Road Traffic Congestion Analysis and Traffic Flow Modeling at Meskel Square Signalized Control Intersections

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This is to certify that the thesis prepared by G.Michael G.Medhn entitled: *Road Traffic Congestion Analysis and Traffic Flow Modeling at Meskel Square Signalized Control Intersections* and submitted in partial fulfillment of the requirements for the degree of Masters of Science (Industrial Engineering) complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

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DECLARATION

I certify that this research work, entitled "Road Traffic Congestion Analysis and Traffic Flow Modeling at Meskel Square Signalized Control Intersections" is my own work. The work has not been presented elsewhere for assessment. Where materials used from other sources has been properly acknowledged / referred.

Gebremichael Gebremedhn	____________	____________
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IN MEMORY OF MY FATHER AND MY MOTHER

I dedicate this research to both of my mother and my father whom I lost when I was seven and during my BSc. Study in ASTU respectively. It was extremely sad and heart breaking situation in my life when I heard my father's death. I remember both of you subsequently in every movement of my life and I proud of you.

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ABSTRACT

Transportation systems are essential to economic and the security of the nations. The effectiveness of a transportation system depends on its ability to support the reliable movement of people, goods, and vehicles from one place to another. An urban traffic system is an important yet complex transportation system composed of vehicles, pedestrians, traffic lights, and a traffic network structure. Problems related to urban traffic is increasingly important, and many researchers are trying hard to solve them. The huge number of vehicles causes serious problems like for example traffic congestion/jams, air and noise pollution, stress to drivers, and fuel and energy consumption.

Traffic congestion at intersections, the main focus of this research, is one of many serious global transportation problems of both developed and developing countries for many years and it always exerts a negative externality upon the society. In Africa, vehicle traffic congestion is a new phenomenon with its economic cost on the productivity of the cities' communities. Despite the lower car ownership levels and the intensive road network expansion in Addis Ababa, traffic congestion at intersections has become a serious problem in the day to day activities, specifically, during morning and evening peak hours.

The overall goal of this research work is to analyze road traffic congestion and to develop traffic flow model that describes the current as well as the future traffic flows at Meskel Square signalized control intersections. To achieve this objective, an extensive literature review and collection of primary and secondary data related to traffic congestion were conducted. The secondary data were collected by volume counting using a stopwatch for 12 successive days (i.e. 3 hours in the morning, 2 hours in the mid-day and 3 hours in the evening) for each intersection. Using these data, first effective analysis and discussion was made and then, a simulation model using Arena 14.00 version software was developed. The model were tested and validated under ten scenarios using the secondary data collected by choosing only one intersection.

The finding of the study shows that, traffic flow at Meskel Square intersections is outlying comparing to the Highway Capacity Manual (HCM) requirements. This is not due to the low capacity of the road only but also due to poor traffic signal phase controlling systems in the corridor. As per the analysis result shows, the Level of Service

(LOS) of both intersections lays on “F” value in the morning and evening peak times based on the Highway Capacity Manual (HCM) standards. This shows there is high traffic congestion and flow delay at Meskel Square intersections in the peak hours. After various scenario analysis is tested on the signal time controlling phase, the level of service shifts from “F” to “D” in almost all approaches.

At the end of this paper the developed arena simulation model was running for 10 different scenarios time policy. The simulation result shows, the waiting times was decreasing from scenario to scenario and the number of vehicles served at the green phase increases. Even though the queuing lengths were comparable in all scenario simulation results, but it displays a minimum value in scenario 3 taken as the optimal time control policy. These values are (162 seconds red, 75 seconds green) to Meskel Street, (169 seconds red, 68 seconds green) to Bambis street, (142 seconds red, 95 seconds green) to Dembel Street and (178 seconds red, 59 seconds green) to Betemengist Street. At this scenario the queue length per entity across each street reaches minimum value.

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CHAPTER 1 BACKGROUND AND JUSTIFICATION OF THE STUDY

1.1. Introduction

Transportation systems are essential to economic and the security of the nations. The effectiveness of a transportation system depends on its ability to support the reliable movement of people, goods, and vehicles from one place to another. An urban traffic system is an important yet complex transportation system composed of vehicles, pedestrians, traffic lights, and a traffic network structure (1; 2; 3). Problems related to urban traffic is increasingly important, and many researchers are trying hard to solve them. The huge number of vehicles causes serious problems like for example traffic congestion/jams, air and noise pollution, stress to drivers, and fuel and energy consumption (2; 3; 4) were traffic congestion is the main focus of this thesis work.

Traffic congestion on motorways is becoming an ever more pressing problem in countries all over the world. Congestion results in a higher traffic density (and lower speeds) during a longer time and thus the total time spent will increase with an increasing level of congestion (3). Besides the total time spent in the network, which is directly related with congestion, also other terms can be added to the cost function such as terms expressing environmental costs (e.g. air pollution, fuel consumption), social costs (e.g. stress) and economic costs (e.g. delayed deliveries) (5; 6). One approach to tackle congestion could be the construction of new roads to enlarge the capacity of the traffic infrastructure. This approach is very costly and it is often not possible due to environmental or societal constraints. In addition, it can only be executed on the longer term. So there is a need for another, short-term solution. This short-term solution consists of controlling traffic in such a way that congestion is solved, reduced, or at least postponed (7; 8).

According to Taylor, 1999, traffic congestion is a phenomenon of increased disruption of traffic movement on an element of the transport system and it is a growing problem in many metropolitan areas as it increases travel time, air pollution, carbon dioxide (CO2) emissions and fuel use because cars cannot run efficiently. It is most visible when the level of demand for movement approaches or exceeds the present capacity of the element

(9). Traffic models allow for a simulation of future traffic densities and average velocities. These predictions can help traffic operators to determine which control measures to take. Another advantage of simulation models is that they allow for a prediction of the traffic state that takes exceptional situations such as (partially) blocked roads into account (7; 10).

Urban traffic signal control is an important element of the safety for both pedestrians and vehicles when crossing an intersection or other paths. The time between different flows is controlled by traffic signals which can be lead to the flow conflicts being resolved. This was the first reason for the invention of traffic signal in the early 1900s (1; 11). An urban traffic signal control system is a complex system characterized by randomness, burst, and uncertainty. Utilizing a dependable model that can reflect the behavior of traffic control system is very important to realize traffic signal real-time control. Traffic control systems reduce as much as possible the delay by vehicles tripping by a network of intersections. By utilizing a suitable control policy, a suitably designed urban traffic signal control can decrease problems like overcrowd, stop delay, air and noise pollution, fuel consumption, discomfort and stress (11).

1.2. Background of the Study

As history tells us, cities and traffic have developed parallel side-by-side since human settlements. Though their magnitude or patterns are more complex today, cities still provide access to various social and economic activities, such as services, goods, markets, ideas, network, and these which determines the development of the urban areas (12).

Fast growth in urbanization and industrialization demands the use of more vehicles fleet leads to an imbalance between the infrastructures availability and mobility demand. In the third world the roads are narrow or incapable to accommodate a heavy traffic that slow the traffic flow, accompanied by inadequate provision for parking and loading and boarding facilities, sidewalk along the street, and mixed land use (13; 14).

According to the World Bank report in 2012, traffic congestion became common characteristics in urban road transportation system of cities in developing countries which result in high operating cost, loss of users' productive time, and more fuel consumption among others (15; 16). Traffic congestion is a condition on road networks that occurs when the number of vehicles on the roads exceeds the capacity of the roads, and is indicated by deceleration, delay in travel time, and long queues.

Traffic congestion is a regular occurrence on road networks in major cities of the world, the frequency of its occurrence is a concern to all road users. This situation has prompted transport researchers to carry out research on traffic congestion and thereby develop models to help reduce congestion on road networks (17). Increasing traffic flow on existing roadways results in an inevitable rise in congestion. Congestion leads to delays, decreasing flow rate, higher fuel consumption and thus has negative environmental effects. Poor traffic managements associated with insufficient road infrastructure are the main cause of this congestion issue as many writers have discussed.

1.3. Statement of the Problem

Traffic congestion is one of many serious global problems of both developed and developing countries for many years and it always exerts a negative externality upon the society (18; 19; 20; 6)**.** In Africa, vehicle traffic congestion is a new phenomenon. It has an economic cost on the productivity of the cities' communities. Despite the lower car ownership levels and the intensive road network expansion in Addis Ababa, traffic congestion is becoming a more serious problem in the day to day activities, specifically, during morning and evening peak hours due to the poor traffic controlling and management system in our capital (15; 21; 14). In addition to this, traffic signals are poorly adjusted which leads to long time delays and conflicting vehicle flows at many intersections.

In general, insufficient traffic management in the city, insufficient capacity of the roads to cope up with the existing traffic volume, inadequate public transport, fixed working time, and poor land-use or transport- land-use planning integration and illegal on-street parking habit are the major problems that lead to vehicles traffic congestion in the city (22; 23). As a result, long queuing and excessive delay or long travel time to reach destination that affect business users time productivity, increasing fuel consumption are the main impact of vehicles congestion which still prevail. Even though; the problem being recognized by all road users and transport professionals, little attention has been paid to this problem. Hence, questions on current level of traffic congestion are still not well investigated and answered. Therefore, this research work initiates to analyze and develop a model to find solutions to mitigate the problem in the capital by taking two selected signalized intersection in detail at Meskel Square.

1.4. Basic Research Question

In line with the above statement of the problem, the study tries to answer the following basic research questions.

- What is the current traffic congestion level at Meskel Square intersections?
- What is the level of flow rates and queue discharge flow rates at Meskel Square intersections during congestion flow?
- What are the different factors that significantly influence traffic flow rate and cause traffic congestions at the intersections of Meskel Square?
- How can the traffic flow rates, level of service and congestion level at intersections be improved?

1.5. Objective of the Study

1.5.1. General Objective

The overall goal of this research work is to analysis road traffic congestion and to develop traffic flow model that describes the current as well as the future traffic flows at Meskel Square signalized control intersections.

1.5.2. Specific Objective

As the general objective of this study is to analysis traffic congestion and to develop traffic flow model so as to forecast the future traffic flow in the selected corridor, it has the following specific objectives;

- To find out the current traffic congestion level and flow rate at meskel square intersections.
- To determine the different factors that significantly influence traffic flow rate and causes traffic congestion at Meskel Square intersections.
- To build a model of the traffic flow rate at Meskel Square intersections.
- To suggest different strategies to minimize traffic congestion and improve the traffic flow rate at this intersection.

1.6. Significance of the Study

Road traffic congestion in Addis Ababa is now a major concern of the government and the road users. Hence, this research study is mainly focused on traffic congestion flow analysis and modeling to estimate the future traffic flow condition in the selected corridor. **Therefore**; the findings of this research work will have the following significance in general.

- The data obtained in this study, can be used by the road safety authorities for planning and evaluating road safety measures as well as to stimulate further investigations.
- It can be an important reference material for someone who is interested in undertaking similar research in the future and it can be used for academic purpose as well.
- The study also contributes to review the effectiveness of existing traffic signal control mechanisms at intersections and it will add knowledge on understanding what risk factors contribute to the occurrence of road traffic congestion in most intersections of Addis Ababa.
- **Finally**, results from the model in this paper will help road traffic engineers in building of road traffic lights to function at various green phase times in order to indicate the location and density of cars on a particular road.

1.7. Scope of the Study

The scope of this study is to focuses on analyzing and modeling the congestion traffic flow severity in Addis Ababa roads. To simplify the analysis and modeling, two intersections, which have high traffic congestion flow, are selected by the researcher and data were recorded three times per day (morning, mid-day and afternoon) for successive 12 days. The model is developed based on the fixed traffic signal control system.

1.8. Limitation of the Study

Obtaining up-to-date data, and in some cases even any data at all, has been the main challenge of the study and also the organization/institution for confidentiality purpose is not willing to provide the whole documents which are susceptible to personal judgment. Recording data visually lacks significant level of consistency and accuracy as well as it is not feasible. Shortage of time and budget and uncertainties during the time of data record has been taken as the limitation of this research.

1.9. Structural Framework of the Study

The thesis is organized in six chapters that are linked to the issues in relation to the study:

Chapter one: gives the background and justifications of the study, problem statement and states the main objective of the study, it also highlights ways of investigating issues in relation to the study.

Chapter two: reviews some of the related theories and theoretical model as a base of knowledge of this study.

Chapter three: gives the research design and methodology used in the study, it elaborates the qualitative and quantitative methods used, types of data collected and the challenges faced during data collection. Description of the study area, focusing on geographical location, is also discussed here.

Chapter four: presents the collected data from different sources and by different methods. This data are analyzed mathematically and statistically to come up with a vital discussion. **Chapter five:** Develops traffic flow model and simulation to minimize the congestion traffic flow in the selected intersections roads. **Chapter six:** contains the final conclusions, recommendations and the future research area.

CHAPTER 2 RELATED LITERATURE REVIEW

2.1 Introduction

In analyzing and modeling of traffic congestion, it is worth exploring the definitions of congestion (24). The definition of congestion influences what measures are introduced to address it. According to the review, many definitions have been proposed to describe traffic congestion on roadways in urban areas (20). However, there is no universally accepted definition of traffic congestion so far. As the Australasian Transport Research Forum discusses in (25) these definitions can be broadly categorized into three groups: (i) demand capacity related (Occurs when travel demand exceeds the existing road system capacity), (ii) delay-travel time related (travel time or delay in excess of that normally incurred under light or free-flow travel conditions), and (iii) cost related (increases the transportation cost and causes loss business, because of long time travel and high fuel consumptions).

Generally speaking, traffic congestion results when the number of vehicles attempting to use a network or network element (e.g. road, intersection) exceeds the capacity or ability of the infrastructure to carry the load. In practice, there are a variety of situations from which congestion may emerge, and these situations often work together to create or increase congestion. For instance, congestion may be caused by (a combination of) high traffic densities, temporary reductions in normal road capacity (e.g. accidents, vehicle breakdowns, severe weather), conflicts among road users (e.g. parking maneuvers) or among different types of traffic (e.g. trucks, pedestrians) and improper use of traffic controls. Given the variety of situations that may lead to congestion, a classification of different types of congestion is useful. Three basic types of congestion can be distinguished as recurring, non-recurring congestion and pre-congestion according to (26; 27).

Recurring congestion results from traffic patterns that occur cyclically on a relatively stable and predictable basis, e.g. every weekday or weekends day. Recurring congestion generally occurs at the same place and time due to excessive traffic volumes (due to high traffic demand), which is most obvious during morning and afternoon peak hours when a large number of people travel to and from work. In this respect, road junctions are frequently the capacity 'pinch points' or bottlenecks in the urban road network from where queues and congestion can form.

Non-recurring congestion can result from special events such as planned road works, concerts and sport meetings and from unpredictable sources that occur on a random basis such as accidents, traffic signal failures, adverse weather and vehicle breakdown.

Pre-congestion (Borderline congestion) occurs where free-flow conditions breakdown but full congestion has not yet occurred. This may occur either side of the time period when congestion occurs or upstream or downstream of congestion that is already occurring.

2.2 Traffic Congestion in Developed and Developing Countries

2.2.1 Traffic Congestion in Developed Countries

Nowadays due to rapid population growth and hence increasing demand for transportation, traffic congestion at road intersections as well as in the main roads become a serious problem for developed as well as developing countries. It is predicted, in the developed countries, that the rate of vehicle ownership will increase from about one vehicle for every four persons in the year 2000 to about two vehicles for every five persons in 2020. According to Tom-tom 2012, the top five of the most congested cities in North America range between 33% for Los Angeles to 25% for Tampa (table 2-1). In Europe, the top five most congested cities ranges from 42% for Warsaw to 32% for Paris. In Africa, Johannesburg ranks top amongst South African cities with congestion level of 32%, which represents a travel delay of 37 minutes for every hour, driven in peak hour traffic (28; 29; 21).

Table 2-1: Traffic congestion index, Source: Tom-tom Congestion Index 2013

City	Congestion level	Average free flow/speed	Average speed at peak	Delay/hour at peak
Los Angeles	33%	62,7 km/h	54.7 km/h	40 min
Vancouver	30%	56.3 km/h	48.3 km/h	34 min
Miami	26%	67.6 km/h	61.2 km/h	29 min
Seattle	25%	61.2 km/h	54.7 km/h	35 min
Tampa	25%	69.2 km/h	64.3 km/h	28 min
Johannesburg	32%	63 km/h	56 km/h	37 min

2.2.2 Traffic Congestion in Developing Countries

This section describes the mobility characteristics of cities of developing countries in general and the detailed mobility characteristics of Addis Ababa as well.

Mobility characteristics of cities in developing countries

According to, (Gakenheimer, 1999), which is stated in (21; 6) concerning the field of mobility, numerous unique characteristics of cities in developing countries are:

- Rapid growth of motorization, intense desire for car ownership and travel demand that far exceeds the supply of facilities as well as high share of trips by public transit
- Urban structure incompatible with motorization, greater differences in vehicle performance and inadequate street and highway maintenance
- Irregular response to impacts of new construction, Fewer legal constraints on the use of new technologies and weak driver discipline in many countries
- Very limited agreement on planning approaches, scarcity of capital and operating subsidies are difficult to sustain and Local transportation development is more centralized in the hands of a few elite players

Developing countries are characterized by a high travel demand, chaotic traffic behavior and a low supply of networks and means. Although fewer legal restraints exist for the use of new technologies, the transport sector as a whole is not likely to be innovative: capital is scarce and the number of involved stakeholders is limited. The lack of adequate and accessible transportation options causes a high share of non-motorized transport. This stressed mobility situation in developing countries results in premature congestion, a deteriorating environment and a high incident rate (29; 8).

It has to be noted that these characteristics concern the average of the whole group of developing countries. Individual exceptions of countries that have different mobility characteristics exist.

Within the group of developing countries, the subgroup of Sub Saharan African countries distinguishes themselves on a number of characteristics. While other regions in developing countries are industrializing rapidly as a result of the new global economy, the African cities remain economically marginalized.

However, the population in African cities is growing despite poor macroeconomic performance and without significant foreign direct investment. Even more, Sub Saharan

Africa has globally the highest urban population growth in percentages (29). By 2025, African society is expected to become predominantly urban. The institutional weaknesses of political instability, corruption and chronic mismanagement of economic resources put extra stress on the level of services in cities. It can be concluded that world's challenges concerning urban mobility will be particularly significant in Sub Saharan Africa (32). According to Tom-Tom 2015 congestion index report, nine of the ten most congested cities are in developing countries. This finding shows in the table below (28; 12).

Table 2-2: Tom-Tom Congestion Levels in the Top 10 Congested Cities

City	Country	Congestion Level	Morning Peak	Evening Peak
Mexico City	Mexico *	59	97	94
Bangkok	Thailand*	57	85	114
Istanbul	Turkey *	50	62	94
Rio De Janeiro	Brazil *	47	66	79
Moscow	Russia*	44	71	91
Bucharest	Romani*a	43	83	87
Recife	Brazil *	43	72	75
Salvador	Brazil *	43	67	74
Chengdu	China *	41	73	81
Los Angeles	United State	41	60	81

* Classified as developing countries by the World Bank, 2014/15

Mobility characteristics of Addis Ababa

By 2015, the Sub Sahara African region is expected to have five cities larger than 5 million inhabitants: Abidjan, Addis Ababa, Lagos, Luanda and Kinshasa (29; 21). This thesis will focus on Addis Ababa, the capital city of Ethiopia, a city with numerous similarities with other Sub Saharan cities. The mobility problems in Addis Ababa are emergent, since the recent state of road traffic management is considerably poor.

Table 2-3 below shows a benchmark of Addis Ababa with the average urban area in Africa, the developing and developed world (Europe and the US). It can be seen that Addis Ababa has a relatively high population density and a high urban population growth; both facts combined with a low GDP per capita put high stress on the quality of mobility services. This stress is reflected by the very low supply of infrastructure: the current road density measured in kilometer of road per 1000 habitant in Addis Ababa is significantly lower than the average of developing countries; moreover, it is only one third of the African average. The public transport plays a dominant role in urban mobility in Ethiopia. The current average number of cars per 1000 inhabitants in whole Ethiopia is only one. In Addis Ababa, the car ownership has not gone up corresponding to the population growth. However, the number of trips per public transport is directly related to the urbanization. In general, for every additional 1000 people in developing world cities, an increase of 350-400 public transport trips will be realized per day (21).

Table 2-3: Benchmarking Addis Ababa, Africa average, Developing average, Europe average and US average

City	Addis Ababa	Africa Average	Developing countries Average	Europe Average	US Average
Urban density habitants/km^2	12 400	8 200	9 200	3 050	1 150
Annual national urbanization rate %	4.3	3.6	2.7	0.3	1.3
National GDP per capita USD	700	3700	2 926	28 700	46 300
Road density km/1000 habitants	0.13	0.32	1.0	3.3	6.4

Similarly, for every square kilometer of urban growth, an increase of 500 public transport trips will be realized per day according to the World Bank, 2002 (21). It can be concluded that the current supply of infrastructure is significantly below average and the demand is significantly increasing. An extension of infrastructure is necessary; however, the basic state of the economic development and the institutional challenges will make a development of infrastructure a complex and long term solution. To be able to maximize the use of the current infrastructure on the short term, the poor road traffic management has to be improving.

2.3 Causes and Impacts of Traffic Congestion

2.3.1 Causes of Traffic Congestion

According to the European Conference of Ministers of Transport (33), causes of congestion are numerous such as; too many vehicles, land use patterns, employment patterns, income levels, car ownership trend, infrastructure investment, regional economic dynamics etc. and casual factors of congestion can be categorized into two ways; micro and macro or recurrent and non-recurrent. Micro-level factors are those that relate to traffic on the road and macro-level factors that relate to overall demand for road use. Recurrent factors occur when demand approaches the technical maximum throughput capacity on a link or in the network and non-recurrent factors are unexpected, unplanned or large events (e.g. road works, crashes, special events and so on) and cannot be easily predicted (33; 20; 25; 16).

According to the engineering theory of traffic congestion, congestion could be caused by obstruction, or inefficient use of the roads (20). Hassan identified some causes of traffic congestion and presented in graphical form. According to him, causes can be categorized into two types; recurrent and non-recurrent. Recurrent includes excess demand for travel and shortage of infrastructure supply whereas non-recurrent causes include unexpected events such as; accidents or other emergency events. He further identified some causes which exhilarates the demand which are; population and economic growth, desire to travel by private vehicle, unawareness of full costs of driving, influence of land use pattern and concentration of work trips in time. Lack of investment in transport infrastructure and reduction of road space due to road construction and maintenance are two other identified factors which are leading the shortage of infrastructure supply. He further mentioned that improper traffic controls and management represents intervention failure is one of the causes of traffic congestion also.

The Department of transportation, United States (2005, pp.1-2) (20), states that; congestion is the result of seven root causes. These seven sources can be grouped into three broad categories; traffic influencing events, traffic demand and physical highway features.

Traffic influencing events includes; traffic incidents, work zones and weather. Vehicular crashes, breakdowns, debris in travel lanes, events occur on the shoulder or roadside etc. are the example of traffic incidents. Construction activities on the roadway is the example of work zone and reduced visibility, bright sunlight on the horizon, presence of fog or smoke, wet, snowy or icy roadway are the example of poor weather. Traffic demand includes; fluctuations in normal traffic such as day to day variability in demand and special events such as cricket tournament may increase the congestion at the surrounding streets of the stadium. Physical highway features includes; poor traffic control devices and physical bottlenecks (capacity) of the road. As the literature survey of (31), shows also, traffic congestion is the result of seven root causes, often interacting with one another.

Table 2-4: Causes of traffic congestion summary

Causes of traffic congestion	
Recurrent cause/transport system	**Non-Recurrent cause/traffic influencing event**
▪ Execs Demand - Population and economic growth - Desire to travel by private vehicle - Unawareness of full cost of driving - Influence of land use pattern - Concentration of work trip in time - Day to day variability in demand ▪ Shortage of infrastructure supply - Luck of investment in transport infrastructure ▪ Physical bottleneck / insufficient capacity ▪ Improper traffic control and management - Poor traffic control device - Inefficient management system	▪ Traffic incident and special events - Vehicular crashes - Breakdowns - Debris in travel time - Event occur on the shoulder or roadsides - Emergency situation - Incidence of the road way ▪ Work zone - Construction activities on the road way ▪ Poor weather - Reduce visibility - Bright sunlight in the horizon - Presence of fog or smog - Wet, snowy or icy roadway

2.3.2 Impacts of Traffic Congestion

According to (Austroads, 2000) road transport has grown rapidly over the last decades. For instance, in Australia over a period of twenty years (1979-1998) the total number of vehicle-kilometers travelled by cars has increased by 56%; and the total number of ton-kilometers by trucks has increased by a factor of 3 (26). As a consequence, traffic-related emissions and air pollution have increased substantially, despite the increasing use of abatement measures such as catalytic converters.

Due to the growth in road traffic, congested traffic conditions have become increasingly common and severe worldwide, particularly in major cities of developing countries. A strong further increase in the demand for transport and congestion is projected around the world (26).Traffic congestion has been indicated as being one of the main contributors to environmental, economic and health impacts in urban areas. Various publications explicitly state that congestion has an adverse effect on either traffic emissions, air quality or both in urban areas. As Oduyemi and Davidson (1998) remark that: “traffic related air pollution is most severe in urban areas and particularly city centers, where large traffic volumes and congestion commonly result in a significant degradation of the air quality in these areas” (26).

2.4 Traffic Congestion Measurements and Indicators

Traffic congestion is an unavoidable part of modern-day life. To understand the nature of congestion and to control its growth, a system for measuring the severity of traffic congestion is needed. Such a measure provides the foundation for traffic engineers and policy makers to identify problems and determines the effectiveness of mitigation strategies. In addition, a consistent and uniform measure will allow comparison of traffic conditions at different locations and also over time at the same location so that priorities for improvements can be developed, which helps the public to understand the traffic conditions objectively (19; 16; 25; 31).

According to, Schrank & Lomax, 2005, traffic congestion continues to grow in America’s urban areas. In 2003, congestion caused increase of 79 million hours and 69 million gallons of wasted fuel from 2002 to a total cost of more than $63 billion (19). this result shows that how traffic congestion has a great effect on once national economy and need to be measured or quantified before it cause irreversible problem. And, the following parameters are used to measure traffic congestion in this research.

2.4.1 Travel Time and Space Mean Speed

Time mean speed (V_{at}) is the arithmetic mean of measured speeds ("spot speeds") of all vehicles passing a fixed roadside point over a short measured distance L during a given time interval, i.e.:

$$V_{at} = \frac{\sum_{k=0}^{n} \frac{T}{L}}{n} \dots\dots\dots\dots\dots\dots..(2.1)$$

In this equation, T is the travel time of an individual vehicle in the traffic stream and n is the total number of vehicles sampled. Travel time is a directly measurable physical quantity and it is the time required for a vehicle to traverse distance L. T will depend on many factors such as length of road (or journey), speed limits, and presence of parked vehicles, traffic composition and number of vehicles on the road.

Space mean speed (V_{space}), which is used in the basic traffic stream model, is the arithmetic mean of the measured travel times (T) over a short measured distance L of all vehicles passing a fixed roadside point during a given time interval, in other words distance divided by mean travel time.

$$V_{space} = \frac{L}{\frac{\sum_{k=0}^{n} T}{n}} = \frac{L}{T} \dots\dots\dots\dots\dots\dots(2.2)$$

It is noted that time mean speed is always greater than or equal to space mean speed. The above two equations shows that speed and travel time are (mathematically) related and can be expressed as a function of each other.

2.4.2 Traffic Volume (V)

Commonly expressed as veh and veh/h lane, are two measures that quantify the amount of traffic passing a point on a road or lane during a given time interval. Traffic volume is an important traffic variable for air quality assessments as total emissions are a direct function of the number of vehicles that pass over a (section of) of road. In fact, vehicle kilometers travelled (VKT) is the traffic variable that is commonly needed for emission estimation. This variable is derived from traffic volume and road length data, as will be seen later.

2.4.3 Traffic Density (k), and Delay (D)

Commonly expressed as veh/km or veh/km./lane, quantifies the number of vehicles located in a given length of roadway or lane averaged over time. Traffic density is related to percent occupancy and can be estimated by:

$$k = \frac{q}{u} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.3)$$

Where: k = density (vehicles/kilometer), q = rate of flow (vehicles/hour), u = average travel speed (kilometers/hour).

Delay may be used as one measure of the extent of travel time. A commonly accepted definition of delay is the system delay (d), defined as the excess travel time above the minimum (free flow) travel time needed to traverse a network element (e.g. a link, road section, or intersection) (24; 34). If T is the actual travel time and T_0 is the free flow travel time, then the system delay is:

$$D = T - T_o \dots\dots\dots\dots\dots (2.4)$$

$$D_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - [\min(1, X)\ g/C]} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.5)$$

$$D_2 = 900\mathrm{T}\left[(\mathrm{X} - 1) + \sqrt{(X-1)^2 + \frac{4X}{cT}}\ \right] \dots\dots\dots\dots\dots\dots\dots (2.6)$$

$$D = D1\ (PF) + D2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (2.7)$$

Where:

D_1 = is uniform delay (s/veh) D_2 = is incremental delay(s/veh)

X = volume-to-capacity ratio c = capacity (veh/h)

T = analysis period duration (h) C = cycle length (s),

D = control delay (s/veh) PF = progression adjustment factor

The analysis period is equal to 0.25 h if a peak hour factor is used to estimate peak 15-min flow rates. If a peak hour factor is not used and the input volumes represent forecast hourly traffic demands, then the analysis period is 1.0 h. the PF value is from 0.04 to 0.50. In this paper T is taken 0.25 h. (24; 34).

2.4.4 Traffic Congestion index (CI)

Delay time may be used as a measure of congestion for a specific road section but is not particularly useful when making comparisons between different road sections or routes. This is because delay time may depend on specific features (e.g. length) relating to the section.

The units of time (e.g. hours, minutes or seconds) used to describe the delay may also mask the interpretation of the actual level of delay unless compared with some other parameter relating to the travel time on the section or route. A more general measure of delay may thus be sought. The level of delay as defined by the system delay can be expressed in terms of a dimensionless congestion index (CI) (35) (24).

According to Tailor et al. (2000) congestion index (CI) is generated by the difference between the actual travel time (T) and the free flow travel time (T_0) divided by the free flow travel time (35). A higher value of CI represents a higher level of congestion (24).

$$CI = \frac{T - T_o}{T_o} = \frac{D}{T_o} \dots\dots\dots\dots\dots.. (2.8)$$

This index takes values greater than or equal to zero. A CI value of zero means that the actual travel time is equal to the free flow travel time. A value of one means that the actual travel time is twice the free flow travel time (and that the system delay takes up 50% of the total travel time). The index allows for comparisons between routes, links, and sections because it is independent of route length, route geometry or intersection control and capacity factors that may distort comparisons of actual travel times and delays at different sites. Alternative dimensionless parameters that may be of use include the ratio of actual speed to free speed or the degree of saturation. (35) (24).

2.4.5 Traffic Flow Rates

Flow rates are collected directly through point measurements, and by definition require measurement over time. They cannot be estimated from a single snapshot of a length of road (20). Flow rates and time headways are related to each other as follows. Flow rate, q, is the number of vehicles counted N, divided by the elapsed time, T:

$$q = \frac{N}{T} \dots\dots\dots\dots\dots\dots\dots\dots (2.9)$$

The total elapsed study time is made up of the sum of the headways recorded for each vehicle.

$$T = \sum h_i \qquad when\ i\ rans\ from\ 1 - N$$

$$q = \frac{N}{\sum_{i-1}^{N} h_i} = \frac{N}{\frac{1}{N}\sum_{i-1}^{N} h_i} = \frac{1}{h^-} \dots\dots\dots\dots\dots\dots\dots\dots (2.10)$$

2.4.6 Traffic Level of Service

The level of service at any intersection on a highway has a significant effect on the overall operating performance of that highway. Thus, improvement of the level of service at each intersection usually results in an improvement of the overall operating performance of the highway. An analysis procedure that provides for the determination of capacity or level of service at intersections is therefore an important tool for designers, operation personnel, and policy makers. Factors that affect the level of service at intersections include the flow and distribution of traffic, the geometric characteristics, and the signalization system.

A major difference between considerations of level of service on highway segments and level of service at intersections is that only through flows are used in computing the levels of service at highway segments, whereas turning flows are significant when computing the levels of service at signalized intersections (19; 36)**.**

The concept of quality of service uses quantitative measures that characterize operational conditions within a traffic stream. Level of service is defined as a term which denotes a range of operating conditions which occur on a transportation facility when it is accommodating a range of traffic volumes. Highway capacity manual (HCM 2000 and 2010) developed by the transportation research board of USA provides some procedure to determine level of service. It divides the quality of traffic into six levels ranging from level A to level F. Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed (i.e. the road is not congested) and level F represents the worst quality of traffic (i.e. the road is extremely congested) (19) the rest are summarized in the table 2.5 below as discussed in Highway Capacity Manual 2000 and 2010.

Level of service is defined based on the measure of effectiveness (MOE). Typically three parameters are used under this and they are **speed and travel time, density, and delay**. One of the important measures of service quality is the amount of time spent in travel.

Table 2-5: Road traffic level of serves descriptions

LOS	Description
A	Traffic flows at or above posted speed limit or with a free flow speed and Motorists have complete mobility between lanes.
B	Slightly congested, with some impingement of maneuverability.
C	Ability to pass or change lanes constrained. Posted Speeds maintained but roads are close to capacity. This is the target LOS for most urban highways.
D	Speeds somewhat reduced, vehicle maneuverability limited. Typical urban peak-period highway conditions.
E	Flow becomes irregular, speed vary and rarely reach the posted limit. This is considered a system failure.
F	Flow is forced; with frequent drops in speed to nearly zero mph. Travel time is unpredictable and the road is extremely congested.

Therefore, speed and travel time are considered to be more effective in defining level of services of a facility. Density gives the proximity of other vehicles in the stream. Since it affects the ability of the driver to maneuver in the traffic stream, it is also used to describe level of services. Delay is a term that describes excess or unexpected time spent in travel. Many specific delay measures are defined in the highway capacity manual 2000 and 2010. Generally, the level of service criteria on the Highway Capacity Manual are given in the form of average travel speed in kilometer per hour for roadway sections and as a maximum delay in second per vehicle for signalized and unsignalized intersection and summarized in the Table 2.6 below.

Table 2-6: Urban Levels of Service by Class for both street and intersection

Aver. free flow	**80 km/h**	**65 km/h**	**55 km/h**	**45 km/h**		
LOS	Average Travel Speed (km/h)				Flow(v/h/L)	Density(v/k)
A	>72	> 59	> 50	> 41	Under 700	Under 12
B	> 56-72	> 46-59	> 39-50	> 32-41	700-1100	12-20
C	> 40-56	> 33-46	> 28-39	> 23-32	1100-1550	20-30
D	> 32-40	> 26-33	> 22-28	> 18-23	1550-1850	30-42
E	> 26-32	> 21-26	> 17-22	> 14-18	1850-2200	42-67
F	< = 26	< = 21	< = 17	< = 14	Unstable	> = 67
	Signalized Intersections			**Un- Signalized Intersections**		
LOS	Average Control Delay (s/veh)					
A	<=10			0-10		
B	10-20			> 10-15		
C	20-35			> 15-25		
D	35-55			> 25-35		
E	55-80			> 35-50		
F	> 80			> 50		

2.4.7 Capacity and Volume to Capacity Ratio

At signalized intersections, capacity for a particular movement is defined by two elements: the maximum rate at which vehicles can pass through a given point in an hour under prevailing conditions (known as saturation flow rate), and the ratio of time during which vehicles may enter the intersection. These are shown in Equation (30; 34; 2).

$$C = S\frac{g}{CT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.11)$$

Where C is the capacity, S is the saturation flow rate of the lane group in vehicles per hour, g is the effective green time for the movement in seconds, and CT is the cycle length in seconds. Figure 2.1 shows the graphical representation of signalized intersection.

Figure 2-1: Illustration of volume and capacity of a signalized movement

The volume-to-capacity ratio, also known as the v/c ratio or the degree of saturation, is calculated for each movement using Equation.

$$\frac{V}{C} = \frac{V}{S\frac{g}{CT}} = \frac{VCT}{sg} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(2.12)$$

Where v is the demand volume of the subject movement in vehicles per hour and the remaining variables are as defined previously.

Using the graphical tool from the previous section, the volume-to-capacity ratio represents the proportion of the area defining capacity that is occupied by volume.

According to the Highway Capacity Manual 2000 and 2010 (30; 34; 37) Movements or lane groups with volume-to-capacity ratios less than 0.85 are considered under saturated and typically have sufficient capacity and stable operations.

For movements or lane groups with a volume-to-capacity ratio of 0.85 to 1.00, traffic flow becomes less stable due to natural cycle-to-cycle variations in traffic flow. The closer a movement is to capacity; the more likely that a natural fluctuation in traffic flow (higher demand, large truck, timid driver, etc.) may cause the demand during the cycle to exceed the green time for that cycle.

The result would be a queue that is carried over to the next cycle, even though the overall demand over the analysis period is below capacity. In cases where the projected volume-to-capacity ratios exceed 1.00 (demand exceeding capacity) over the entire analysis period, queues of vehicles not served by the signal each cycle are likely to accumulate and either affect adjacent intersections or cause shifts in demand patterns. These conditions are described as oversaturated and require significantly different approaches for signal timing.

2.5 Traffic Flow Related Models

Traffic flow models have been developed and used since the beginning of the twentieth century and are part of a long history of mathematical modeling of physical and other systems. Scientists and engineers use these models as simplified representations of real-world systems.

They are applied to explain and predict weather or chemical reactions, behavior of materials or humans, fluid or traffic flow (38; 3).Traffic flow models are used to describe and predict traffic on roads. For example, they model the number of vehicles, their velocity, their acceleration and the distance and time between vehicles. By doing simulations based on these models, the performance of roads or traffic networks can be assessed. This includes answering questions about the presence and duration of congestion, travel times and travel time delays. This information can be used in many applications including providing information on congestion to road users, and in traffic control (21).

A wide variety of traffic models exists. These models can be classified based on their properties (3; 7**.** But in this section, we illustrate two types of traffic models from the point of view of a (traffic) control engineering as follows.

- Microscopic Traffic Flow Modeling
- Macroscopic Traffic Flow Modeling.

2.5.1 Microscopic Traffic Models

Microscopic traffic models are models in which all vehicles or ‘particles’ in the system are described individually. A model for the behavior of every single vehicle is defined.

These vehicle models include e.g. the interaction between the vehicles or between the vehicles and the motorway.

During simulation, all the individual cars and their interactions are simulated using the models. Combination of all simulation results of the vehicle models leads to an image or snapshot of the traffic situation.

Microscopic traffic simulators can be implemented based on different microscopic traffic models. Some microscopic simulators start from a description of the motorway network we want to simulate where the network is characterized by the speed limit, the number of lanes, overtaking prohibitions for all motorway sections. Every vehicle in the network is characterized by some parameters describing its origin, its destination, the desired velocity, acceleration and deceleration abilities, vehicle type, driver's patience, aggressiveness and so on. During simulation, a flow of vehicles is entered into the network.

The vehicle parameters (mass, acceleration) and the driver parameters (aggressiveness, reaction time) are sampled from a stochastic distribution function, which is determined based on measurements of real-life traffic. The vehicles each attempt to reach their desired destination by traveling through the network.

On their way from their origin to their destination, the vehicles interact with each other (e.g. by overtaking slower vehicles) and with the motorway network (e.g. by obeying speed limits) according to their microscopic vehicle models.

The two most important microscopic models are:

1. The car following model, which describes how a vehicle follows preceding vehicles. The car following model describes e.g. the headway a driver preserves between himself and the preceding vehicle, how the driver reacts on acceleration or deceleration of the vehicle in front of him, etc. The car following model uses vehicle and motorway specific parameters. The acceleration ability, the aggressiveness of the driver, and the mass of the vehicles is vehicle specific parameters that can be used in the car following model. The maximal speed limit and the number of lanes are motorway specific parameters influencing the way a car follows its predecessor.
2. The overtaking model describes how a driver decides whether or not to overtake its predecessor. Vehicle and driver properties that are important in the overtaking model

are e.g. the desired speed of the driver and acceleration abilities of the vehicle. The number of lanes is a motorway property that influences overtaking behavior. Vehicle interaction is also important. A driver will decide to overtake based on the speed difference between his lane and the adjacent lane and on the available gap on the other lane.

2.5.2 Macroscopic Traffic Models

Macroscopic traffic models are models that use aggregate variables in order to describe the traffic situation. Typically, a macroscopic model defines a relation between the traffic densities, the average velocity and the traffic flow. The traffic densities is defined as the number of vehicles per kilometer and per lane, while the traffic flow or the traffic intensity is defined as the number of vehicles passing a certain point per hour. Within the class of macroscopic models, a classification based on the order of the models can be made.

Since macroscopic traffic models only work with aggregate variables and do not describe the traffic situation on the level of independent vehicles, they are less computationally intensive than microscopic models. This allows a fast simulation of the studied motorway network that is imperative for on-line predictive control. Often, the cost function is expressed in terms of the aggregate variables, which makes it easy to calculate the cost corresponding to a model state. Due to the fact that a macroscopic traffic model has fewer parameters to estimate than a microscopic model, it is easier to identify and to tune a macroscopic model. Macroscopic models are written as state space models, which are linked to control theory. As a result of the above, macroscopic models are very well suited for optimal predictive and adaptive control. Although there are many different macroscopic models, but the most important models among others are: the Lighthill-Whitham- Richards's model, the Payne model, and the model of Papageorgiou.

Based on the Lighthill-Whitham- Richards's**,** macroscopic models use aggregated variables to describe the behavior of traffic. Macroscopic traffic models are often derived using the analogy between traffic flows and the fluid flows as well as with the existing of a law of conservation of mass in fluid dynamics, we can write down a law of conservation of vehicles in the traffic context:

$$\frac{n(x)\,\partial C(x,t)}{\partial t} + \frac{\partial q(x,t)}{\partial x} = 0 \dots\dots\dots\dots\dots\dots\dots (2.13)$$

Where C(x, t) denotes the traffic density in vehicles per lane per kilometer at location x and at time t, with n(x) the number of lanes at position x and with q(x, t) the traffic flow in vehicles per hour at location x at time t, sometimes also called the traffic intensity.

The aggregated variables C(x, t) and q(x, t) are continuous functions of time and space; although the system they describe is intrinsically discrete (the cars on the motorway are discrete entities). This equation is a 'physical law' in traffic theory stating that no cars can vanish nor appear out of the blue. By consequence, the equation holds exactly for every possible traffic regime and at all times.

The traffic flow from the above equation can be expressed in terms of the traffic density and the traffic speed v(x, t):

$$q(x,t) = C(x,t).V(x,t).n(x) \dots\dots\dots\dots\dots\dots. (2.14)$$

Lighthill and Whitham [1955] and also Richards [1956] observed that the average equilibrium speed of the vehicles is a function of the traffic density:

$$V(x,t) = F(C(x,t) \dots\dots\dots\dots\dots\dots\dots\dots\dots. (2.15)$$

This model is a continuum model in both time and space. An analytical solution of these equations for a motorway network is hard or even impossible to find. In practice the model is discretized in time and in space to allow for a computer simulation of the difference equations describing the behavior of the motorway network.

The second macroscopic traffic model is the Payne model. Where the first order LWR-model contained only one partial differential equation but the second order Payne model contains two partial differential equations. Observations of traffic show that, the average speed in sections is not only dependent on the traffic density in that section but also on the state of the neighboring sections and on the dynamics of the average speed itself (3). Three major mechanisms that influence the average speed can be distinguished: relaxation, convection and anticipation.

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} = \frac{V^e(C) - v}{T} = \frac{{C_o}^2 \partial C}{C\partial x} \dots\dots\dots\dots\dots\dots\dots\dots. (2.16)$$

Where, V^e is the average speed in equilibrium C_o is the anticipation constant and T is the relaxation constant. This equation is derived from a simple car following model that describes the behavior and interaction of the vehicles as they follow a leading vehicle on the road.

It describes the change in average speed in a motorway section over time due to convection (term 1), relaxation (term 2) and anticipation (term 3) (7)**.**

2.6 Discrete Versus Continuous traffic Modeling

A motorway traffic model describes the evolution of the state variables of the traffic network over time. This means that there will be two independent variables, namely space and time. These independent variables can be considered to be either continuous or discretized. Since the continuous traffic models are generally too complicated to solve analytically, especially if the size of the considered traffic network is large, they are discrete in time and space in order to simulate their behavior using a computer. In the remainder of this paper, we will more extensively look at macroscopic traffic models, since this kind of model is better suited for model-based control design methods than microscopic traffic flow models (33).

2.7 Deterministic Versus Stochastic Traffic Modeling

In a deterministic traffic model there is a deterministic relation between the input, the states and the output of the model. If we simulate a traffic situation twice, starting from the same initial conditions and with the same inputs and boundary conditions, the outputs of the model will be the same. Payne's macroscopic traffic simulation model, discussed later on, is an example of a deterministic traffic model.

A stochastic traffic model contains at least one stochastic variable. This implies that two simulations of the same model starting from the same initial conditions, the same boundary conditions and the same inputs may give different results, depending on the value of the stochastic variable during each simulation. The stochastic variable is characterized by a distribution function or a histogram. For example, in the microscopic simulation package a distribution of the level of patience over different drivers needs to be defined.

During simulation, this distribution is sampled to determine a level of patience for every simulated driver in the network.

It is clear that a second simulation, and thus a new sampling of the distribution, will result in drivers with other levels of patience. Therefore, stochastic models need to be simulated repeatedly and an average over the results needs to be taken in order to be able to draw conclusions. If we aim at online traffic simulation for predictive control purposes, this requires a lot of computational power, especially if we consider large traffic networks. As such, this is one of the major drawbacks of stochastic simulation models.

2.8 The Fundamental Diagram

The fundamental diagram is a basic tool in understanding the behavior of traffic systems: it relates the traffic flow and the traffic density at a given location or section of the motorway. When observing traffic on a motorway and plotting the traffic flow [vehicles/hour] versus the traffic density [vehicles/ kilometer/lane] for a location along the motorway, a curve as shown in Figure below occurs. This curve has a characteristic shape that is the same for every motorway section and is known in the traffic literature as the “fundamental diagram”. The fundamental diagram was already described by Green shields in 1935 (9; 18; 3).

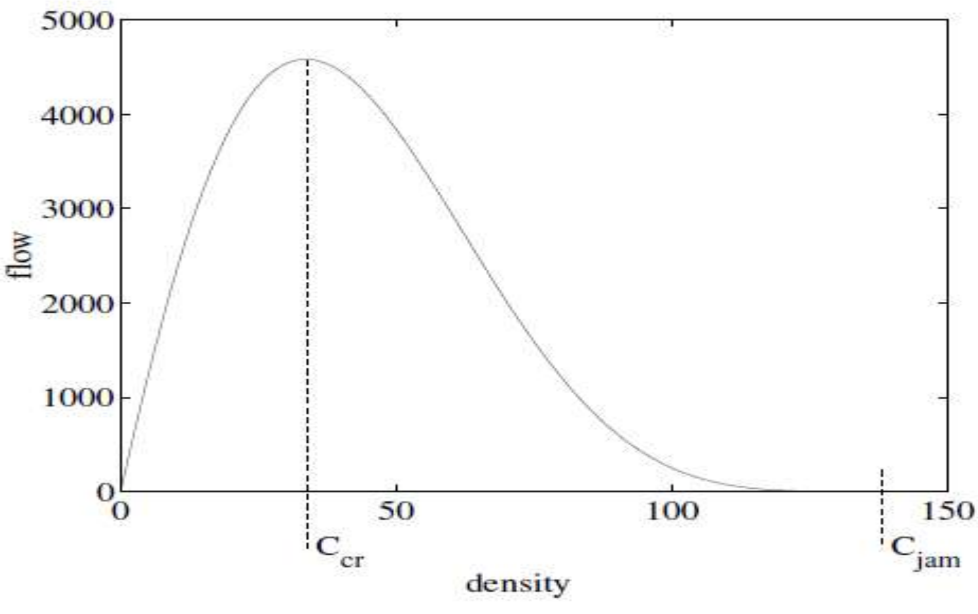

Figure 2-2: The Fundamental Diagram of traffic flow

A plot of traffic flow versus traffic density on a motorway results in the figure above. The density at which the traffic flow is maximal is called the critical density C_{cr}. The (non-zero) traffic density at which the flow equals zero (i.e. the vehicles come to a full stop) is called the jam density C_{jam}.The figure tells as, for zero traffic density (no cars on the motorway), the traffic flow is obviously zero. With increasing traffic density (more vehicles on the motorway), the traffic flow also increases. If the traffic density increases further, the increase of the traffic flow will slow down.

At a certain point, the flow reaches a maximum for a density that we call the critical density C_{cr}. The traffic flow on the motorway decreases with increasing density if the density is greater than the critical density. Eventually the flow becomes zero again for a density we define to be the jam density C_{jam} (9; 7). Based on the above figure**;** two important properties of traffic flow-density relationship of traffic on motorways can be distinguished:

- The traffic flow reaches a maximum at the critical density C_{cr}.
- With increasing traffic density on the motorway, traffic will eventually come to a halt (average speed equal to zero) when the density reaches the maximal possible value C_{jam}.

2.9 Basic Traffic Stream Mode

The most important diagram in macroscopic traffic flow theory is shown in the fig. below. Macroscopic theory considers the performance and behavior of a traffic stream, whereas microscopic traffic flow theory considers the motion of individual vehicles. This basic traffic stream model applies to uninterrupted flow situations in steady-state traffic conditions (9).

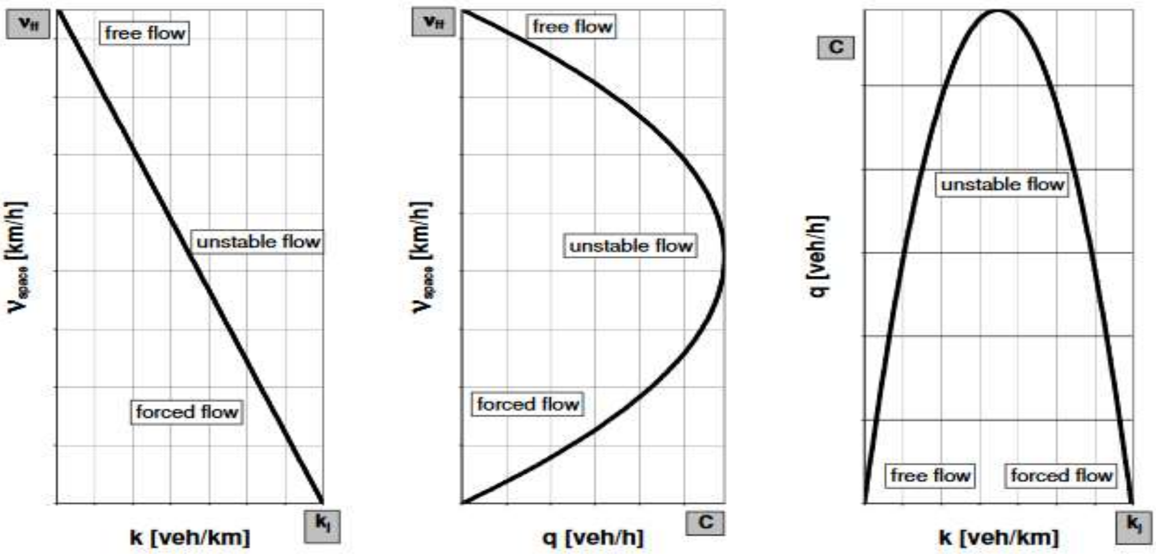

Figure 2-3: Fundamental Macroscopic Relationships of Uninterrupted Traffic Flow

The above figure presents the theoretical relationships between the three basic traffic variables that are common descriptors of a traffic stream: (i.e. traffic volume (V) or flow rate (q); average speed (v_{space}) and traffic density (k)). At low traffic densities, traffic conditions can be described as free-flow conditions (indicated with V_{ff} shown in the Figure, which is the mean free-flow speed, i.e. the average of the desired speeds at which vehicles travel). Drivers can choose to travel at their own preferred speeds within the restrictions of the road environment as imposed by e.g. Road characteristics and speed limits.

When traffic volume increases, most vehicles still experience little or no interaction with other vehicles, although mean speed drops slightly. When traffic flow increases further, the proportion of the traffic travelling at their desired speed decreases and so does the mean speed.

This is so because there are fewer opportunities for vehicles to overtake and speeds of most vehicles are limited by the speed of the preceding vehicle. In addition, drivers decrease their speeds as the number of cars around them increases for safety reasons.

When the traffic volume approaches the road capacity C (shown in Figure), which is the maximum volume that the road can accommodate under prevailing conditions, the traffic stream enters a transitional regime between non-congested and congested flow conditions. Near capacity, most of the traffic is unstable and strongly influenced by the vehicles around them.

When density increases further, traffic flow may become extremely interacted, which results in breakdown (traffic jam) or low speed stop-and-go conditions. These conditions with continuous change between standstill (stationary queue indicated with k_j in Figure shown, which is the maximum density or jam density) and driving at slow speed represent forced flow or congested flow conditions. This implies that the presence of queues is a good indicator of congestion.

2.10 Applications of Queuing Theory for Traffic Flow

Queuing theory is the mathematical study of waiting lines, or the act of joining a line (queues). In queuing theory a model is constructed so that queue lengths and waiting times can be predicted.

The issue of queuing has been a subject of scientific debate for there is no known society that is not confronted with the problem of queuing. Wherever there is competition for limited resource queuing is likely to occur. The role of transportation in human life cannot be overemphasized (11). According to Intikhab et al. (2008), efficient transportation system plays an important role in catering for the daily necessities in the lives of the citizens. These include access to amenities and services that are central to the lives of all individuals, like employment, education, health services and leisure.

At the individual level, Wane (2001, p.1) also points out that 'transportation is a crucial factor for urban insertion since it gives access to economic activity, facilitates family life and helps in spinning social networks (9).At present, queuing system model has been widely used in all kinds of management system. Such as production management, inventory management, business management, transportation, banking, medical services, computer design and performance evaluation, and so on**.**

2.10.1 Poisson Arrivals and Service Time

M/M/1 queuing systems assume a Poisson arrival process. This assumption is a very good approximation for arrival process in real systems that meet the following rules:

1. The number of customers in the system is very large.
2. The impact of a single customer for the performance of the system is very small, that is, a single customer consumes a very small percentage of the system resources.

3. All customers are independent, i.e. their decisions to use the system are independent of other users.

These assumptions are fairly general, so they apply to a large variety of systems. For instance cars entering a highway could follow these assumptions. This means that assuming a Poisson arrival process will be a good approximation of the car arrivals on the highway. If any one of the three conditions is not met, one cannot assume Poisson arrivals (eventhelix.com, 2013) (9)**.**

The probability density distribution equation for a Poisson process describes the probability of seeing **n** arrivals in a period from 0 to **t**.

$$P_n(t) = \frac{(\lambda \mathrm{t})^n}{n!} e^{-\lambda t} \dots \dots \dots \dots \dots \dots \dots \dots (2.17)$$

The probability of no arrivals taking place over a given interval is obtained by substituting n with 0, and arrives at getting the following equation:

$$P_0(t) = e^{-\lambda t} \dots \dots \dots \dots \dots \dots \dots \dots (2.18)$$

In an M/M/1 queuing system we assume that service times for customers are also negative exponentially distributed (i.e. generated by a Poisson process). Unfortunately, this assumption is not as general as the arrival time distribution. A queuing discipline determines the manner in which the exchange handles calls from customers.

The most common queue discipline is “first- come, first served”, abbreviated as FCFS, in some inventory applications, the same rule is called “first in- first out” and abbreviated as FIFO. This principle also serves customers one at a time; however the customer with the shortest waiting time will be served first.

The equations describing an M/M/1 queuing system are fairly straightforward and easy to use. First we define the traffic intensity (ρ), (sometimes called occupancy). It is defined as the average arrival rate (λ) divided by the average service rate (µ).

For a stable system the average service rate should always be higher than the average arrival rate. (Otherwise the queues would rapidly race towards infinity).

Thus (ρ) should always be less than one (9). Also note that we are talking about average rates here, the instantaneous arrival rate may exceed the service rate. Over a longer time period, the service rate should always exceed an arrival rate.

$$\rho = \frac{\lambda}{\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.19)$$

Mean number of customers in the system (N) can be found using the following equation.

$$N = \sum_{i=0}^{\infty} i\rho_i = \frac{\rho(1-\rho)}{(1-\rho)^2} = \frac{\rho}{(1-\rho)}\ or\ \frac{\lambda}{(\mu-\lambda)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.20)$$

The number of customer in queue (prior to service) is given as:

$$N_q = \sum_{i=0}^{\infty}(i-1)\rho_i = \frac{\rho}{(1-\rho)} - \big(1-(1-\rho)\big) = \frac{\rho^2}{(1-\rho)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.21)$$

From this equation, as ρ approaches 1 the number of customers would become very large. This can be easily justified in figuratively, ρ will approach 1 when the average arrival rate starts approaching the average service rate. In this situation, the server would always be busy hence leading to a queue build up (large N).

Lastly we obtain the total (mean) waiting time (including the service time) as shown below:

$$T = W = \frac{N}{\lambda} = \frac{\rho}{(1-\rho)\lambda} = \frac{1}{\mu(1-\rho)} = \frac{1}{\mu-\lambda}\ or\ T = W_q + \frac{1}{\mu} \ldots\ldots\ldots\ldots\ldots (2.22)$$

Mean time spent waiting in queue (prior to service) is also calculated as:

$$T_q = W_q = \frac{\rho}{\mu(1-\rho)} \ldots\ldots\ldots\ldots\ldots\ldots. (2.23)$$

Again we see that as mean arrival rate approaches mean service rate, the waiting time becomes very large (eventhelix.com, 2013**)** (9). Queuing theory can be divided into single channel queuing system and multi-channel queuing system.

2.10.2 Single Channel Queuing System

The single channel queuing system is called *M* /*M* /1 system. Assume that customers arrive randomly, follows Poisson distribution, λ is the average arrival rate, μ is the average output or service rate, and $\rho = \frac{\lambda}{\mu}$ is traffic intensity or utilization coefficient. When $\rho < 1$, the arrival rate is less than the rate of output or service, and then the intersection traffic will be smooth. If, $\rho \geq 1$, the arrival rate is greater than the rate of output and then the queuing length will be infinity, the system is not steady or smooth. Therefore, $\rho < 1$is the necessary and sufficient condition for the system to be steady.

Combined with the little formula, the quantity indexes of single channel queuing system can be obtained, as follows (9; 3; 6).

2.10.3 Multi-Channel Queuing System

The multi-channel queuing system is called M / M / N system. Its traffic intensity is $\frac{\rho}{N}$ which is different from the single channel queuing system. The system is stable when $\frac{\rho}{N} < 1$, otherwise, it is not. At the same time, $\frac{\rho}{N} < 1$ is the necessary and sufficient condition for the system to be steady (9).

2.11 Intersection Flow Control

(Papageorgiou et al., 2003) as discussed in (21) provide a useful overview of two different intersection control strategies. Based on the description in this study, both strategies will be discussed in the following sections. An old type intersection control is officer control. In developed countries, this strategy is hardly applied. However, in developing countries, where wages are low, officer control is very common. As a result of its unique character, officer control will be considered as a separate control strategy. Not all types of control are applicable to all traffic modes (42). Under saturated traffic flow can be controlled in many ways, while oversaturated flow is hard to control.

2.11.1 Fixed-Time Control

Fixed-time control for an isolated intersection is the most basic non-human type of control. Each of the involved lanes receives the right-of-way for a fixed-time. No sensors are needed. Based on different optimization methods, the length of the right-of-way periods are set to minimize the delay at each approach.

A maximum cycle and a minimum-green constraint are taken into account. Different phases of the day can have different fixed-time strategies (42).

By optimizing the fixed-time settings of multiple intersections and taking travel times in between the intersections into account, green waves can be created. During green waves, a vehicle will not encounter a red signal. This type of control can only be applied to under-saturated conditions.

2.11.2 Traffic Responsive Control

Traffic-responsive strategies make use of real-time measurements provided by inductive loop detectors. Different strategies within this class exist. Most of the responsive control strategies for a single intersection function according to the same basic principle. Minimum green phases are assigned to each approach.

These minimum green phases can be extended as a result of a higher traffic demand. The green phases are limited by the maximum-green value.

At the end of the green phase, either caused by a decreased traffic demand or by the maximum-green value, the right-of-way will change. In case of oversaturated conditions at all streams of an intersection, the length of the green-phases equals the maximum-green value. Traffic responsive control can also be applied to networks. A central system will measure the demand and supply in the network and will calculate the optimal lengths of green phases (42). This type of control can handle oversaturated traffic demand by limiting the number of vehicles entering a network. Compared the use of simple fixed time control and advanced traffic responsive control in Indonesia by means of simulation. The conclusion was that only in specific cases the application of a more advanced responsive system would result in a better traffic performance.

2.11.3 Officer Control

Officer control can be considered as single intersection traffic responsive control. Intersection control by traffic officers has numerous advantages compared to signal control (21):

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

However the advantages of officer control will decrease at the more complicated intersections as the number, volume, and regularity of different kinds of movements increase. The disadvantages of officer control are (21):

- No coordination or communication with other intersections, disobedience of traffic due to bad visibility of officer and distraction of officers as a result of answering questions, social chatting or law enforcement
- Leaving of officers in case of emergency and high costs of officer control as well as Personal differences between officers.

2.12 Types of Traffic Signal Control

According to the HCM 2010, In general, two types of traffic signal controller unit are in use today. They are broadly categorized as pre timed or actuated according to the type of control they provide. These two types of control are described as follows (2; 40; 41):

2.12.1 Pre-Timed Control

Pre-time control consists of a fixed sequence of phases that are displayed in repetitive order. The duration of each phase is fixed. However, the green interval duration can be changed by time of day or week to accommodate traffic variations. The combination of a fixed phase sequence and duration produces a constant cycle length.

2.12.2 Actuated Control

Actuated control consists of a defined phase sequence in which the presentation of each phase depends on whether the phase is on recall or the associated traffic movement has submitted a call for service through a detector. The green interval duration is determined by the traffic demand information obtained from the detector, subject to preset minimum and maximum limits. The termination of an actuated phase requires a call for service from a conflicting traffic movement.

2.13 Intersection Traffic Movements

Figure 2.3: illustrates typical vehicle and pedestrian traffic movements at a four-leg intersection. Three vehicular traffic movements and one pedestrian traffic movement are shown for each intersection approach. Each movement is assigned a unique number or a number and letter combination. The letter P denotes a pedestrian movement. The number assigned to each left-turn and through movement is the same as the number typically assigned to each phase by National Electrical Manufacturers Association specification.

Intersection traffic movements are assigned the right-of-way by the signal controller. Each movement is assigned to one or more signal phases. A phase is defined as the green, yellow change and red clearance intervals in a cycle that are assigned to a specified traffic movement. The assignment of movements to phases varies in practice, depending on the desired phase sequence and the movements present at the intersection (40).

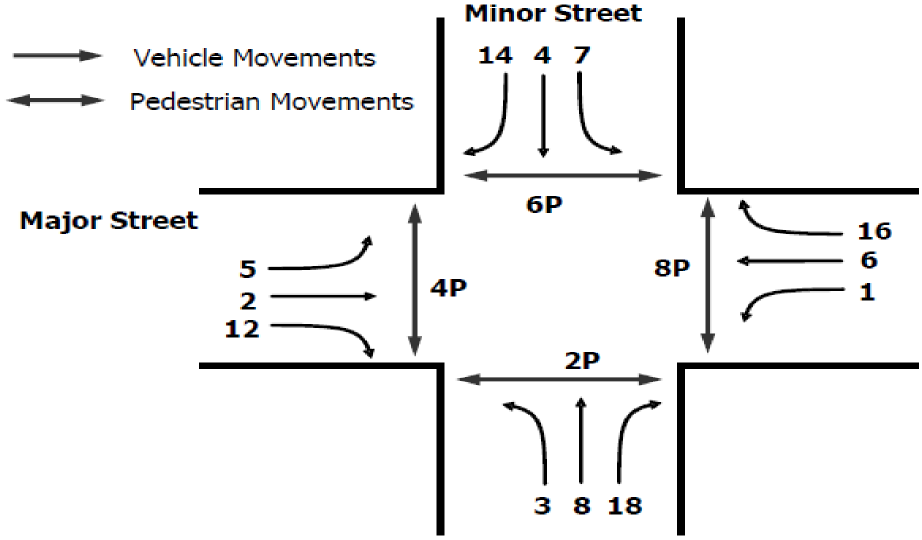

Figure 2-4: Intersection Traffic Movements and Numbering Scheme

2.14 Saturation Flow at Intersections

The saturation flow is frequently used as a performance measure of a lane at intersections and is applied extensively in intersection and control design. It is an indication of the maximum flow of a junction during green phase when operating under ideal conditions (21). Zwarteveen argue that it is a well-known property of signals that when the light turns green on a stream gaining right-of-way, the flow across the stop line quickly rises to a steady value, the saturation flow, of the stream (41).

$$S = s_o \; x \; f_1 \; x \; f_2 \;\; x \ldots \ldots x \; f_n \quad \ldots \ldots \ldots \ldots \ldots (2.24)$$

Where: S = saturation flow, S_0 = basis saturation flow, f_n = correction factors.

Table 2-7: International saturation flow benchmark of intersection

Country	City	Saturation Flow (pcu/h)	Lane width (m)	Traffic composition (%)	Signal Control	Data size int. /veh.
Ethiopia	A.A	1522	2.8 – 4.0	C71 mb27 hv2	Yes/no	3int. /3108veh.
China	Chegdu	1477	3.2	C98 lb1 l1	Yes	1int. /1957veh.
	Gangsha	1399	3.0	C98 lb1 l1	Yes	1int. /830veh.
	Beijing	1284	3.0	C93 lb7	Yes	1int. /182veh.
	Nanjing	1537	3.0	C98 lb1 l10	Yes	1int. /1806veh.
Malaysia	Various	1660	Unk.	C60 mc30 lb5 l5	Yes	64 int/unk
Developing Countries	Various	1200-1920	3.5	Unk	Yes	217 int./unk
Developed Countries	Various	1700-2080	3.5	Unk	Yes	204 int./unk
C = car, mc = motorcycle, mb = minibus, lb = large bus, l =lorry, hv = heavy vehicle, int. = intersection, unk. = unknown, cntr. = countries, h = hour, pcu = passenger car unit						

2.15 Traffic Congestion Controlling Mechanisms

According to, (19), Many researchers identified different traffic congestion mitigation measures depends on the causes and the type of congestion. From those researches Managing Urban

Traffic Congestion, 2007 conclude there is no prescribe specific congestion management strategies since the appropriateness and applicability of these depends largely on the local context. The report suggests three strategic congestion management principles that should serve to guide policies in this field.

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

Transportation engineers and planners of Cambridge Systematics, Inc. & Texas Transportation Institute have developed a variety of strategies to deal with congestion. The strategies can be grouped into three as follows and each group has key strategies to address congestion:

1. Adding more capacity for highway, transit and railroads Key Strategies to Address Congestion. This includes:
    - Adding travel lanes on major freeways and streets (including truck climbing lanes on grades), adding capacity to the transit system (buses, urban rail or commuter rail systems) Closing gaps in the street network as well as removing bottlenecks and overpasses or underpasses at congested intersections and high-occupancy vehicle (HOV) lanes as well as increasing intercity freight rail capacity to reduce truck use of highways
2. Operating existing capacity more efficiently Key Strategies to Address Congestion:
    - Optimizing the timing of traffic signals, faster and anticipatory responses to traffic incidents, providing travelers with information on travel conditions as well as alternative routes and modes, improved management of work zones and geometric to roads and intersections and converting streets to one-way operations as well as access management.
3. Encouraging travelers to use the system in less congestion producing ways Key Strategies to Address Congestion: Programs that encourage transit use and ridesharing, curbside and parking management, flexible work hours and telecommuting programs.

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

This chapter is about the methods that were used for collecting information in the field and mainly explains how the study was conducted, the applied methods and techniques in data collection as well as the reasons they were used according to the research aims and its main objectives. This chapter involves discussion of the research process, the selection of the study area, justification and sources of data used in the study. Analytical techniques used in analyzing the data for the study are also discussed. Obviously, it is impossible to examine all elements of a given target population owing to high cost, time, and inconvenience of a large data administration. However, it is possible to investigate and generalize to the given population by selecting representative sample elements. As a result, a sampling technique of the study chosen based on the aim on hand, and other related subtitles are going to be presented in this chapter.

3.2. Selection of Study Area

According to the World Bank report in 2015/16 Addis Ababa, the capital of Ethiopia, contributes a lot to the economic development of the country and it is where most significant changes in the socio- political sphere of the land emanate from. Addis Ababa has been manifesting to be a fast growing city in recent decades and contributes about 40% to the national GDP. However, the growth is accompanied with several constraints as it has not been provided with an equal growth in urban transport provisions is lagged behind the existing demand. Moreover, the sector is expressed by many traffic problems.

According to Addis Ababa traffic management office, Comparative to other cities in the nation, the greater numbers of motor vehicles are found in Addis Ababa with a total share of 56.1% of the total motor vehicles in the nation. Thus, traffic problem in the city goes up together with the increase of motor vehicles and population size. Moreover the rise in automobile ownership together with the condition of the roads has resulted in the high level of traffic risk and congestion problems.

Even though there are many intersections, facing with traffic congestion, in Addis Ababa, Due to time and budget constraint, it is difficult to cover the hole. So that the researcher selects only two main intersections having four approaches legs each in meskel square after deep observations and field surveying. According to the field survey and observation meskel is one of the largest intersections found in Addis Ababa with its high traffic congestion especially in the morning and evening peak hours due to poor signal controlling system.

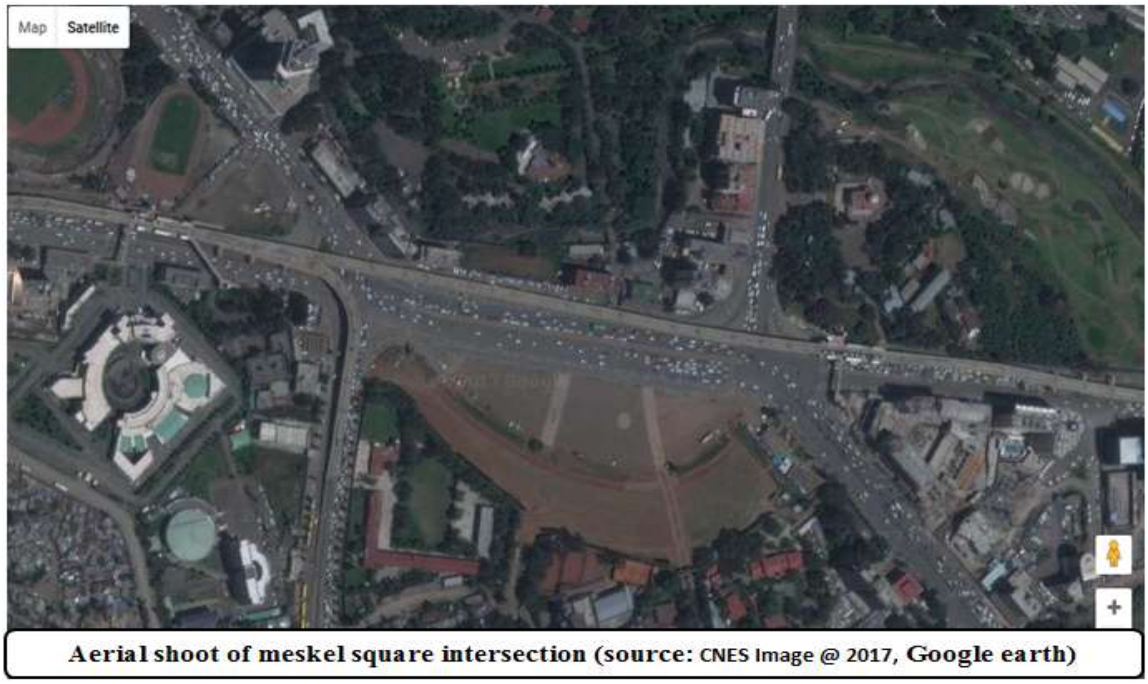

Figure 3-1: Aerial shoot of meskel square intersection

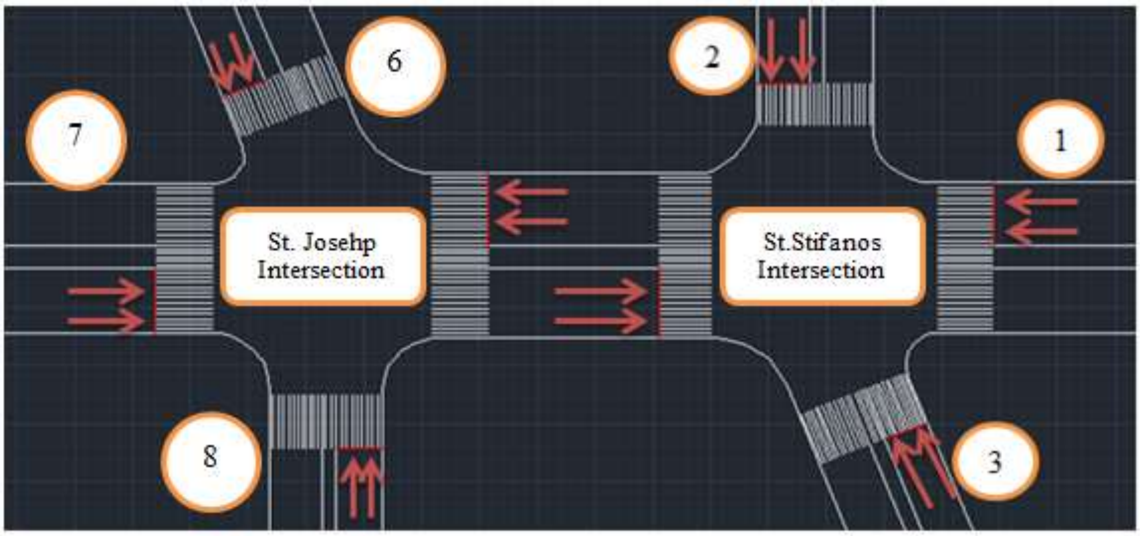

Figure 3-2: Graphical representation of the study area

Table 3-1: Study area/intersection description

Location	Intersection Name	Approaches leg	No of lane	Ar. Lane width	Control Type
Meskel Square (kirkos sub-city)	St. Stifanos	1. Bambis	3	3.5 m	Signal
		2. Betemengist	3	3.5 m	Signal
		3. Dembel	4	3.5 m	Signal
		4. Meskel Square	5	3.5m	Signal
	St. Joseph	5. St. Stifanos	4	3.5 m	Signal
		6. Ambassador	3	3.5 m	Signal
		7. Legehar	3	3.5 m	Signal
		8. Saris	3	3.5 m	Signal

3.3. Sources of Data

In order to achieve the objectives of this study, both primary and secondary sources data are used. **The primary data** are obtained through observation, interview, manual road data recording (traffic volume and travel time) and focus group desiccation with traffic police officers who are concerned with the issue and comfortable to the researcher, especially with regard to availability, knowledge about the issue, and experience aspects. **The secondary sources** of data were also taken from reviews of relevant books, journals, articles, and reports (extracted from the Highway Capacity Manual) and other published and unpublished documents. Information was also gathered from Addis Ababa Traffic Police who were on duty.

The secondary sources were then integrated with the primary sources so that the research became comprehensive enough to incorporate elements of the phenomenon under study. The data gathered through primary and secondary sources are translated into viable meanings and analyses. Tables, charts and figures are also used to clarify and substantiate explanations. The data obtained from different sources are placed together or compared for the purpose of critical examination of the various claims. Arena 14.00 version software is then used to model and simulate traffic flow at the study intersections.

3.4. Methods of Data Collection and Equipment

In order to test the specific objective of investigation, data's has been collected from the primary and secondary sources as discussed above. For both data sources recommended techniques and steps has been followed to minimize errors.

The secondary data are gathered by literature review. Whereas, the primary data's are collected using the following techniques:

- Interview and focus group desiccation
- Manual traffic volume counts
- Manual travel time measure and Field measures

Interviews and focus group discussions were held with traffic police, offices and some experts in the field to gather information about the traffic congestion at major intersection in the city, possible causes of congestion and to identify the most congested intersections.

3.4.1. Traffic Volume Count

Traffic volume count was conducted to determine the number, movements and classifications of roadway movements at a given location. These data can help identify critical flow time periods. The length of the sampling period depends on the type of count being taken and the intended use of the data recorded. For example, an intersection count may be conducted during the peak flow period. If so, manual count with 15-minute intervals could be used to obtain the traffic volume data.

The traffic volume count was made for 8 hours per day starting from the morning 7:30 AM to the evening 7:30 PM at 15 minutes interval for 12 days as shown in appendix A1-A8. This is done 3 hours in the morning (7:00-4:00 AM, 2 hours in the midday (6:00-8:00) PM and 3 hours in the evening (9:30-7:300) PM.

3.4.2. Travel Time Measure

For this research, travel time has been measured manually using stop watch by fixing the length in which the vehicle is travelling to determine congestion measures. To perform this, first the researcher had selected only one approach with the highest traffic volume for each intersection

3.5. Research Design Framework

As shown in the figure 3.3 below, the research problem will be identified through literature review and investigation of the real world problem. To come up with solution to this problem, appropriate research objectives and research questions were carefully defined. Next, research gap will be identified based on the problem and then necessary data will be gathered from primary and secondary sources and integrate them to analysis easily and properly. This analysis result gives a clear understanding about the present statutes of the traffic congestion and a clue to find appropriate solutions to address the problem so that it gives constructive conclusions and recommendations.

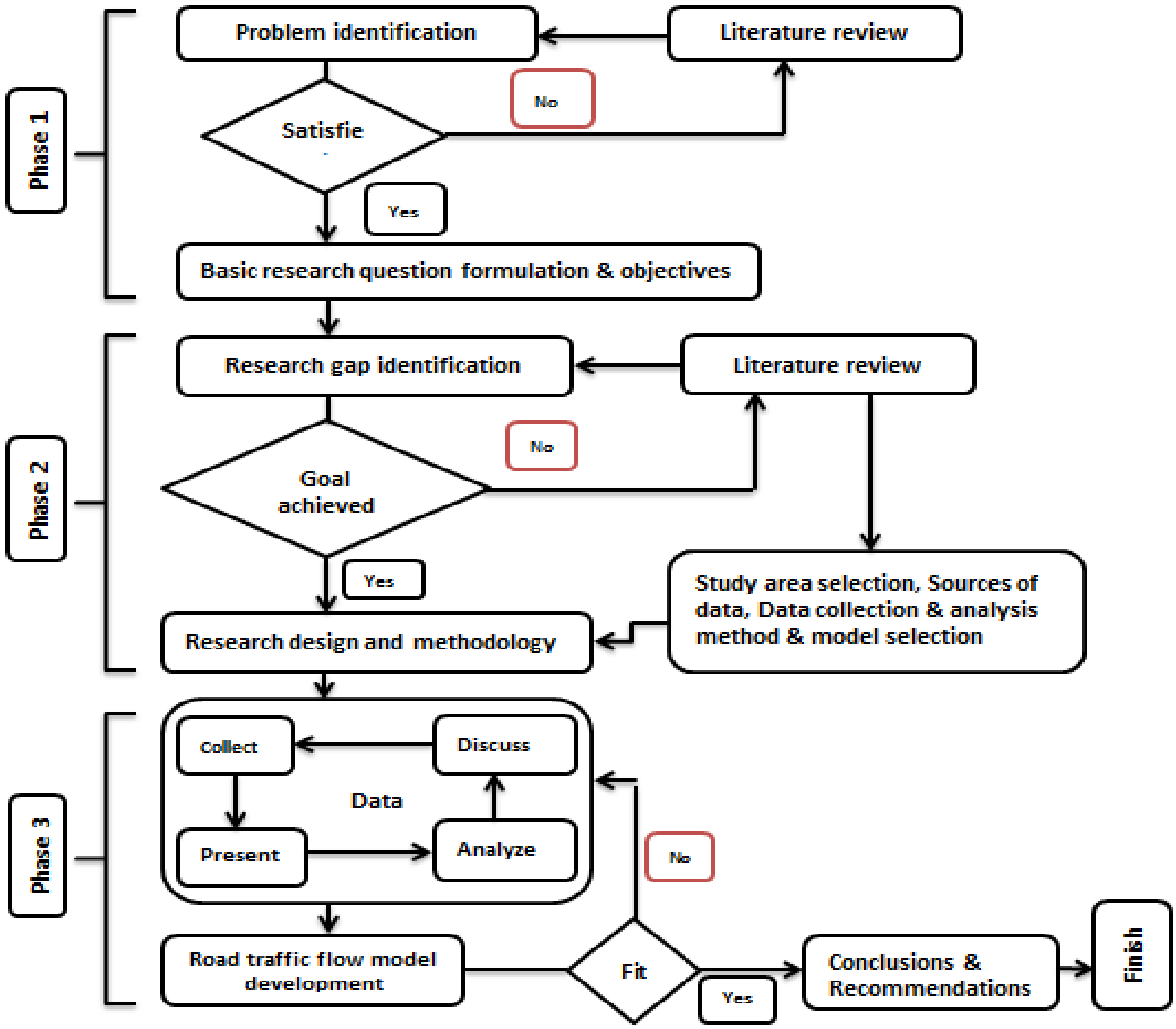

Figure 3-3: Research design framework description

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND DISCUSSIONS

4.1 Introduction

The analysis was made on the gathered quantitative and qualitative data to look into the trend of the traffic flow within the day and identify the peak hour volumes. The level of service for the identified intersections was analyzed using the highway capacity manual and the intersections were checked if they fall as congested or not congested based on HCM 2010 criteria. Congestion analysis also made on the sections where the travel time data was collected and the results are interpreted and discussed. In the congestion analysis, parameters for quantifying congestion were calculated based on travel time approach for each intersection.

4.2 Traffic Volume and Flow Pattern Analysis

The traffic volume and flow analysis was conducted on a traffic volume data which is counted at 15 minutes interval and for 8 solid hours of a day starting from the early morning to the late afternoon for seven successive days in the first phase and five additional days were recorded during holidays to know the traffic flow variation at holidays. The traffic volume analysis is done for two intersections along the research corridor. Meskel Square is the considered segment with its two main intersections, these are:

1. St. Stifanos intersection
2. St. Joseph intersection

These two intersections are considered with their four approaches and traffic volumes were counted in these eight approaches. The traffic volume flow level at the intersections show 23% increase in number from each approach during holidays. The average Traffic volume data for the above two intersections and the percentage of share from each approach to the main intersection in the three peak hours are summarized and reported in the table 4-1 below.

4.2.1 Traffic Volume at St. Stifanos Intersection

This intersection is located at front of St. Stifanos church in kirkos sub-city and considered as the most congested by the road users' perception. The traffic count was done for 8 hr. starting from 7:30AM up to 7:30PM per day on each approach.

As the graphs plotted below, tells us the traffic volume at St. Stifanos intersection in the morning (8:15-9:15) AM and in the evening (5:15-6:15) PM for one hour is maximum but lower in midday.

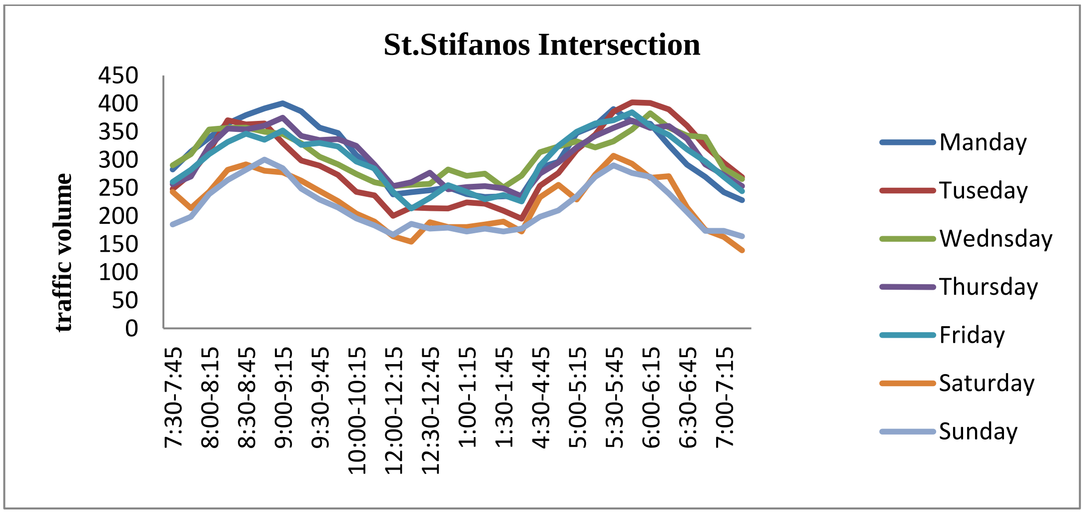

Figure 4-1: Weekly Average Traffic Flow at St. Stifanos intersection per 15 min

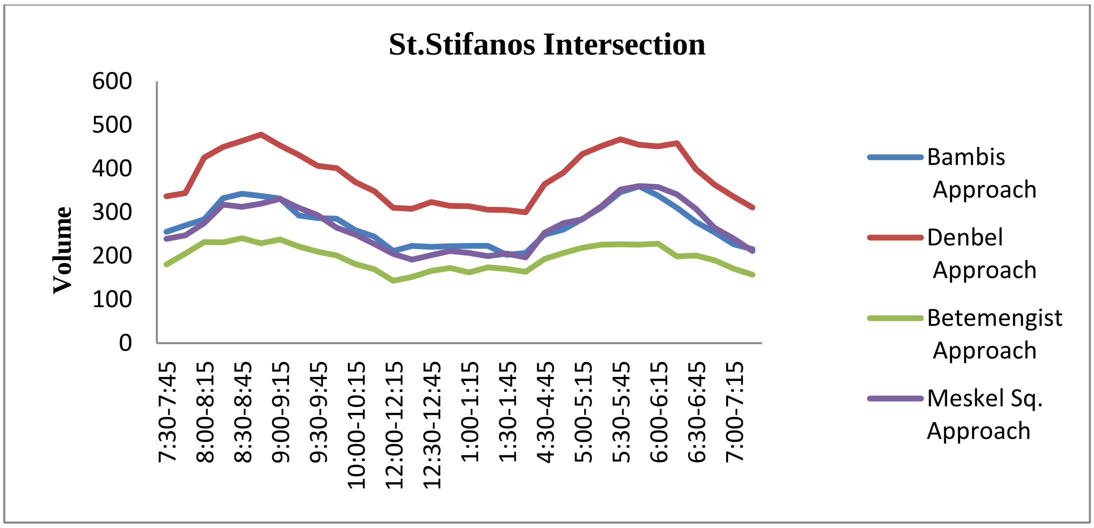

Figure 4-2: Average Traffic Flow at St. Stifanos intersection from each approach

Table 4-1 shows the volume flow share from each approach at St. Stifanos intersection. Accordingly Denbel have the highest percentage of share in the morning and evening as well as in the mid-day peaks.

Table 4-1 Average traffic flow and percentage of share at St. Stifanos intersection

Intersection Name	**Approach Leg**	**Traffic Volume Entry Per one Cycle Time**					
		Morning	% of Share	Mid-Day	% of Share	Evening	% of Share
St. Stifanos	Bambis	104	25%	77	24%	102	24%
	Denbel	145	34%	110	35%	145	34%
	Betemengist	75	18%	58	18%	72	17%
	Meskel Sq.	100	24%	72	23%	105	25%
Total volume per one cycle		425	100%	317	100%	424	100%

The volume flow in St. Stifanos intersection per approach per month is shown in figure 4-3. Accordingly Denbel have the highest value of all approach from Monday to Friday. In general, the flow volume decreases in Saturday and Sunday for each street.

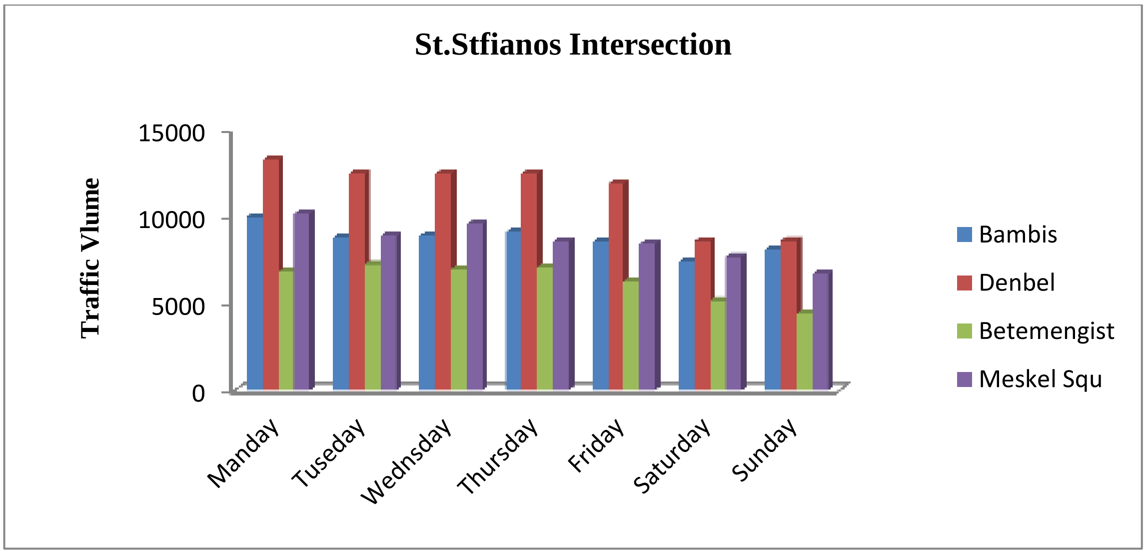

Figure 4-3 Traffic flow share from each approach per week at St. Stifanos intersection

4.2.2 Traffic Volume at St. Joseph Intersection

This intersection is located in front of stadium in the same sub-city and considered as the most congested by the road users' perception. The traffic count was done for 8 hr.

starting from 7:30AM up to 7:30PM per day on each approach's same to that of St. Stifanos intersection.

Figure 4-4 tells us the traffic volume at St. Joseph intersection in the morning (8:15-9:15) AM and in the evening (5:15-6:45) PM for one hour is found to be high, but slightly lower in the morning. The volume flow share from each approach at St. Joseph intersection is also shown in table 4-2. Accordingly both Legehar and Stifanos approaches have the highest percentage of share in the morning and evening as well as in the mid-day. The volume flow share per approach as well as per day is also shown in the bar graph again.

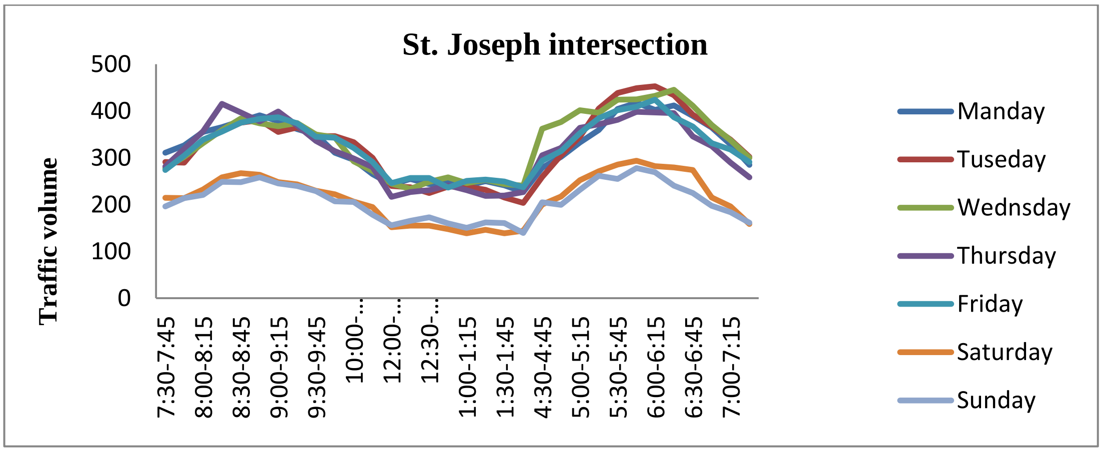

Figure 4-4: Weekly Average Traffic Flow at St. Joseph intersection per 15 min period

The volume flow from each approach at St. Joseph intersection is shown in figure 4.5. It tells as, Legehar and St. Stifanos both have the highest volume share in relative to the remaining two approaches.

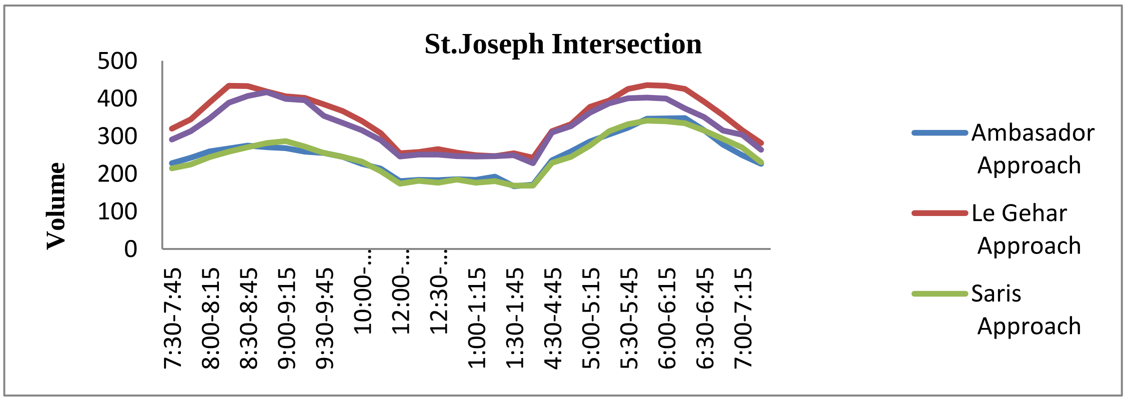

Figure 4-5: Average Traffic Flow at St. Joseph intersection from each approach

Table 4-2: Average traffic flow and percentage of share at St. Joseph intersection

Intersection Name	**Approach Leg**	**Traffic Volume Entry Per one Cycle Time**					
		Morning	% of Share	Mid-Day	% of Share	Evening	% of Share
St. Joseph	Ambassador	97	20%	70	21%	114	22%
	Legehar	147	31%	98	30%	145	29%
	Saris	97	20%	68	21%	114	22%
	Stifanos	137	29%	95	29%	136	27%
Total volume per one cycle		478	100%	332	100%	508	100%

Table 4-2 and figure 4-5 describes the volume entry of the intersection from each approach in the effective green period at St. Joseph intersection in the morning, mid-day and evening. Accordingly, Le Gehar and Stifanos approaches have the highest values.

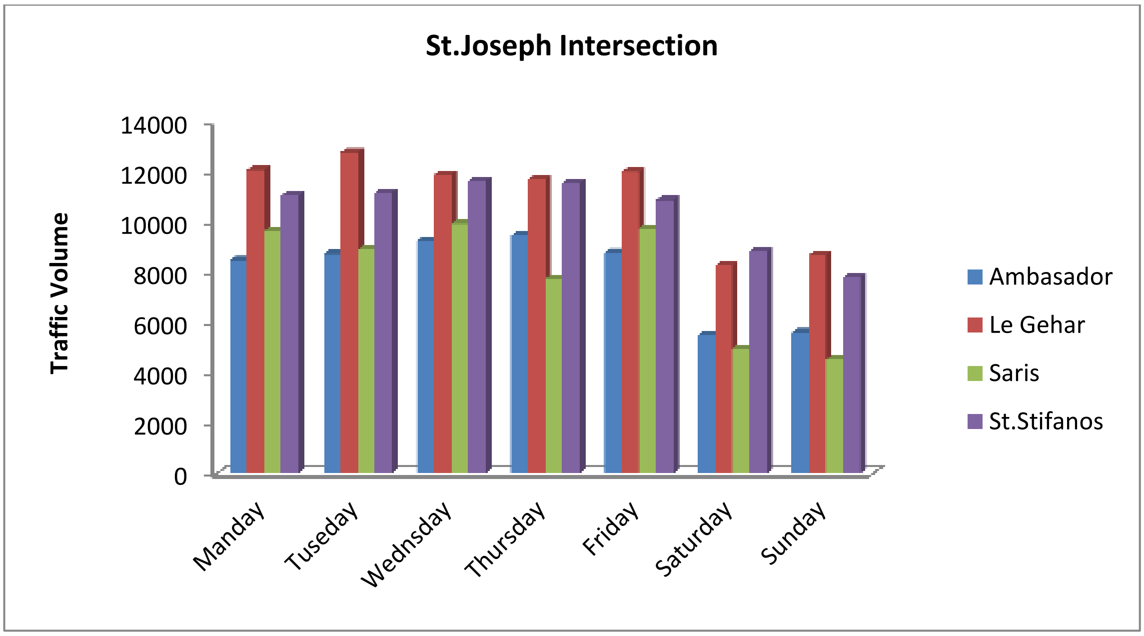

Figure 4-6: Traffic volume flow share per week at St. Joseph intersection

The above bar graph shows that there is a slit constant traffic volume from Monday to Friday, but the volume reduces in the weekends. In this intersection Legehar and Stifanos approach have the highest traffic flow share value.

4.3 Traffic Congestion Analysis

Congestion analysis was made based on the travel time approach for the determination of congestion measures. These congestion measures are delay, Level of Service, average travel time, average travel speed, congestion index, flow rate and density. While performing the analysis the average value recorded on each approach was taken for each intersection.

4.3.1 Traffic Flow Rate, Delay and Level of Service (LOS) Analysis

Using the data collected in the previous section level of service analysis was made. In order to get the right result proper selection was made to make it compatible with Ethiopian driving rule and Highway Capacity Manual 2010 metric version was used. Directional traffic hourly flow data, number of lane, lane width, median width used from field measure for the analysis of level of service are being taken. However default values like saturated flow with the average value of 1200 - 1900 Veh/hr. which is 1550 veh/hr. from table 2.7 have been used as input data for the analysis.

Based on this information and the Highway Capacity Manual 2010 criteria in table 2.7, the LOS of each approach in the intersections and the over all of the level of service is calculated as shown in the following tables below. The flow rate of each intersection reduces in the weekend so that cars are moving smoothly with small amount of traffic delay.

Table 4-3: Average directional traffic volume flow of each approach per day

Intersecti on	Approach	Peak Hour	**Monday-Friday**				**Saturday-Sunday**			
			Queuing	TH	RT	LT	Queuing	TH	RT	LT
St. Stifanos	Bambis	Morning	1377	98	11	6	669	47	6	3
		Mid-Day	1023	72	9	4	490	35	4	2
		Evening	1371	97	11	6	621	44	5	3
	Dembel	Morning	2080	107	5	61	705	36	2	21
		Mid-Day	1577	81	4	46	536	28	1	16
		Evening	2058	106	5	60	715	37	2	21
	Beteme	Morning	1051	53	13	22	395	20	5	8
		Mid-Day	794	40	10	17	325	16	4	7
		Evening	1015	51	13	21	377	19	5	8
	Mes kel	Morning	1328	72	22	17	631	34	11	8
		Mid-Day	981	53	16	12	411	22	7	5

		Evening	1456	79	24	18	582	32	10	7
St. Joseph	Amba	Morning	1218	46	10	46	480	18	4	18
		Mid-Day	876	33	7	33	349	13	3	13
		Evening	1419	53	12	53	568	21	5	21
	Legeha	Morning	1781	117	22	9	988	65	12	5
		Mid-Day	1192	78	15	6	659	43	8	3
		Evening	1776	117	22	9	936	62	12	5
	Saris	Morning	1246	88	10	5	387	27	3	2
		Mid-Day	871	62	7	4	331	23	3	1
		Evening	1484	105	12	6	398	28	3	2
	St.Stifa	Morning	1641	96	27	14	1032	60	17	9
		Mid-Day	1185	69	20	10	618	36	10	5
		Evening	1622	95	27	14	1011	59	17	8

TH =Through, TL = Turn Left, TR =Turn Right

In the first intersection (St.Stifanos) Denbel approach has the highest flow rate (Q) from Monday to Friday, the values are 2080, 1577 and 2058 Veh/hr. respectively in the morning, mid-day as well as in the evening.

These values in the morning and evening are even more than the saturated flow rate considered 1550 veh. /hr. in the second intersection (St. Joseph) Legehar approach has the highest flow rate (Q) from Monday to Friday the values 1781, 1192 and 1776 Veh/hr. respectively in the morning, mid-day and evening which are also higher than the saturated flow rate 1550 veh/hr.

Table 4-4: Average traffic volume flow and cycle time of each approach per day

Intersection	Approach	Peak Hour	**Monday - Friday**						**Saturday - Sunday**					
			Volume (Veh.)	Red (sec)	Green (sec)	Cycle Time	Delay(sec)	LOS	Volume (veh.)	Red (sec)	Green	Cycle Time	Delay (sec)	LOS
St. Stifanos	Bambis	Morning	115	192	75	271	84	F	56	128	35	**166**	49	D
		Mid-Day	85	157	55	214	62	E	41	113	28	144	41	D
		Evening	114	184	76	263	78	E	52	123	34	**160**	46	D
	Denbel	Morning	173	189	108	**301**	98	F	59	120	38	161	44	D
		Mid-Day	131	161	87	**251**	64	E	45	106	31	140	37	D
		Evening	171	186	108	**297**	93	F	60	117	39	159	42	D
	Beteme	Morning	88	207	55	265	84	F	33	132	23	157	52	D
		Mid-Day	66	190	38	231	62	F	27	132	19	**153**	54	D
		Evening	85	202	52	257	83	F	31	133	22	158	52	D

	Meskel	Morning	111	186	72	262	80	F	53	127	34	164	48	D
		Mid-Day	82	165	51	219	69	E	34	118	24	145	43	D
		Evening	121	193	81	277	84	F	48	123	33	159	44	D
St. Joseph	Amba	Morning	101	185	67	255	78	E	40	90	28	121	31	C
		Mid-Day	73	165	43	211	73	E	29	75	20	98	26	C
		Evening	118	195	79	277	85	F	47	95	32	130	33	C
	Legeha	Morning	148	197	98	298	92	F	82	122	54	**179**	43	D
		Mid-Day	99	177	65	245	73	E	55	100	36	**138**	35	C
		Evening	148	200	100	**303**	92	F	78	112	52	166	39	D
	Saris	Morning	104	185	65	**253**	83	F	32	72	23	98	24	C
		Mid-Day	73	162	41	206	75	E	28	68	19	90	23	C
		Evening	124	197	81	281	90	F	33	72	23	98	24	C
	St.Stifa	Morning	137	204	92	**299**	94	F	86	106	62	**171**	35	D
		Mid-Day	99	181	63	247	77	E	51	73	35	111	24	C
		Evening	135	203	92	297	92	F	84	104	56	163	35	D

As shown in the above table 4-4 the cycle time (CT) and the level of service (LOS) vary in the morning, mid-day and evening for each intersection. The highest value of the cycle time for each recording period (morning, mid-day and evening) are highlighted in the table above shown, it is high in the morning and evening. Since the traffic volume flow is different for Monday-Friday and Saturday-Sunday the cycle time and the level of service also becomes different as well.

The amount of delay time in second in each intersection per approach per vehicle is shown in the following graphs. The variation of delay time at both intersections in the weekend and in the first five days is also shown below in figure 4-7 and 4-8 respectively. Accordingly the delay time is nearly constant in the weekend throughout the day but it varies from Monday to Friday in three phase recording time. Based on this, morning and evening peak hours have the lowest level of service “F” value in each approach for both intersections.

Traffic flow in both intersection depends on the highest cycle time, and since the two intersections are inter related each other, this cycle time should be the same to make the traffic flow smooth. So that by taking the average of highest value for the three peaks from the above table 4-4 it will be as follows.

Table 4-5: highest cycle time at both intersections per peak hour

Day of week	Monday- Friday			Saturday and Sunday		
Peak hour	Morning	Mid-Day	Evening	Morning	Mid-Day	Evening
Cycle Time (sec)	300	250	300	165	150	165

Note that, this value of cycle time is the highest value. If the value is more than this the queue length becomes very high, the number of cars at the end of the green phase will be also high.

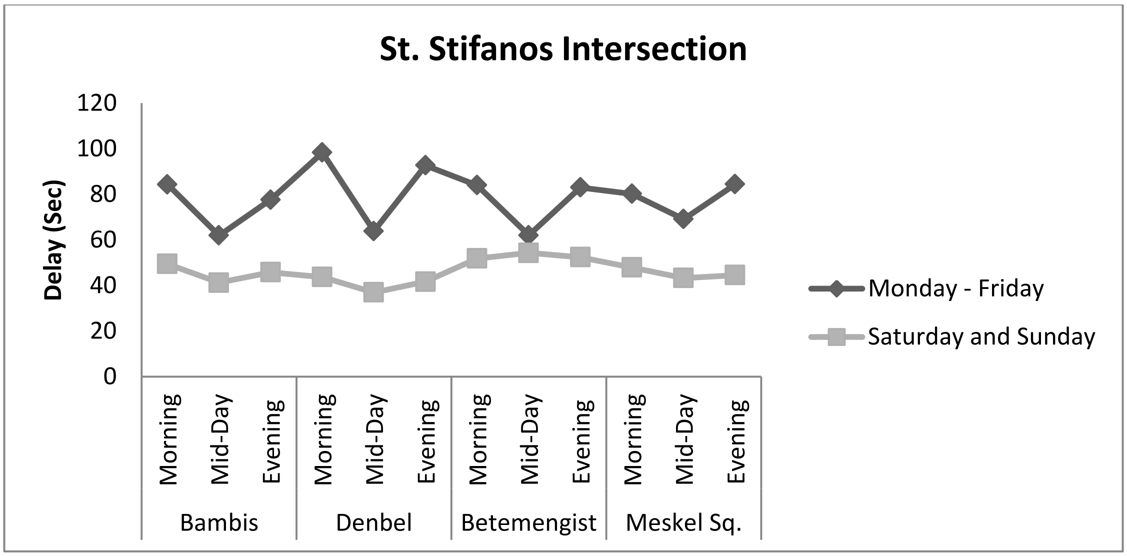

Figure 4-7: Weekly traffic flow delay time at St. Stifanos intersection per approach

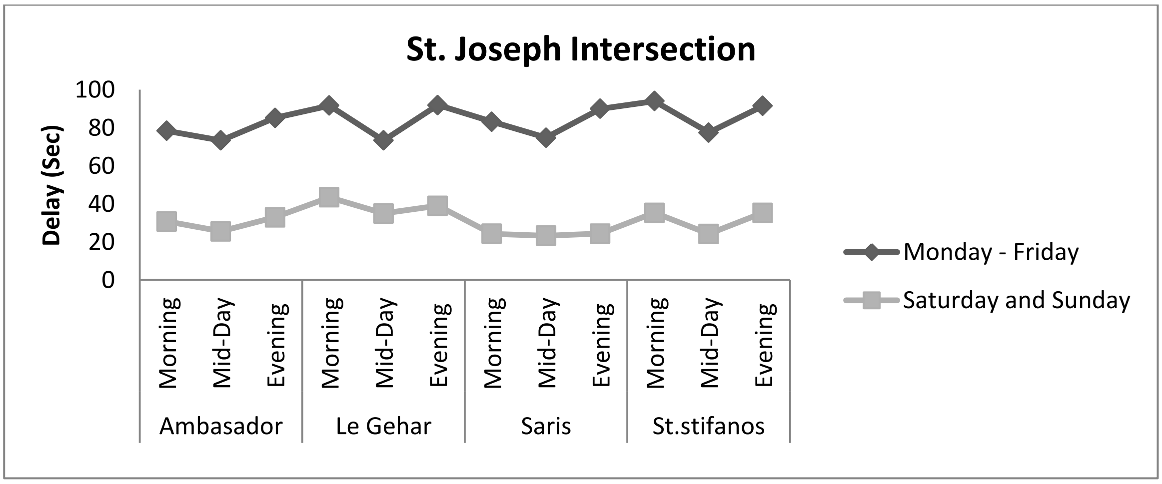

Figure 4-8: Weekly traffic flow delay time at St. Joseph intersection per approach

4.3.2 Average Travel Time

Average travel time at 15 min interval was determined for each approach in both intersections. According to the result shown in the Figure 4-9 and 4-10 below, it shows the morning and evening peak periods recorded has highest travel time and the lowest travel time recorded during mid-day for both intersections.

Denbel approach in the first intersection and both Le Gehar and Stifanos approach in the second intersection takes longer travel time. This tells, these approaches need longer green time percentage from the cycle time than the rest approaches.

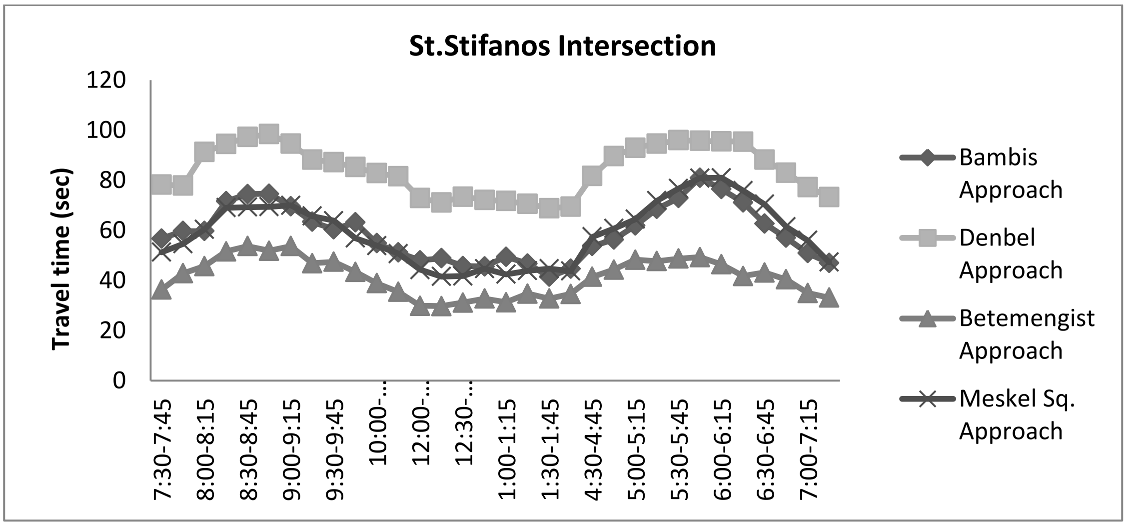

Figure 4-9: Average travel time at St.Stifanos intersection from each approach per day

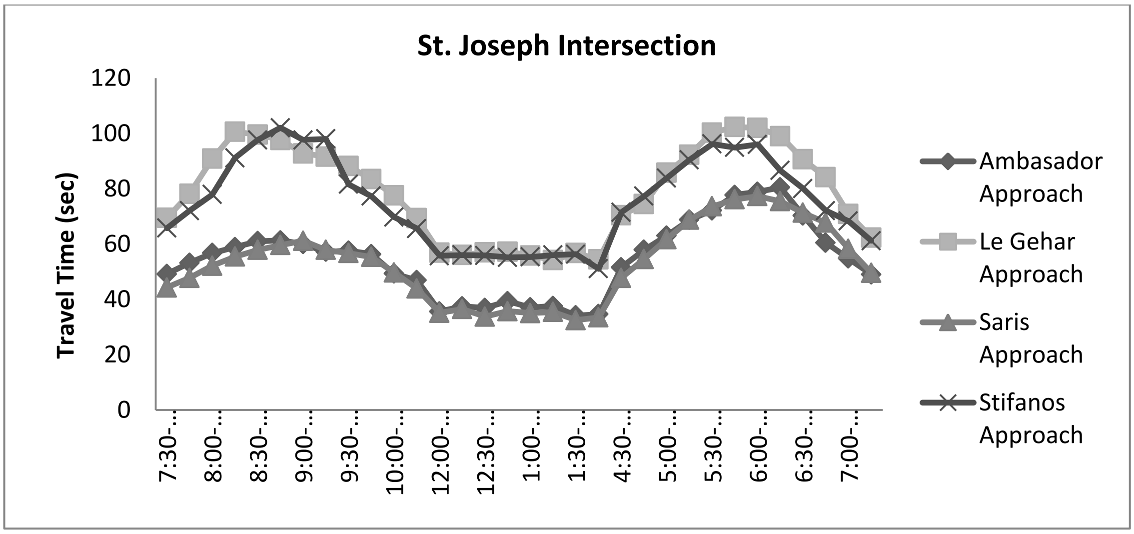

Figure 4-10: Average travel time at St. Joseph intersection from each approach per day

4.3.3 Average Travel Speed

Approaching speed on the selected intersections leg has been performed. This is done for the intersection approaches previously selected based on traffic volume and effective green period. Figure 4-11 and 4-12 below shows average speed distribution throughout the day of recording pick time for all approaches in both intersections. As per the result during morning and evening period the travel speed is lower up to 8 km/hrs. But maximum speed occurs at the midday period.

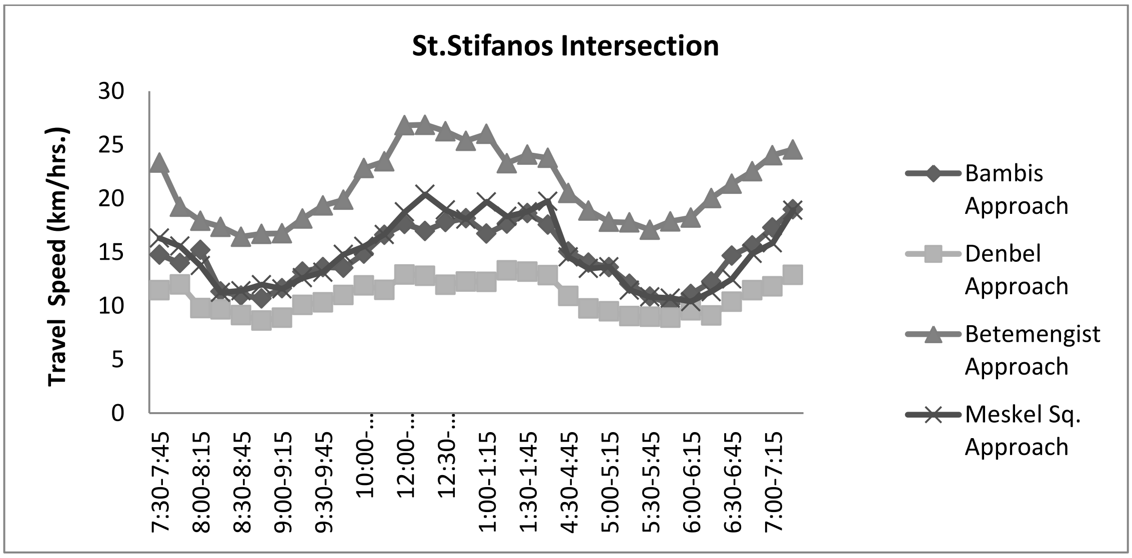

Figure 4-11: Average travel time at St.Stifanos intersection per approach per day

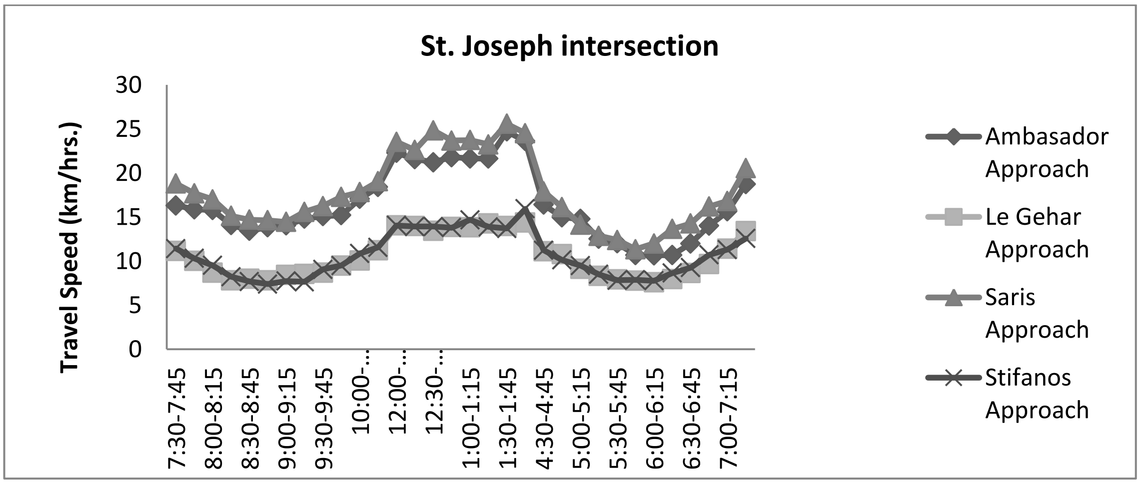

Figure 4-12: Average travel time at St. Joseph intersection from each approach per day

4.3.4 Congestion Index

The congestion index of each approach for both intersections is shown in figure 4-11 and 4-12 below respectively. As discussed in the literature, the index takes values greater than or equal to zero.

A congestion index value of zero means that the actual travel time is equal to the free flow travel time. A value of one means that the actual travel time is twice the free flow travel time (and that the system delay takes up 50% of the total travel time) and a value of more than one indicates the actual travel time is more than twice the free flow travel time and the approach delay takes more than 50% of the total travel time. This percentage of system delay indicates the level of approach congestion and its value is indicated in table 4.6.

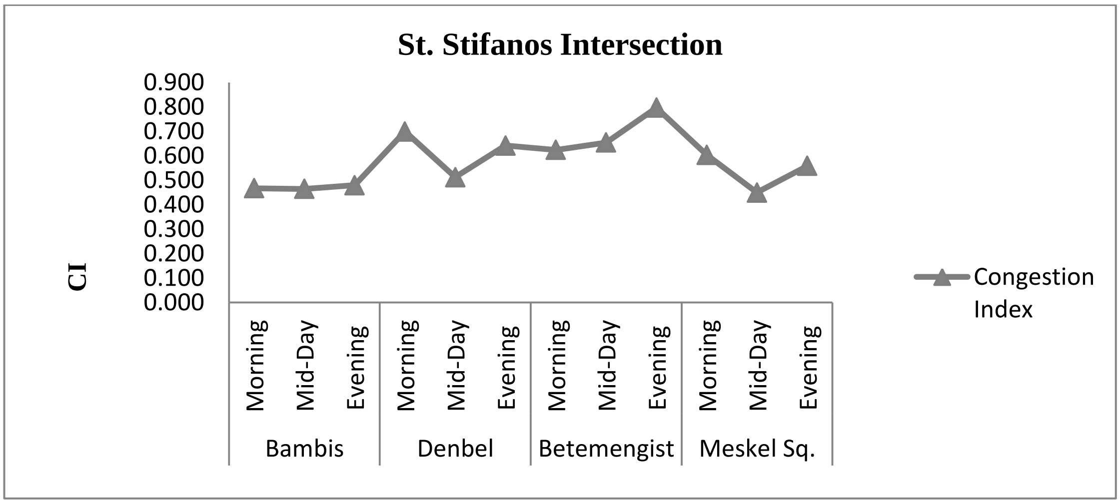

Figure 4-13: Congestion Index at St. Stifanos intersection

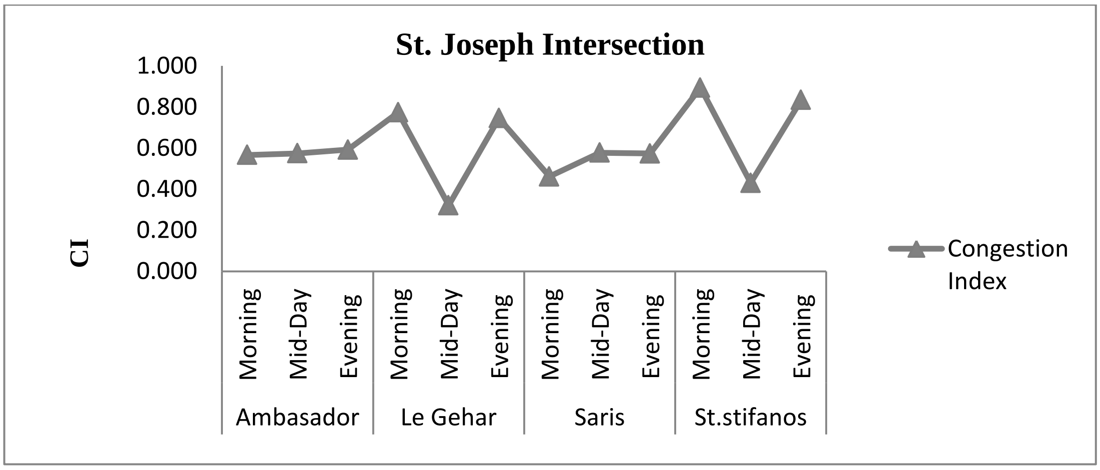

Figure 4-14: Congestion Index at St. Joseph intersection

Table 4-6: Intersection approaching congestion level from each approach

Intersection Name	approach Leg	Congestion Level		
		Morning	Mid-Day	Evening
St. Stifanos	Bambis	23%	23%	24%
	Denbel	35%	26%	38%
	Betemengist	31%	23%	30%
	Meskel Sq.	30%	22%	28%
St. Joseph	Ambassador	28%	29%	30%
	Legehar	39%	16%	37%
	Saris	23%	29%	29%
	St.Stifanos	45%	21%	42%

4.3.5 Capacity and Volume to Capacity Ratio Analysis

The signalized intersections capacity and V/C are well described in the literature. Accordingly, Movements or lane groups with volume-to-capacity ratios less than 0.85 are considered under saturated and typically have sufficient capacity and stable operations. For movements or lane groups with a volume-to-capacity ratio of 0.85 to 1.00, traffic flow becomes less stable due to natural cycle-to-cycle variations in traffic flow. The closer a movement is to capacity; the more likely that a natural fluctuation in traffic flow (higher demand, large truck, timid driver, etc.) may cause the demand during the cycle to exceed the green time for that cycle. These all shows in following table 4-7 for each approach for both intersections. Default values like saturated flow with the average value of 1200 - 1900 veh/hr. which is 1550 veh/hr. from table 2-7 have been used as input data for the analysis inputs of equations 8 and 9. As per the analysis result, the intersection movement in Saturday and Sunday is stable or the traffic demand is under the capacity of the road intersection. But the traffic demand at the morning and evening peak hour from Monday-Friday is unstable in most cases in the approaching leg. Traffic flow is more than the capacity of the road. Thus, a congested traffic flow occurs in this peak period at both intersections.

Table 4-7: Capacity and volume to capacity ratio (V/C) of each approaching leg

Intersection Name	**Approach Leg**	**Peak Hour**	**Monday-Friday**		**Saturday and Sunday**	
			Capacity (veh/h)	Volume to Capacity Ratio	Capacity (veh/h)	Volume to Capacity Ratio
St. Stifanos	Bambis	Morning	144	0.80	108	0.52
		Mid-Day	132	0.65	99	0.41
		Evening	149	0.77	109	0.48
	Denbel	Morning	186	0.93	122	0.48
		Mid-Day	180	0.73	115	0.39
		Evening	188	0.91	128	0.47
	Betemengist	Morning	107	0.82	74	0.44
		Mid-Day	84	0.79	62	0.43
		Evening	104	0.81	72	0.44
	Meskel Sq.	Morning	143	0.78	107	0.49
		Mid-Day	120	0.68	87	0.40
		Evening	151	0.81	107	0.45
St. Joseph	Ambassador	Morning	135	0.75	119	0.34
		Mid-Day	105	0.69	107	0.27
		Evening	147	0.80	126	0.38
	Legehar	Morning	170	0.87	156	0.53
		Mid-Day	137	0.73	133	0.41
		Evening	170	0.87	160	0.49
	Saris	Morning	132	0.78	119	0.27
		Mid-Day	103	0.71	109	0.25
		Evening	148	0.83	120	0.28
	St.Stifanos	Morning	159	0.86	186	0.46
		Mid-Day	132	0.75	161	0.32
		Evening	159	0.85	179	0.47

4.3.6 Traffic Intensity (ρ) Analysis

As discussed in the literature, traffic intensity, ρ (sometimes called occupancy) is defined as the average arrival rate (λ) divided by the average service rate (μ). For a stable system the average service rate should always be higher than the average arrival rate. (Otherwise the queues would rapidly race towards infinity). Thus, ρ should always be less than one so that the flow is stable. The two intersections are examined as per the result of these variables as shown in the figure 4-15 and 4-16 shown below.

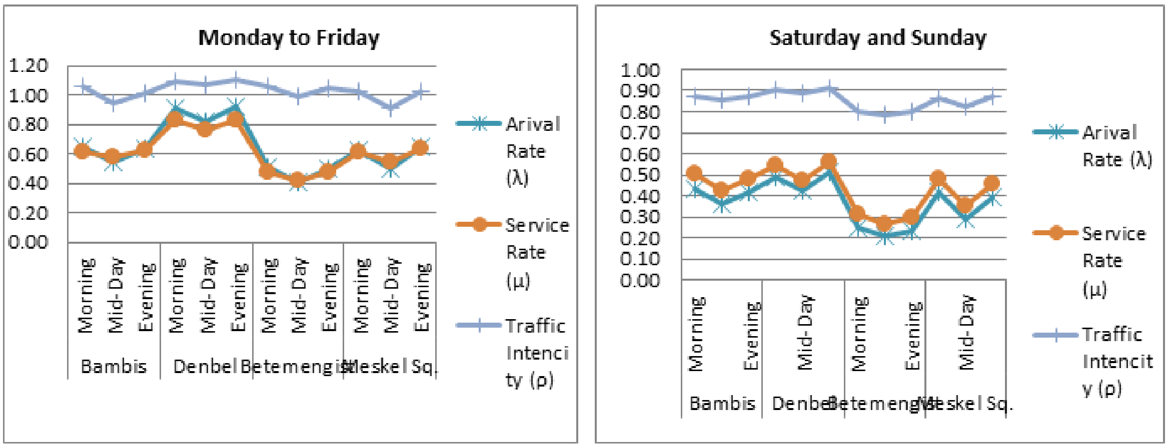

Figure 4-15: Weekly Arrival, service and traffic intensity values at St. Stifanos

As we can see from the figure 4-15 the arrival rate is greater than the service rate almost in all approaches in St.Stifanos intersection in the morning and evening peak time. As a result the value of the traffic intensity (ρ) is greater than one. The number of cars arrive in the first queue will not serve in the first green phase; they keep to the second service time. Thus, flow of traffic from the approaches as well as at the intersection is unstable traffic flow.

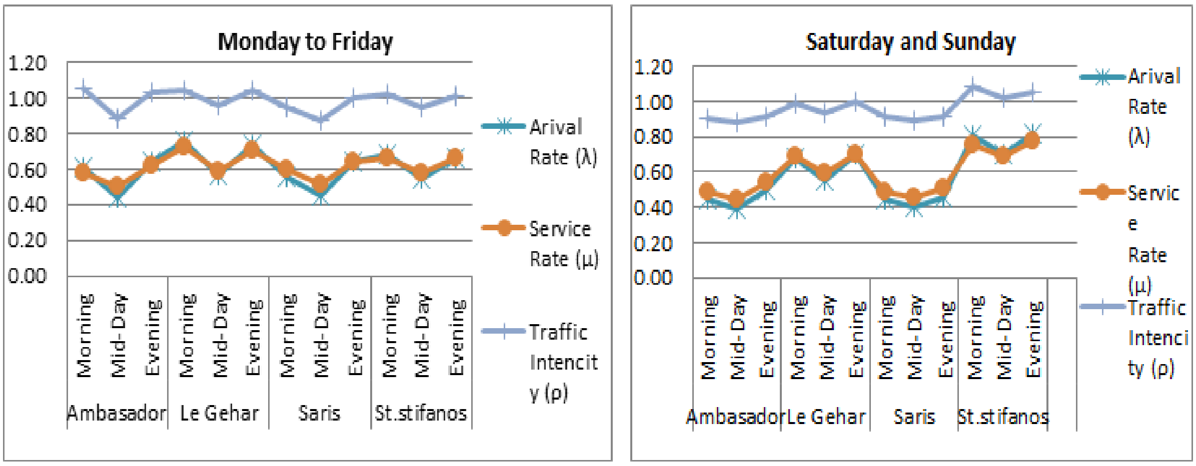

Figure 4-16: weekly Arrival, service and traffic intensity values at St. Joseph

According to the above figure 4-16, similar to St.Stifanos intersection, the arrival rate is greater than the service rate almost in all approaches in St. Joseph intersection in the morning and evening peak time. As a result the value of the traffic intensity (ρ) is greater than one. The number of cars arrive in the first queue will not serve in the first green phase; they keep to the second service time. Thus, flow of traffic from the approaches as well as at the intersection is unstable traffic flow.

In general, as explained in the introduction of this chapter, analysis was made on the gathered quantitative and qualitative data to look into the trend of the traffic flow within the day and identify the peak period and peak hour volumes. Accordingly the selected intersections are in the congested range based on the analysis.

4.4 Intersection Traffic Congestion Mitigation Measures

Traffic congestion causes in the meskel square could be minimized with simple traffic signal management at the pick time. Due to increasing traffic volume and poor signal time phase management, the capacity of these two intersections reduces especially in the morning and evening peak times. To improve the capacity of both intersections, there is one possible solution in this paper work.

One way to increase the capacity of these intersections is taking the highest and equal cycle time in both intersection and reduces this cycle time in the same proportion until the optimum value is found. The effect of this in the congestion measuring parameters will be seen in the rest of this chapter step by step as follows.

4.4.1 Capacity, Delay and LOS Improvements

In this section the previous values of capacity, delay and LOS witch are calculated based on equation (2.4) to (2.7) will be compared with the new one after taking a maximum and equal cycle time in both intersections using the same equation. This comparison is shown in the next table 4-8. As per the analysis result, the capacity of the intersection improved, the delay time reduces in sum amount of seconds and the LOS shifts one step on average towards the preferable level. Thus, the overall stability of the intersections improved but the queuing length increases. As a result the probability of vehicles at the end of the green phase increases and this has its own impact on the second green phase. For this new effect a scenario analysis will be come up with its own solution based on the green cycle time proportion value as shown in table 4.9.

Table 4-8: Capacity, Delay and LOS comparisons of both intersections

		Monday-Friday						Saturday and Sunday					
Appr.	Peak Hour	Capacity		Delay		LOS		Capacity		Delay		LOS	
		Old	New	Old	New	Old	New	Old	New	Old	New	Old	New
Bam.	Morning	144	432	84	65	F	E	108	323	49	37	D	D
	Mid-Day	132	395	62	53	E	D	99	297	41	33	D	C
	Evening	149	447	78	63	E	E	109	326	46	36	D	D
De.	Morning	186	558	98	65	F	E	122	367	44	35	D	C
	Mid-Day	180	539	64	48	E	D	115	344	37	32	D	C
	Evening	188	565	93	62	F	E	128	383	42	34	D	C
Bet.	Morning	107	321	101	75	F	E	74	222	52	40	D	D
	Mid-Day	84	252	100	70	F	E	62	187	54	38	D	D
	Evening	104	313	99	76	F	E	72	215	52	40	D	D
Mes.	Morning	143	428	80	64	F	E	107	320	48	37	D	D
	Mid-Day	120	360	69	56	E	E	87	260	43	35	D	C
	Evening	151	452	84	64	F	E	107	322	44	36	D	D
Amb.	Morning	135	405	78	65	E	E	119	357	31	34	C	C
	Mid-Day	105	316	73	60	E	E	107	322	26	31	C	C
	Evening	147	441	85	65	F	E	126	377	33	33	C	C
Le	Morning	170	511	92	64	F	E	156	468	43	32	D	C
	Mid-Day	137	410	73	55	E	D	133	398	35	30	C	C
	Evening	170	511	92	63	F	E	160	480	39	31	D	C
Sa	Morning	132	397	83	67	F	E	119	358	24	33	C	C
	Mid-Day	103	309	75	61	E	E	109	327	23	31	C	C
	Evening	148	444	90	66	F	E	120	360	24	33	C	C
St.	Morning	159	476	94	66	F	E	186	559	35	28	D	C
	Mid-Day	132	397	77	56	E	E	161	484	24	27	C	C
	Evening	159	477	92	65	F	E	179	537	35	29	D	C

App = Approach, Bam = Bambis, De = Dembel, Bet = Betemengist, Mes = Meskel, Amb = Ambassador, Le = Le Gehar, Sa. = Saris, St = Stifanos

4.4.2 Cycle Time Scenario Analysis

For this scenario analysis, even though all approaches have different red and green time phase, but both intersections has to be the same cycle length so that traffic flow becomes stable in the corridor. This scenario analysis is to find, the optimal cycle length in the intersections so that it reduces the probability of cares at the end of green phase which are not served. To do this, it is considered five scenarios by reducing this cycle time by 10% successively in the first St.Stifanos intersection which is applicable to the second intersection also, the result will be shown in the table 4-9 below.

Table 4-9: Different cycle time scenarios at St.Stifanos intersection

Approach Leg	Peak Hour	Cycle Time				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Bambis	Morning	300	270	240	210	180
	Mid-Day	250	225	200	175	150
	Evening	300	270	240	210	180
Denbel	Morning	300	270	240	210	180
	Mid-Day	250	225	200	175	150
	Evening	300	270	240	210	180
Betemengist	Morning	300	270	240	210	180
	Mid-Day	250	225	200	175	150
	Evening	300	270	240	210	180
Meskel Sq.	Morning	300	270	240	210	180
	Mid-Day	250	225	200	175	150
	Evening	300	270	240	210	180

The above scenario analysis is based on equations (2.5), (2.6), (2.7) and (2.12). Assuming the volume to capacity ratio and the green to cycle time ratio are constant, the delay and LOS values are slightly improved from scenario to scenario in each approaches, and obviously the number of vehicles per one phase and the queue length decreases from scenario 1 to scenario 5. But as the probability of vehicles found at the end of green phase not served decreases whereas the probability of pedestrians at the end of the red phase who are not crossed the road increases. This makes discomfort on the foot travelers, so making balance these two issues is desirable. The trend of the delay and LOS as well as the optimum value of the cycle time in the intersection are shown in the following table 4-10 and figure 4-17 respectively.

Table 4-10: Improved values of delay and LOS from scenario to scenario

App	Peak Hour	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
		Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS
Bam	Morning	65	E	60	E	54	D	49	D	44	D
	Mid-Day	53	D	49	D	44	D	39	D	35	C
	Evening	63	E	58	E	52	D	47	D	41	D
Den	Morning	65	E	60	E	55	E	50	D	46	D
	Mid-Day	48	D	44	D	39	D	35	D	31	C
	Evening	62	E	58	E	53	D	48	D	43	D
Bet	Morning	75	E	69	E	63	E	58	E	52	D
	Mid-Day	70	E	64	E	59	E	54	D	49	D
	Evening	76	E	70	E	64	E	58	E	52	D
Mes	Morning	64	E	59	E	54	D	48	D	43	D
	Mid-Day	56	E	51	D	47	D	42	D	37	D
	Evening	64	E	59	E	54	D	48	D	43	D

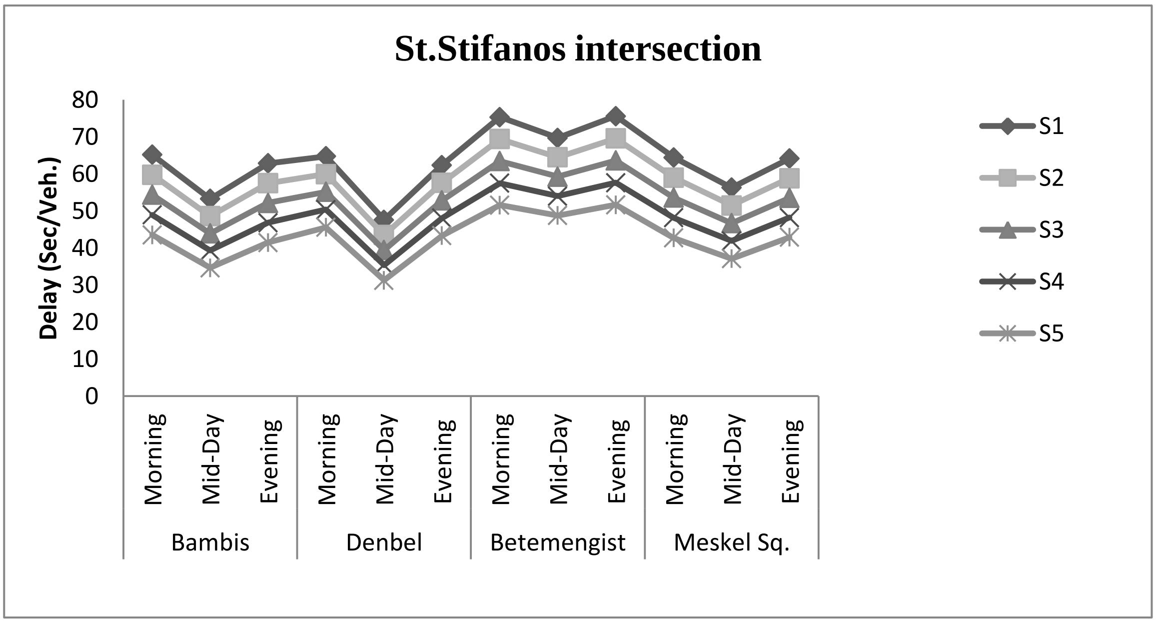

Figure 4-17: Traffic delay value at St. Stifanos intersection for five scenarios

According to the graph above shown, both the drivers and the pedestrians satisfy equally at the medium scenario 3. Thus, the optimum values of cycle time is found in this scenario and as previously discussed this optimum value serves for both intersections from Monday to Friday and from Saturday to Sunday.

Based on this explanation the optimal value of cycle time, red phase, green phase and the amber phase for both intersections is given as summary in table 4-11 and 4-12 below.

Table 4-11: Optimum values time phase at St.Stifanos intersection per peak hour

St.Stifanos Intersection									
		Monday-Friday				**Saturday and Sunday**			
	Approach	C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Morning	Bambis	240	187	50	3	130	104	23	3
	Denbel	240	157	80	3	130	87	40	3
	Betemengis	240	197	40	3	130	107	20	3
	Meskel Sq.	240	179	58	3	130	92	35	3
		Monday-Friday				**Saturday and Sunday**			
	Approach	C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Mid-Day	Bambis	200	157	40	3	120	97	20	3
	Denbel	200	132	65	3	120	82	35	3
	Betemengis	200	162	35	3	120	99	18	3
	Meskel Sq.	200	149	48	3	120	82	35	3
		Monday-Friday				**Saturday and Sunday**			
	Approach	C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Evening	Bambis	240	187	50	3	130	104	23	3
	Denbel	240	157	80	3	130	87	40	3
	Betemengis t	240	197	40	3	130	107	20	3
	Meskel Sq.	240	179	58	3	130	92	35	3

Table 4-12: Optimum values of time phase at St. Joseph intersection per peak hour

St. Joseph Intersection									
	Approach	**Monday-Friday**				**Saturday and Sunday**			
		C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Morning	Ambassador	240	187	50	3	130	104	23	3
	Le Gehar	240	157	80	3	130	87	40	3
	Saris	240	197	40	3	130	107	20	3
	Stifanos	240	179	58	3	130	92	35	3
	Approach	**Monday-Friday**				**Saturday and Sunday**			
		C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Mid-Day	Ambassador	200	157	40	3	120	97	20	3
	Le Gehar	200	132	65	3	120	82	35	3
	Saris	200	162	35	3	120	99	18	3
	Stifanos	200	149	48	3	120	82	35	3
	Approach	**Monday-Friday**				**Saturday and Sunday**			
		C.Time	Red	Green	Amber	C.Time	Red	Green	Amber
Evening	Ambassador	240	187	50	3	130	104	23	3
	Legehar	240	157	80	3	130	87	40	3
	Saris	240	197	40	3	130	107	20	3
	Stifanos	240	179	58	3	130	92	35	3

According to the above two tables, the value of the red and green signal time period is the same for each approaches at both intersections in the morning and evening, because the traffic volume flow is almost similar in the morning and evening peak time. This value is calculated based on scenario 3 shown in table 4-9 above. If the signal time in both intersections is adjusted with the values indicated in table 4-11 and 4-12 the traffic flow becomes stable and the delay time per vehicle decreases as well.

CHAPTER 5 TRAFFIC FLOW MODELING AND SIMULATION

5.1. Introduction

A model can be introduced as a schematic description of a real-world system and theory or phenomenon that accounts for its known or inferred properties used for further study of its characteristics or to predict and evaluate the intrinsic dynamic behavior. The objective of the model that has to be developed in this paper is to quantify the different factor that influences traffic flow in the selected intersections and to suggest improvements as well as to find the optimal traffic signal controlling policy.

Traffic simulation has developed into a productive instrument to encounter the essential needs of transportation modeling and examination. Simulation has the capability in modeling the complex nature of an actual transportation system. By creating a computer model and moving it through time, simulation is generally delineated as the dynamic and powerful representation of the process of the actual world performed. Traffic simulation has proven to be a useful and cost effective approach for providing real time traffic information in support of incident discovery and incident analysis.

In this simulation model, even though there are two main intersections where the data is being recorded at meskel square; one intersection (i.e. St. Stifanos) is taken so that the model will apply for both intersections. St.Stifanos is one of the main intersections with high conflicting flow in Addis Ababa.

5.2. Arena Simulation Model Development

5.2.1. Assumptions

The arrival manner is considered Markovian and independently distributed with respect to the Poisson arrival rate (λ). Where there are multiple lanes regulated by the same traffic light, it is assumed that all the lanes are treated as one, hence it is considered a single server case and no overtaking is allowed. It is also assumed that during the green phase, S_K (k = 1, 2, 3...m) cars can be served, but no queue is allowed ahead of the phase. The initial queue size may or may not be zero at the beginning of the green phase.

A maximum number of cars (Q_{Max}) are allowed at any given green phase without blocking other junctions. We further assume that the light cycle is between red and green, the amber phase is considered to be either part of the red or green phase. The cars leaving the green phase is not constant, but that the green phase (green light duration) is constant and that the traffic light is 100% effective.

5.2.2. Simulation Model

In this paper, discrete event simulation has been applied to provide a simulation model of an isolated traffic intersection using ARENA 14.00 Rockwell Software. The traffic system consists of Bambis, Denbel, Betemengist and meskel streets. Cars crossing the intersection have the options to go straight or turn to either of the side roads as shown in figure 5-1. The intersection traffic light control uses a three phase policy consisting green, amber, and red coding lights. If the light is green, a waiting vehicle can go straight or turn to left or right, depending only on the driver's decision.

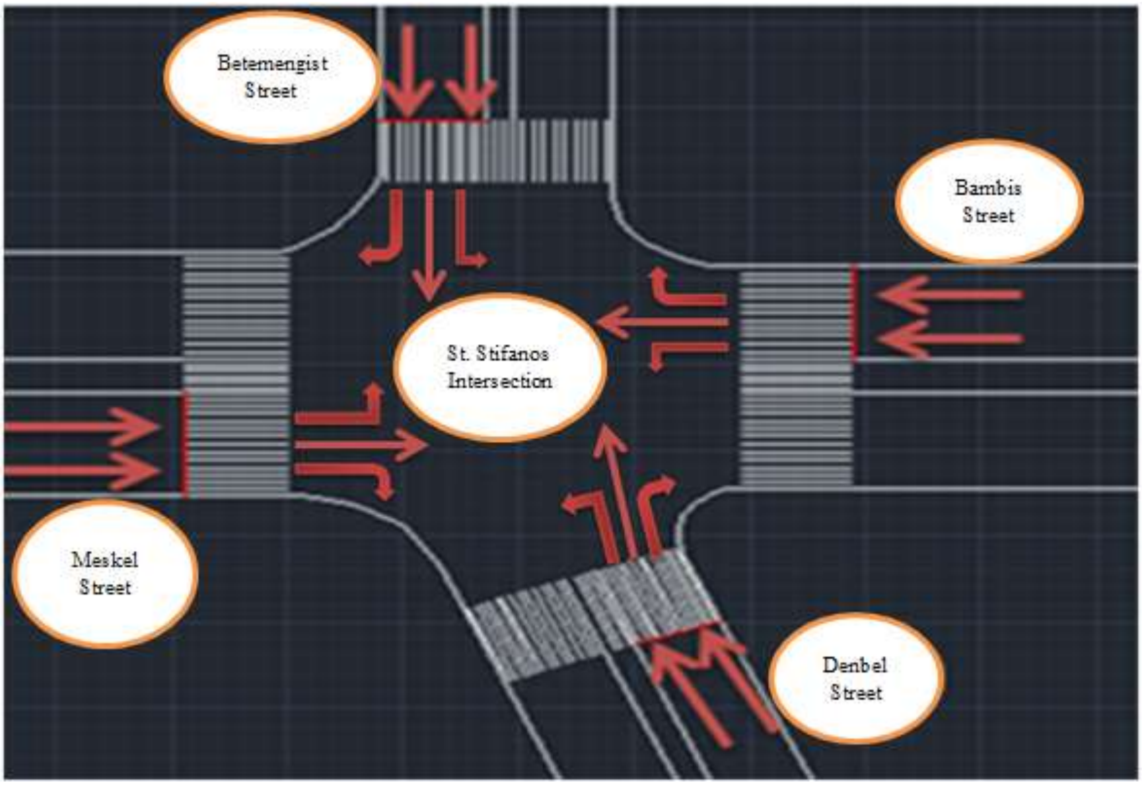

Figure 5-1: Graphical representation of St. Stifanos intersection

The model that is displayed in Figure 5-2 is the basic model of the traffic system. This model is composed of 16 public modules called Create, Process, Decide and Dispose.

The 4 Create modules demonstrating the arrival of the vehicles to the center of intersection from each approach while the other 4 Process modules demonstrate traffic lights, and 4 Decide modules represent branching probabilities of vehicles at the time of leaving the intersection. The other 4 Dispose modules capture cars leaving the traffic system.

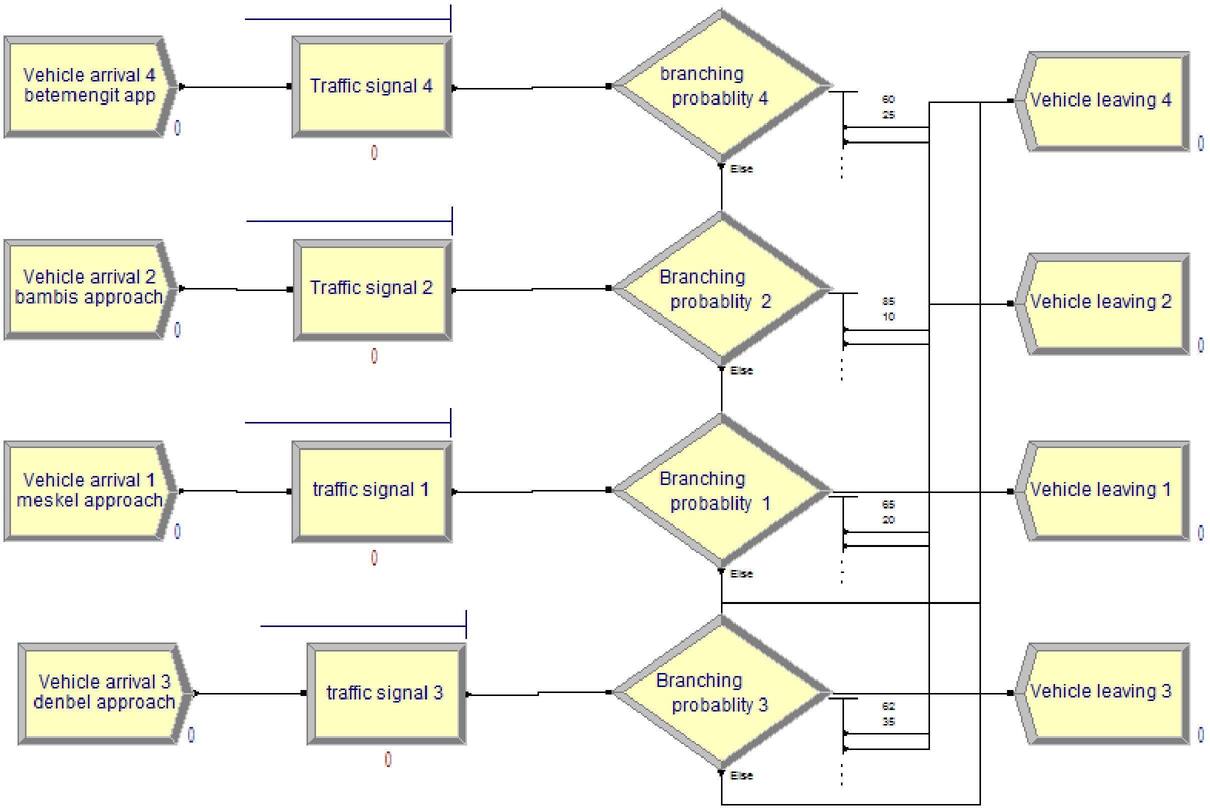

Figure 5-2: Arena simulation model of St.Stifanos intersection

5.2.3. Simulation Results

After the model developed is running for 5 consecutive days 6 hour per day and 10 numbers of replications based on the analysis time phase policy indicated in table 4.10; the following results are derived.

a. Average waiting time of vehicles

Table 5-1 represents the waiting time (in hours) of cars in different queues. For example, incoming vehicles from Denbel and Betemengist Streets should wait for 0.6594 and 0.6568 hour on average behind the traffic light on the 3 hour recording period respectively. This time is 0.6564 and 0.6562 hour for Bambis and Meskel approaches respectively. The minimum and maximum waiting time of vehicles flowing towards the intersection from each approach is also indicated in the same table below for the specified simulation period.

Table 5-1: Waiting time of vehicles at St.Stifanos intersection

Arrival Approach	Waiting Time (hr.) per entities		
	Average	Minimum	Maximum
Meskel Sq.	0.6562	0.00670291	1.5448
Bambis	0.6564	0.00811308	1.5427
Dembel	0.6594	0.00351656	1.5352
Betemengist	0.6568	0.00128333	1.5366

b. Vehicle queue length

Table 5-2 represents the length of different queues of each approach at St.Stifanos intersection. It is easily understandable that the path from Denbel Street has the highest queue length 36 vehicles per lane of the system peak time. It is comparable to the other paths.

Table 5-2: Vehicles queuing length at St.Stifanos intersection

Arrival Approach	Queuing Length		
	Average	Minimum	Maximum
Meskel Sq.	12.7958	0.00	31.0000
Bambis	12.2633	0.00	29.0000
Dembel	14.5566	0.00	36.0000
Betemengist	11.6914	0.00	29.0000

c. Percentage of branching of vehicles

Percentage of turning vehicles is described in Table 5-3. The indicated percentage is the amount of cares coming and leaving the intersection per each street from the total conflicting number. As it can be seen in the table, a total of max value 401 cars can entered to the system in one cycle (red, green and amber) time phase. From this number 338 cars leave straight ahead of the road and the remaining 63 cares leave the system in either said of the road. Thus, the branching percentage is 15.7% per one cycle time in the intersection. Denbel and meskel Streets play the most important role in the actual traffic management system.

Table 5-3: Branching probability of vehicles in St.Stifanos intersection

Approach	Average Number in	Number out Through	Branching Number	Branching percentage
Meskel Sq.	100	84	16	16%
Bambis	96	81	15	15.6%
Dembel	114	96	18	15.8%
Betemengist	91	77	14	15.4%
Total	**401**	**338**	**63**	**15.7%**

5.3. Simulation Scenario Comparison

In order to evaluate the performance of the traffic signal system and the resulting traffic flow, the system should be analyzed under different control time policy as shown in Table 5-4. This scenario represents a timing policy for red and green light code of each traffic signal. These scenarios are defined based on the extensive analysis of the data recorded and the result of the data input analyzer. Ten scenarios are tested in the same simulation model by decreasing the red time phase by 5% and add the decrement in to the green phase considering the amber phase as a part of the green phase at a constant cycle time of 240 second as shown below.

Table 5-4: traffic signal phase scenario analysis at St. Stifanos intersection

Approach	**phase**	**Scenarios**									
		1	2	3	4	5	6	7	8	9	10
Meskel	Red	179	170	162	153	146	139	132	125	119	113
	Green	58	67	75	84	91	98	105	112	118	124
Bambis	Red	187	178	169	160	152	145	137	131	124	118
	Green	50	59	68	77	85	92	100	106	113	119
Dembel	Red	157	149	142	135	128	121	115	110	104	99
	Green	80	88	95	102	109	116	122	127	133	138
Betemen	Red	197	187	178	169	160	152	145	138	131	124
	Green	40	50	59	68	77	85	92	99	106	113

The model developed is now running for this ten scenario red and green time phases. As per the result, the system performance differs slightly under each scenario. For example, if the timing policy number 8 is applied, the length of the queue in Meskel Street reaches 36 cars in average per lane, while it will be 34, 40 and 32 vehicles in the queue for Bambis, Denbel and Betemengist Streets respectively.

Table 5-5: Operational scenario queuing length at St. Stifanos intersection

	Approaches			
Scenario	Meskel Sq.	Bambis	Dembel	Betemengist
1	31	29	36	29
2	33	31	32	30
3	30	28	35	32
4	36	34	41	32
5	36	35	41	33
6	36	35	40	33
7	35	34	39	33
8	36	34	40	32
9	35	33	39	32
10	33	30	36	30

Fig. 5-3 below shows that the system has a generally better performance if the timing policy 3 is applied. That is, the length of queue in the whole system reaches the lowest value. At this traffic controlling policy the performance of the system is approaching to the optimal value.

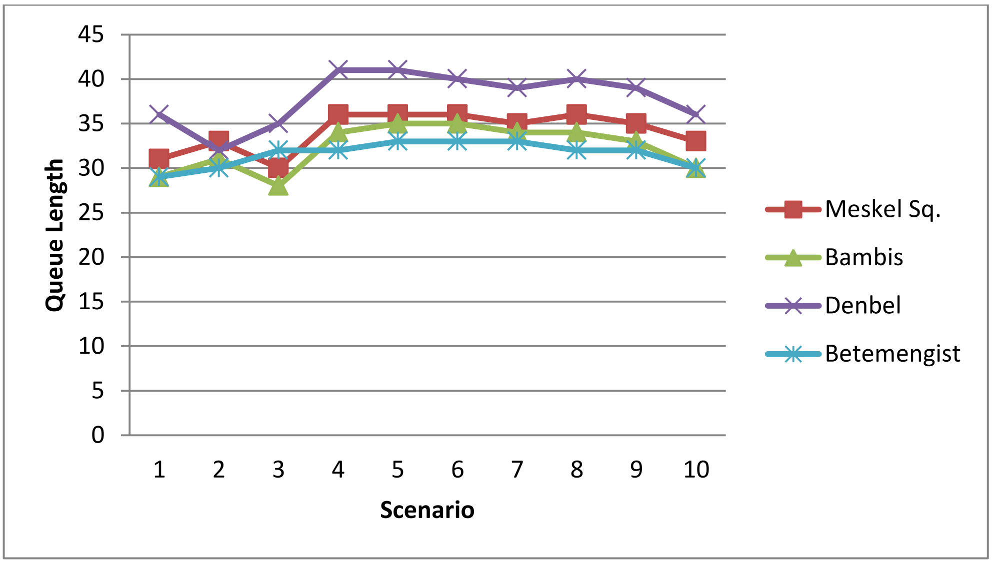

Figure 5-3: Intersection performance under difference scenarios analysis

The number flow in and out of vehicles across each street is shown in figure 5-4. It increases from scenario to scenario. But the performance of the system is better at the third scenario as indicated in figure 5.3.

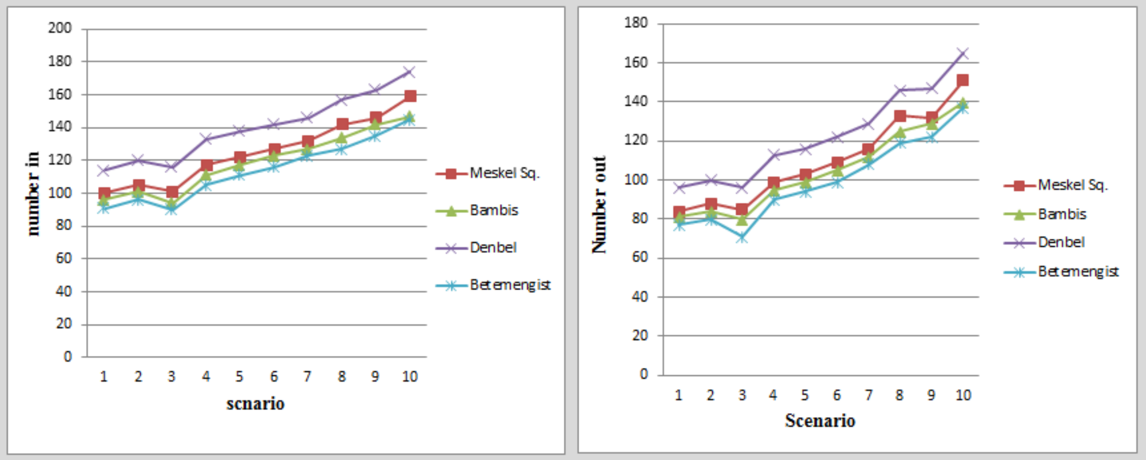

Figure 5-4: Operational scenarios of traffic flow in and out to the system

Based on the above scenario comparisons, the optimal traffic signal control time policy at St.Stifanos intersection is scenario 3. Thus, the optimal traffic signal timing phase control policies at this scenario are: (162 seconds red, 75 seconds green) to Meskel street, (169 seconds red, 68 seconds green) to Bambis street, (142 seconds red, 95 seconds green) to Denbel street and (178 seconds red, 59 seconds green) to Betemengist street at the morning and evening peak time. In general this model can be used as a basis for the analysis of different control policies such as in high and low traffic volume flow periods.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Intersection signal traffic control system is a very complex process in its adjustment. After comprehensive literature review related to road traffic flow problems, the research focuses on traffic congestion analysis and then develop traffic simulation model at Meskel Square intersections. The research first evaluated the current level of traffic congestion, and then develops Arena simulation model that could improve the current level of traffic congestion at the corridor based on the data recorded.

From the findings of the study it can be concluded that the current level of traffic flow at Meskel Square signalized control intersections, as compared with the Highway Capacity Manual standards, are relatively low in most of the traffic congestion measuring parameters, especially, during the morning and evening peaks. This is mainly due to poor traffic management and traffic signal phase adjustment problems, which is fixed the whole day without considering the variability of vehicles flow, in the corridor.

As per the analysis result shows the Level of Service of both intersections lays on “F” which is the lowest category based on the Highway Capacity Manual standards in the morning and evening peak times. This shows there is high traffic congestion and long traffic delay at Meskel Square intersections in the morning and evening peak hours. After various scenario analysis is tested on the signal time controlling phase the level of serves shifts from “F” to “D” in almost all approaches of the intersections, as a result the time delay and the queuing length improves.

After running the model developed using ARENA 14.00 version software for 10 different scenario time policy, the best controlling time phase was found at scenario 3. These values are (162 seconds red, 75 seconds green) to Meskel Street, (169 seconds red, 68 seconds green) to Bambis street, (142 seconds red, 95 seconds green) to Denbel Street and (178 seconds red, 59 seconds green) to Betemengist Street. At this scenario the waiting time and queue length per entity across each street reaches minimum value.

6.2. Recommendations

Intersection traffic signal managements are a very complex and conflicting decision making condition because you need to consider all the directional movements (i.e. vehicles and pedestrians movements) attempting to the road. Within such a complex decision making condition the Addis Ababa Road Traffic Management Office tries to install traffic signal systems in most intersections of our capital. As findings of this research work shows however, there is a problem in adjusting the green and red cycle phases. The issue still needs to go beyond in improving time management policies. Therefore, based on the major findings of this research work, the following major recommendations are forwarded to Addis Ababa Road Traffic Management Office.

1. Vehicles leaving St.Stifanos intersection at the green phase are accumulated to serve in the second St. Joseph intersection and vice versa. Thus, the two intersections are interrelated. Also traffic volume flow and cycle time record data are almost the same in both intersections on average. Therefore, to reduce the long vehicle queuing and time delay as well as to overcome the conflicting level the cycle time (i.e. the sum of red, green and amber time phase) at both intersections is recommended to be adjusted to the same value.
2. As per the analysis of the data, the congestion level at the morning, mid-day and evening is too different, long vehicle queuing occurs in the morning and evening peak time. Thus, it is recommended to have three different fixed cycle time policies (i.e. at morning, mid-day and evening) rather than fixing the whole day the same value.
3. Even though the Addis Ababa Road Traffic Management Office tries to install many traffic signals at major intersections, the installation is not based on scientific research. Thus, it is recommended to install traffic signals based on scientific evidences.

6.3. Future research work

When the light turns green, and cars depart from the queue, the study has shown that the number of cars leaving the service point is not necessarily constant. Observation shows, however, that the nature and type of vehicles (for example, it takes a longer time for a truck vehicle to leave the queue compared to a car) are a factor in determining the number of vehicles that can leave the queue at the turn of the green phase. Motor bikes also struggle to receive service at the start of green phase. When the light turns red, pedestrians start to cross the road. The study shows that, one of the best traffic control policies could be an increase in the length of green time phase. But as we increase the green time in the same cycle length what could happen to the probability of the pedestrians crossing the road at the red time phase? Incorporating these into the model assumptions can be an interesting formulation in future research work.

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APPENDICES

APPENDIX A

Complete Traffic Volume and Signal Time Record Tables

Table A1: Traffic Volume and Signal Time recorded at St.Stifanos intersection from Bambis Approach.

Intersection: St.Stifanos Approach: Bambis , Number of Lane: 3 Arrival Distance: 200 m, Lane Width: 4 m					Monday: March/13/2017			Tuesday: March/14/2017			Wednesday: March/15/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	209	60	3	94	186	71	84	178	68	84	192	68
	7:45-8:00	209	60	3	101	193	82	83	190	67	90	187	73
	8:00-8:15	209	60	3	109	203	87	82	202	68	92	206	75
	8:15-8:30	209	60	3	121	216	95	96	212	78	90	196	72
	8:30-8:45	209	60	3	130	211	105	104	209	88	81	204	69
	8:45-9:00	209	60	3	122	212	109	121	204	99	81	194	67
	9:00-9:15	209	60	3	125	208	99	103	218	84	84	210	66
	9:15-9:30	209	60	3	120	216	102	84	216	67	85	189	68
	9:30-9:45	209	60	3	117	187	98	76	192	57	85	182	67
	9:45-10:00	209	60	3	121	172	105	82	172	65	80	198	65
	10:00-10:15	209	60	3	96	168	75	66	158	51	84	200	63
	10:15-10:30	209	60	3	92	163	72	68	160	54	72	189	57
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	209	60	3	80	140	68	52	140	43	73	185	68
	12:15-12:30	209	60	3	87	128	72	61	128	44	76	178	64
	12:30-12:45	209	60	3	84	117	69	53	117	40	68	187	57
	12:45-1:00	209	60	3	81	132	65	58	132	39	84	190	61
	1:00-1:15	209	60	3	72	128	57	57	128	56	92	200	72
	1:15-1:30	209	60	3	63	108	38	64	112	54	81	201	67
	1:30-1:45	209	60	3	65	141	43	53	137	42	67	202	49
	1:45-2:00	209	60	3	61	126	49	50	136	37	83	196	68
After noon (4:30 - 7:30) pm	4:30-4:45	209	60	3	68	167	58	68	167	47	92	203	78
	4:45-5:00	209	60	3	69	172	56	79	172	61	90	200	74
	5:00-5:15	209	60	3	98	180	78	89	180	78	85	186	67
	5:15-5:30	209	60	3	116	192	98	94	192	77	92	202	77
	5:30-5:45	209	60	3	131	208	87	105	208	87	91	204	76
	5:45-6:00	209	60	3	128	216	123	111	204	88	94	206	79
	6:00-6:15	209	60	3	112	184	112	114	206	94	95	207	72
	6:15-6:30	209	60	3	96	175	109	106	195	88	89	196	62
	6:30-6:45	209	60	3	86	143	64	104	163	84	77	176	64
	6:45-7:00	209	60	3	67	152	53	101	154	85	86	187	67
	7:00-7:15	209	60	3	54	138	43	93	148	78	75	168	60
	7:15-7:30	209	60	3	49	124	37	88	128	67	81	170	64
Total Value					3015	5406	2479	2649	5458	2135	2679	6191	2156

R.T = Record Time

Table A1: Continued

Intersection: St.Stifanos Approach: Bambis , Number of Lane: 3 Arrival Distance: 200 m, Lane Width: 4 m					Thursday: March/16/2017			Friday: March/17/2017		
Pik Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	209	60	3	67	176	69	79	165	63
	7:45-8:00	209	60	3	79	187	65	80	173	69
	8:00-8:15	209	60	3	85	206	68	83	187	68
	8:15-8:30	209	60	3	116	214	99	91	195	76
	8:30-8:45	209	60	3	104	204	87	105	198	88
	8:45-9:00	209	60	3	89	194	75	96	194	81
	9:00-9:15	209	60	3	93	210	78	97	197	79
	9:15-9:30	209	60	3	87	189	73	81	184	67
	9:30-9:45	209	60	3	84	182	69	81	182	65
	9:45-10:00	209	60	3	92	198	74	84	185	70
	10:00-10:15	209	60	3	88	178	67	79	178	67
	10:15-10:30	209	60	3	83	173	65	71	173	59
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	209	60	3	64	175	51	67	165	56
	12:15-12:30	209	60	3	65	168	53	62	168	55
	12:30-12:45	209	60	3	82	180	54	61	167	47
	12:45-1:00	209	60	3	75	165	50	61	165	52
	1:00-1:15	209	60	3	71	159	60	59	159	48
	1:15-1:30	209	60	3	78	175	63	64	165	53
	1:30-1:45	209	60	3	64	164	54	61	159	48
	1:45-2:00	209	60	3	65	167	53	55	156	47
After noon (4:30 - 7:30) pm	4:30-4:45	209	60	3	75	178	63	80	187	68
	4:45-5:00	209	60	3	70	168	64	88	189	71
	5:00-5:15	209	60	3	72	173	69	99	198	78
	5:15-5:30	209	60	3	78	186	65	108	197	88
	5:30-5:45	209	60	3	109	204	94	95	192	79
	5:45-6:00	209	60	3	122	213	103	100	202	86
	6:00-6:15	209	60	3	113	208	97	95	198	81
	6:15-6:30	209	60	3	110	207	93	94	190	78
	6:30-6:45	209	60	3	116	208	98	88	182	76
	6:45-7:00	209	60	3	98	193	78	77	176	64
	7:00-7:15	209	60	3	80	184	68	71	170	58
	7:15-7:30	209	60	3	75	173	60	68	167	56
Total Value					2749	5959	2279	2580	5763	2141

R.T = Record Time

Table A1: Continued

Intersection: St.Stifanos Approach: Bambis , Number of Lane: 3 Arrival Distance: 200 m, Lane Width: 4 m					**Saturday: March/18/2017**			**Sunday: March/19/2017**		
Pik Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	129	30	3	42	125	32	36	122	26
	7:45-8:00	129	30	3	44	130	34	38	126	28
	8:00-8:15	129	30	3	41	128	30	48	128	22
	8:15-8:30	129	30	3	51	131	38	61	131	43
	8:30-8:45	129	30	3	61	132	47	58	130	37
	8:45-9:00	129	30	3	60	131	45	61	134	46
	9:00-9:15	129	30	3	60	129	46	58	131	35
	9:15-9:30	129	30	3	51	123	36	45	121	31
	9:30-9:45	129	30	3	49	132	33	48	126	34
	9:45-10:00	129	30	3	43	126	31	43	126	32
	10:00-10:15	129	30	3	41	124	32	39	120	29
	10:15-10:30	129	30	3	39	129	23	38	118	28
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	129	30	3	31	109	22	35	109	28
	12:15-12:30	129	30	3	29	105	23	42	112	31
	12:30-12:45	129	30	3	32	106	24	38	106	29
	12:45-1:00	129	30	3	26	110	21	40	110	31
	1:00-1:15	129	30	3	31	111	25	40	123	28
	1:15-1:30	129	30	3	32	113	25	40	121	27
	1:30-1:45	129	30	3	33	114	26	37	117	28
	1:45-2:00	129	30	3	32	115	27	41	121	32
After noon (4:30 - 7:30) pm	4:30-4:45	129	30	3	42	123	31	43	123	31
	4:45-5:00	129	30	3	46	124	34	46	124	34
	5:00-5:15	129	30	3	38	120	28	56	131	35
	5:15-5:30	129	30	3	44	128	33	57	130	42
	5:30-5:45	129	30	3	61	134	44	58	134	43
	5:45-6:00	129	30	3	60	130	42	62	134	46
	6:00-6:15	129	30	3	52	127	34	58	123	45
	6:15-6:30	129	30	3	51	123	33	45	116	35
	6:30-6:45	129	30	3	31	116	24	38	111	29
	6:45-7:00	129	30	3	29	127	23	35	108	29
	7:00-7:15	129	30	3	25	115	21	38	115	28
	7:15-7:30	129	30	3	21	112	18	35	111	27
Total Value					1328	3902	985	1457	3892	1049

R.T = Record Time

Table A2: Traffic Volume and Signal Time recorded at St.Stifanos intersection from Denbel Approach.

Intersection: St.Stifanos Approach: Denbel , Number of Lane: 4 Arrival Distance: 250 m, Lane Width: 4 m					Monday: March/13/2017			Tuesday: March/14/2017			Wednesday: March/15/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	179	90	3	104	190	85	107	178	93	113	181	96
	7:45-8:00	179	90	3	106	188	83	120	176	98	120	192	98
	8:00-8:15	179	90	3	119	184	98	135	182	103	166	202	121
	8:15-8:30	179	90	3	124	186	105	152	176	113	168	204	118
	8:30-8:45	179	90	3	139	187	115	152	178	114	167	200	126
	8:45-9:00	179	90	3	155	191	116	147	181	106	154	196	124
	9:00-9:15	179	90	3	148	188	106	131	180	99	154	194	120
	9:15-9:30	179	90	3	145	191	102	121	175	95	152	191	115
	9:30-9:45	179	90	3	126	194	98	125	178	97	139	186	117
	9:45-10:00	179	90	3	121	196	96	114	182	89	140	182	113
	10:00-10:15	179	90	3	117	194	98	105	180	86	127	178	108
	10:15-10:30	179	90	3	111	192	93	99	167	83	130	181	110
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	179	90	3	78	156	67	88	161	72	123	175	106
	12:15-12:30	179	90	3	85	148	68	94	157	78	118	178	99
	12:30-12:45	179	90	3	87	148	73	94	166	81	129	174	100
	12:45-1:00	179	90	3	92	165	76	89	163	74	125	177	95
	1:00-1:15	179	90	3	92	153	74	94	156	72	112	169	93
	1:15-1:30	179	90	3	100	168	84	82	148	70	114	165	98
	1:30-1:45	179	90	3	95	158	75	84	155	69	106	163	88
	1:45-2:00	179	90	3	92	171	73	72	168	67	109	169	91
After noon (4:30 - 7:30) pm	4:30-4:45	179	90	3	126	176	94	97	175	85	134	179	110
	4:45-5:00	179	90	3	136	188	107	105	179	91	143	176	114
	5:00-5:15	179	90	3	149	198	113	123	177	98	142	182	112
	5:15-5:30	179	90	3	151	196	115	132	182	108	127	174	108
	5:30-5:45	179	90	3	142	188	109	155	192	116	134	183	111
	5:45-6:00	179	90	3	128	190	103	161	196	121	137	187	113
	6:00-6:15	179	90	3	128	183	100	157	189	118	162	206	123
	6:15-6:30	179	90	3	123	178	99	162	188	112	165	212	125
	6:30-6:45	179	90	3	118	181	98	142	184	110	129	189	107
	6:45-7:00	179	90	3	112	175	93	115	174	94	139	194	112
	7:00-7:15	179	90	3	113	164	88	106	176	92	112	186	99
	7:15-7:30	179	90	3	108	157	83	97	163	86	103	179	89
Total Value					3770	5722	2987	3757	5582	2990	4293	5904	3459

R.T = Record Time

Table A2: Continued

Intersection: St.Stifanos **Approach: Denbel , Number of Lane: 4** **Arrival Distance: 250 m, Lane Width: 4 m**					**Thursday: March/16/2017**			**Friday: March/17/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	179	90	3	115	179	98	124	179	108
	7:45-8:00	179	90	3	118	181	97	131	185	107
	8:00-8:15	179	90	3	161	208	121	147	194	116
	8:15-8:30	179	90	3	148	201	118	170	207	128
	8:30-8:45	179	90	3	152	206	116	166	204	123
	8:45-9:00	179	90	3	176	214	126	162	196	120
	9:00-9:15	179	90	3	160	210	128	154	191	113
	9:15-9:30	179	90	3	148	198	111	159	194	117
	9:30-9:45	179	90	3	141	193	110	155	189	113
	9:45-10:00	179	90	3	149	197	113	166	197	118
	10:00-10:15	179	90	3	139	182	117	147	183	111
	10:15-10:30	179	90	3	134	182	110	137	178	109
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	179	90	3	125	165	108	120	164	98
	12:15-12:30	179	90	3	127	162	107	99	148	85
	12:30-12:45	179	90	3	119	153	98	109	153	94
	12:45-1:00	179	90	3	104	149	96	125	169	99
	1:00-1:15	179	90	3	112	152	98	114	158	98
	1:15-1:30	179	90	3	111	150	93	112	160	93
	1:30-1:45	179	90	3	120	153	95	116	162	96
	1:45-2:00	179	90	3	110	146	94	122	172	99
After noon (4:30 - 7:30) pm	4:30-4:45	179	90	3	118	157	98	134	185	113
	4:45-5:00	179	90	3	128	167	110	150	192	121
	5:00-5:15	179	90	3	153	196	121	168	195	123
	5:15-5:30	179	90	3	164	201	123	163	195	117
	5:30-5:45	179	90	3	163	204	118	170	212	127
	5:45-6:00	179	90	3	149	196	116	168	208	124
	6:00-6:15	179	90	3	155	197	122	173	215	125
	6:15-6:30	179	90	3	162	204	125	164	203	118
	6:30-6:45	179	90	3	140	189	116	152	194	113
	6:45-7:00	179	90	3	120	179	108	140	183	110
	7:00-7:15	179	90	3	118	176	99	128	168	98
	7:15-7:30	179	90	3	111	168	102	125	165	96
Total Value					4350	5815	3512	4570	5898	3530

R.T = Record Time

Table A2: Continued

Intersection: St.Stifanos **Approach: Denbel , Number of Lane: 4** **Arrival Distance: 250 m, Lane Width: 4 m**					**Saturday: March/18/2017**			**Sunday: March/19/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	109	50	3	47	120	35	41	116	33
	7:45-8:00	109	50	3	41	121	32	38	112	30
	8:00-8:15	109	50	3	51	123	38	51	123	42
	8:15-8:30	109	50	3	63	123	42	49	120	37
	8:30-8:45	109	50	3	59	123	39	62	124	48
	8:45-9:00	109	50	3	60	127	46	69	128	51
	9:00-9:15	109	50	3	57	121	44	69	126	52
	9:15-9:30	109	50	3	52	119	40	59	121	38
	9:30-9:45	109	50	3	50	121	38	53	118	37
	9:45-10:00	109	50	3	45	120	37	49	115	31
	10:00-10:15	109	50	3	44	117	32	42	114	28
	10:15-10:30	109	50	3	35	114	29	40	116	37
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	109	50	3	36	104	31	36	109	28
	12:15-12:30	109	50	3	38	103	32	38	111	29
	12:30-12:45	109	50	3	48	100	37	39	110	31
	12:45-1:00	109	50	3	39	98	33	38	108	32
	1:00-1:15	109	50	3	46	109	37	37	106	30
	1:15-1:30	109	50	3	39	103	29	37	104	27
	1:30-1:45	109	50	3	38	110	31	36	107	28
	1:45-2:00	109	50	3	40	109	31	37	105	31
After noon (4:30 - 7:30) pm	4:30-4:45	109	50	3	53	112	38	43	111	34
	4:45-5:00	109	50	3	53	113	47	45	121	37
	5:00-5:15	109	50	3	58	114	45	50	123	39
	5:15-5:30	109	50	3	68	128	46	62	118	45
	5:30-5:45	109	50	3	65	125	43	68	116	48
	5:45-6:00	109	50	3	63	118	46	67	118	47
	6:00-6:15	109	50	3	44	117	35	62	116	46
	6:15-6:30	109	50	3	53	123	44	62	115	45
	6:30-6:45	109	50	3	43	118	33	54	117	41
	6:45-7:00	109	50	3	40	109	30	44	123	34
	7:00-7:15	109	50	3	43	119	36	36	114	29
	7:15-7:30	109	50	3	32	105	29	35	110	28
Total Value					1543	3686	1185	1548	3695	1173

R.T = Record Time

Table A3: Traffic Volume and Signal Time recorded at St.Stifanos intersection from Betemengist Approach.

Intersection: St.Stifanos Approach: Betemengist, Number of Lane: 3 Arrival Distance: 150 m, Lane Width: 4 m					Monday: March/13/2017			Tuesday: March/14/2017			Wednesday: March/15/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	219	50	3	51	186	39	54	198	46	69	209	56
	7:45-8:00	219	50	3	75	197	58	75	205	58	71	213	58
	8:00-8:15	219	50	3	88	219	69	85	218	49	79	218	62
	8:15-8:30	219	50	3	84	217	63	92	223	75	80	219	65
	8:30-8:45	219	50	3	81	223	67	93	217	76	85	221	67
	8:45-9:00	219	50	3	84	222	68	84	213	70	77	217	58
	9:00-9:15	219	50	3	90	221	79	72	209	58	71	208	51
	9:15-9:30	219	50	3	84	219	70	64	206	47	65	198	48
	9:30-9:45	219	50	3	86	219	71	55	200	42	57	187	46
	9:45-10:00	219	50	3	80	219	68	57	210	47	52	186	39
	10:00-10:15	219	50	3	61	216	48	57	212	47	45	179	34
	10:15-10:30	219	50	3	53	221	45	55	198	43	43	178	34
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	219	50	3	45	206	36	40	186	31	47	183	35
	12:15-12:30	219	50	3	43	210	33	41	196	30	52	190	37
	12:30-12:45	219	50	3	54	197	37	51	197	34	47	182	31
	12:45-1:00	219	50	3	57	198	38	49	189	37	54	184	32
	1:00-1:15	219	50	3	51	203	34	52	199	39	47	175	30
	1:15-1:30	219	50	3	51	199	37	58	201	42	57	185	42
	1:30-1:45	219	50	3	50	205	33	48	190	33	51	182	38
	1:45-2:00	219	50	3	51	196	37	51	206	37	61	197	52
After noon (4:30 - 7:30) pm	4:30-4:45	219	50	3	62	217	53	67	214	51	71	203	57
	4:45-5:00	219	50	3	62	218	52	71	219	57	72	206	59
	5:00-5:15	219	50	3	77	219	59	81	221	68	76	211	62
	5:15-5:30	219	50	3	72	213	57	91	223	73	75	213	57
	5:30-5:45	219	50	3	76	213	58	94	219	75	69	208	51
	5:45-6:00	219	50	3	68	217	49	90	215	72	82	215	64
	6:00-6:15	219	50	3	77	218	56	86	213	67	85	217	67
	6:15-6:30	219	50	3	61	212	44	83	213	68	65	198	47
	6:30-6:45	219	50	3	49	222	33	84	214	67	92	223	78
	6:45-7:00	219	50	3	51	202	36	77	199	56	80	214	68
	7:00-7:15	219	50	3	44	198	32	67	198	49	68	198	45
	7:15-7:30	219	50	3	41	185	30	58	187	44	61	187	43
Total Value					2059	6727	1589	2182	6608	1688	2106	6404	1613

R.T = Record Time

Table A3: Continued

Intersection: St.Stifanos Approach: Betemengist, Number of Lane: 3 Arrival Distance: 150 m, Lane Width: 4 m					**Thursday: March/16/2017**			**Friday: March/17/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	219	50	3	60	198	43	50	185	33
	7:45-8:00	219	50	3	59	195	41	53	189	37
	8:00-8:15	219	50	3	64	205	47	61	199	41
	8:15-8:30	219	50	3	77	213	67	61	204	45
	8:30-8:45	219	50	3	77	214	68	69	210	49
	8:45-9:00	219	50	3	70	210	67	67	209	51
	9:00-9:15	219	50	3	89	218	72	80	214	68
	9:15-9:30	219	50	3	85	216	68	66	205	47
	9:30-9:45	219	50	3	89	221	74	70	213	58
	9:45-10:00	219	50	3	85	219	69	58	198	36
	10:00-10:15	219	50	3	86	220	71	51	176	33
	10:15-10:30	219	50	3	70	214	53	53	183	35
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	219	50	3	59	187	43	39	167	29
	12:15-12:30	219	50	3	62	189	42	48	176	31
	12:30-12:45	219	50	3	67	195	44	54	183	37
	12:45-1:00	219	50	3	54	178	43	68	198	42
	1:00-1:15	219	50	3	54	182	42	59	191	38
	1:15-1:30	219	50	3	66	189	47	53	185	36
	1:30-1:45	219	50	3	66	193	46	57	190	38
	1:45-2:00	219	50	3	56	184	41	48	175	37
After noon (4:30 - 7:30) pm	4:30-4:45	219	50	3	58	187	43	58	186	44
	4:45-5:00	219	50	3	62	192	45	66	198	49
	5:00-5:15	219	50	3	71	197	54	59	189	48
	5:15-5:30	219	50	3	69	204	49	65	196	50
	5:30-5:45	219	50	3	63	195	48	70	205	57
	5:45-6:00	219	50	3	73	207	58	72	207	57
	6:00-6:15	219	50	3	58	179	40	66	197	46
	6:15-6:30	219	50	3	62	187	45	60	193	44
	6:30-6:45	219	50	3	58	183	43	56	185	42
	6:45-7:00	219	50	3	58	179	43	60	195	43
	7:00-7:15	219	50	3	62	195	45	51	183	38
	7:15-7:30	219	50	3	54	172	44	43	168	33
Total Value					2143	6317	1645	1891	6152	1372

R.T = Record Time

Table A3: Continued

Intersection: St.Stifanos **Approach: Betemengist, Number of Lane: 3** **Arrival Distance: 150 m, Lane Width: 4 m**					**Saturday: March/18/2017**			**Sunday: March/19/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	129	30	3	33	130	19	23	134	18
	7:45-8:00	129	30	3	33	131	26	27	133	22
	8:00-8:15	129	30	3	37	132	28	30	133	24
	8:15-8:30	129	30	3	28	133	23	28	135	23
	8:30-8:45	129	30	3	32	125	25	29	129	24
	8:45-9:00	129	30	3	30	131	24	30	134	25
	9:00-9:15	129	30	3	33	130	27	27	131	21
	9:15-9:30	129	30	3	34	128	26	28	133	22
	9:30-9:45	129	30	3	27	131	21	24	136	20
	9:45-10:00	129	30	3	30	131	24	25	135	21
	10:00-10:15	129	30	3	22	131	16	27	133	23
	10:15-10:30	129	30	3	25	128	20	25	132	18
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	129	30	3	22	132	18	21	132	17
	12:15-12:30	129	30	3	21	131	17	23	131	18
	12:30-12:45	129	30	3	25	132	20	21	134	15
	12:45-1:00	129	30	3	30	131	23	19	135	14
	1:00-1:15	129	30	3	27	130	21	20	132	15
	1:15-1:30	129	30	3	25	129	20	24	134	19
	1:30-1:45	129	30	3	30	135	23	22	132	18
	1:45-2:00	129	30	3	26	128	21	21	132	17
After noon (4:30 - 7:30) pm	4:30-4:45	129	30	3	30	133	24	24	133	18
	4:45-5:00	129	30	3	39	131	29	23	135	19
	5:00-5:15	129	30	3	32	133	26	26	134	21
	5:15-5:30	129	30	3	34	131	25	29	133	23
	5:30-5:45	129	30	3	35	134	28	29	133	24
	5:45-6:00	129	30	3	28	132	22	27	134	23
	6:00-6:15	129	30	3	36	133	27	29	134	22
	6:15-6:30	129	30	3	27	132	23	26	132	21
	6:30-6:45	129	30	3	26	133	20	25	135	19
	6:45-7:00	129	30	3	26	133	22	19	134	15
	7:00-7:15	129	30	3	21	132	18	20	135	18
	7:15-7:30	129	30	3	24	131	21	20	136	17
Total Value					928	4197	727	791	4268	634

R.T = Record Time

Table A4: Traffic Volume and Signal Time recorded at St.Stifanos intersection from Meskel Sq. Approach.

Intersection: St.Stifanos Approach: Mskel Squ. , Number of Lane: 4 Arrival Distance: 200 m, Lane Width: 4 m					Monday: March/13/2017			Tuesday: March/14/2017			Wednesday: March/15/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	209	60	3	93	182	87	52	178	43	85	186	73
	7:45-8:00	209	60	3	98	182	87	54	182	42	94	195	83
	8:00-8:15	209	60	3	94	188	82	80	180	68	91	193	78
	8:15-8:30	209	60	3	112	181	88	108	190	89	93	196	81
	8:30-8:45	209	60	3	109	178	92	90	189	78	99	200	84
	8:45-9:00	209	60	3	112	180	89	89	184	75	111	206	92
	9:00-9:15	209	60	3	121	189	81	93	189	83	109	199	87
	9:15-9:30	209	60	3	118	181	89	92	190	79	96	198	78
	9:30-9:45	209	60	3	103	187	92	94	198	78	88	188	71
	9:45-10:00	209	60	3	98	188	82	77	176	59	81	185	67
	10:00-10:15	209	60	3	99	189	81	66	165	46	76	176	61
	10:15-10:30	209	60	3	87	189	80	64	167	47	69	168	52
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	209	60	3	85	167	74	62	162	45	63	164	48
	12:15-12:30	209	60	3	78	158	70	64	168	47	63	165	46
	12:30-12:45	209	60	3	72	159	60	61	159	44	67	169	51
	12:45-1:00	209	60	3	73	161	62	62	164	43	79	178	67
	1:00-1:15	209	60	3	74	157	52	68	169	47	77	179	63
	1:15-1:30	209	60	3	69	153	59	64	165	48	81	182	68
	1:30-1:45	209	60	3	74	165	69	68	167	49	79	185	67
	1:45-2:00	209	60	3	82	176	76	63	162	46	76	176	62
After noon (4:30 - 7:30) pm	4:30-4:45	209	60	3	90	187	74	75	178	58	82	185	69
	4:45-5:00	209	60	3	91	194	73	79	185	63	86	195	72
	5:00-5:15	209	60	3	96	197	82	91	193	78	99	199	79
	5:15-5:30	209	60	3	98	183	87	100	198	83	95	196	81
	5:30-5:45	209	60	3	123	189	98	112	196	95	108	203	88
	5:45-6:00	209	60	3	121	195	95	124	202	104	115	213	97
	6:00-6:15	209	60	3	123	191	94	128	203	109	121	215	102
	6:15-6:30	209	60	3	114	199	91	120	199	103	113	202	98
	6:30-6:45	209	60	3	99	189	87	106	193	89	117	211	101
	6:45-7:00	209	60	3	96	188	74	99	190	79	106	199	92
	7:00-7:15	209	60	3	82	182	73	90	189	77	89	187	73
	7:15-7:30	209	60	3	78	178	69	82	182	73	76	178	54
Total Value					3062	5782	2549	2677	5812	2167	2884	6071	2385

R.T = Record Time

Table A4: Continued

Intersection: St.Stifanos Approach: Mskel Squ. , Number of Lane: 4 Arrival Distance: 200 m, Lane Width: 4 m					**Thursday: March/16/2017**			**Friday: March/17/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	209	60	3	68	171	48	62	164	49
	7:45-8:00	209	60	3	71	175	56	77	180	55
	8:00-8:15	209	60	3	82	186	68	84	187	64
	8:15-8:30	209	60	3	89	192	69	79	180	67
	8:30-8:45	209	60	3	95	195	80	79	182	66
	8:45-9:00	209	60	3	101	198	84	81	187	72
	9:00-9:15	209	60	3	111	203	85	95	199	77
	9:15-9:30	209	60	3	94	196	78	89	192	67
	9:30-9:45	209	60	3	91	198	76	93	198	64
	9:45-10:00	209	60	3	81	184	69	83	186	63
	10:00-10:15	209	60	3	80	187	67	82	187	65
	10:15-10:30	209	60	3	65	167	59	83	195	64
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	209	60	3	58	167	47	68	174	48
	12:15-12:30	209	60	3	60	167	46	49	154	39
	12:30-12:45	209	60	3	67	171	44	57	163	42
	12:45-1:00	209	60	3	66	168	48	54	168	40
	1:00-1:15	209	60	3	67	169	48	62	167	43
	1:15-1:30	209	60	3	51	161	42	49	150	35
	1:30-1:45	209	60	3	51	158	40	53	159	38
	1:45-2:00	209	60	3	53	154	42	48	157	34
After noon (4:30 - 7:30) pm	4:30-4:45	209	60	3	82	187	84	78	187	56
	4:45-5:00	209	60	3	97	198	79	89	190	71
	5:00-5:15	209	60	3	93	194	76	97	199	78
	5:15-5:30	209	60	3	103	201	82	105	198	94
	5:30-5:45	209	60	3	96	199	78	113	209	98
	5:45-6:00	209	60	3	103	198	84	125	213	108
	6:00-6:15	209	60	3	105	202	86	101	203	93
	6:15-6:30	209	60	3	101	198	83	98	199	78
	6:30-6:45	209	60	3	94	196	77	89	196	73
	6:45-7:00	209	60	3	77	178	63	82	187	70
	7:00-7:15	209	60	3	70	173	56	76	183	63
	7:15-7:30	209	60	3	66	169	43	59	164	49
Total Value					2588	5860	2087	2539	5857	2023

R.T = Record Time

Table A4: Continued

Intersection: St.Stifanos **Approach: Mskel Squ. , Number of Lane: 4** **Arrival Distance: 200 m, Lane Width: 4 m**					**Saturday: March/18/2017**			**Sunday: March/19/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	119	40	3	53	126	33	33	121	26
	7:45-8:00	119	40	3	36	125	29	40	131	30
	8:00-8:15	119	40	3	46	124	31	43	129	32
	8:15-8:30	119	40	3	61	128	44	52	127	45
	8:30-8:45	119	40	3	58	120	38	54	124	47
	8:45-9:00	119	40	3	52	127	32	56	129	42
	9:00-9:15	119	40	3	50	118	39	51	131	38
	9:15-9:30	119	40	3	52	123	33	47	133	36
	9:30-9:45	119	40	3	50	121	36	40	136	30
	9:45-10:00	119	40	3	45	120	31	38	134	27
	10:00-10:15	119	40	3	40	123	29	33	135	28
	10:15-10:30	119	40	3	38	123	29	29	135	24
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	119	40	3	29	112	25	28	121	23
	12:15-12:30	119	40	3	23	109	20	31	122	23
	12:30-12:45	119	40	3	31	107	26	30	132	25
	12:45-1:00	119	40	3	35	115	27	32	130	26
	1:00-1:15	119	40	3	26	110	22	27	121	22
	1:15-1:30	119	40	3	37	112	30	27	123	25
	1:30-1:45	119	40	3	36	116	28	29	125	22
	1:45-2:00	119	40	3	26	108	21	29	126	25
After noon (4:30 - 7:30) pm	4:30-4:45	119	40	3	43	120	34	33	132	27
	4:45-5:00	119	40	3	46	121	38	37	134	29
	5:00-5:15	119	40	3	37	118	29	37	134	29
	5:15-5:30	119	40	3	51	124	38	46	132	38
	5:30-5:45	119	40	3	60	123	42	54	134	38
	5:45-6:00	119	40	3	60	125	45	43	132	33
	6:00-6:15	119	40	3	61	122	47	45	135	36
	6:15-6:30	119	40	3	64	121	48	40	132	30
	6:30-6:45	119	40	3	55	119	38	32	117	28
	6:45-7:00	119	40	3	31	108	28	27	116	24
	7:00-7:15	119	40	3	28	102	25	31	121	25
	7:15-7:30	119	40	3	23	103	20	28	118	23
Total Value					1383	3773	1035	1202	4102	956

R.T = Record Time

Table A5: Traffic Volume and Signal Time recorded at St. Joseph intersection from Ambassador Approach.

Intersection: St.Josph **Approach: Ambasador, Number of Lane: 3** **Arrival Distance: 150 m, Lane Width: 4 m**					**Monday: March/20/2017**			**Tuesday: March/21/2017**			**Wednesday: March/22/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	211	45	3	77	175	59	72	176	58	69	178	51
	7:45-8:00	211	45	3	82	187	69	64	169	47	81	187	68
	8:00-8:15	211	45	3	89	195	73	64	173	46	90	198	73
	8:15-8:30	211	45	3	79	186	61	81	183	68	86	192	71
	8:30-8:45	211	45	3	83	188	68	83	184	71	89	193	72
	8:45-9:00	211	45	3	85	191	72	83	187	72	80	186	68
	9:00-9:15	211	45	3	87	191	73	74	178	58	77	178	61
	9:15-9:30	211	45	3	71	176	61	79	184	61	80	183	68
	9:30-9:45	211	45	3	79	183	71	81	184	67	85	187	72
	9:45-10:00	211	45	3	75	178	67	85	193	72	70	178	61
	10:00-10:15	211	45	3	59	167	47	81	184	69	67	173	49
	10:15-10:30	211	45	3	53	168	42	81	187	71	67	170	47
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	211	45	3	50	156	38	58	167	43	59	165	39
	12:15-12:30	211	45	3	56	164	42	59	167	47	60	167	43
	12:30-12:45	211	45	3	46	156	38	48	156	36	65	168	49
	12:45-1:00	211	45	3	52	164	41	58	164	48	65	171	50
	1:00-1:15	211	45	3	52	165	40	57	168	43	58	164	42
	1:15-1:30	211	45	3	56	164	43	61	169	47	67	175	46
	1:30-1:45	211	45	3	47	157	38	51	158	43	60	164	43
	1:45-2:00	211	45	3	49	159	39	49	156	37	60	167	42
After noon (4:30 - 7:30) pm	4:30-4:45	211	45	3	72	178	58	70	178	58	83	187	71
	4:45-5:00	211	45	3	85	186	71	76	183	64	93	197	78
	5:00-5:15	211	45	3	94	198	78	84	189	68	104	201	89
	5:15-5:30	211	45	3	89	192	74	101	199	88	99	200	86
	5:30-5:45	211	45	3	96	199	79	112	203	99	108	204	91
	5:45-6:00	211	45	3	98	197	81	121	208	104	112	211	99
	6:00-6:15	211	45	3	108	202	92	120	211	102	114	208	101
	6:15-6:30	211	45	3	112	212	99	110	201	100	125	216	111
	6:30-6:45	211	45	3	98	201	85	98	198	80	111	206	98
	6:45-7:00	211	45	3	87	195	73	87	192	72	93	198	73
	7:00-7:15	211	45	3	84	189	69	78	183	63	87	191	71
	7:15-7:30	211	45	3	74	179	61	69	174	53	82	187	69
Total Value					2424	5798	2002	2495	5806	2055	2646	5950	2152

R.T = Record Time

Table A5: Continued

Intersection: St.Josph **Approach: Ambasador, Number of Lane: 3** **Arrival Distance: 150 m, Lane Width: 4 m**					**Thursday: March/23/2017**			**Friday: March/24/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	211	45	3	72	176	62	70	176	58
	7:45-8:00	211	45	3	76	178	67	82	187	67
	8:00-8:15	211	45	3	92	196	78	89	195	76
	8:15-8:30	211	45	3	93	197	77	89	195	74
	8:30-8:45	211	45	3	91	189	72	92	199	79
	8:45-9:00	211	45	3	97	202	80	91	195	77
	9:00-9:15	211	45	3	100	200	86	93	197	80
	9:15-9:30	211	45	3	93	196	74	92	198	78
	9:30-9:45	211	45	3	85	189	71	82	187	69
	9:45-10:00	211	45	3	81	185	68	85	188	72
	10:00-10:15	211	45	3	73	179	59	83	186	70
	10:15-10:30	211	45	3	71	175	61	72	178	61
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	211	45	3	56	167	42	64	167	45
	12:15-12:30	211	45	3	58	165	45	58	167	43
	12:30-12:45	211	45	3	64	165	47	65	169	41
	12:45-1:00	211	45	3	70	175	57	55	158	40
	1:00-1:15	211	45	3	65	177	49	60	165	42
	1:15-1:30	211	45	3	63	175	42	66	168	44
	1:30-1:45	211	45	3	58	165	40	56	159	41
	1:45-2:00	211	45	3	63	167	47	53	158	39
After noon (4:30 - 7:30) pm	4:30-4:45	211	45	3	79	183	65	74	176	58
	4:45-5:00	211	45	3	83	186	71	81	184	67
	5:00-5:15	211	45	3	95	198	78	91	195	77
	5:15-5:30	211	45	3	102	206	87	93	197	81
	5:30-5:45	211	45	3	103	207	86	97	199	82
	5:45-6:00	211	45	3	116	213	99	96	200	80
	6:00-6:15	211	45	3	115	215	101	92	198	76
	6:15-6:30	211	45	3	120	213	106	86	187	68
	6:30-6:45	211	45	3	103	200	89	85	189	67
	6:45-7:00	211	45	3	99	202	79	81	185	65
	7:00-7:15	211	45	3	82	187	69	73	178	57
	7:15-7:30	211	45	3	84	186	71	67	172	48
Total Value					2702	6014	2225	2513	5852	2022

R.T = Record Time

Table A5: Continued

Intersection: St.Josph Approach: Ambasador, Number of Lane: 3 Arrival Distance: 150 m, Lane Width: 4 m					**Saturday: March/25/2017**			**Sunday: March/26/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	158	27	3	35	93	29	33	100	27
	7:45-8:00	158	27	3	33	76	27	37	101	27
	8:00-8:15	158	27	3	33	75	26	34	93	25
	8:15-8:30	158	27	3	35	88	30	40	94	31
	8:30-8:45	158	27	3	37	83	32	42	98	33
	8:45-9:00	158	27	3	36	95	30	38	93	30
	9:00-9:15	158	27	3	35	91	28	39	108	34
	9:15-9:30	158	27	3	32	81	25	40	107	33
	9:30-9:45	158	27	3	34	78	26	35	96	27
	9:45-10:00	158	27	3	33	89	27	33	88	27
	10:00-10:15	158	27	3	32	86	26	31	96	25
	10:15-10:30	158	27	3	29	78	23	29	81	23
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	158	27	3	25	68	20	27	78	22
	12:15-12:30	158	27	3	25	84	19	29	73	23
	12:30-12:45	158	27	3	25	67	21	30	76	26
	12:45-1:00	158	27	3	22	67	17	28	77	22
	1:00-1:15	158	27	3	24	70	19	29	79	24
	1:15-1:30	158	27	3	24	83	20	26	71	21
	1:30-1:45	158	27	3	20	79	16	23	73	18
	1:45-2:00	158	27	3	25	76	21	23	73	17
After noon (4:30 - 7:30) pm	4:30-4:45	158	27	3	34	68	25	32	74	26
	4:45-5:00	158	27	3	35	72	27	36	92	27
	5:00-5:15	158	27	3	33	81	23	40	88	28
	5:15-5:30	158	27	3	43	95	32	45	97	33
	5:30-5:45	158	27	3	47	97	37	43	98	31
	5:45-6:00	158	27	3	52	112	39	53	103	42
	6:00-6:15	158	27	3	53	114	41	49	111	39
	6:15-6:30	158	27	3	50	120	38	50	109	41
	6:30-6:45	158	27	3	56	118	42	40	97	31
	6:45-7:00	158	27	3	42	101	35	34	94	26
	7:00-7:15	158	27	3	37	106	31	30	83	23
	7:15-7:30	158	27	3	28	77	21	26	78	20
Total Value					1104	2768	873	1124	2879	882

R.T = Record Time

Table A6: Traffic Volume and Signal Time recorded at St. Joseph intersection from Legehar Approach.

Intersection: St.Josph Approach: Le Gehar, Number of Lane: 3 Arrival Distance: 200 m, Lane Width: 4 m					Monday: March/20/2017			Tuesday: March/21/2017			Wednesday: March/22/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	161	95	3	117	168	98	95	198	79	92	197	71
	7:45-8:00	161	95	3	122	173	106	109	205	92	101	199	86
	8:00-8:15	161	95	3	121	168	108	133	212	118	116	213	98
	8:15-8:30	161	95	3	128	158	112	135	218	123	130	216	112
	8:30-8:45	161	95	3	131	157	113	145	212	128	126	212	110
	8:45-9:00	161	95	3	131	156	114	145	221	120	119	215	108
	9:00-9:15	161	95	3	126	158	107	136	217	118	116	214	98
	9:15-9:30	161	95	3	121	161	105	138	213	121	113	210	97
	9:30-9:45	161	95	3	121	162	106	131	214	118	104	205	84
	9:45-10:00	161	95	3	111	164	96	132	214	120	103	199	83
	10:00-10:15	161	95	3	100	157	94	122	213	108	90	195	71
	10:15-10:30	161	95	3	95	154	81	107	198	89	80	182	68
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	161	95	3	86	146	72	80	187	69	76	178	58
	12:15-12:30	161	95	3	82	154	68	82	189	70	68	169	49
	12:30-12:45	161	95	3	84	152	69	86	191	71	69	172	51
	12:45-1:00	161	95	3	80	143	65	83	187	70	76	182	62
	1:00-1:15	161	95	3	80	158	65	84	180	68	73	178	60
	1:15-1:30	161	95	3	79	154	67	79	183	67	73	176	58
	1:30-1:45	161	95	3	80	157	67	73	178	65	78	189	65
	1:45-2:00	161	95	3	74	160	62	76	178	67	70	178	55
After noon (4:30 - 7:30) pm	4:30-4:45	161	95	3	90	161	74	86	189	71	128	219	108
	4:45-5:00	161	95	3	99	164	82	106	198	88	126	215	105
	5:00-5:15	161	95	3	107	174	88	126	213	104	128	213	112
	5:15-5:30	161	95	3	108	168	91	139	221	121	125	214	108
	5:30-5:45	161	95	3	130	161	121	147	217	128	146	218	126
	5:45-6:00	161	95	3	136	162	128	145	218	123	146	217	121
	6:00-6:15	161	95	3	125	158	112	143	221	121	145	212	119
	6:15-6:30	161	95	3	136	157	124	146	223	123	137	212	112
	6:30-6:45	161	95	3	127	159	115	131	213	116	125	218	108
	6:45-7:00	161	95	3	123	162	116	117	209	102	117	213	104
	7:00-7:15	161	95	3	104	168	89	104	198	87	106	206	84
	7:15-7:30	161	95	3	96	173	81	90	191	71	96	198	75
Total Value					3450	5127	2996	3651	6519	3136	3398	6434	2826

R.T = Record Time

Table A6: Continued

Intersection: St.Josph **Approach: Le Gehar, Number of Lane: 3** **Arrival Distance: 200 m, Lane Width: 4 m**					**Thursday: March/23/2017**			**Friday: March/24/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	161	95	3	93	198	75	94	197	73
	7:45-8:00	161	95	3	104	205	86	100	201	81
	8:00-8:15	161	95	3	124	214	108	114	213	95
	8:15-8:30	161	95	3	163	232	126	124	216	108
	8:30-8:45	161	95	3	152	231	118	135	223	113
	8:45-9:00	161	95	3	113	210	92	133	221	117
	9:00-9:15	161	95	3	128	213	98	129	218	113
	9:15-9:30	161	95	3	126	216	97	126	219	108
	9:30-9:45	161	95	3	118	216	93	118	213	98
	9:45-10:00	161	95	3	112	209	91	110	209	93
	10:00-10:15	161	95	3	111	207	89	103	200	83
	10:15-10:30	161	95	3	98	200	78	99	202	82
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	161	95	3	78	187	68	83	189	64
	12:15-12:30	161	95	3	80	180	67	87	187	67
	12:30-12:45	161	95	3	74	176	65	86	185	65
	12:45-1:00	161	95	3	86	187	73	83	187	62
	1:00-1:15	161	95	3	75	178	66	80	184	60
	1:15-1:30	161	95	3	68	172	51	82	187	64
	1:30-1:45	161	95	3	71	174	56	92	196	73
	1:45-2:00	161	95	3	70	172	54	88	190	74
After noon (4:30 - 7:30) pm	4:30-4:45	161	95	3	88	191	75	90	192	75
	4:45-5:00	161	95	3	97	199	83	99	200	78
	5:00-5:15	161	95	3	108	202	92	114	211	96
	5:15-5:30	161	95	3	112	207	97	123	216	108
	5:30-5:45	161	95	3	112	210	95	131	221	113
	5:45-6:00	161	95	3	130	221	108	131	220	118
	6:00-6:15	161	95	3	135	220	112	139	223	121
	6:15-6:30	161	95	3	128	217	108	123	215	107
	6:30-6:45	161	95	3	112	210	92	114	213	91
	6:45-7:00	161	95	3	103	199	88	104	208	86
	7:00-7:15	161	95	3	93	193	75	100	201	82
	7:15-7:30	161	95	3	80	180	69	95	198	76
Total Value					3342	6426	2745	3429	6555	2844

R.T = Record Time

Table A6: Continued

Intersection: St.Josph **Approach: Le Gehar, Number of Lane: 3** **Arrival Distance: 200 m, Lane Width: 4 m**					**Saturday:** **March/25/2017**			**Sunday:** **March/26/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	158	57	3	63	123	47	64	110	43
	7:45-8:00	158	57	3	66	112	49	64	113	47
	8:00-8:15	158	57	3	73	118	53	73	123	56
	8:15-8:30	158	57	3	78	123	56	81	131	67
	8:30-8:45	158	57	3	80	137	58	71	120	57
	8:45-9:00	158	57	3	81	138	64	85	128	68
	9:00-9:15	158	57	3	79	133	61	71	118	54
	9:15-9:30	158	57	3	79	127	58	73	122	55
	9:30-9:45	158	57	3	75	122	60	75	126	58
	9:45-10:00	158	57	3	74	120	54	66	112	47
	10:00-10:15	158	57	3	63	131	49	68	111	49
	10:15-10:30	158	57	3	60	121	45	57	109	42
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	158	57	3	38	94	29	52	105	38
	12:15-12:30	158	57	3	45	89	32	54	104	39
	12:30-12:45	158	57	3	49	85	35	63	111	43
	12:45-1:00	158	57	3	38	92	31	51	110	37
	1:00-1:15	158	57	3	41	100	33	49	104	39
	1:15-1:30	158	57	3	42	97	31	53	104	41
	1:30-1:45	158	57	3	37	84	28	61	107	43
	1:45-2:00	158	57	3	39	99	31	52	111	38
After noon (4:30 - 7:30) pm	4:30-4:45	158	57	3	55	113	42	67	103	48
	4:45-5:00	158	57	3	58	121	43	58	106	42
	5:00-5:15	158	57	3	78	132	61	69	105	47
	5:15-5:30	158	57	3	80	128	63	75	115	58
	5:30-5:45	158	57	3	77	113	56	80	125	63
	5:45-6:00	158	57	3	78	122	57	77	123	61
	6:00-6:15	158	57	3	75	131	69	78	126	60
	6:15-6:30	158	57	3	80	125	62	74	118	57
	6:30-6:45	158	57	3	78	112	58	70	104	54
	6:45-7:00	158	57	3	60	95	46	65	104	47
	7:00-7:15	158	57	3	47	87	38	58	98	41
	7:15-7:30	158	57	3	37	81	29	54	99	35
Total Value					2003	3605	1528	2108	3605	1574

R.T = Record Time

Table A7: Traffic Volume and Signal Time recorded at St. Joseph intersection from Saris Approach.

Intersection: St.Josph **Approach: Saris, Number of Lane: 3** **Arrival Distance: 150 m, Lane Width: 4 m**					**Monday: March/20/2017**			**Tuesday: March/21/2017**			**Wednesday: March/22/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	214	42	3	69	176	47	67	175	56	71	174	56
	7:45-8:00	214	42	3	76	177	54	53	163	42	74	178	58
	8:00-8:15	214	42	3	86	186	59	70	176	56	77	179	62
	8:15-8:30	214	42	3	80	185	55	71	178	57	83	187	68
	8:30-8:45	214	42	3	84	186	56	81	186	67	95	198	76
	8:45-9:00	214	42	3	101	198	67	80	183	65	97	197	78
	9:00-9:15	214	42	3	99	198	65	85	187	69	101	200	86
	9:15-9:30	214	42	3	100	200	65	76	178	58	112	210	98
	9:30-9:45	214	42	3	89	193	63	78	181	61	103	202	99
	9:45-10:00	214	42	3	72	178	54	82	187	65	112	212	101
	10:00-10:15	214	42	3	78	181	53	83	189	67	82	187	68
	10:15-10:30	214	42	3	66	168	46	69	171	51	71	176	59
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	214	42	3	61	164	46	54	158	41	61	167	43
	12:15-12:30	214	42	3	67	168	48	48	156	38	62	165	45
	12:30-12:45	214	42	3	65	168	45	42	154	31	67	169	46
	12:45-1:00	214	42	3	68	171	46	52	158	38	79	182	58
	1:00-1:15	214	42	3	58	161	43	50	156	36	68	176	49
	1:15-1:30	214	42	3	64	165	46	53	158	37	67	173	51
	1:30-1:45	214	42	3	64	167	47	47	154	33	65	173	43
	1:45-2:00	214	42	3	62	166	45	39	148	28	66	169	47
After noon (4:30 - 7:30) pm	4:30-4:45	214	42	3	71	175	58	58	165	37	91	195	76
	4:45-5:00	214	42	3	77	179	69	78	183	67	86	187	71
	5:00-5:15	214	42	3	87	191	74	91	195	78	94	196	79
	5:15-5:30	214	42	3	104	201	78	115	212	99	102	203	87
	5:30-5:45	214	42	3	118	212	87	117	217	106	110	208	96
	5:45-6:00	214	42	3	124	221	98	121	219	111	104	201	86
	6:00-6:15	214	42	3	123	217	95	131	221	116	107	200	92
	6:15-6:30	214	42	3	124	215	84	125	216	112	120	214	98
	6:30-6:45	214	42	3	125	214	91	110	208	96	123	215	106
	6:45-7:00	214	42	3	121	209	102	113	205	97	103	199	87
	7:00-7:15	214	42	3	98	198	73	108	201	87	96	197	76
	7:15-7:30	214	42	3	75	175	54	97	198	78	88	192	72
Total Value					2756	5963	2013	2544	5836	2080	2837	6081	2317

R.T = Record Time

Table A7: Continued

Intersection: St.Josph Approach: Saris, Number of Lane: 3 Arrival Distance: 150 m, Lane Width: 4 m					**Thursday: March/23/2017**			**Friday: March/24/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	214	42	3	74	178	56	69	176	49
	7:45-8:00	214	42	3	86	187	66	79	184	65
	8:00-8:15	214	42	3	86	189	69	88	189	72
	8:15-8:30	214	42	3	91	193	76	91	193	75
	8:30-8:45	214	42	3	84	186	71	94	197	78
	8:45-9:00	214	42	3	86	187	73	97	199	79
	9:00-9:15	214	42	3	88	192	75	98	200	78
	9:15-9:30	214	42	3	78	183	64	85	189	69
	9:30-9:45	214	42	3	71	176	56	86	187	70
	9:45-10:00	214	42	3	68	174	51	87	189	72
	10:00-10:15	214	42	3	63	168	47	83	184	68
	10:15-10:30	214	42	3	65	169	48	73	176	58
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	214	42	3	47	154	35	61	165	44
	12:15-12:30	214	42	3	51	157	37	67	173	48
	12:30-12:45	214	42	3	52	157	36	65	168	43
	12:45-1:00	214	42	3	46	148	32	58	162	39
	1:00-1:15	214	42	3	49	157	34	64	167	46
	1:15-1:30	214	42	3	45	148	31	63	164	44
	1:30-1:45	214	42	3	40	148	27	59	163	41
	1:45-2:00	214	42	3	52	156	39	55	156	37
After noon (4:30 - 7:30) pm	4:30-4:45	214	42	3	63	168	48	80	183	65
	4:45-5:00	214	42	3	67	176	51	90	193	73
	5:00-5:15	214	42	3	81	185	69	92	194	75
	5:15-5:30	214	42	3	79	180	67	112	212	88
	5:30-5:45	214	42	3	83	185	71	119	211	92
	5:45-6:00	214	42	3	79	182	65	125	218	99
	6:00-6:15	214	42	3	81	185	68	124	218	106
	6:15-6:30	214	42	3	89	196	74	121	214	107
	6:30-6:45	214	42	3	74	176	62	114	215	94
	6:45-7:00	214	42	3	74	178	63	103	201	84
	7:00-7:15	214	42	3	66	168	47	97	198	81
	7:15-7:30	214	42	3	54	161	39	86	185	69
Total Value					2212	5547	1747	2785	6023	2208

R.T = Record Time

Table A7: Continued

Intersection: St.Josph **Approach: Saris, Number of Lane: 3** **Arrival Distance: 150 m, Lane Width: 4 m**					**Saturday: March/25/2017**			**Sunday: March/26/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	151	34	3	32	86	25	26	84	21
	7:45-8:00	151	34	3	28	81	23	32	95	26
	8:00-8:15	151	34	3	33	88	26	27	86	21
	8:15-8:30	151	34	3	40	112	30	34	91	27
	8:30-8:45	151	34	3	38	109	28	37	108	29
	8:45-9:00	151	34	3	38	104	27	37	122	28
	9:00-9:15	151	34	3	38	100	29	37	112	26
	9:15-9:30	151	34	3	33	87	24	36	98	27
	9:30-9:45	151	34	3	32	94	23	29	115	25
	9:45-10:00	151	34	3	28	82	22	23	81	22
	10:00-10:15	151	34	3	29	88	22	27	78	23
	10:15-10:30	151	34	3	27	79	23	24	81	22
Mid-Day (12:00 am -2:00 pm)	12:00-12:15	151	34	3	23	82	18	24	78	19
	12:15-12:30	151	34	3	25	73	19	24	75	20
	12:30-12:45	151	34	3	23	86	18	22	63	17
	12:45-1:00	151	34	3	25	78	19	24	71	18
	1:00-1:15	151	34	3	23	88	18	23	73	19
	1:15-1:30	151	34	3	25	94	19	25	73	20
	1:30-1:45	151	34	3	25	87	20	21	70	16
	1:45-2:00	151	34	3	25	76	21	21	70	17
After noon (4:30 - 7:30) pm	4:30-4:45	151	34	3	34	73	27	36	92	23
	4:45-5:00	151	34	3	37	93	29	30	72	22
	5:00-5:15	151	34	3	42	100	31	35	95	26
	5:15-5:30	151	34	3	42	112	32	42	116	30
	5:30-5:45	151	34	3	48	110	35	37	108	28
	5:45-6:00	151	34	3	48	121	36	47	121	38
	6:00-6:15	151	34	3	41	120	33	41	119	31
	6:15-6:30	151	34	3	39	118	32	27	98	21
	6:30-6:45	151	34	3	33	94	28	28	98	22
	6:45-7:00	151	34	3	29	83	22	23	76	19
	7:00-7:15	151	34	3	30	83	24	24	72	20
	7:15-7:30	151	34	3	23	73	18	22	73	17
Total Value					1036	2954	801	945	2864	740

R.T = Record Time

Table A8: Traffic Volume and Signal Time recorded at St. Joseph intersection from St.Stifanos Approach

Intersection: St.Josph Approach: St.Stifanos, Number of Lane: 4 Arrival Distance: 200 m, Lane Width: 4 m					Monday: March/20/2017			Tuesday: March/21/2017			Wednesday: March/22/2017		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	191	65	3	92	197	78	99	203	78	85	186	70
	7:45-8:00	191	65	3	93	196	76	105	204	88	89	193	73
	8:00-8:15	191	65	3	110	196	86	119	209	100	96	198	75
	8:15-8:30	191	65	3	131	211	112	121	211	103	112	211	93
	8:30-8:45	191	65	3	135	210	128	120	213	101	129	216	110
	8:45-9:00	191	65	3	130	209	121	127	215	111	131	221	121
	9:00-9:15	191	65	3	121	203	112	111	208	91	126	215	112
	9:15-9:30	191	65	3	121	210	110	124	212	108	123	216	108
	9:30-9:45	191	65	3	111	204	89	106	202	87	108	203	93
	9:45-10:0	191	65	3	97	195	81	97	198	81	108	206	89
	0:00-10:1	191	65	3	101	200	84	95	196	78	95	197	78
	0:15-10:3	191	65	3	89	195	78	86	187	71	93	194	75
Mid-Day (12:00 am -2:00 pm)	2:00-12:1	191	65	3	80	184	75	82	183	66	84	187	67
	2:15-12:3	191	65	3	86	186	76	82	186	67	77	181	62
	2:30-12:4	191	65	3	84	187	73	81	186	65	83	186	67
	12:45-1:0	191	65	3	82	184	71	80	184	63	75	178	60
	1:00-1:15	191	65	3	85	189	72	82	187	65	82	186	64
	1:15-1:30	191	65	3	87	184	74	72	176	58	82	184	66
	1:30-1:45	191	65	3	85	186	72	75	178	59	76	178	58
	1:45-2:00	191	65	3	74	178	61	69	171	52	79	182	61
After noon (4:30 - 7:30) pm	4:30-4:45	191	65	3	86	187	70	82	186	68	112	208	98
	4:45-5:00	191	65	3	84	186	68	89	194	75	125	205	112
	5:00-5:15	191	65	3	92	194	78	93	197	79	133	222	118
	5:15-5:30	191	65	3	110	207	91	108	202	98	127	219	113
	5:30-5:45	191	65	3	118	211	98	125	211	111	121	210	106
	5:45-6:00	191	65	3	119	203	101	126	214	110	124	209	108
	6:00-6:15	191	65	3	104	198	84	124	212	108	128	212	111
	6:15-6:30	191	65	3	99	196	81	115	209	98	127	210	109
	6:30-6:45	191	65	3	95	197	78	109	205	91	111	204	91
	6:45-7:00	191	65	3	86	186	68	102	200	86	110	202	93
	7:00-7:15	191	65	3	90	194	71	97	198	81	97	198	81
	7:15-7:30	191	65	3	81	185	67	89	192	73	77	180	67
Total Value					3158	6248	2684	3192	6329	2670	3325	6397	2809

R.T = Record Time

Table A8: Continued

Intersection: St.Josph Approach: St.Stifanos, Number of Lane: 4 Arrival Distance: 200 m, Lane Width: 4 m					**Thursday: March/23/2017**			**Friday: March/24/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	191	65	3	83	185	71	80	183	68
	7:45-8:00	191	65	3	99	202	82	87	188	72
	8:00-8:15	191	65	3	106	205	84	96	197	78
	8:15-8:30	191	65	3	128	221	104	103	202	89
	8:30-8:45	191	65	3	127	218	108	108	203	88
	8:45-9:00	191	65	3	136	223	121	117	211	93
	9:00-9:15	191	65	3	140	221	124	122	216	106
	9:15-9:30	191	65	3	125	213	113	124	219	107
	9:30-9:45	191	65	3	110	208	89	108	204	87
	9:45-10:0	191	65	3	98	198	78	110	209	88
	0:00-10:1	191	65	3	94	195	73	98	199	79
	0:15-10:3	191	65	3	86	187	71	89	191	74
Mid-Day (12:00 am -2:00 pm)	2:00-12:1	191	65	3	67	169	48	73	174	61
	2:15-12:3	191	65	3	70	176	51	82	186	64
	2:30-12:4	191	65	3	74	178	53	78	179	62
	12:45-1:0	191	65	3	74	176	56	74	175	60
	1:00-1:15	191	65	3	75	175	58	83	187	67
	1:15-1:30	191	65	3	74	178	57	79	180	66
	1:30-1:45	191	65	3	82	186	68	78	181	64
	1:45-2:00	191	65	3	74	175	61	75	178	65
After noon (4:30 - 7:30) pm	4:30-4:45	191	65	3	119	210	101	92	194	78
	4:45-5:00	191	65	3	120	209	106	89	191	76
	5:00-5:15	191	65	3	132	217	118	106	201	91
	5:15-5:30	191	65	3	132	219	113	112	209	96
	5:30-5:45	191	65	3	138	221	121	112	212	98
	5:45-6:00	191	65	3	130	217	112	116	211	94
	6:00-6:15	191	65	3	123	212	108	130	221	116
	6:15-6:30	191	65	3	115	208	91	112	209	96
	6:30-6:45	191	65	3	106	201	88	106	203	88
	6:45-7:00	191	65	3	96	198	79	91	197	84
	7:00-7:15	191	65	3	90	197	71	93	193	86
	7:15-7:30	191	65	3	77	179	69	85	188	72
Total Value					3300	6377	2747	3108	6291	2613

R.T = Record Time

Table A8: Continued

Intersection: St.Josph Approach: St.Stifanos, Number of Lane: 4 Arrival Distance: 200 m, Lane Width: 4 m					**Saturday: March/25/2017**			**Sunday: March/26/2017**		
Pick Hour	Duration	Actual Signal Time (Ses)			R.T (Sec) and volume (veh)			R.T (Sec) and volume (veh)		
		Red	Green	Amber	Volume	Red	Green	Volume	Red	Green
Morning (7:30 -10:30) am	7:30-7:45	135	94	3	69	90	51	59	88	44
	7:45-8:00	135	94	3	73	106	64	65	94	49
	8:00-8:15	135	94	3	78	112	65	72	103	57
	8:15-8:30	135	94	3	88	118	78	76	114	59
	8:30-8:45	135	94	3	95	123	81	80	112	67
	8:45-9:00	135	94	3	92	120	78	81	124	69
	9:00-9:15	135	94	3	79	117	68	81	121	70
	9:15-9:30	135	94	3	84	117	73	73	109	67
	9:30-9:45	135	94	3	73	108	58	75	108	68
	9:45-10:00	135	94	3	73	110	59	72	96	65
	10:00-10:1	135	94	3	68	97	49	66	86	47
	10:15-10:3	135	94	3	66	97	48	56	76	42
Mid-Day (12:00 am -2:00 pm)	12:00-12:1	135	94	3	55	89	42	41	68	31
	12:15-12:3	135	94	3	49	78	39	46	68	33
	12:30-12:4	135	94	3	47	78	37	45	69	34
	12:45-1:00	135	94	3	52	82	41	45	71	35
	1:00-1:15	135	94	3	40	75	32	37	62	29
	1:15-1:30	135	94	3	44	78	34	46	68	37
	1:30-1:45	135	94	3	47	79	38	45	71	35
	1:45-2:00	135	94	3	44	76	32	33	62	25
After noon (4:30 - 7:30) pm	4:30-4:45	135	94	3	62	89	46	54	86	39
	4:45-5:00	135	94	3	71	93	58	60	98	46
	5:00-5:15	135	94	3	82	108	49	70	110	54
	5:15-5:30	135	94	3	87	112	53	80	123	69
	5:30-5:45	135	94	3	92	123	76	76	109	63
	5:45-6:00	135	94	3	93	122	74	78	110	65
	6:00-6:15	135	94	3	92	128	74	80	121	71
	6:15-6:30	135	94	3	90	112	73	71	107	58
	6:30-6:45	135	94	3	86	110	68	71	103	56
	6:45-7:00	135	94	3	68	97	47	62	98	47
	7:00-7:15	135	94	3	67	92	45	59	85	43
	7:15-7:30	135	94	3	59	78	43	48	71	37
Total Value					2265	3214	1773	2003	2991	1611

R.T = Record Time

APPENDIX B

Average directional traffic movements in each approach in both intersections

Table CB: Percentage of directional movement for each approach in both intersections

Intersection	ApproachLeg	Pick Hour	Man Day - Fri Day									
Name			Volume	Red	Green	Cycle Time	Flow Rate	TH	RT	%	LT	%
		Morning	115	192	75	271	1377	98	11	10%	6	5%
		Mid-Day	85	157	55	214	1023	72	9	10%	4	5%
	Bambis	Evening	114	184	76	263	1371	97	11	10%	6	5%
		Morning	173	189	108	301	2080	107	5	3%	61	35%
		Mid-Day	131	161	87	251	1577	81	4	3%	46	35%
St. Stifanos	Denbel	Evening	171	186	108	297	2058	106	5	3%	60	35%
		Morning	88	207	55	265	1051	53	13	15%	22	25%
		Mid-Day	66	190	38	231	794	40	10	15%	17	25%
	Betemengist	Evening	85	202	52	257	1015	51	13	15%	21	25%
		Morning	111	186	72	262	1328	72	22	20%	17	15%
		Mid-Day	82	165	51	219	981	53	16	20%	12	15%
	Meskel Sq.	Evening	121	193	81	277	1456	79	24	20%	18	15%
		Morning	101	185	67	255	1218	46	10	10%	46	45%
		Mid-Day	73	165	43	211	876	33	7	10%	33	45%
	Ambasador	Evening	118	195	79	277	1419	53	12	10%	53	45%
		Morning	148	197	98	298	1781	117	22	15%	9	6%
		Mid-Day	99	177	65	245	1192	78	15	15%	6	6%
St. Josph	Le Gehar	Evening	148	200	100	303	1776	117	22	15%	9	6%
		Morning	104	185	65	253	1246	88	10	10%	5	5%
		Mid-Day	73	162	41	206	871	62	7	10%	4	5%
	Saris	Evening	124	197	81	281	1484	105	12	10%	6	5%
		Morning	137	204	92	299	1641	96	27	20%	14	10%
		Mid-Day	99	181	63	247	1185	69	20	20%	10	10%
	St.stifanos	Evening	135	203	92	297	1622	95	27	20%	14	10%
Intersection	ApproachLeg	Pick Hour	Satur Day - Sun Day									
Name			Volume	Red	Green	Cycle Time	Flow Rate	TH	RT	%	LT	%
		Morning	56	128	35	166	669	47	6	10%	3	5%
		Mid-Day	41	113	28	144	490	35	4	10%	2	5%
	Bambis	Evening	52	123	34	160	621	44	5	10%	3	5%
		Morning	59	120	38	161	705	36	2	3%	21	35%
		Mid-Day	45	106	31	140	536	28	1	3%	16	35%
St. Stifanos	Denbel	Evening	60	117	39	159	715	37	2	3%	21	35%
		Morning	33	132	23	157	395	20	5	15%	8	25%
		Mid-Day	27	132	19	153	325	16	4	15%	7	25%
	Betemengist	Evening	31	133	22	158	377	19	5	15%	8	25%
		Morning	53	127	34	164	631	34	11	20%	8	15%
		Mid-Day	34	118	24	145	411	22	7	20%	5	15%
	Meskel Sq.	Evening	48	123	33	159	582	32	10	20%	7	15%
		Morning	40	90	28	121	480	18	4	10%	18	45%
		Mid-Day	29	75	20	98	349	13	3	10%	13	45%
	Ambasador	Evening	47	95	32	130	568	21	5	10%	21	45%
		Morning	82	122	54	179	988	65	12	15%	5	6%
		Mid-Day	55	100	36	138	659	43	8	15%	3	6%
St. Josph	Le Gehar	Evening	78	112	52	166	936	62	12	15%	5	6%
		Morning	32	72	23	98	387	27	3	10%	2	5%
		Mid-Day	28	68	19	90	331	23	3	10%	1	5%
	Saris	Evening	33	72	23	98	398	28	3	10%	2	5%
		Morning	86	106	62	171	1032	60	17	20%	9	10%
		Mid-Day	51	73	35	111	618	36	10	20%	5	10%
	St.stifanos	Evening	84	104	56	163	1011	59	17	20%	8	10%

APPENDIX C

Table 1C: Arena data input analyzer result

St.Stifanos Intersection								
Approach	**Pick Time**	**Distribution Type**	**Square Error**	**Number of Data Points**	**Min**	**Mean**	**Max**	**Standard Deviation**
Bambis	Morning	Triangular	0.019653	84	22	63.3	109	22.1
	Mid-day	Beta	0.012652	56	21	46.3	72	15.1
	Evening	Normal	0.018525	84	18	63.3	123	24..3
Denbel	Morning	Beta	0.051027	84	28	88.1	128	33.5
	Mid-day	Beta	0.028139	56	27	71.3	108	27.8
	Evening	Beta	0.016113	84	28	88.6	127	33.1
Meskel	Morning	Beta	0.010836	84	24	61.3	92.	21.1
	Mid-day	Beta	0.021265	56	20	43.4	76	15.5
	Evening	Beta	0.014841	84	20	67	109	25.3
Betemengist	Morning	Beta	0.016189	84	16	45.6	79	18.5
	Mid-day	Triangular	0.029160	56	14	32.2	52	9.8
	Evening	Beta	0.016032	84	15	43.3	78	16.7
St. Joseph Intersection								
Approach	**Pick Time**	**Distribution Type**	**Square Error**	**Number of Data Points**	**Min**	**Mean**	**Max**	**Standard Deviation**
Ambassador	Morning	Beta	0.016032	84	15	43.3	78	16.7
	Mid-day	Triangular	0.028112	56	16	36.6	57	11
	Evening	Beta	0.013372	84	20	65.4	111	25.2
Le Gehar	Morning	Beta	0.016527	84	42	86.6	128	24.8
	Mid-day	Beta	0.026114	56	28	56	74	14.3
	Evening	Beta	0.016741	84	29	86.2	128	27.2
Stifanos	Morning	Triangular	0.019980	84	42	83	128	20.3
	Mid-day	Triangular	0.016355	56	25	55.2	76	14.4
	Evening	Beta	0.015930	84	37	81.5	121	21.9
Saris	Morning	Beta	0.017266	84	21	53.2	101	21
	Mid-day	Beta	0.025256	56	16	34.7	58	11.7
	Evening	Beta	0.010895	84	17	65.2	116	29.1

APPENDIX D

Arena Scenario Simulation Results

Scenario 1

1:01:20PM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

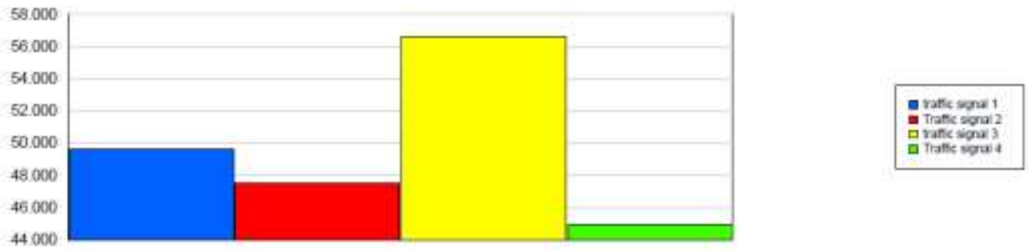
Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6562	0.11	0.4242	0.8816	0.00670291	1.5448
Traffic signal 2	0.6564	0.11	0.4304	0.8834	0.00811308	1.5427
traffic signal 3	0.6594	0.11	0.4308	0.8815	0.00351656	1.5352
Traffic signal 4	0.6568	0.11	0.4287	0.8791	0.00128333	1.5366

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6562	0.11	0.4242	0.8816	0.00670291	1.5448
Traffic signal 2	0.6564	0.11	0.4304	0.8834	0.00811308	1.5427
traffic signal 3	0.6594	0.11	0.4308	0.8815	0.00351656	1.5352
Traffic signal 4	0.6568	0.11	0.4287	0.8791	0.00128333	1.5366

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	49.5892	6.42	35.6322	62.5941
Traffic signal 2	47.5302	6.16	34.8593	60.0726
traffic signal 3	56.6404	7.05	41.3572	70.5223
Traffic signal 4	44.9642	5.60	33.0113	56.2595



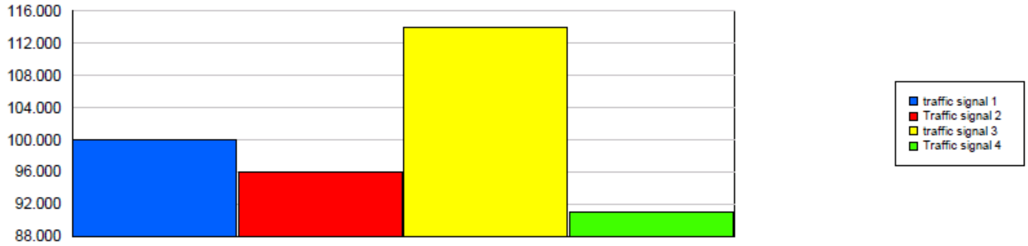
Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.6426	0.11	0.4158	0.8673	0.00	1.5402
Traffic signal 2.Queue	0.6440	0.11	0.4161	0.8663	0.00	1.5064
traffic signal 3.Queue	0.6397	0.11	0.4117	0.8633	0.00	1.5304
Traffic signal 4.Queue	0.6552	0.11	0.4226	0.8816	0.00789235	1.5329

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	12.7958	1.98	8.3515	16.8106	0.00	31.0000
Traffic signal 2.Queue	12.2633	1.88	8.0308	16.0801	0.00	29.0000
traffic signal 3.Queue	14.5566	2.24	9.5051	19.0751	0.00	36.0000
Traffic signal 4.Queue	11.6914	1.80	7.6352	15.3610	0.00	29.0000

Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	100.00	0.00	100.00	100.00
Traffic signal 2	96.0000	0.00	96.0000	96.0000
traffic signal 3	114.00	0.00	114.00	114.00
Traffic signal 4	91.0000	0.00	91.0000	91.0000



Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	76.4000	3.38	70.0000	84.0000
Traffic signal 2	73.2000	3.11	68.0000	81.0000
traffic signal 3	86.9000	4.01	80.0000	96.0000
Traffic signal 4	69.3000	3.22	63.0000	77.0000

Model Filename: F:\GG 2009 21\scenario 1\sinario 1 Page 8 of 8

Scenario 2

8:37:09AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6599	0.10	0.4418	0.8638	0.00637325	1.5320
Traffic signal 2	0.6580	0.10	0.4425	0.8568	0.00773311	1.5294
traffic signal 3	0.6630	0.10	0.4462	0.8653	0.00334708	1.5394
Traffic signal 4	0.6596	0.10	0.4424	0.8631	0.00122364	1.5138

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6599	0.10	0.4418	0.8638	0.00637325	1.5320
Traffic signal 2	0.6580	0.10	0.4425	0.8568	0.00773311	1.5294
traffic signal 3	0.6630	0.10	0.4462	0.8653	0.00334708	1.5394
Traffic signal 4	0.6596	0.10	0.4424	0.8631	0.00122364	1.5138

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	52.3732	6.56	38.8815	64.7845
Traffic signal 2	49.9413	6.20	37.1688	60.8342
traffic signal 3	59.9818	7.47	44.6151	73.5471
Traffic signal 4	47.5536	5.92	35.3908	58.6916

Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	105.00	0.00	105.00	105.00
Traffic signal 2	101.00	0.00	101.00	101.00
traffic signal 3	120.00	0.00	120.00	120.00
Traffic signal 4	96.0000	0.00	96.0000	96.0000

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	80.1000	3.02	74.0000	88.0000
Traffic signal 2	76.6000	3.02	71.0000	84.0000
traffic signal 3	91.3000	3.44	85.0000	100.00
Traffic signal 4	72.8000	2.92	66.0000	80.0000

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.6458	0.10	0.4295	0.8495	0.00	1.5275
Traffic signal 2.Queue	0.6479	0.10	0.4297	0.8504	0.00	1.5261
traffic signal 3.Queue	0.6438	0.10	0.4308	0.8411	0.00	1.5068
Traffic signal 4.Queue	0.6584	0.10	0.4368	0.8643	0.00799306	1.5151

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	13.5661	1.97	9.1562	17.3954	0.00	33.0000
Traffic signal 2.Queue	12.9894	1.87	8.7823	16.6306	0.00	31.0000
traffic signal 3.Queue	15.4309	2.22	10.4108	19.7576	0.00	37.0000
Traffic signal 4.Queue	12.3819	1.79	8.3618	15.8800	0.00	30.0000

Model Filename: F:\GG 2009 21\scenario 2\scenario 2 Page 7 of 8

Scenario 3

9:11:30AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

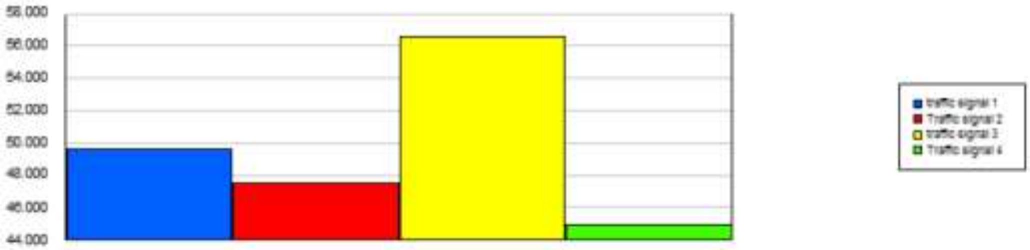
Time per Entity

Wait Time per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Traffic signal 1	0.6462	0.11	0.4242	0.8416	0.00670291	1.5448
Traffic signal 2	0.5564	0.11	0.4104	0.8534	0.00811308	1.5427
Traffic signal 3	0.6594	0.11	0.4308	0.8815	0.00351656	1.4352
Traffic signal 4	0.5768	0.11	0.4287	0.7791	0.00128333	1.5366

Total Time per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Traffic signal 1	0.6362	0.11	0.4042	0.8916	0.00670291	1.5448
Traffic signal 2	0.5564	0.11	0.3304	0.8734	0.00811308	1.5427
Traffic signal 3	0.6594	0.11	0.4308	0.8615	0.00351656	1.4352
Traffic signal 4	0.5768	0.11	0.3287	0.7791	0.00128333	1.5366

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	49.5892	6.42	35.6322	62.5941
Traffic signal 2	47.5302	6.16	34.8593	60.0726
traffic signal 3	56.6404	7.05	41.3572	70.5223
Traffic signal 4	44.9642	5.60	33.0113	56.2595



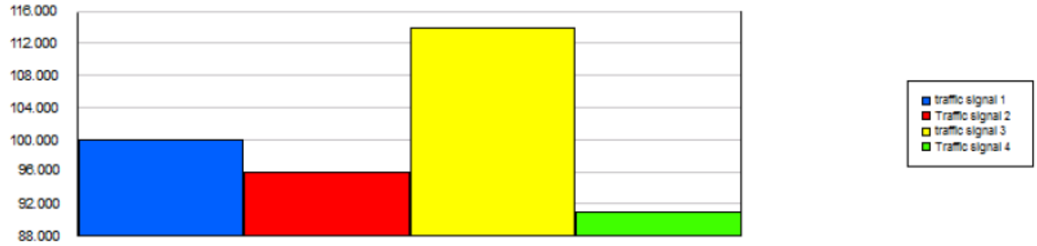
Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Traffic signal 1.Queue	0.6526	0.11	0.4158	0.8573	0.00	1.5402
Traffic signal 2.Queue	0.6640	0.11	0.4161	0.8863	0.00	1.5064
Traffic signal 3.Queue	0.6397	0.11	0.4117	0.8633	0.00	1.5304
Traffic signal 4.Queue	0.6652	0.11	0.4226	0.8616	0.00789235	1.5029

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Traffic signal 1.Queue	12.7958	1.98	8.3515	16.8106	0.00	30.0000
Traffic signal 2.Queue	11.2633	1.88	8.0308	15.8801	0.00	28.0000
Traffic signal 3.Queue	14.5566	2.24	9.5051	19.0751	0.00	35.0000
Traffic signal 4.Queue	11.5914	1.80	7.6352	15.5610	0.00	32.0000

Number In	Average	Half Width	Minimum Average	Maximum Average
Traffic signal 1	101.00	0.00	99.00	101.00
Traffic signal 2	92.0000	0.00	94.0000	94.0000
Traffic signal 3	116.00	0.00	116.00	116.00
Traffic signal 4	90.0000	0.00	90.0000	90.0000



Number Out	Average	Half Width	Minimum Average	Maximum Average
Traffic signal 1	72.4000	3.38	72.0000	85.0000
Traffic signal 2	75.2000	3.11	65.0000	80.0000
Traffic signal 3	84.9000	4.21	78.0000	96.0000
Traffic signal 4	62.3000	3.22	65.0000	71.0000

Model Filename: F:\GG 2009 21\scenario 3\scenario 3 Page 7 of 8

Scenario 4

9:38:11AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

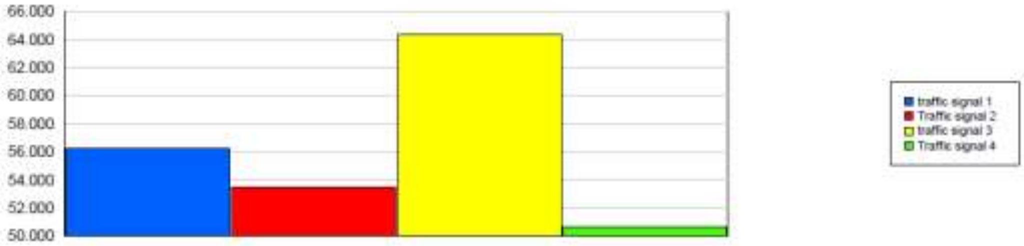
Replications: 10 Time Units: Hours

Key Performance Indicators

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6418	0.10	0.4225	0.8272	0.00571395	1.5294
Traffic signal 2	0.6403	0.10	0.4271	0.8268	0.00693563	1.5065
traffic signal 3	0.6448	0.10	0.4284	0.8293	0.00300814	1.5218
Traffic signal 4	0.6405	0.10	0.4258	0.8273	0.00110426	1.5144

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.6418	0.10	0.4225	0.8272	0.00571395	1.5294
Traffic signal 2	0.6403	0.10	0.4271	0.8268	0.00693563	1.5065
traffic signal 3	0.6448	0.10	0.4284	0.8293	0.00300814	1.5218
Traffic signal 4	0.6405	0.10	0.4258	0.8273	0.00110426	1.5144

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	56.2216	6.83	41.6804	68.6564
Traffic signal 2	53.4645	6.32	39.8379	65.3182
traffic signal 3	64.3396	7.93	46.9432	77.9567
Traffic signal 4	50.6310	6.16	37.2825	62.0447



Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	117.00	0.00	117.00	117.00
Traffic signal 2	111.00	0.00	111.00	111.00
traffic signal 3	133.00	0.00	133.00	133.00
Traffic signal 4	105.00	0.00	105.00	105.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	88.6000	3.92	82.0000	99.00
Traffic signal 2	84.5000	3.94	78.0000	95.0000
traffic signal 3	100.90	4.40	94.0000	113.00
Traffic signal 4	80.0000	3.74	73.0000	90.0000

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.6287	0.10	0.4164	0.8156	0.00	1.5079
Traffic signal 2.Queue	0.6316	0.10	0.4151	0.8122	0.00	1.5106
traffic signal 3.Queue	0.6286	0.10	0.4114	0.8147	0.00	1.5060
Traffic signal 4.Queue	0.6378	0.10	0.4198	0.8271	0.00483110	1.5029

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	14.7380	2.24	9.6752	18.6948	0.00	36.0000
Traffic signal 2.Queue	14.0651	2.13	9.2269	17.7955	0.00	34.0000
traffic signal 3.Queue	16.7651	2.54	10.9831	21.2360	0.00	41.0000
Traffic signal 4.Queue	13.3450	2.03	8.7413	16.8936	0.00	32.0000

Model Filename: F:\GG 2009 21\scenario 4\scenario 4 Page 7 of 8

Scenario 5

10:21:22AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

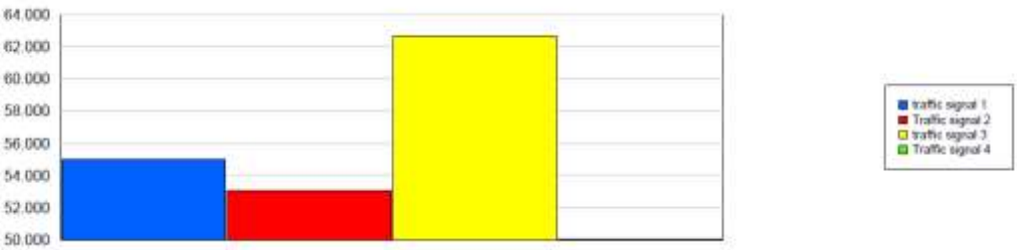
Key Performance Indicators

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.5944	0.09	0.3968	0.7932	0.00538430	1.4733
Traffic signal 2	0.5955	0.09	0.3978	0.7963	0.00657211	1.4729
traffic signal 3	0.5991	0.09	0.4000	0.7954	0.00279630	1.4703
Traffic signal 4	0.5953	0.09	0.3973	0.7933	0.00101473	1.4622

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.5944	0.09	0.3968	0.7932	0.00538430	1.4733
Traffic signal 2	0.5955	0.09	0.3978	0.7963	0.00657211	1.4729
traffic signal 3	0.5991	0.09	0.4000	0.7954	0.00279630	1.4703
Traffic signal 4	0.5953	0.09	0.3973	0.7933	0.00101473	1.4622

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	54.9820	6.27	40.8734	69.8000
Traffic signal 2	53.0854	6.10	39.3807	67.6891
traffic signal 3	62.7112	6.96	46.3977	78.7475
Traffic signal 4	50.0838	5.73	37.3480	63.4624



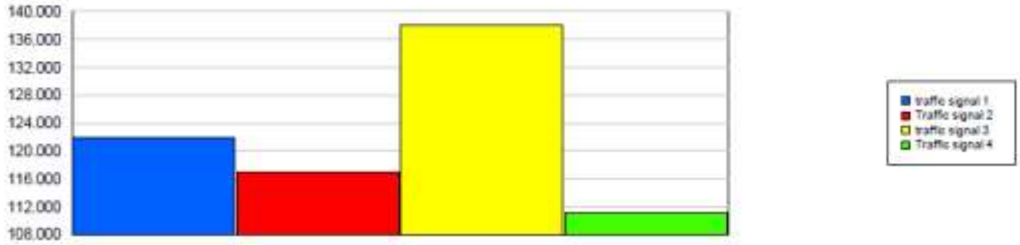
Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.5840	0.09	0.3874	0.7799	0.00	1.4662
Traffic signal 2.Queue	0.5863	0.09	0.3865	0.7843	0.00	1.4591
traffic signal 3.Queue	0.5821	0.09	0.3856	0.7819	0.00	1.4605
Traffic signal 4.Queue	0.5930	0.09	0.3928	0.7929	0.00	1.4491

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	14.4383	1.98	9.6078	18.7169	0.00	36.0000
Traffic signal 2.Queue	13.8934	1.91	9.2113	18.0049	0.00	35.0000
traffic signal 3.Queue	16.2819	2.25	10.7652	21.1222	0.00	41.0000
Traffic signal 4.Queue	13.1357	1.81	8.7035	17.0274	0.00	33.0000

Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	122.00	0.00	122.00	122.00
Traffic signal 2	117.00	0.00	117.00	117.00
traffic signal 3	138.00	0.00	138.00	138.00
Traffic signal 4	111.00	0.00	111.00	111.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	93.3000	3.59	88.0000	103.00
Traffic signal 2	89.9000	3.53	84.0000	99.00
traffic signal 3	105.60	4.13	99.00	116.00
Traffic signal 4	84.9000	3.41	79.0000	94.0000

Model Filename: F:\GG 2009 21\scenario 5\scenario 5 Page 7 of 8

Scenario 6

10:52:53AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

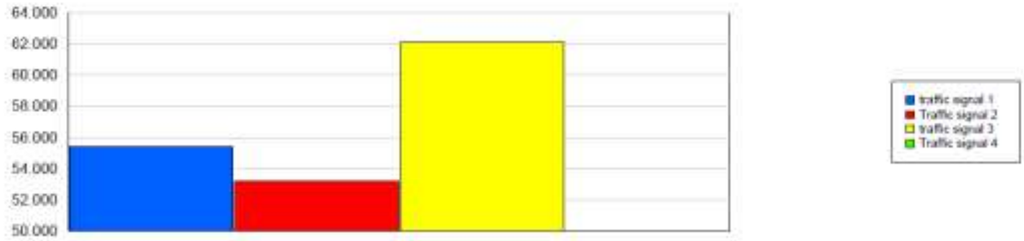
Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.5610	0.08	0.3447	0.7034	0.00526343	1.3880
Traffic signal 2	0.5589	0.08	0.3432	0.7062	0.00598338	1.3902
traffic signal 3	0.5631	0.08	0.3491	0.7087	0.00266919	1.4153
Traffic signal 4	0.5584	0.08	0.3420	0.7008	0.00092519	1.3877

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.5610	0.08	0.3447	0.7034	0.00526343	1.3880
Traffic signal 2	0.5589	0.08	0.3432	0.7062	0.00598338	1.3902
traffic signal 3	0.5631	0.08	0.3491	0.7087	0.00266919	1.4153
Traffic signal 4	0.5584	0.08	0.3420	0.7008	0.00092519	1.3877

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	55.3970	6.61	37.5738	66.8244
Traffic signal 2	53.2038	6.45	36.0309	64.9667
traffic signal 3	62.0903	7.42	42.5863	75.1268
Traffic signal 4	50.0162	5.96	33.8585	60.2663



Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	127.00	0.00	127.00	127.00
Traffic signal 2	123.00	0.00	123.00	123.00
traffic signal 3	142.00	0.00	142.00	142.00
Traffic signal 4	116.00	0.00	116.00	116.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	99.50	3.71	92.0000	109.00
Traffic signal 2	95.9000	3.46	89.0000	105.00
traffic signal 3	111.10	4.04	103.00	122.00
Traffic signal 4	90.3000	3.52	82.0000	99.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.5496	0.08	0.3338	0.6938	0.00	1.3861
Traffic signal 2.Queue	0.5497	0.08	0.3365	0.6931	0.00	1.3832
traffic signal 3.Queue	0.5478	0.08	0.3337	0.6897	0.00	1.3891
Traffic signal 4.Queue	0.5569	0.08	0.3371	0.7058	0.00	1.4002

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	14.1402	1.96	8.7149	17.4915	0.00	36.0000
Traffic signal 2.Queue	13.6709	1.90	8.4185	16.8543	0.00	35.0000
traffic signal 3.Queue	15.7815	2.19	9.7390	19.5078	0.00	40.0000
Traffic signal 4.Queue	12.9005	1.79	7.9459	15.9213	0.00	33.0000

Model Filename: F:\GG 2009 21\scenario 6\scenario 6 Page 7 of 8

Scenario 7

11:26:45AM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4866	0.09	0.3072	0.6835	0.00461512	1.3193
Traffic signal 2	0.4878	0.09	0.3075	0.6873	0.00588723	1.3131
traffic signal 3	0.4907	0.09	0.3120	0.6916	0.00245735	1.3241
Traffic signal 4	0.4859	0.09	0.3061	0.6898	0.00089535	1.3039

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4866	0.09	0.3072	0.6835	0.00461512	1.3193
Traffic signal 2	0.4878	0.09	0.3075	0.6873	0.00588723	1.3131
traffic signal 3	0.4907	0.09	0.3120	0.6916	0.00245735	1.3241
Traffic signal 4	0.4859	0.09	0.3061	0.6898	0.00089535	1.3039

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	51.2534	7.35	35.6340	68.3475
Traffic signal 2	49.6471	7.17	34.4447	66.6685
traffic signal 3	57.2537	8.20	40.2474	76.7684
Traffic signal 4	47.5680	6.97	33.0618	64.8443

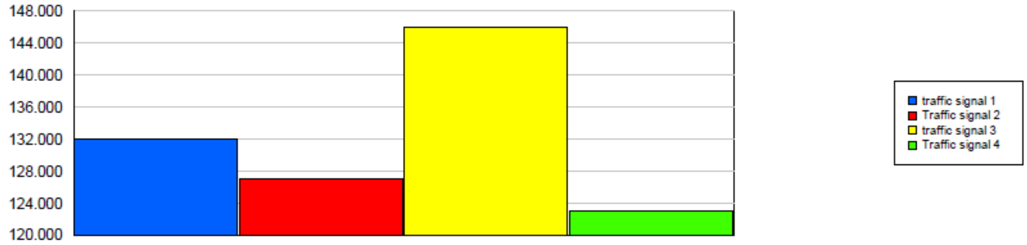
Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.4766	0.09	0.2974	0.6800	0.00	1.3155
Traffic signal 2.Queue	0.4775	0.09	0.2960	0.6748	0.00	1.3020
traffic signal 3.Queue	0.4756	0.09	0.2980	0.6735	0.00	1.3048
Traffic signal 4.Queue	0.4850	0.09	0.3047	0.6877	0.00	1.3070

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	12.7565	2.29	7.9744	17.5708	0.00	35.0000
Traffic signal 2.Queue	12.3096	2.21	7.6547	16.8968	0.00	34.0000
traffic signal 3.Queue	14.0589	2.52	8.7778	19.3446	0.00	39.0000
Traffic signal 4.Queue	11.9178	2.13	7.4704	16.3921	0.00	33.0000

Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	132.00	0.00	132.00	132.00
Traffic signal 2	127.00	0.00	127.00	127.00
traffic signal 3	146.00	0.00	146.00	146.00
Traffic signal 4	123.00	0.00	123.00	123.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	106.60	4.51	98.0000	116.00
Traffic signal 2	103.00	4.25	95.0000	112.00
traffic signal 3	118.10	5.00	109.00	129.00
Traffic signal 4	99.10	4.26	90.0000	108.00

Model Filename: F:\GG 2009 21\scenario 7\scenario 7 Page 7 of 8

Scenario 8

12:14:30PM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

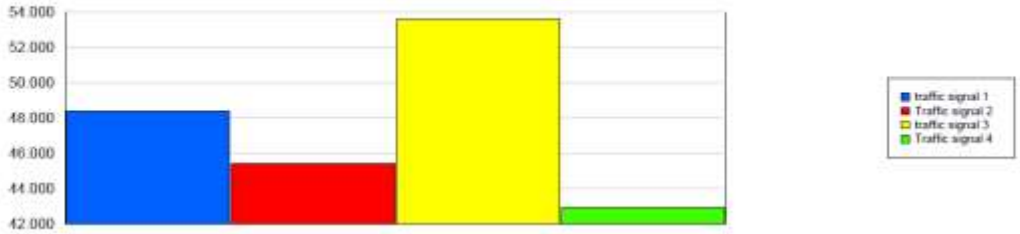
Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4083	0.09	0.1834	0.5973	0.00428546	1.2584
Traffic signal 2	0.4070	0.09	0.1825	0.5942	0.00482702	1.2517
traffic signal 3	0.4101	0.09	0.1853	0.5996	0.00236838	1.2620
Traffic signal 4	0.4065	0.09	0.1809	0.5952	0.00099200	1.2492

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4083	0.09	0.1834	0.5973	0.00428546	1.2584
Traffic signal 2	0.4070	0.09	0.1825	0.5942	0.00482702	1.2517
traffic signal 3	0.4101	0.09	0.1853	0.5996	0.00236838	1.2620
Traffic signal 4	0.4065	0.09	0.1809	0.5952	0.00099200	1.2492

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	48.4019	9.41	24.3950	66.9017
Traffic signal 2	45.3980	8.79	22.8064	62.3913
traffic signal 3	53.5910	10.22	27.0568	73.7538
Traffic signal 4	42.9485	8.27	21.5280	59.5244



Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	142.00	0.00	142.00	142.00
Traffic signal 2	134.00	0.00	134.00	134.00
traffic signal 3	157.00	0.00	157.00	157.00
Traffic signal 4	127.00	0.00	127.00	127.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	120.60	5.39	108.00	133.00
Traffic signal 2	113.50	5.12	102.00	125.00
traffic signal 3	133.00	6.10	119.00	146.00
Traffic signal 4	107.60	5.12	95.0000	119.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.3980	0.09	0.1746	0.5871	0.00	1.2570
Traffic signal 2.Queue	0.3996	0.09	0.1744	0.5864	0.00	1.2478
traffic signal 3.Queue	0.3964	0.09	0.1730	0.5855	0.00	1.2372
Traffic signal 4.Queue	0.4036	0.10	0.1756	0.5935	0.00	1.2476

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	11.4139	2.69	5.0208	16.6721	0.00	36.0000
Traffic signal 2.Queue	10.7524	2.53	4.7192	15.6920	0.00	34.0000
traffic signal 3.Queue	12.5727	2.96	5.4974	18.3228	0.00	40.0000
Traffic signal 4.Queue	10.2383	2.41	4.4742	14.9045	0.00	32.0000

Model Filename: F:\GG 2009 21\scenario 8\scenario 8 Page 7 of 8

Scenario 9

12:34:29PM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Key Performance Indicators

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4392	0.07	0.2728	0.6244	0.00340384	1.1707
Traffic signal 2	0.4382	0.07	0.2725	0.6240	0.00478485	1.1703
traffic signal 3	0.4412	0.07	0.2723	0.6305	0.00224551	1.1691
Traffic signal 4	0.4373	0.07	0.2700	0.6227	0.00091569	1.1646

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.4392	0.07	0.2728	0.6244	0.00340384	1.1707
Traffic signal 2	0.4382	0.07	0.2725	0.6240	0.00478485	1.1703
traffic signal 3	0.4412	0.07	0.2723	0.6305	0.00224551	1.1691
Traffic signal 4	0.4373	0.07	0.2700	0.6227	0.00091569	1.1646

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	53.1330	7.36	36.0067	72.4257
Traffic signal 2	51.6601	7.10	35.1481	70.5135
traffic signal 3	59.6736	8.36	40.0249	81.9621
Traffic signal 4	48.7661	6.75	32.9359	66.6302

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.4285	0.07	0.2615	0.6146	0.00	1.1631
Traffic signal 2.Queue	0.4309	0.07	0.2641	0.6145	0.00000891	1.1530
traffic signal 3.Queue	0.4281	0.07	0.2619	0.6146	0.00	1.1658
Traffic signal 4.Queue	0.4357	0.08	0.2669	0.6257	0.00	1.1597

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	12.5839	2.15	7.6564	17.5120	0.00	35.0000
Traffic signal 2.Queue	12.3191	2.09	7.5349	17.1149	0.00	33.0000
traffic signal 3.Queue	14.0306	2.40	8.5482	19.5424	0.00	39.0000
Traffic signal 4.Queue	11.6925	1.98	7.1687	16.2560	0.00	32.0000

Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	146.00	0.00	146.00	146.00
Traffic signal 2	142.00	0.00	142.00	142.00
traffic signal 3	163.00	0.00	163.00	163.00
Traffic signal 4	135.00	0.00	135.00	135.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	122.20	4.87	113.00	132.00
Traffic signal 2	119.10	4.77	110.00	129.00
traffic signal 3	136.60	5.35	126.00	147.00
Traffic signal 4	112.70	4.75	103.00	122.00

Model Filename: F:\GG 2009 21\scenario 9\scenario 9 Page 7 of 8

Scenario 10

12:53:29PM **Category Overview** June 13, 2017

Values Across All Replications

Traffic Flow Arena simulation modeling at St.Stifanos intersection

Replications: 10 Time Units: Hours

Key Performance Indicators

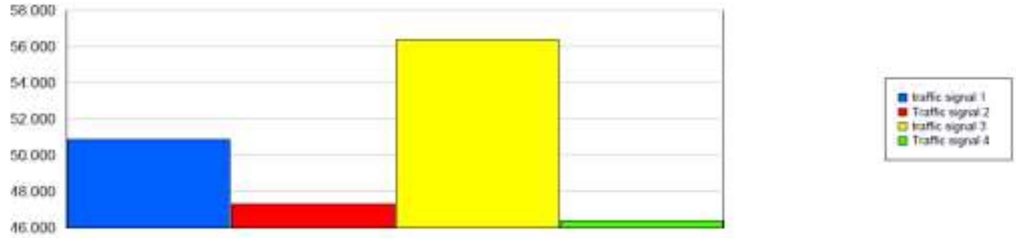
Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.3796	0.07	0.2118	0.5366	0.00395581	1.0070
Traffic signal 2	0.3797	0.07	0.2107	0.5372	0.00224714	1.0145
traffic signal 3	0.3825	0.07	0.2126	0.5388	0.00211841	1.0145
Traffic signal 4	0.3797	0.07	0.2097	0.5372	0.00156276	1.0061

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1	0.3796	0.07	0.2118	0.5366	0.00395581	1.0070
Traffic signal 2	0.3797	0.07	0.2107	0.5372	0.00224714	1.0145
traffic signal 3	0.3825	0.07	0.2126	0.5388	0.00211841	1.0145
Traffic signal 4	0.3797	0.07	0.2097	0.5372	0.00156276	1.0061

Accumulated Time

Total Accum Time	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	50.9093	8.11	31.9784	70.2892
Traffic signal 2	47.3015	7.65	29.4988	65.5362
traffic signal 3	56.4044	9.06	35.0857	77.5880
Traffic signal 4	46.3772	7.58	28.7315	64.4636



Number In	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	159.00	0.00	159.00	159.00
Traffic signal 2	147.00	0.00	147.00	147.00
traffic signal 3	174.00	0.00	174.00	174.00
Traffic signal 4	145.00	0.00	145.00	145.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
traffic signal 1	135.70	5.61	127.00	151.00
Traffic signal 2	126.00	5.07	118.00	140.00
traffic signal 3	149.10	5.78	140.00	165.00
Traffic signal 4	123.50	4.91	115.00	137.00

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	0.3723	0.07	0.2030	0.5296	0.00	1.0050
Traffic signal 2.Queue	0.3720	0.07	0.2030	0.5284	0.00	1.0023
traffic signal 3.Queue	0.3700	0.07	0.2010	0.5250	0.00	1.0026
Traffic signal 4.Queue	0.3765	0.07	0.2069	0.5361	0.00	1.0016

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
traffic signal 1.Queue	11.9153	2.28	6.3749	16.4073	0.00	33.0000
Traffic signal 2.Queue	11.0452	2.11	5.9038	15.1945	0.00	30.0000
traffic signal 3.Queue	13.0263	2.49	6.9344	17.9173	0.00	36.0000
Traffic signal 4.Queue	10.9308	2.08	5.8722	15.0295	0.00	30.0000

Model Filename: F:\GG 2009 21\scenario 10\scenario 10 Page 7 of 8