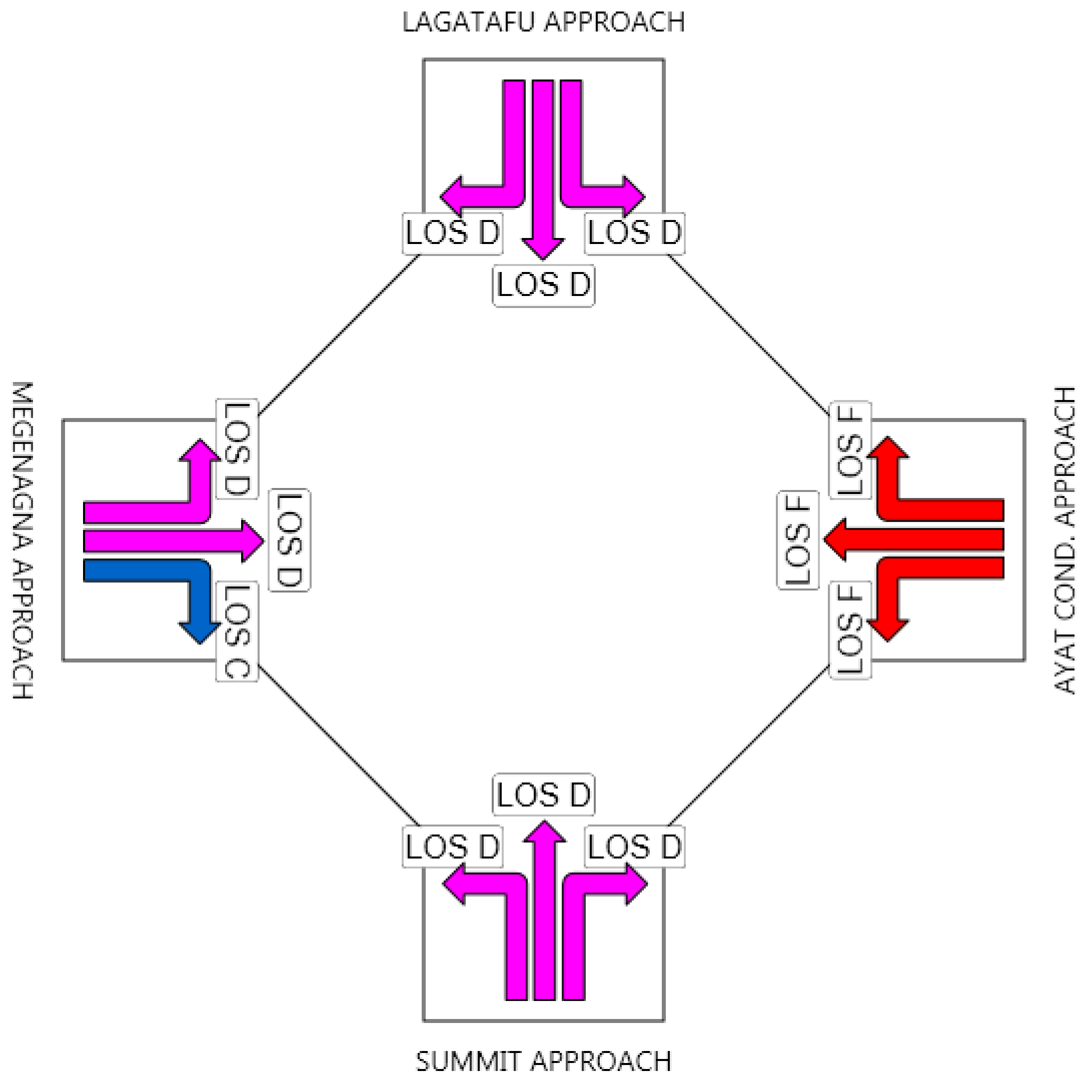
Site: AYAT ROUND ABOUT BEFORE LRT



	South	East	North	West	Intersection
Delay (Average)	31.2	107.2	33.6	26.3	51.3
LOS	D	F	D	D	F

LEVEL OF SERVICE

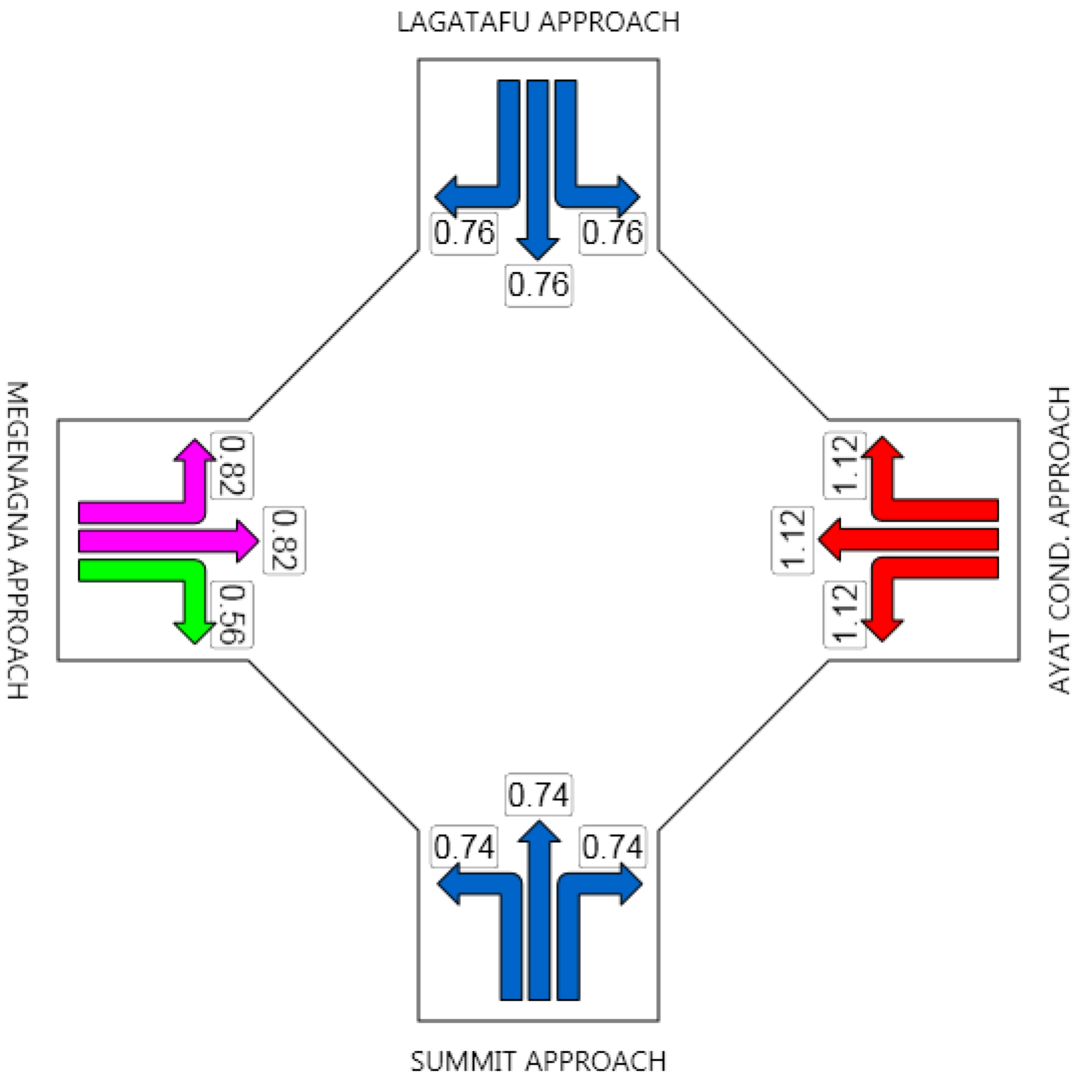
Site: AYAT ROUND ABOUT BEFORE LRT



	South	East	North	West	Intersection
LOS	D	F	D	D	F

DEGREE OF SATURATION

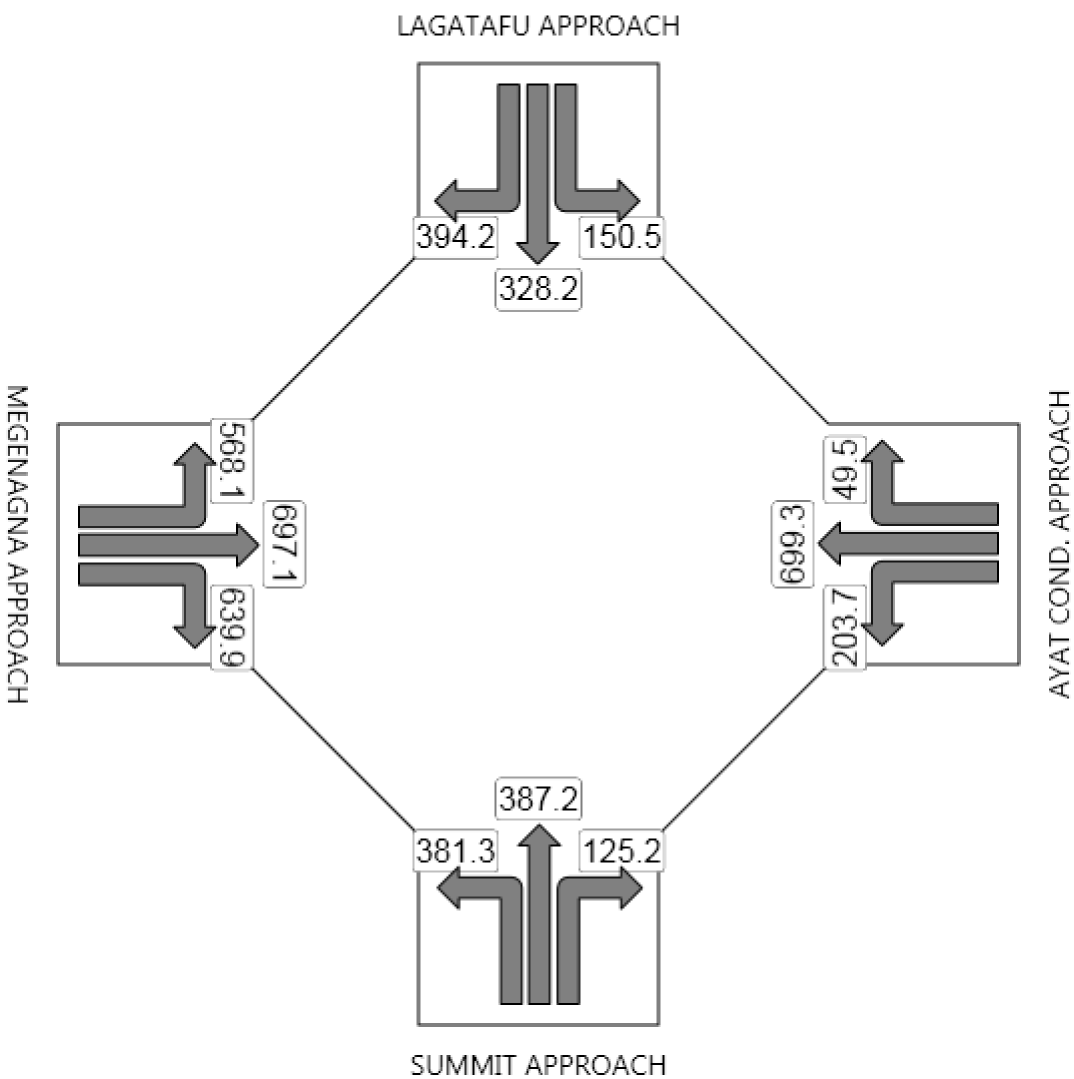
Site: AYAT ROUND ABOUT BEFORE LRT



	South	East	North	West	Intersection
Degree of Saturation	0.74	1.12	0.76	0.82	1.12

CAPACITY

Site: AYAT ROUND ABOUT BEFORE LRT



MOVEMENT SUMMARY

Site: AYAT ROUND ABOUT AFTER LRT

AYAT ROUND ABOUT
Stop (Two-Way)

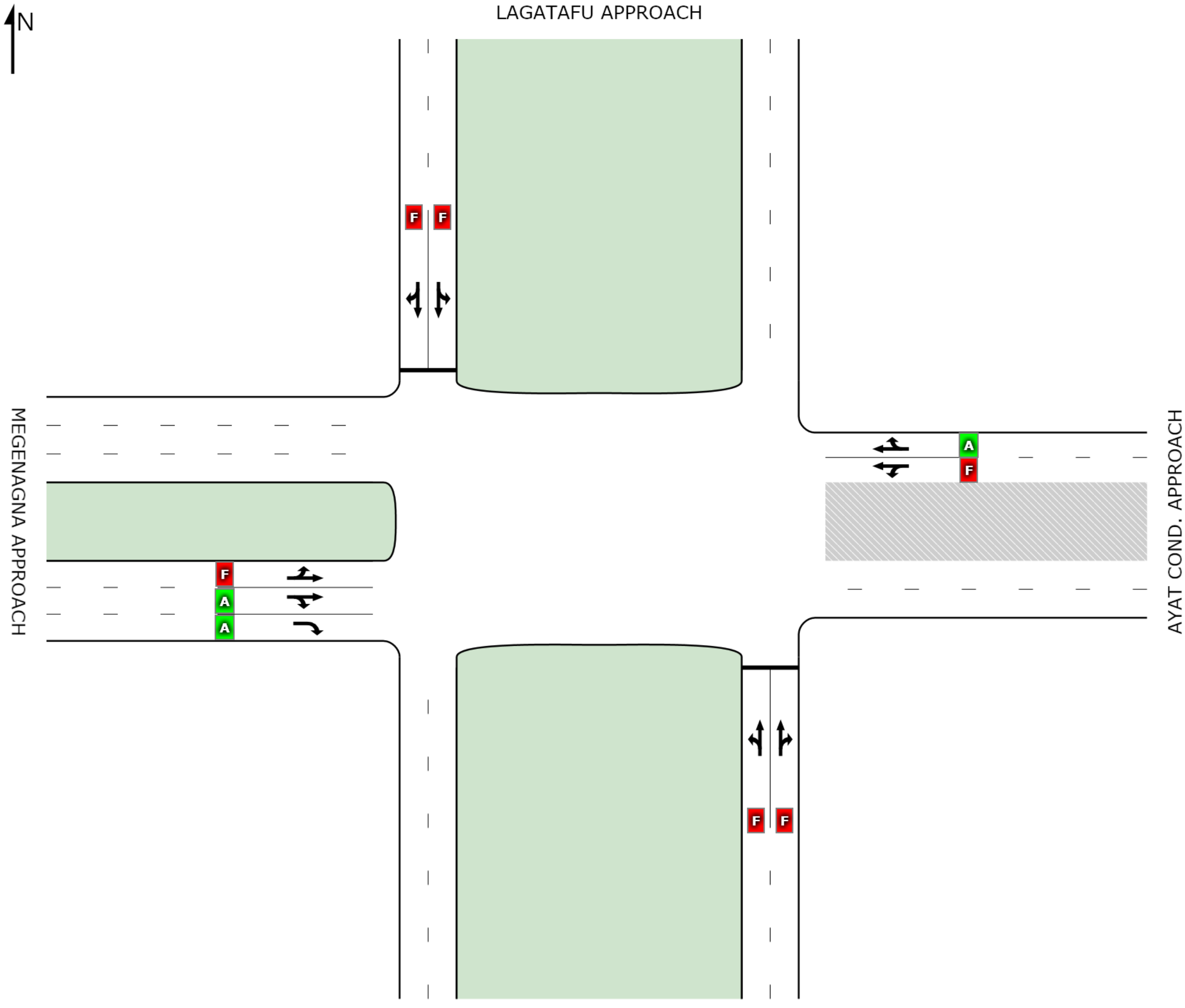
Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: SUMMIT APPROACH											
1	L	171	2.5	2.844	978.9	LOS F	43.7	339.1	1	2.65	0.6
8	T	179	6.7	2.11	591.2	LOS F	47.3	382.6	1	3.38	3.2
2	R	59	11.1	2.11	591.2	LOS F	47.3	382.6	1	4.4	0.9
Approach		409	5.6	2.844	753.1	LOS F	47.3	382.6	1	3.22	1.6
East: AYAT COND. APPROACH											
3	L	140	4.7	1.046	141.9	LOS F	11.8	93.3	1	1.85	4
4	T	498	11.4	0.434	5.1	LOS A	2.7	22.7	0.44	0.29	27.9
16	R	37	11.8	0.434	5.1	LOS A	2.7	22.7	0.44	0.67	34
Approach		675	10	1.046	33.5	NA	11.8	93.3	0.56	0.63	12.9
North: LAGATAFU APPROACH											
7	L	72	7.6	1.962	592.2	LOS F	25.2	201.7	1	2.39	3.2
4	T	152	4.3	1.962	536.3	LOS F	52.9	413.5	1	3.11	3.5
14	R	184	3	1.962	508.5	LOS F	52.9	413.5	1	4.64	3.5
Approach		408	4.3	1.962	533.6	LOS F	52.9	413.5	1	3.67	3.4
West: MEGENAGNA APPROACH											
5	L	285	3.8	1.511	289.2	LOS F	41.1	322.8	1	3.32	6.1
5	T	366	12.5	0.268	4	LOS A	1.4	12.1	0.21	0.09	30.5
6	R	220	4.5	0.161	3.4	LOS A	0.7	5.9	0.29	0.53	25.3
Approach		871	7.6	1.511	97.1	NA	41.1	322.8	0.49	1.26	8.5
All Vehicles		2362	7.4	2.844	267.8	NA	52.9	413.5	0.68	1.84	3.8

Level of Service (LOS) Method: Delay (HCM 2000).
Vehicle movement LOS values are based on average delay per movement
Minor Road Approach LOS values are based on average delay for all vehicle movements.
NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road movements.
HCM Delay Model used. Geometric Delay not included.

LEVEL OF SERVICE SUMMARY

Site: AYAT ROUND ABOUT AFTER LRT

AYAT ROUND ABOUT
Stop (Two-Way)



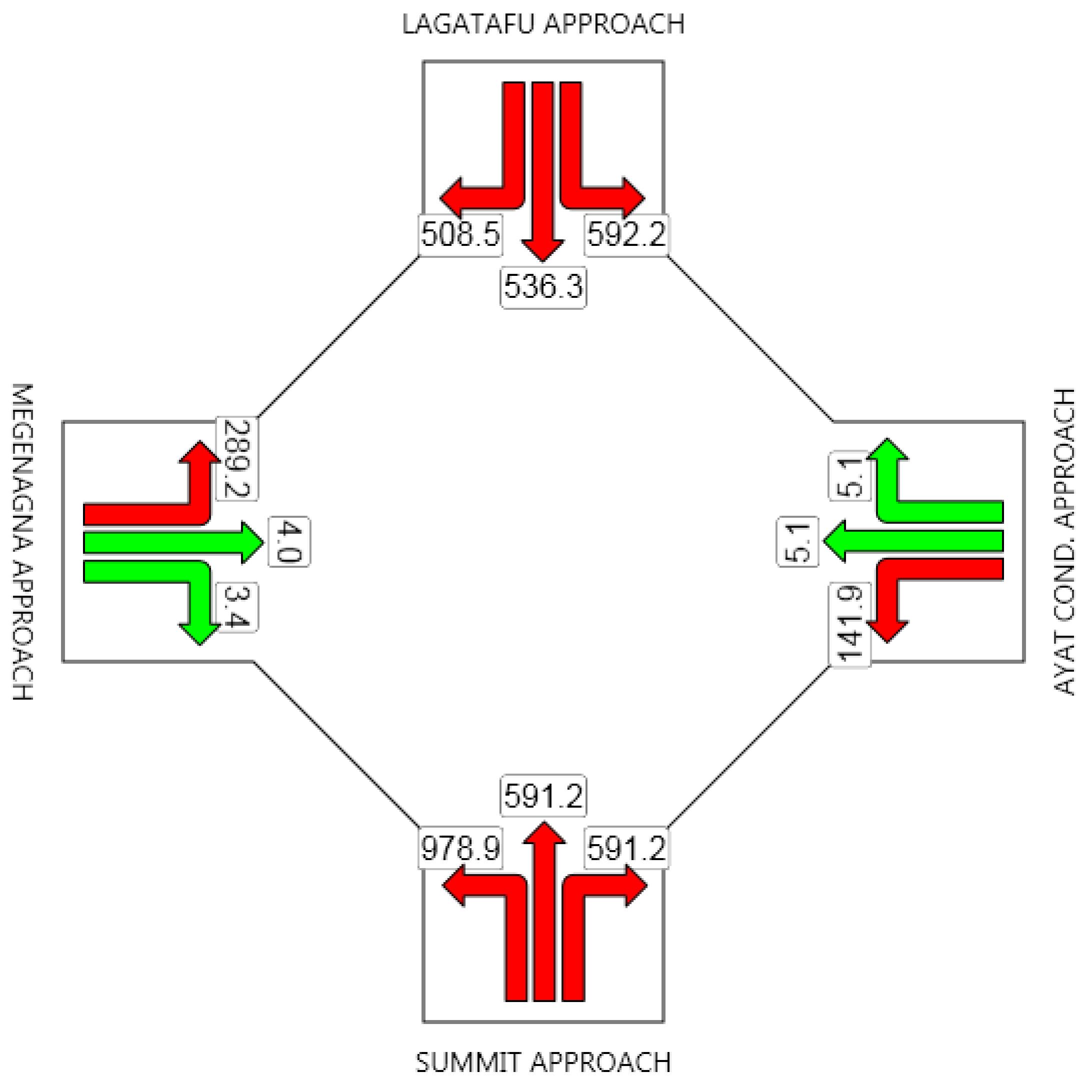
	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

Level of Service (LOS) Method: Delay (HCM 2000).
Lane LOS values are based on average delay per lane.
Minor Road Approach LOS values are based on average delay for all lanes.
NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road lanes.
HCM Delay Model used. Geometric Delay not included.

DELAY (AVERAGE)

Site: AYAT ROUND ABOUT
AFTER LRT

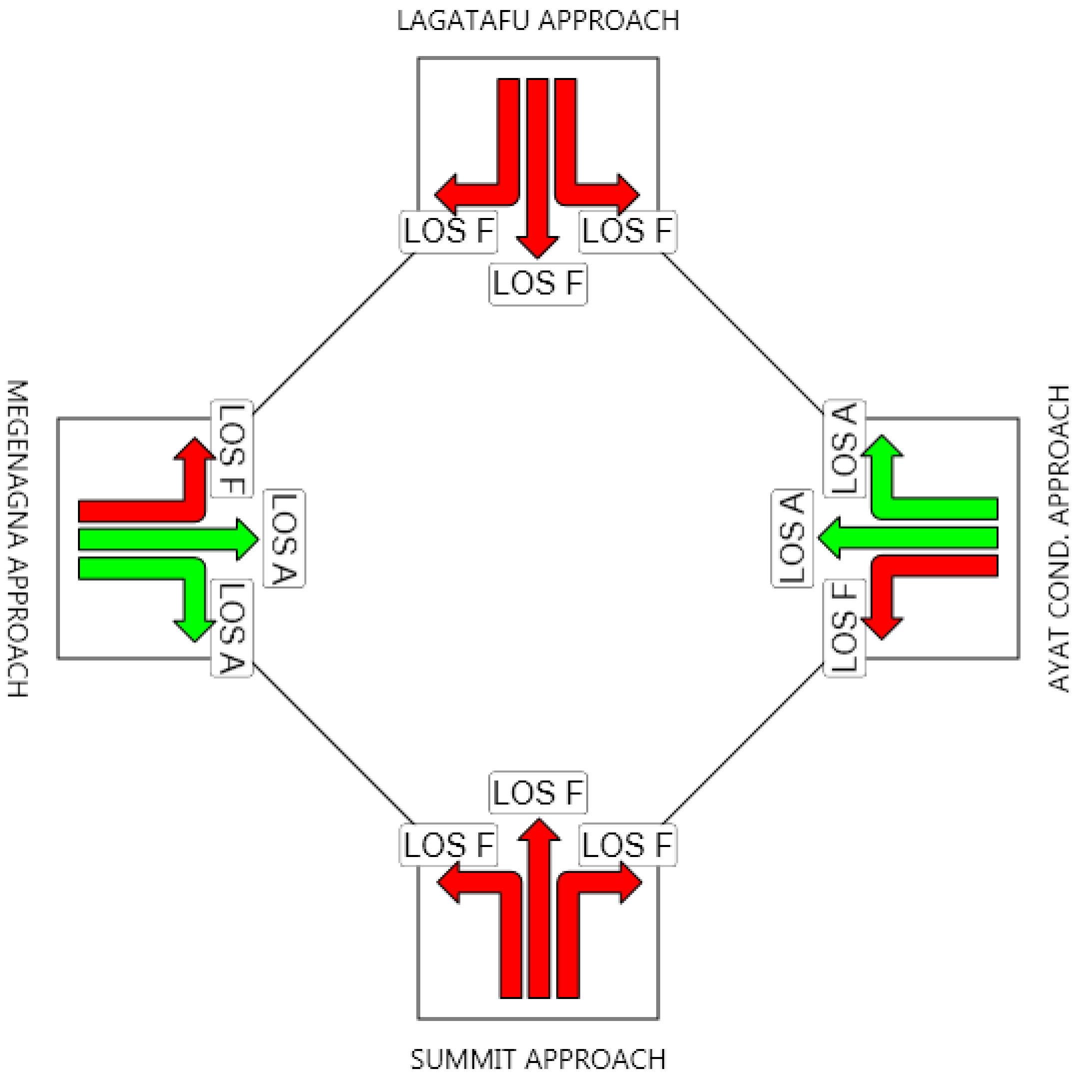
AYAT ROUND ABOUT
Stop (Two-Way)



	South	East	North	West	Intersection
Delay (Average)	753.1	33.5	533.6	97.1	267.8
LOS	F	NA	F	NA	NA

LEVEL OF SERVICE

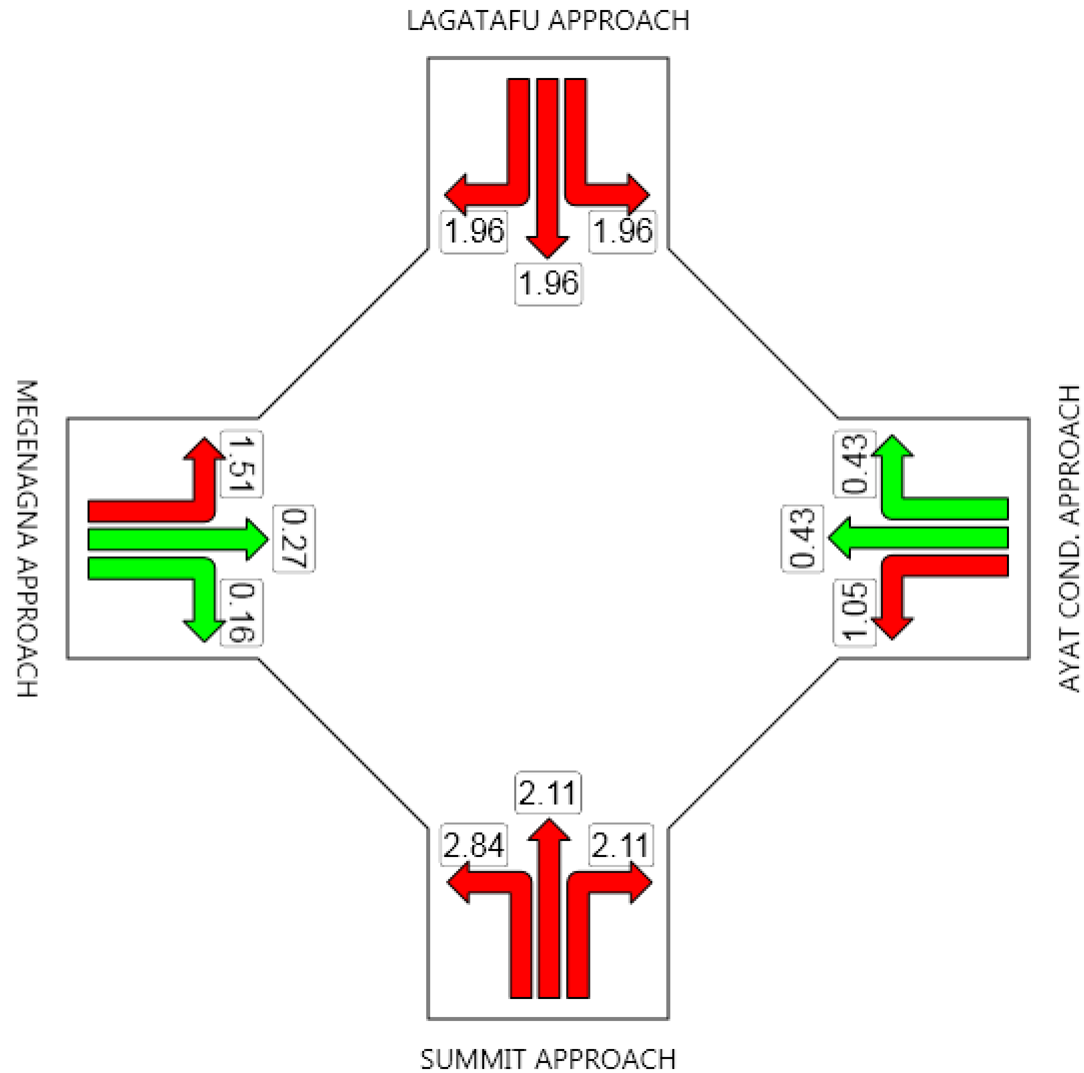
Site: AYAT ROUND ABOUT AFTER LRT



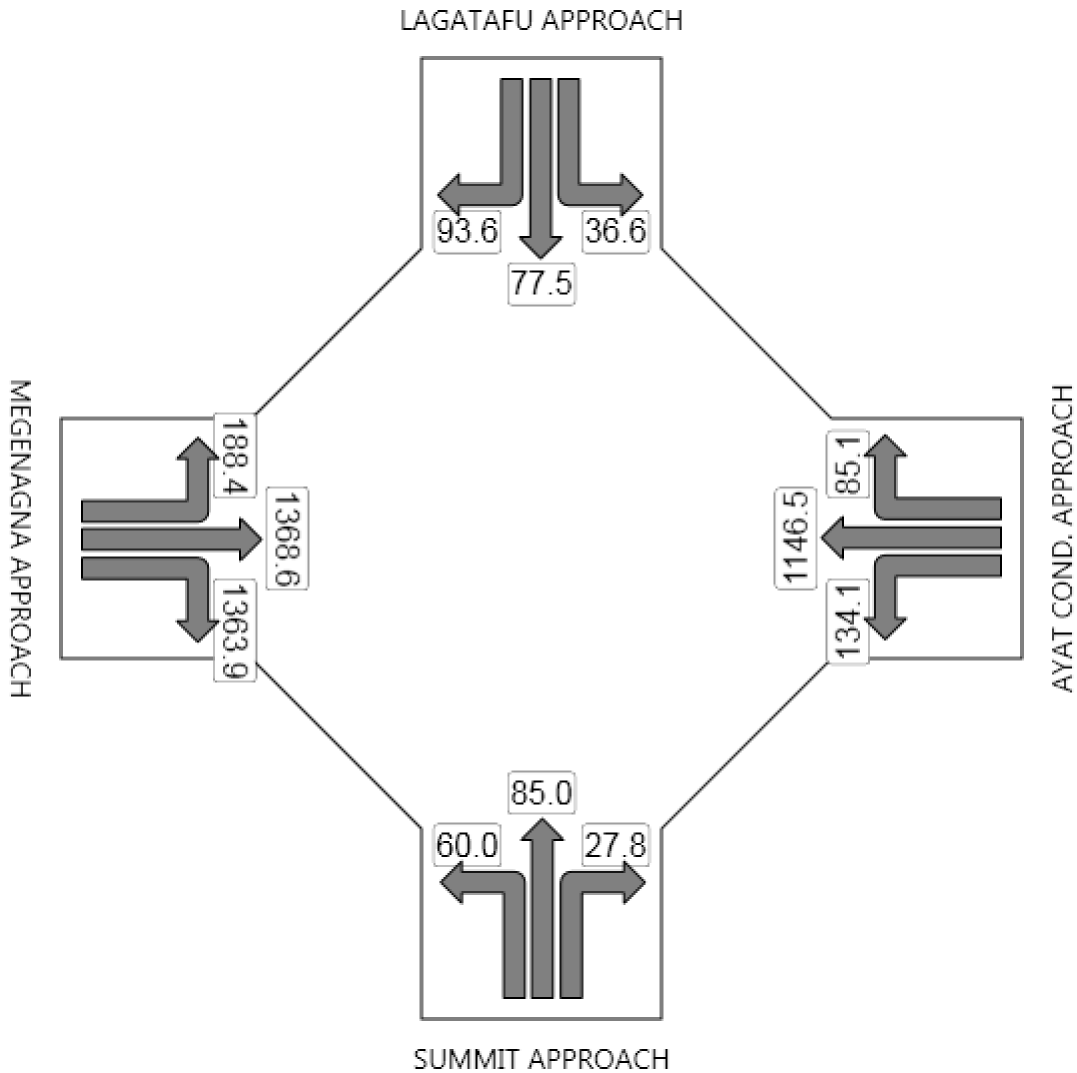
	South	East	North	West	Intersection
LOS	F	NA	F	NA	NA

DEGREE OF SATURATION

Site: AYAT ROUND ABOUT AFTER LRT



	South	East	North	West	Intersection
Degree of Saturation	2.84	1.05	1.96	1.51	2.84


LAGATAFU APPROACH
93.6
36.6
77.5
MEGENAGNA APPROACH
188.4
1368.6
1363.9
AYAT COND. APPROACH
85.1
1146.5
134.1
85.0
60.0
27.8
SUMMIT APPROACH