



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

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa
A Case Study of Meskel Square to Kality Interchange

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the requirements for Degree of Master of Science in Civil Engineering
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LIST OF ACRONYMS

AACRA: Addis Ababa City Road Authority

AACTM: Addis Ababa City Traffic Management

CO: Carbon Monoxide

CO_x: Carbon Oxides

CO₂: Carbon Dioxide

CSA: Central Statics Agency

DEFRA: Department for Environment, Food and Rural Affairs

ECEFC: Expected Cost of Extra Fuel Consumed per hour

ETB: Ethiopian Birr

FFC: Free Flow Condition

HC: Hydro Carbon

HCM: Highway Capacity Manual

HCV: Heavy Commercial Vehicle

HTS: Highly Time Sensitive

JIT: Just in Time

LOS: Level of Service

LT: Left Turn

LTS: Low Time Sensitive

MTS: Moderately Time Sensitive

NCHRP: National Cooperative Highway Research Program

NO_x: Nitrogen Oxides

NO₂: Nitrogen Dioxide

N₂O: Nitrogen Monoxide

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PCU: Passenger Car Unit

P/W: Power - Weight Ratio

RT: Right Turn

SO_x: Sulfur Oxides

SO₂: Sulfur Dioxide

SIDRA: Traffic Signalized & Un-Signalized Intersections Design and Research Aid

TH: Though Turn

TW: Two Wheelers

UMR: Urban Mobility Report

V_p: Vehicle Occupancy

ABSTRACT

Cities in the world have faced many challenges like traffic congestion, air pollution, noise pollution and accidents. These challenges especially traffic congestion, is however, expected to aggravate in the nearest future. Due to congestion commuters travel time and vehicle operating costs increase with fuel consumption and emission rates increase with pollutants increases.

Following its economic development, Addis Abba has faced traffic congestion problems which cause chronic problems to both the road users and non-users. This paper mainly focuses on traffic congestion analysis and its economic cost by addressing traffic congestion causes, effects, patterns and especially its economic cost on the North-South corridor of Addis Ababa. In order to analyze traffic congestion, travel time approach was used whereas analysis of level of service analysis was made using SIDRA intersection based on delay. Afterward, traffic cost is calculated considering delay to passenger vehicles which includes operating costs, extra fuel wasted due to congestion, delay to truck vehicles including operating cost, extra fuel wasted due to congestion by truck, business cost and finally environmental cost of traffic congestion. Then finally, measures to mitigate traffic congestion are recommended based on questionnaire and field visit study.

Based on the analysis, it was found that total congestion cost including delay, wasted fuel and operating cost of passenger vehicles and truck vehicles at each road segments on average is about **Birr 53.2 million** per year. In addition, congestion has costs on the environment and results show that when traffic congestion increases fuel consumption and emission of pollutants increase.

From the different traffic congestion measures, improving current light rail transit is the most important since by improving the current status of light rail transit, on the average **Birr 25.5 million per year** cost of congestion is saved and **11,281.20 kg of CO₂** emission is reduced per each road segment.

1. INTRODUCTION

1.1.General

Economic development and high urbanization rate has caused many challenges to transportation system As the living standard of the people becomes more modernized and increased in number, transportation demand being increasing rapidly and it must be copped with the proper transportation planning. If there is no such good transportation planning and so traffic congestion, air and noise pollution, accidents and economic loss are occurring largely affecting the nation in general and particularly the residents of specific areas.

Addis Ababa is currently showing low motorization rates by global standards, with about a total vehicle fleet estimated at 500, 000 which is 60 percent of the total fleet of the country in 2015, faces challenges of providing provision of reliable, efficient and safe transportation (Addis Ababa City Roads and Transport Bureau, 2016). Furthermore, the rapid economic growth currently experienced in the city leads attracting business organizations, growth in private vehicle ownership which is also provoking the challenges. Growth in urbanization and industrialization requires more vehicle usage which tends to create imbalance between the available infrastructures and mobility demand.

Nowadays, cities in the world are faced with traffic congestion, air and noise pollution and accidents. These urban challenges especially traffic congestion, is however, expected to aggravate in the nearest future. Thus, Addis Ababa is nowadays experiencing traffic congestion and individuals are incurring different effects like delays which is time during their day to activities, air pollution, noise pollution, excess fuel consumption of vehicles, excess vehicle operating costs like additional costs for spare parts, excess fuel, for those business men, it creates additional costs since supply may not be available at time, extra inventory cost to minimize congestion effects on their business, losing their workers time, their workers may not perform to their capacities because of being tired, stressed and bored as a result of congestion. In this paper,

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economic cost of traffic congestion is considered since congestion aggravates and affects the day-to-day activities of the residents of Addis Ababa.

As a result of the above effects it is important to analyze the patterns of congestion, causes and effects on both the road users and non-users, evaluation of economic, social and environmental cost of traffic congestion. Nowadays the city transport authority has been restructured and has started taking some actions.

In order to address congestion challenges, the following mitigation measures have significances as observed through questionnaires and site visits conducted the following measures are expected to reduce traffic congestion: Improve LRT (Light rail transit), use mass transport, improve geometric design of roads, increase road capacity, improve traffic management strategies, improve parking management and parking capacity increasing especially off road-way parking facilities, mitigate illegal on street trade, flexible work schedule and introducing bus rapid transit. Encouraging the development of other urban centers in Ethiopia with fulfillment of basic needs for the residents might reduce the stress on Addis Ababa.

1.2.Statement of the problem

As a result of increasing urbanization and industrialization, Addis Ababa has been experiencing over the year's traffic congestion problems which hinder citizens' mobility and timely delivery of commodities. So, traffic congestion in Addis Ababa causes problems like waiting longer time for buses and taxies, delay to work places and school, longer transient time, more energy consumption, air and noise pollution, commodity deliverance delays, environmental costs. All these problems also cause different negative effects on the health of citizens such as stress and headache, significant economic loses for the business companies arrive on time at work places, negative impact on the delivery of goods and services, increased fuel use, traffic accidents even though the severity might be less as compared to those of uncongested street, adversely affects the learning processes of students at schools.

The main causes of traffic congestion on the selected road corridor are different. The following are among the prominent contribution factors which aggravates traffic congestion: shortage of mass transport, poor traffic management, imbalance of vehicle volume and road capacity especially at intersections, parking of passenger cars for loading and unloading of passengers near intersection entry and exit, parking on walkways and road ways which forces passengers to use roadways and conflicts with vehicles, inflexible work zone and to some extent traffic accidents are the major causes of traffic congestion:

In view of the above, it was found to conduct a research to estimate the negative impacts of traffic congestion in Addis Ababa and come up with possible actions to be undertaken to counter that. This thesis is mainly focused on identifying the causes of traffic congestion, analysis of traffic congestion considering selected road segments and intersections using travel time approach and LOS using SIDRA software.

1.3.Objectives the Study

1.3.1. General Objective

The general objective of this research is to examine the causes of traffic congestion in Addis Ababa and to analyze its patterns of traffic congestion on selected segments of the city routes and to calculate its economic costs.

1.3.2. Specific Objectives

- ✚ Identifying the causes of traffic congestion;
- ✚ Analyze traffic congestion on the selected route using delay and level of service parameters;
- ✚ Estimate associated impacts of congestion and their economic costs based on delay parameters, person value time, fuel waste due to congestion, business delay cost;
- ✚ Estimate environmental costs of traffic congestion; and
- ✚ Suggest possible solutions to minimize traffic congestion.

1.4. Thesis structure

The study is divided into five chapters including the introduction as Chapter I; Chapter II reviews relevant studies to further demonstrate the literature gaps; Chapter III details the methods used in for the analysis; Chapter IV discusses the results and Chapter V presents a summary of the research, concluded with key findings and its unique contribution to alleviate traffic congestion economic impact with incorporation of the forwarded recommendations. Finally Chapter VI deals with proposals for future areas.

2. LITERATURE REVIEW

2.1.General

As a result of development and increase population the need for transportation demands increases. Due to this, traffic volume increases incurring different costs to both the road users and non- road users. Traffic congestion needs additional facilities and proper traffic management to control traffic congestion.

Cities in the world have varies transport challenges. According to the Ministry of Transport of Ethiopia (2014), the challenges of the urban transport include: continuous increases in transport fare especially for low income groups, lack of smooth traffic flow, lack of infrastructures for non-motorized transport for walking and cycling, high rate of traffic accidents and increasing air and noise pollution.

2.2.Definition of Traffic Congestion

There is no single, broadly accepted definition of traffic congestion. One of the principal reasons for this lack of consensus is that congestion is both: a physical phenomenon relating to the manner in which vehicles impede each other's progression as demand for limited road space approaches full capacity and a relative phenomenon relating to user expectations with road system performance (European Conference of Ministers of Transport, 2007). Traffic congestion is defined as a condition of traffic delay (when the flow of traffic is slowed below reasonable speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them. The resulting traffic slowdowns can have a wide range of negative effects on people and on the business economy, including impacts on air quality, quality of life due to personal time delays, and business activity due to the additional costs and reduced service areas for workforce, supplier, and customer markets (NCHRP report 463, 2011).

According to Wallis and Lupton, 2013 three possible ways of defining congestion are identified:

- ✚ Economists define congestion as the presence of interactions between vehicles on the road. In effect, all roads that carry significant traffic volumes are congested.
- ✚ Users perceive roads to be congested when speeds fall below an acceptable level, which may differ by location and over time i.e. 'perceived congestion'.
- ✚ Engineers classify a road as congested when more vehicles are attempting to use the road than it has capacity to carry.

So, traffic congestion has three important dimensions of variations according to the NCHRP Report 463(2011): The spatial pattern of traffic congestion may vary it can be area wide or location specific: The temporal pattern of traffic congestion may vary; it can occur during morning or afternoon peak periods or during off-peak periods. There is also a stochastic element of traffic congestion, it can occur on a continuing basis at predictable times or sporadically (at random times) as a result of traffic accidents or other types of incidents.

Lomax et al (1997) describe traffic congestion as having four components that interact and vary between and within urban areas:

- ✚ Duration: The amount of time that congestion affects the road system;
- ✚ Extent: The number of people or vehicles affected and the geographic distribution of the congestion;
- ✚ Intensity: The severity of the delay; and
- ✚ Reliability: The variation in the other three elements.

2.3.Causes of Traffic Congestion

Traffic congestion is caused by different factors. According to Schrank et al (2013), the causes of traffic congestion are: firstly, many people and lots of freight moving at the same time; secondly, the slow growth in supply; and thirdly that causes many trips to be delayed by events that are

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irregular. However, frequent crashes, vehicle breakdowns, improperly timed traffic signals; special events and weather are factors that cause a variety of traffic congestion problems.

Another research done by Mekonnen (2015) summarizes the major causes of traffic congestion as follows: traffic accident, work zone environment, damage of existing traffic signals, reduction of road capacity, vehicle damage and on street parking.

In addition to the above, a research done by Mahmud1 et al, (2012) summarizes the major causes of traffic congestion as follows:

(i). Narrow roads

Streets are not that wide spread, due to illegal possession on the road they are getting narrow and becoming a reason behind traffic jam. So, every possibility is there to expand the road as per their right- of- way to reduce traffic congestion. Moreover this will be less expensive and less time consuming due to land acquisition that won't be required in this process.

(ii). Illegal Parking

Illegal parking on the road has been creating congestion every day. On-road parking of vehicles is one of the main reasons behind serious traffic congestion on different parts of the routes.

(iii). Increasing number of population

All the areas under cities are facing an increasing number of populations which is a bad indicator for the traffic management and this could be a vital reason behind traffic.

(iv). Higher purchasing power of the public

Due to the higher purchasing power of the citizen of cities, the popularity of private transportation is increasing and but existing roads and highways are not supportive or changing according to the increasing number of vehicle. As a result vehicle congestion is increasing at an alarming rate.

(v). Improper planning of city development

Development Plan has its long term city development planning. However, that planning is not proper. Most of the time it is seen that some illegally ceased roadside land, but due to the vague development plan these kinds of movements are going in vain.

(vi). Improper lane management

Lane management is an important fact in managing the traffic. Many types of the vehicles try to overtake other vehicles even in the single undivided road. This is the main reason that the city roads are unequipped with the lane dividers which divide the lane into incoming and outgoing traffic.

2.4.Measuring Traffic Congestion

Congestion can be measured in various ways depending on the purpose of analysis. In order to measure congestion, there are parameters which indicate the intensity of traffic congestion. As stated by Aftabuzzaman (2007), measures of traffic congestion can be categorized into four broad groups: basic measures, ratio measures, level of service measures and indices.

Basic measures are related to delay estimation. Delay has been defined as the additional time experienced by a road user in comparison to the free flow travel or the acceptable travel time. Lomax et al (1997) developed segment delay, congested travel (volume or person weighted congested roadway length), and congested roadway length to estimate an individual segment delay as basic measures of congestion. Ratio measures of traffic congestion are usually developed by dividing one travel time or delay element by another. Several ratio measures (delay rate, relative delay rate and delay ratio) were developed by Lomax et al (1997) based on travel rate. Level of service (LOS) is also used as one measure of traffic congestion. The LOS concept as adopted in the 1985 Highway Capacity Manual (1985) represents a range of operating conditions. The LOS of a facility is determined by traffic flow characteristics such as vehicle density, volume-to-capacity ratio, average speed and intersection delay, depending on facility type. The scale of LOS measure has six discrete classes ranging from A to F in which LOS A

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represents a free flow, individual users are virtually unaffected by others in the traffic stream and there is freedom to select desired speeds and to maneuver within the traffic stream is extremely high. LOS F represents the most congested flow, forced or breakdown flow. The last congestion measure parameters are indices which includes congestion index, travel rate index, congestion burden index, roadway congestion index and others.

In addition to the above congestion measures as stated by NCHRP report 463 (2011) we can classify impacts of congestion as user impacts of congestion and non-user impacts of congestion. User impacts of congestion also are classified as: time-related measures, volume measures, congestion indices, delay measures, and LOS measures. Time-related measures include average travel speed, average travel time, average travel rate and others. Volume measures include vehicle miles traveled/lane miles, traffic volume. Congestion indices include congestion index, roadway congestion index, and excess delay. LOS measures include lane miles at/of LOS vehicle hours traveled, predominant intersection LOS, and number of congested intersections. Delay measures also include delay/trip, delay/vehicle miles traveled, minutes of miles traveled and delay due to construction/incidents. Non-user impacts of congestion can be summarized as follows: Travel expense, Logistics and JIT processing costs, Market scale and accessibility costs and Business cost of worker commuting. Table 2-1 below shows LOS analysis and volume to capacity ratio.

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Table 2-1: LOS analysis and Volume/capacity ratio

LOS	Description	Volume/ Capacity
A	Free- flow condition with unimpeded maneuverability, stopped at , stopped delay at signalized intersection is minimal	0.00-0.60
B	Reasonably unimpeded operations with restricted maneuverability, stopped delays are not bothersome.	0.61-0.70
C	Stable operations with somewhat more restrictions in making mid-block lane changes than LOS B. Motorists will experience appreciable tension while driving.	0.71-0.80
D	Approaching unstable operations where small increases in volume produce substantial increases in delays and low average speeds.	0.81-0.90
E	Operations with significant intersection approach delays and low average speeds.	0.91-1.10
F	Extremely low speeds caused by intersection congestion, high delay and adverse signal progression.	Greater than 1.0

Based on level of service Joshua and Iyiola (2009) measured average capacity/volume ratio and congestion as depicted in table 2-2 below.

Table 2-2: Average Capacity /volume ratio and congestion

No.	Average traffic volume/capacity ratio	Technical interpretations
I	Less than 0.6	No congestion
Ii	0.6 to 0.8	Slight congestion
Iii	0.8 to 1.0	Congestion
Iv	1.0 to 1.2	Severe congestion
V	Greater than 1.2	Extreme congestion

2.5. Impacts of Traffic Congestion

Congestion involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. Congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, stress, and safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties. (Mahmud1 et al, 2012).

The impacts of traffic congestion can be viewed in three ways: impact on economy, impact on health, and impact on environment. Traffic congestion has great economic impact due the society losing money in four ways as shown below (Mahmud1 et al, 2012):

- ✚ Loosing man-hours;
- ✚ Extra transportation cost;
- ✚ Extra fuel consumptions;
- ✚ Vehicle operating cost; and
- ✚ Miscellaneous cost.

Due to traffic congestion, the main sufferers are classified as follows:

(i). General peoples

Most People are suffering some kind of physical or mental discomfort due to traffic congestion and some ways of suffering are listed as follows: Breathing problem, headache, mental stress, hearing problem, unexpected sweating, tiredness, and eye problem.

(ii). Vehicle operators

The ways of sufferings for the vehicle operators are almost similar to other people. The main sufferings due to traffic congestion are: headache, pain in the body, and excessive sweating.

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Traffic congestion impacts on the environment can be viewed in two ways as sound pollution and air pollution causes environmental pollution in two main ways. The effects of sound pollution are: students in the nearby school are disrupted their study by noise and to the nearby society causes headache difficulty in concentration and sleeping, bad tempers, and experiences hearing problems. So, air pollution as traffic becomes congested it introduces air pollution through SO_x, NO_x, CO_x (SO₂, CO, CO₂, N₂O, NO₂) and in the traffic jam, when vehicles stop for a longer periods of time and their engine is on, they emit SO_x, NO_x much which are lighter than air but very dangerous for our health and they even can cause death (Mahmud et al, 2012).

As a result of traffic congestion the following classes of trips are affected according to NCHRP, 463 (2011)

- ✚ Commuting (Home-Work Car Trips);
- ✚ Regional Freight Delivery (Work-to-Work Internal Truck Trips);
- ✚ Interregional Freight Delivery (Work-to-Work External Truck Trips);
- ✚ Regional Service Delivery (Work-to-Work Non commodity Trips);
- ✚ Personal Travel (Home-Based Non-work Trips).

Congestion has different impacts within the society. Congestion involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. Congestion also has a range of indirect impacts including the marginal environmental and resource impacts of congestion, impacts on quality of life, stress, safety as well as impacts on non-vehicular road space users such as the users of sidewalks and road frontage properties (European Conference of Ministers of Transport, 2007). May and Marsden (2007) argue that congestion impairs us from moving freely and that it disrupts business activities in cities and reduces productivity. It affects a wide range of activities, services, goods, markets opportunities in the cities which can best be delivered through transport mobility. The report continues that congestion also reduces productivity through increased inventory holding by manufacturers and retailers as a result of unreliable travel conditions within cities. Business

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activities depend on timely delivery of logistics. However, freight movement in cities is impaired by traffic congestion, thus making productivity suffer.

For the purposes of analysis, business operation impacts can be reclassified into three classes of costs as stated by NCHRP 463(2011):

- ✚ Direct travel (user) cost, including vehicle operating costs and value of time for drivers and passengers, for all business-related travel;
- ✚ Logistics and scheduling costs, including costs of stocking, perish ability, and just-in-time processing; and
- ✚ Market accessibility and scale, including loss of market-scale economies and reduced access to specialized labor and materials because of congestion.

Koopmans and Kroes (2003) also concludes the inclusion of costs of fuel, accidents and emissions does not seem to affect the estimates strongly, as the total of these costs, if included, is less than 20% of the time costs.

To measure the economic costs of congestion, first it is important to define congestion. Three choices are identified in the literatures as stated by Koopmans and Kroes (2003): (i) most economists implicitly treat anything less than free flow as congested, so the economists' definition of congestion is the presence of interactions between vehicles on the road. Practically all major roads are thus 'congested' which does not seem a very useful definition; (ii) users perceive roads to be congested when speeds fall below an acceptable level (which may differ by location and over time), which perceived congestion; and (iii) engineers classify a road as congested when more vehicles are attempting to use the road than it has capacity to carry. The latter situation is defined by economists as hyper-congestion and corresponds to the lower branch of the speed-flow curve.

Another study done by Litman (2014), which is used to measure economic cost of congestion the first factor that is baseline (threshold) speed below which congestion cost is calculated. As Litman (2014), baseline speed can be based on:

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- ✚ Free-flow speeds (traffic speeds measured during uncongested conditions);
- ✚ Speed limits (maximum legal speeds on a road);
- ✚ Capacity-maximizing speeds (speeds that maximize vehicle traffic capacity on each road); and
- ✚ Economic efficiency-optimizing (consumer-surplus maximizing or deadweight loss minimizing) speeds, which reflect users' willingness-to-pay for faster travel.

Traffic congestion has also a negative effect on supply chain systems. As Weisbrod and Fitzroy (2011) there are many ways of categorizing the impacts of congestion on businesses and the metropolitan business environment, so, defining taxonomy for describing the ways in which congestion can lead to changes affecting businesses and their operations. It is based on seven types of congestion impacts: (a) market & fleet size; (b) business & delivery schedules; (c) inventory management; (d) use of intermodal connections; (e) worker travel; (f) business relocation; and (g) localized interactions with other activities. Table 2-3 below presents business class of congestion impacts on market and fleet size.

Table 2-3: Business class of congestion impacts on market and fleet size

Class of Congestion Impacts	Implications for business and economy
Market and fleet size	Delivery area, market size/type, delivery and reliability cost, assignment reliability
Business and delivery schedule	Delivery time shifts, trucks dispatch, backhaul operations, relief drivers, operating schedules
Intermodal connections	Access to truck/rail/air/sea interchange terminals
Business inventory and operations management	Inventory requirements, stocking costs, inventory management/control, cross-docking opportunities
Worker travel	Workers time/expense, workers schedule reliability, service delivery cost
Business relocation	Distribution from smaller, more dispersed locations, consolidations of production sites
Externalities: Interactions with other activities	Land use and development shifts, cost passed on to worker and customers

Figure 2-1 below present congestion model process by which traffic congestion leads to impact of business activity.

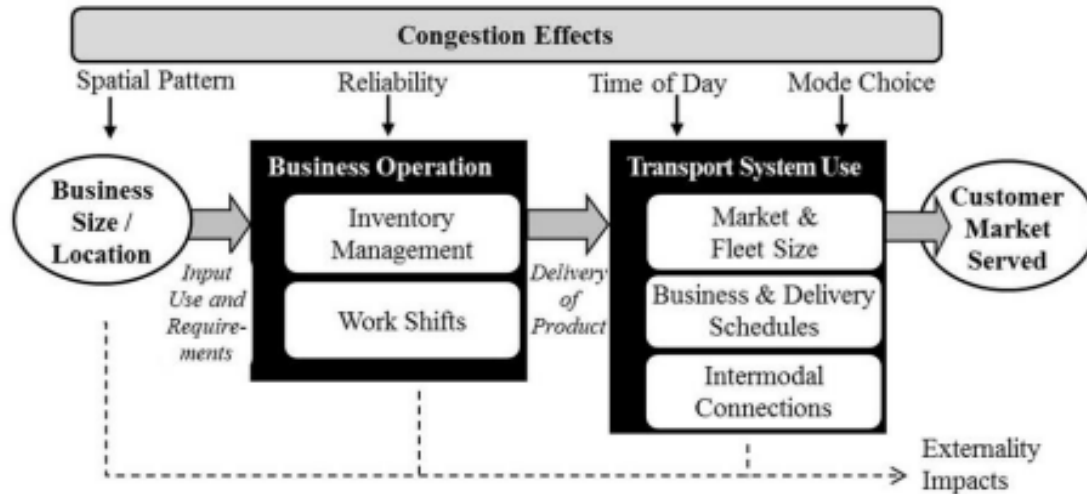


Figure 2-1: Congestion Model process by which traffic congestion leads to impact of business activity

2.6. Measuring Economic Cost of Congestion

As discussed by Mitiku (2015), the major costs incurred due to traffic congestion at cross intersections and roundabouts are mentioned below:

- ✚ Cost of extra fuel consumed by vehicles; and
- ✚ Cost of lost time by passengers and drivers.

(i). Cost of Extra fuel consumed

So, according to Mitiku (2015), to calculate costs due to extra fuel wasted:

- ✚ Average fuel consumption of a single vehicle per hour which is approximately estimated 1.263 liter per vehicle;
- ✚ Unit cost of fuel (assumed about 19 ETB).
- ✚ Expected Cost of Extra Fuel Consumed (ECEFC) per hour for a road junction is in the form of linear function:

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

$$ECEFC = C_u \times FC \times W_d \times L_d$$

Where:

ECEFC= Expected Cost of Extra Fuel Consumed per hour;

C_u =Unit cost of fuel (19 ETB);

FC=Extra fuel consumed by one vehicle per hour (1.263 liter per vehicle);

W_d =Difference in average waiting time at the road junction; and

L_d = the difference in number of vehicles waiting at the road junction.

Thus, Cost of annual extra fuel consumed due to congestion can be calculated as:

$$ACEFC = ECEFC \times ACF$$

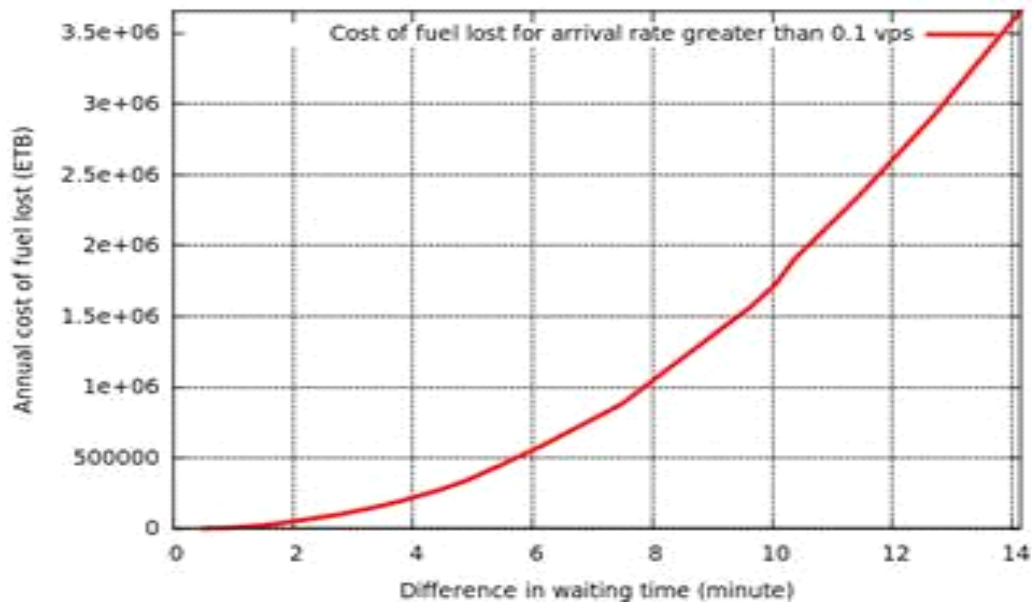
Where:

ACEFC =Annual cost of extra fuel consumed

ECEFC =Expected Cost of Extra Fuel Consumed per hour

ACF =Annual Conversion Factor (1300).

The cost of fuel lost rapidly increase if vehicles are waiting much time For example, the annual cost of extra fuel consumed due to delay was approximately estimated at ETB 560,000 if vehicles are waiting about 6 minutes. Figure 2-2 below illustrates the relationship between annual costs of extra fuel consumed.



Source (Mitiku, 2015)

Figure 2-2: Relationship between annual cost of extra fuel consumed

(ii). Cost of Time Lost due to Waiting at Road Intersection

According to Mitiku (2015), the value of lost time which may be either working time or non-working time that is opportunity cost caused by waiting of passengers' and drivers' at road junctions needs to be calculated.

For calculation of cost for lost time, it is important to calculate the lost time and determine cost for that lost time. But, the value of time varies from person to person because some of them might be business men, intellectuals, workers and others. So, according to Mitiku (2015), by considering various factors the value of time for an individual is estimated to be ETB 11 per hour and vehicle occupancy is approximated $V_p = 10.9$ passengers per vehicle.

Hence, according to Mitiku (2015), the cost of time lost due to vehicles delay at the road intersection could be calculated as:

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$$CT = L_d \times W_d \times t_a \times v_p$$

Where:

C_T = Cost of time lost per hour;

L_d = Difference in number of vehicles waiting in the system;

W_d = Difference in average waiting time per vehicles;

t_a = Average value of time;

v_p = Vehicle occupancy;

Therefore, to the above equation which is cost of time into annually, it is better to use annual conversion factor to convert into annual cost of time. Thus, according to Mitiku (2015), annual cost of time lost due to congestion can be determined by using:

$$ACTL = CT \times ACF$$

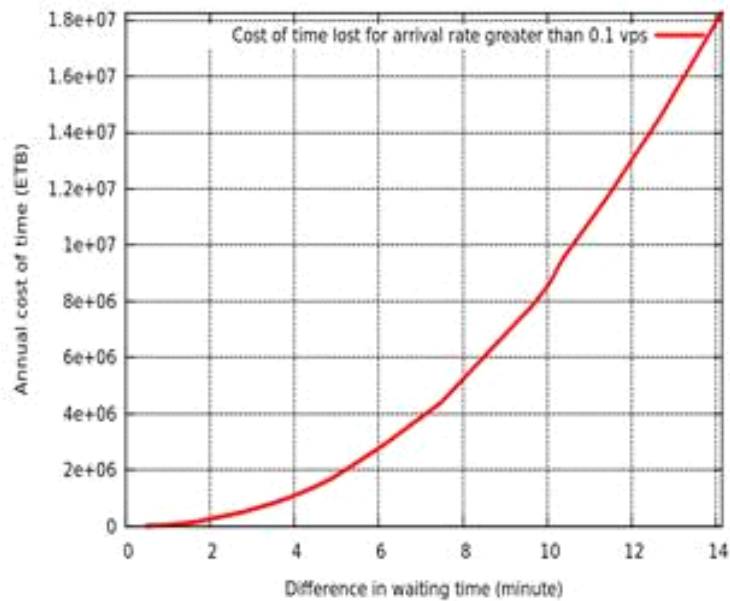
Where:

ACTL = Annual cost of time lost;

C_T = Cost of time lost per hour;

ACF = Annual Conversion Factor (1300)

Figure 2-3 below shows the relationship between annual cost of time lost and difference in waiting time.



Source (Mitiku, 2015)

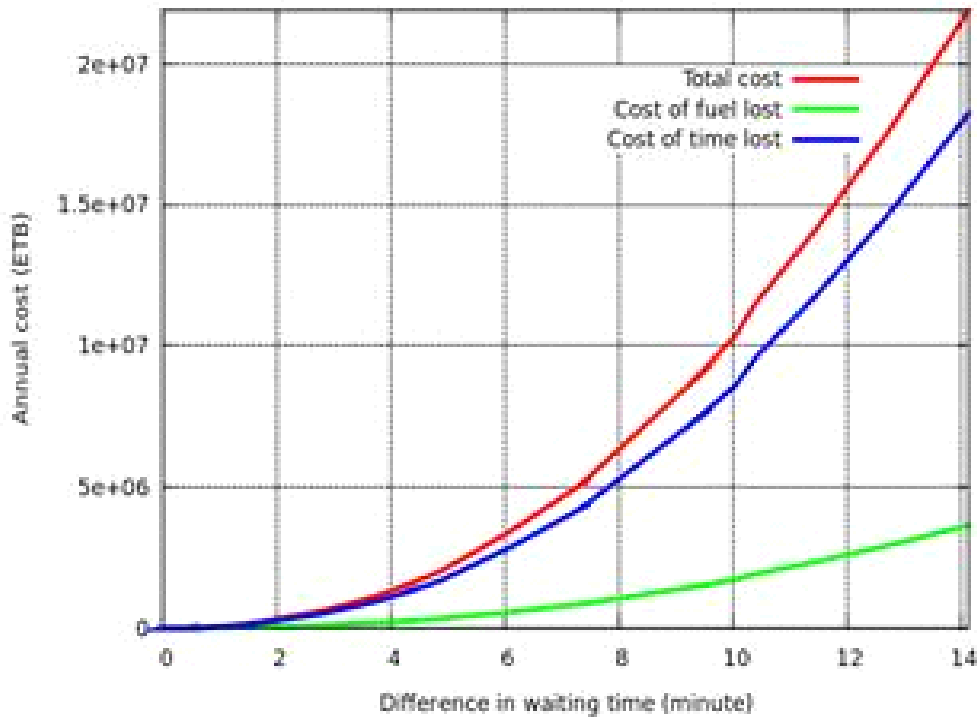
Figure 2-3: The relationship between annual costs of time lost and waiting time

Therefore, Mitiku (2015) concluded that waiting about 6 minutes at the junction costs passengers time lost which was approximately estimated at ETB 2,900,000 per year and costs of time lost were estimated depending on the waiting time of vehicles at road junctions.

V). Cost Comparison of Fuel and Time Lost

From Figure 2-4 below, the cost of time lost is greater than cost of fuel lost when vehicles are waiting at the road junctions.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)



Source (Mitiku, 2015)

Figure 2-4: Comparisons of cost of time with fuel and lost time

Another research done by Eisele et al (2013) to calculate congestion cost used the following procedures.

Travel Delay: according to Eisele et al (2013) travel delay is the amount of extra time spent traveling under congestion and computed as follows:

$$\text{Daily Vehicle Hours of Delay} = \frac{\text{Daily Vehicle Miles of Travel}}{\text{Speed}} - \frac{\text{Daily Vehicle Miles of Travel}}{\text{Free Flow Speed}}$$

Annual Person Delay: To calculate the annual person-hours of delay, Eisele et al (2013) multiply each day-of-the-week delay estimate by the average vehicle occupancy (1.25 persons per vehicle) and by working weeks per year.

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$$\text{Annual person hours of delay} = \sum_{i=1}^7 \frac{\text{Daily vehicle hours of delay on freeways}}{\text{vehicle}} \times \frac{52 \text{ Working weeks}}{\text{vehicle}} \times \frac{1.25 \text{ Persons per}}{\text{vehicle}}$$

Wasted Fuel: according to Eisele et al (2013) the average fuel economy calculation is used to estimate the difference in fuel consumption of the vehicles operating under congested and uncongested conditions.

$$\text{Passenger Car Fuel Efficiency} = ((-0.066) \times (\text{Speed})^2 \times 0.823 \times (\text{Speed}) + 6.1577)$$

$$\text{Truck Fuel Efficiency} = (1.4898 \times \ln(\text{Speed}) - 0.2554)$$

To calculate the wasted fuel due to vehicles moving at speeds slower than free flow throughout the day, Eisele et al (2013) calculated as follows:

$$\text{Annual fuel wasted} = \frac{\text{Travel time (vehicle hours)} \times \text{Average hourly speed}}{\text{Average fuel efficiency}} \times \text{Annual Conversation Factor}$$

Eisele et al (2013) also calculated the fuel that would be consumed in free-flow conditions as follows:

$$\text{Annual Fuel consumed in FFC} = \frac{\text{Travel time} \times \text{Free flow speed}}{\text{Average fuel economy for FFC}} \times \text{Annual conversation factor}$$

The annual fuel wasted due to congestion according to Eisele et al (2013) is estimated as follows:

$$\text{Annual fuel wasted due to congestion} = \text{Annual fuel consumed in congestion} - \text{Annual fuel consumed in free flow speed}$$

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Passenger Vehicle Delay Cost: The delay cost is an estimate of the value of lost time of passenger vehicles in congestion and according Eisele et al (2013) is calculated as follows:

$$\text{Annual passenger delay cost} = \frac{\text{Daily passenger vehicle hours of delay}}{\text{Value of person time}} \times \frac{\text{Vehicle occupancy (person/vehicle)}}{\text{Annual Conversation Factor}}$$

Passenger Vehicle Fuel Cost: according to Eisele et al (2013) this is done by associating the wasted fuel, the percentage of the vehicle mix that is passenger, and the fuel costs.

$$\text{Annual Fuel Cost} = \frac{\text{Daily fuel wasted}}{\text{percent of passenger vehicles}} \times \text{Gasoline cost} \times \text{Annual Conversation Factor}$$

Truck or Commercial Vehicle Delay Cost: The delay cost is an estimate of the value of lost time by commercial vehicles and the increased operating costs of commercial vehicles in congestion than the value of person time value because commercial vehicles carry much number of commodities than person. According to Eisele et al (2013), annual commercial vehicles delay cost is calculated as follows:

$$\text{Annual Commercial Vehicle delay cost} = \frac{\text{Daily Commercial Vehicle Hours of delay}}{\text{Value of commercial Vehicle time}} \times \text{Annual Conversation Factor}$$

Truck or Commercial Vehicle Fuel Cost: this is done by associating the wasted fuel, the percentage of the vehicle mix that is commercial, and the fuel costs as that of passenger vehicle fuel cost and is calculated as follows according to Eisele et al (2013).

$$\text{Annual Fuel Cost} = \frac{\text{Daily Fuel Cost}}{\text{Percentage of commercial Vehicles}} \times \text{Diesel Cost} \times \text{Annual Conversation Factor}$$

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Total Congestion Cost: the total congestion cost is the summation of the cost due to travel delay and wasted fuel to determine the annual cost due to congestion resulting from incident and recurring delay and according to Eisele et al (2013) calculated as follows:

$$\begin{aligned} \text{Annual Cost} &= \text{Annual Passenger vehicle delay cost} + \text{Annual Passenger Fuel Cost} + \text{Annual Commercial Vehicle delay cost} + \text{Annual commercial vehicle fuel Cost} \\ \text{Due to Congestion} & \end{aligned}$$

In addition to the above a research was done by Madhu et al (2015) to estimate fuel loss at congested state as follows: Fuel consumption of the vehicles are highly dependent on the vehicles operating speed and also the road geometry characteristics namely roughness, rise and fall etc. To calculate fuel wasted due to congestion, fuel consumption equations under steady state and under congested state need to be calculated. Fuel consumption in a steady state is influenced by variables of speed, roughness, rise and fall as shown in the following equation: according to Madhu et al (2015) the fuel consumption in ml/km is calculated as follows

$$FC_{SC}^{ST} = 30 + 844.085/V_{SC} + 0.003 * V_{SC}^2 + 0.001 * R + 0.4552 * RS - 0.89 * FL$$

$$FC_{BC}^{ST} = 35 + 983.503/V_{BC} + 0.003 * V_{BC}^2 + 0.002 * R + 0.452 * RS - 1.914 * FL$$

$$FC_{HCV}^{ST} = 50 + 8049.95/V_{HCV} + 0.012 * V_{HCV}^2 + 0.005 * R + 4.565 * RS - 4.904 * FL - 7.285 * P/W$$

Where

FC = Fuel consumption in ml/km;

V = Speed in kmph;

R = Roughness in mm/km;

RS = Rise in m/km;

FL = Fall in m/km;

P/W = Power - Weight Ratio;

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Superscript 'ST' represents steady state condition.

Subscript 'SC', 'BC' and 'HCV' represents Small Car, Big Car and Heavy Commercial Vehicle respective.

Since the data collection for HCV was carried out under varying load conditions namely empty, half and fully loaded, the variable P/W has been introduced in the fuel consumption equation for HCV. According to Madhu et al (2015) the state fuel consumption equation of two wheelers (TW) is given as follows:

$$FC_{TW}^{ST} = 3.38 + 549.57/V_{TW} + 0.00436 * V_{TW}^2 + 0.000196 * R + 0.4552 * RS - 0.3386 * FL$$

Where Subscript 'TW' represents Two Wheelers.

Then, according to Madhu et al (2015) at congested state fuel consumption equations are formulated as a function of steady state fuel consumption and speed as follows

$$FC_i^{CON} = f(V_i) * FC_i^{ST}$$

Where

f (V) is a factor defined as the ratio of congested and steady state FC

Superscript 'CON' and 'ST' represents congested and steady state respectively

Subscript 'i' represents vehicle type

According to Madhu et al (2015) Using the collected fuel consumption data under both steady and congested state condition and associated speed, equations for f(V_i) for different vehicle types have been developed considering speed as influencing variable is given below:

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

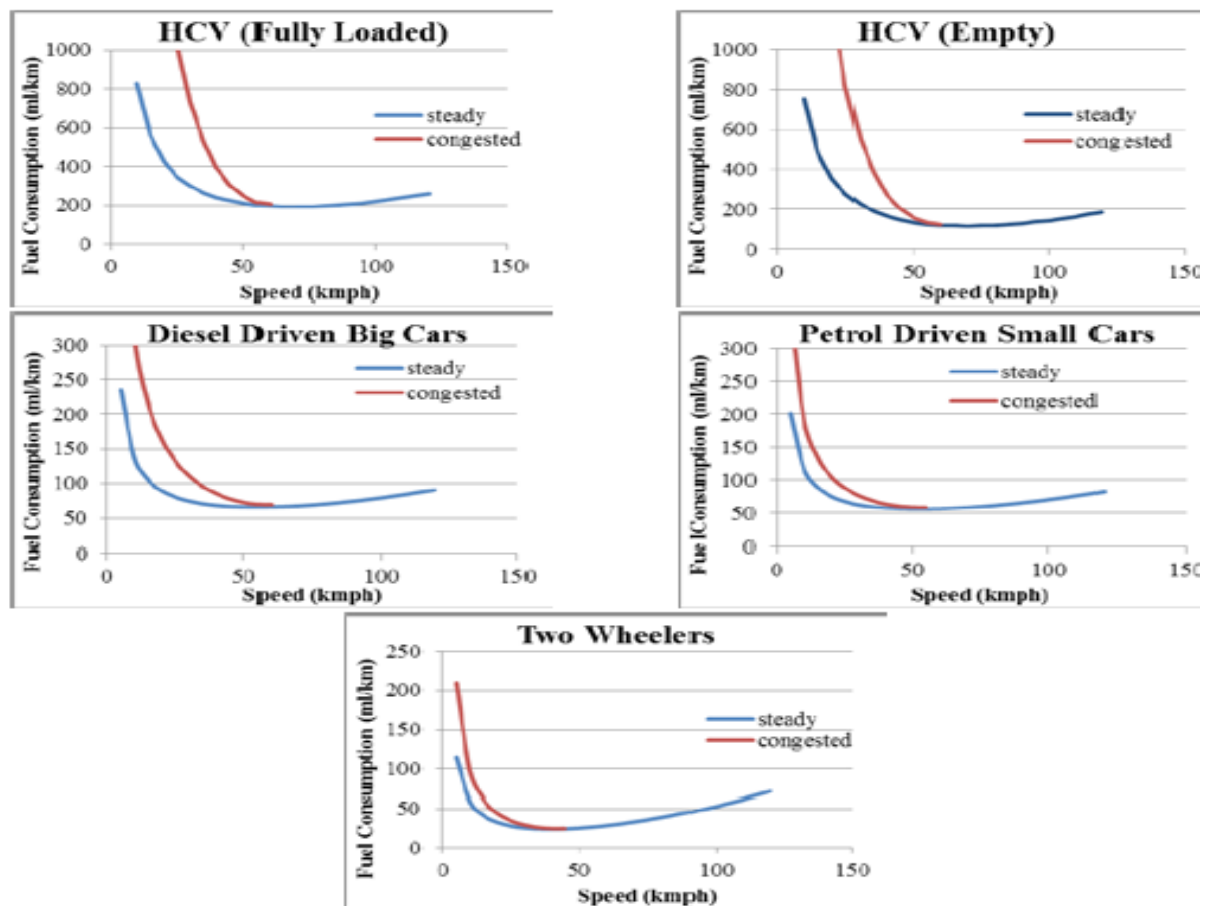
$$f(V_{SC}) = 0.0003 * V_{SC}^2 - 0.0344 * V_{SC} + 1.9555$$

$$f(V_{BC}) = 0.0005 * V_{BC}^2 - 0.0609 * V_{BC} + 2.8175$$

$$f(V_{TW}) = 0.0005 * V_{TW}^2 - 0.0465 * V_{TW} + 2.0556$$

$$f(V_{HCV}) = 0.0017 * V_{HCV}^2 - 0.2014 * V_{HCV} + 7.0539$$

The comparison of steady state and congested state fuel consumptions under varying speeds are illustrated below in Figure 2-5.



Sources (Madhu et al 2015)

Figure 2-5: Comparison of steady state and congested state fuel consumptions under varying speed

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So, according to Madhu et al (2015) Figure 2-6 shows congestion costs percentage of vehicles. In this Figure even the truck percentage is low; the percentage of congestion cost due to trucks is high.

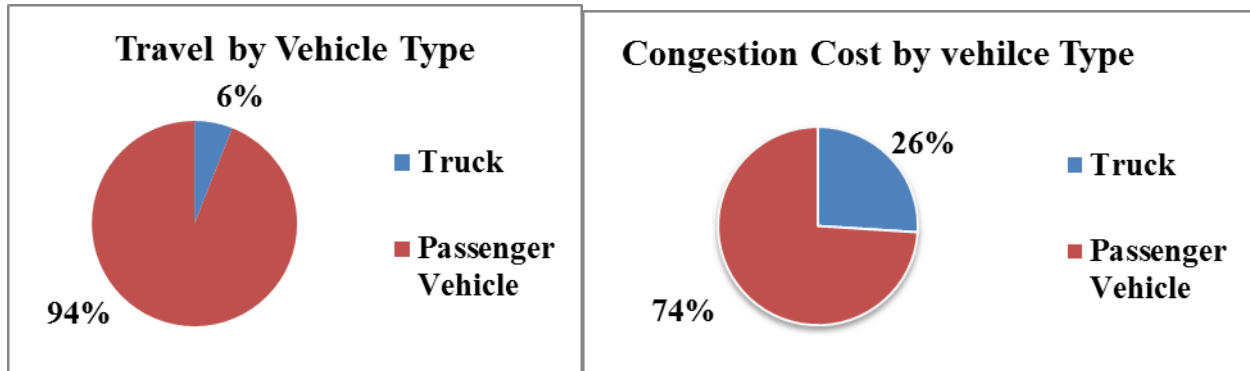


Figure 2-6: Congestion Cost and Percentage of Vehicles

According to the Texas A&M Transportation Institute's Urban Mobility Report (2011), congestion caused urban 28 Americans to travel 4.8 billion hours more and to purchase an extra 1.9 billion gallons of fuel for a congestion cost of \$101 billion. In addition, according to Mekonnen (2015), based on only delay time cost for laborers and vehicles and fuel cost only, on average the cost of congestion at the selected approach varies from Birr 29 to Birr 51 million per year with an average of Birr 39.6 million on one approach per year. Moreover, as Tadesse (2011), on his research at the Addis Ababa East West corridor, the average traffic congestion intensity in Addis Ababa expressed in Veh-min or person-min is very high and the result shows on average about 18,500 Vehicle-min or 38 vehicle-days and 169,000 Per-min or 352-person-days are wasted at each intersection legs or congestion spot per day on average the cost of wasted fuel & idle vehicle time at each entry leg of an intersection is above Birr 7.7 million/year and only the three legs at the Urael intersection costs more than Birr 28 million/year.

2.7. Measures to Mitigate Traffic Congestion

So, due to the above reasons, there must be proper traffic management strategies that minimize traffic congestion. Traffic management strategies might reduce the above impacts if they are addressed properly.

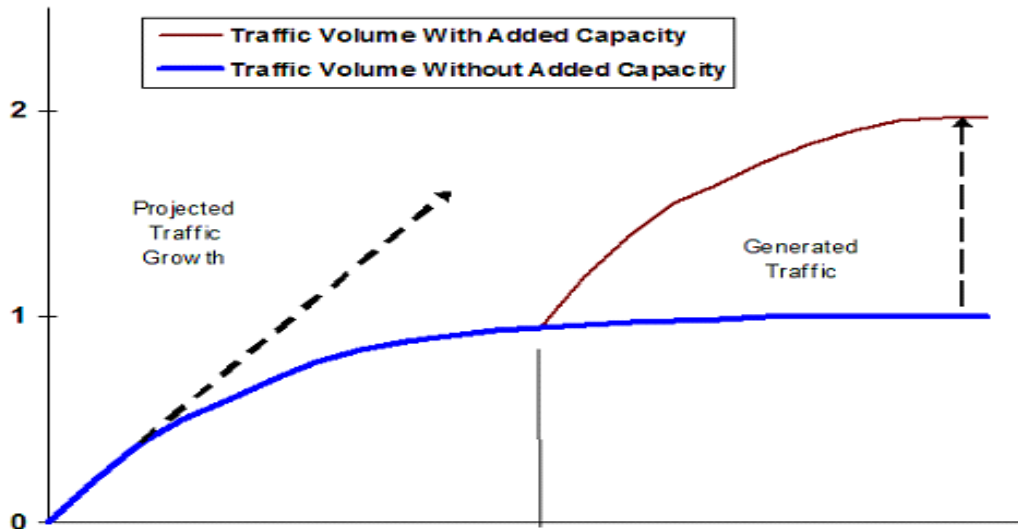
According to Joshua and Iyiola (2009), there are three distinct separate purposes of traffic management;

- ✚ Maximization of vehicle-carrying capacity;
- ✚ The maximization of people-carrying capacity; and
- ✚ The promotion of amenity and safety by assigning some roadway space predominantly or exclusively for pedestrian use.

Furthermore as mentioned by United States Department of Transportation Federal Highway Administration (2005), the key strategies to address congestion are the following:

- ✚ Adding more capacity for highway, transit and railroads;
- ✚ Operating existing capacity more efficiently; and
- ✚ Encouraging travelers to use the system in less congestion-producing ways.

But, increase in road capacity by adding more lanes, grade separated intersection may not mitigate traffic congestion since it induces additional traffic. Traffic grows when roads are uncongested, but growth declines as congestion develops, reaching a self-limiting equilibrium. If capacity increases, traffic volumes grow again until they reach a new equilibrium (Grant-Muller and Laird, 2007). Figure 2-7 below illustrates the road capacity and traffic volume relationship.



Source (Grant-Muller and Laird, 2007)

Figure 2-7: Roadway Capacity and Traffic Volume

A research done by Haregewein (2007) summarizes the main traffic congestion mitigation measures as follows: increasing road network coverage; increase road capacity; applying flexible work schedule; different starting and ending work schedule; ensuring effective parking management; sufficient parking areas, ensuring good traffic management; modern and skilled traffic police introducing effective land use management: arranging residence; market and working place near to each other; discourage car ownership; using high tax on luxurious automobiles; ensuring technical fitness of vehicles every time; managing an informal on-street trade; and participating private sectors in the transport systems.

Another congestion mitigation measures as Odeleye and Iyiola (2010), traffic management is the best cost- effective measure of countering road traffic congestion. As stated by Odeleye and Iyiola (2010) traffic management has three distinct separate purposes: maximization of vehicle-carrying capacity; the maximization of people- carrying capacity; and the promotion of amenity and safety by assessing some roadway space predominantly or exclusively for pedestrian use.

3. MATERIALS AND METHODS

3.1. General

For a complete and proper result of the objectives of any kind of research, the use of appropriate methodology and materials are crucial. But, to perform any research it is impossible to consider all the required data due to budget and time limitations. So sampling the necessary data is critical which represents the whole population of data. In this research both primary and secondary data collection technique were done to gather both qualitative and quantitative data.

3.1.1. Description of the study area

Addis Ababa, the capital city of Ethiopia, is one of the largest urban centers in sub-Saharan Africa located $8^{\circ}49'55.929''$ and $9^{\circ}5'53.853''$ North Latitude and between $38^{\circ}38'16.555''$ and $38^{\circ}19.547''$ East Latitude with an altitudinal zone ranging from 2054 to 3023 meters above sea level. The mean annual maximum and minimum temperatures of the city are 22.8 and 10.6 degree centigrade respectively. The mean annual rainfall of the city is 1180.4mm. The city covers an area of about 519.5 km² of land. (Addis Ababa City Administration Integrated Land Information, Atlas 2014.)

The most recent population estimate for Addis Ababa was 3,201,000 million in July 2015, out of which 1,503,214 are male and the remaining 1,698,448 are female (CSA 2014). Currently, due to the economic and population growth in Ethiopia, especially in Addis Ababa, the transportation demand is increasing highly. As transportation increases traffic congestion becomes worse because of limited road infrastructure.

3.1.2. Description of the study corridor

The study corridor is the very congested route and it is very crucial because it connects southern and eastern part of the country, which is most of the county's imports and exports activities are carried out, to Addis Ababa. The route connects Addis Ababa from the trade center of the east corridor which comes from Djibouti and has a total length of about 8.4km starting from Kality

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Masetegna Interchange which connects the ring road in the East and passes through Gotera Interchange which is the largest interchange in Addis Ababa, and finally ends at Meskel square which is the city core area. In addition, different trip attraction spots and governmental and nongovernmental institutions are found along this route. In this corridor, there are more than thirteen junctions and twelve mid-blocks. The following are some of the road segments.

Table 3-1: Road Segments in the study Road Corridor

No.	Mid-Block Name	Length(m)
1.	Meskel Square – Meshualekiya Intersection	440
2.	Meshualekiya- Riche	340
3.	Riche- Temenja Yaji-	120
4.	Temenja Yaji-- Global	1440
5.	Global – Meskel Flower	320
6.	Meskel Flower- Gotera	140
7.	Gotera- Nifas silk-1	510
8.	Nifas Silk-1- Nifas Silk-2	220
9.	Nifas Silk-2- Adey Abeba	830
10.	Adey Abeba- Saris	1160
11.	Saris- Abo	1040
12.	Abo- Kality Masetegna	800

3.1.3. Description of junctions in the study corridor

In this route, there are different types of junctions which cross, diverges from, converges to route corridor. The following are the major junctions including Gotera interchange, the largest

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interchange in Addis Ababa, starting from Meskel Square in the north and ending at Kality interchange in the south.

Table 3-2: Intersection in the selected Road Corridor

No.	Junction Name	Type of Junctions
1.	Meskel Square	4 leg Junction
2.	Meshualekiya	4 leg Round about
3.	Riche	T junction
4.	Temenja Yaji	T junction
5.	Global	T junction
6.	Meskel Flower	T junction
7.	Gotera	Interchange
8.	Nifas Silk-1	T junction
9.	Nifas Silk-2	T junction
10.	Adey Abeba	4 leg Junction
11.	Saris	T junction
12.	Abo	T junction
13.	Kality Masetegna	Interchange

Figure 3-1 below presents the selected road corridor as acquired from Google earth.

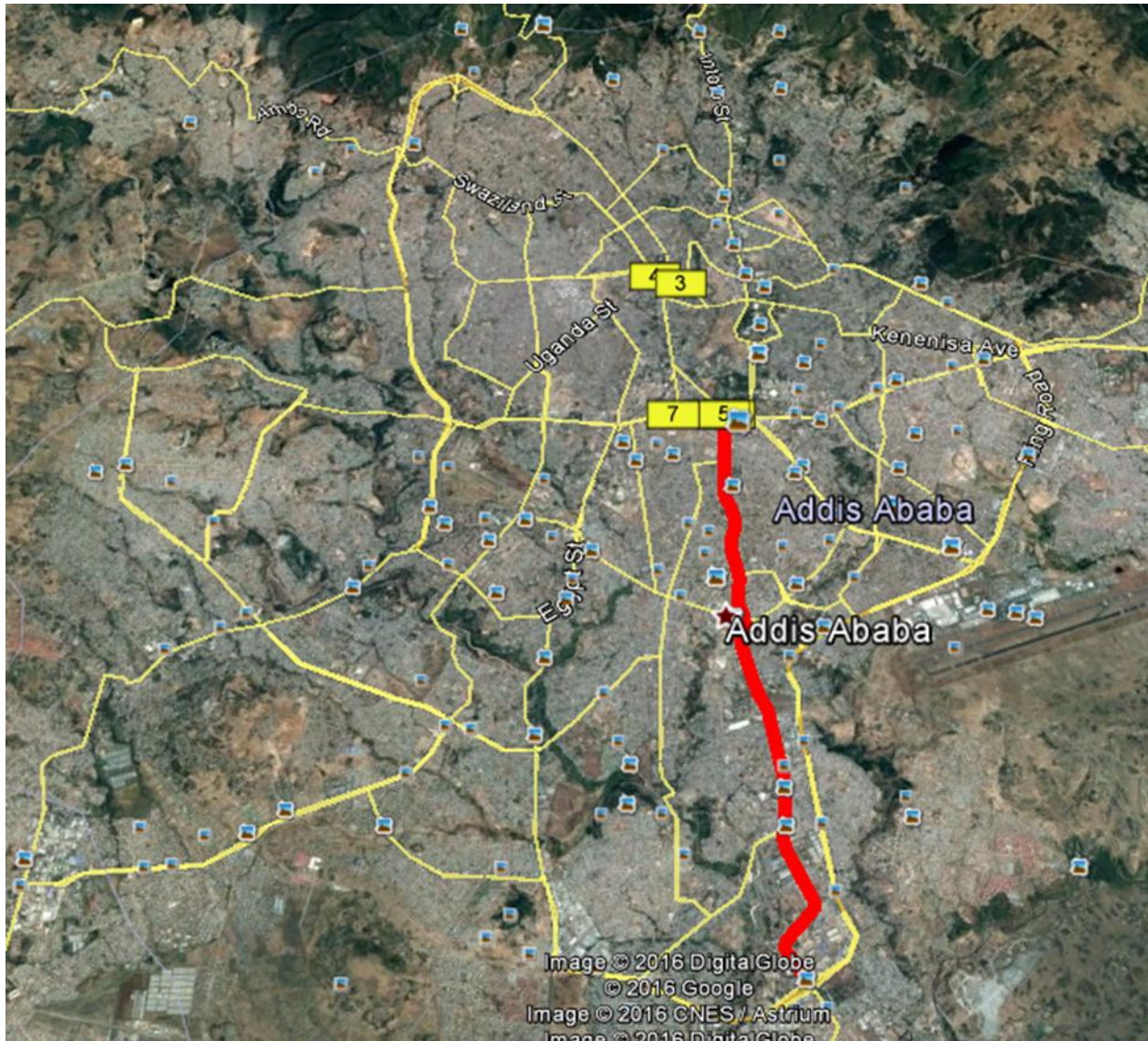


Figure 3-1: Selected road corridor

3.2. Research Methodology Organization/Outline

In order to achieve the objectives outlined above, adopted methodology for analyzing traffic congestion and developing congestion cost equations is illustrated in the figure 3-2 below.

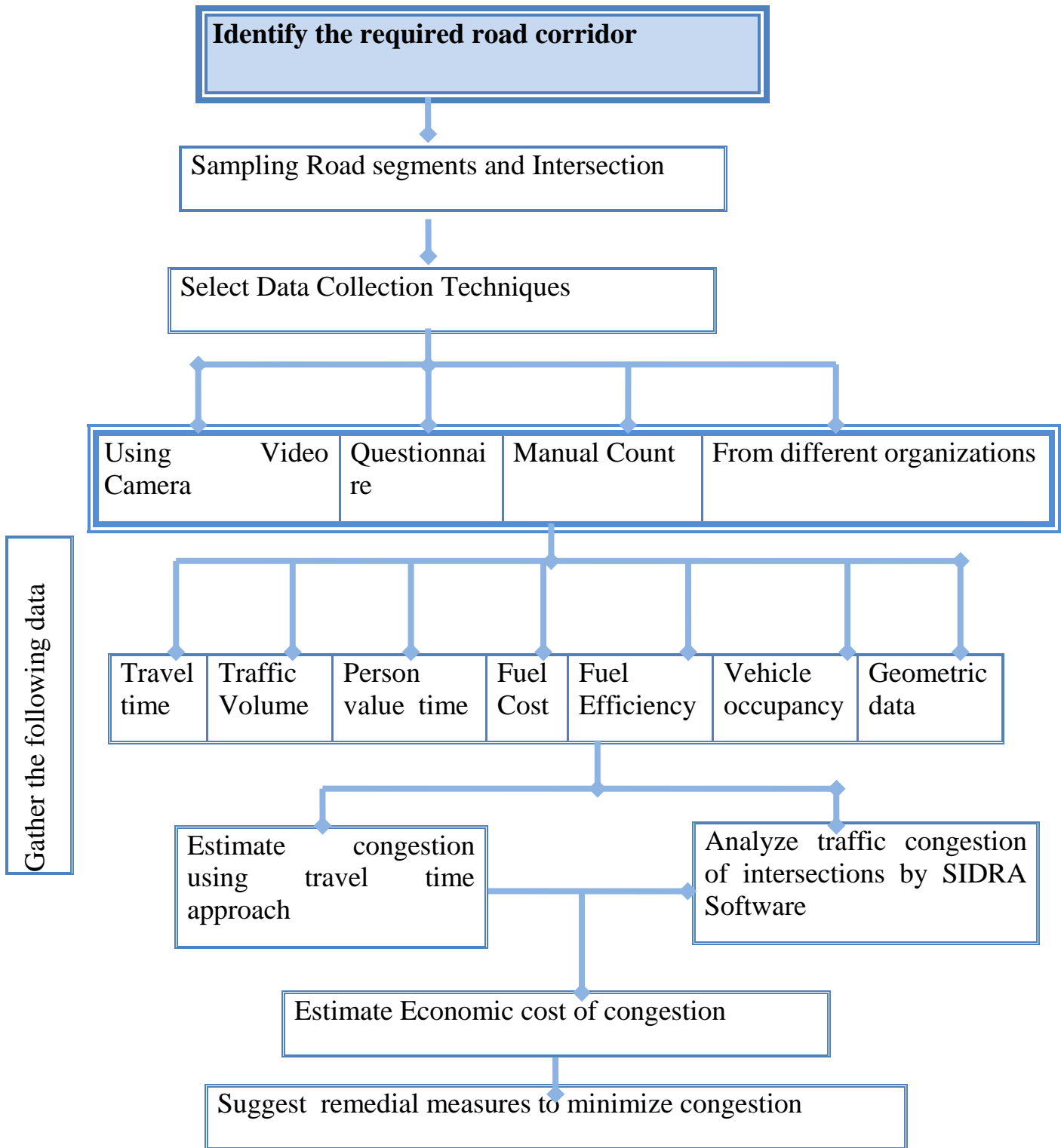


Figure 3-2: Outline of the study

3.3. Methods of data collection

Among different research designs, both qualitative and quantitative descriptive research design was used for the purpose of this study to enable the research to interpret the findings adequately and accurately. Consequently, this paper qualitatively described the existing vehicle traffic flow, road characteristics, travel time, traffic volume, traffic congestion in terms of delay and travel time approach and finally its economic cost. In addition, this paper will be describing the relationship of vehicles kilometers running per litter within a normal and congested traffic conditions, amount of fuel consumption, and its impact on travel time (delay) is using queue measurement along the road from Meskel Square to Kaliti Masetegna.

Both primary and secondary data collection was done to gather both qualitative and quantitative data for the study corridor. Quantitative data were used to determine the level of service and intensity of traffic congestion while qualitative data were used to gather information about people's perception about traffic congestion. So, to analyze those data both primary and secondary traffic data were handled.

Primary data were handled using the following techniques

(i). Video camera from buildings' tops or floor and manual traffic volume count were used to collect the volume/flow per 15 minute interval, to determine vehicular composition and vehicle occupancy rates and classifications of vehicles on selected routes Directional Traffic Volume/flow per 15 min of interval.

(ii). Audit geometric features of the corridors

For analysis of level of service, different road geometric data were required. Accordingly, the following features were collected at intersection: number of lanes, lane width, configuration of lanes and grade of road, circulatory width, entry width and width of median.

(iii). Questionnaires

A structured questioner was prepared in order to gather additional information for the congestion analysis. As congestion is a function of people's perception toward their time and their trip purpose, it was necessary to gather information and data on how the road users in Addis Ababa perceive the current traffic congestion and know how much delay is acceptable for them; because, according to Lomax (1997) road users' element should be included in analyzing traffic congestion. Even though statistical analysis is important to draw the required aim of the research since most of the research is quantitative and because of time and budget limitations, a sample size of one hundred were distributed to different road users (taxi drivers, commuters, students, company owners, traffic polices).

The secondary data were time value, fuel consumption of vehicles, fuel cost and vehicle rental costs which are required and gathered from different organizations like; Addis Ababa Traffic Management Enterprise and Addis Ababa City Road Authority were the main sources of secondary data for this study. The collected data were analyzed and summarized to address the stated objectives of the research.

3.3.1. Travel Time

To analysis traffic congestion and to determine the economic cost of travel time, acquisition of reliable data is critical and very important. Travel time is according to Travel time data handbook (1998) the time necessary to traverse a route between any two points of interest. Travel time can be directly measured by traversing the route(s) that connect any two or more points of interest and it is composed of running time, or time in which the mode of transport is in motion, and stopped delay time, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped, i.e., typically less than 8 km/hr.). From the different travel time data collection techniques, video camera with manual transcription is chosen because:

- ✚ Video provides a permanent record of license plates and traffic conditions;
- ✚ Video permits the reading of license plates in a controlled environment in which plate characters can be closely examined;

- ✚ Video provides information about traffic flow characteristics such as traffic volume and vehicle headway;
- ✚ Video can provide a time stamp for accurate determination of arrival times.
- ✚ Video provides a permanent, easily-review record of traffic conditions;
- ✚ Video accuracy may be better than manual methods; and
- ✚ Video is able to capture a larger sample of the total number of vehicles

Once the video recorded data was acquired, extracting travel time taken by an individual vehicle to travel a specified length of a road section was determined by tracing every individual vehicle. Since many vehicles negotiate the entry point at a time, vehicles were selected randomly. Statistically significant sample size was determined for each 15-30 min of count. The sample size was determined according to the procedure and equation on the handbook.

3.3.2. Sampling

According to travel time data collection Handbook, the sample size for manually transcript travel time data is given by the equation;

$$\text{Sample Size for travel time } (n) = \left(\frac{z \times c.v.}{e} \right)^2$$

Where z = z-statics based on confidence interval

e = relative permitted error level (%)

$c.v.$ = coefficient of variation

The handbook using the above statistical equation provides a sample sizes for different traffic conditions and level of confidence. Accordingly, for congested traffic condition at 90% confidence interval and +10% errors, the minimum sample size was calculated to be 18 for 15-30 min count. Therefore, for 15 min interval, about 15-20 vehicles travel time were recorded in the case of this research.

3.3.3. Days and Time Period for Data Recording

For the proper analysis of the required data, the following points were considered.

- ✚ Monday and Friday have high traffic variation from the normal weekdays;
- ✚ Tuesday, Wednesday and Thursday represent the average value of traffic; and
- ✚ Weekends (Saturday and Sunday) have low traffic volume.

So, due to time and budget limitation, data were collected for the average value of the whole week i.e. at Tuesday, Wednesday and Thursday.

Time period of recording is generally classified in three classes as shown below:

- ✚ Morning Peak Period: it includes time from 06:00-09:30 AM;
- ✚ Off-peak Period: the lowest traffic volume which includes from 10:00 AM- 03:00 PM; and
- ✚ Evening Peak Period: includes from 04:00 PM-07:00 PM.

So, time for recording for this paper was done from 07:00 AM- 06:00 PM which includes all the three time ranges.

3.3.4. Travel Time Data

From the road segments which are located in the route corridor, the following were considered for data collection due to time and budget constraints and these corridors and representative of all road segments for the rest of them in the study corridor. Table 3-3 below presents the selected route segments for analysis.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Maselteгна Interchange)

Table 3-3: Selected road segments

No.	Location	Segment Length(m)	Time for data collection
1.	Riche- Meshualekiya	290	07:00 AM- 06:00 PM
2.	Global-Meskel Flower	320	07:00 AM- 06:00 PM
3.	Nifas Silk- Adey Abeba	280	07:00 AM- 06:00 PM
4.	Akaki- Kality Maselteгна	300	07:00 AM- 06:00 PM

Figures 3-3,3-4 and 3-5 show the aforementioned road segments stated in the table 3-3 above.



Figure 3-3: Meshualekiya-Riche road segment

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)



Figure 3-4: Global- Meskel Flower road segment



Figure 3-5: Nifas Silk- Adey Ababa road segment

3.3.5. Traffic Volume

Traffic volume data is important to determine the level of service, to analyze the relationship between traffic volume and traffic congestion and additionally, it is important to determine the relationship between traffic volume and accident. Traffic volume data was collected by conducting video camera.

3.3.5.1. Passenger Car Unit (PCU)

In order to conduct traffic volume, it is necessary to have a single unit to count the number of vehicles because different types of vehicles in a traffic stream have different effects. So, all vehicles which use the condor must be converted to common unit called passenger car unit. In this research PCU were acquired from the Highway Capacity Manual 2000 are depicted in table 3-4 below.

Table 3-4: Passenger car units for vehicles

	Passenger Car Vehicles					Goods Vehicles		
	Car and Taxi	4-WD	Mini bus taxi	Mini/midi bus	Standard Bus	Small LCV	Medium 2/3 axle	Heavy MAV > 3 Axle
PCU factors	1	1	1.5	1.5	1	1.5	3	3

3.3.5.2. Traffic Volume data

From the junctions which are found in the route corridor, the following junctions were considered for data collection due to time and budget constraints. Table 3-5 below shows the selected junctions for analysis.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Table 3-5: Selected intersections

No.	Junction Name	Type of Junction	Time for Data collection
1.	Meshualekiya Junction	4 leg Round about	07:00 AM- 06:00 PM
2.	Meskel Flower Junction	T junction	07:00 AM- 06:00 PM
3.	Adey Abeba Junction	4 leg Junction	07:00 AM- 06:00 PM
4.	Gotera Interchange	Interchange	07:00 AM- 06:00 PM

Figure 3-6, 3-7, 3-8 and 3-9 presents the aforementioned junctions.



Figure 3-6: Meshualekiya Intersection



Figure 3-7: Meskel Flower intersection



Figure 3-8: Adey Abeba intersection



Figure 3-9: Kality interchange

3.3.6. Vehicle Occupancy

Vehicle occupancy; which is the number of peoples per vehicles, is an extremely important parameter in traffic engineering and transportation planning. Usually, it is used to convert person trip to vehicle trip in the four step travel demand forecasting process and to determine parking space requirements for public facility and spaces. Furthermore, its use is becoming increasingly important in the congestion management process to compute person-delays; person-miles etc. Hence, vehicle occupancy is a very important parameter for calculating congestion intensity parameters.

To obtain vehicle occupancy data, it is necessary to find a single value of vehicle occupancy data. So, in order to acquire a single vehicle occupancy data the weighted average vehicle occupancy is calculated as follows:

$$AVO_w = \frac{\sum_i^n V_{it} \times VO_{it}}{\sum_i^n V_{it}}$$

Where AVO_w = Weighted Average Vehicle Occupancy

V_{it} = Traffic Volume of i^{th} vehicle occupancy

VO_{it} =Traffic Volume of i^{th} Vehicle

So, due to unavailability of data on vehicle occupancy for each vehicle in this paper, all vehicles are assumed to be at its capacity throughout the day and multiplying by the vehicle occupancy of each vehicle by their number.

3.3.7. Value of Time

According to European Academic Research (2015) the Value of Time (VOT) estimated the unit VOT of a person in Ethiopia as Birr 19 assuming the following:

Average monthly earnings per person in Ethiopia is ETB 6858/hour, Hourly income will be Birr 39, considering 8 work hours a day and 22 working days a month, Wage Rate or VOT for business trip is taken as the hourly income of ETB 39 /hour, VOT for Non-business trip at 30% of VOT of business trip will be ETB 19/hour, Business trips are 25% and non-business trips are 75% of total trips. Thus, Average VOT is estimated as ETB 19/hour

4. RESULTS AND DISCUSSION

This section presents and describes key findings from the data which are gathered and discussions will be done on the different aspects of the findings.

4.1. Traffic Volume Analysis

Directional traffic volume analysis is done for twelve hours of a day from 7:00 AM- 7:00 PM. The directional traffic volume is analyzed on the following four intersections:

- ✚ Meshualekiya Junction;
- ✚ Meskel Flower Junction;
- ✚ Adey Abeba Junction
- ✚ Kality Masetegna Interchange; and

4.1.1. Traffic Volume Analysis for Meshualekiya Intersection

This intersection is located near Meskel Square to Saris approach and it has three entry lanes on both approaches and it is planned to be an intersection for the future and has top bridge. It has the highest traffic volume towards the Riche approach in the morning peak period and it has the highest traffic volume in the Meskel Square in the afternoon. At this intersection both from Meskel Square and from Riche directions, left turn moments are affected by the Addis Ababa Light Rail Transit. Figure 4-1 below graphically illustrates the traffic volume at Meshualekiya Intersection.

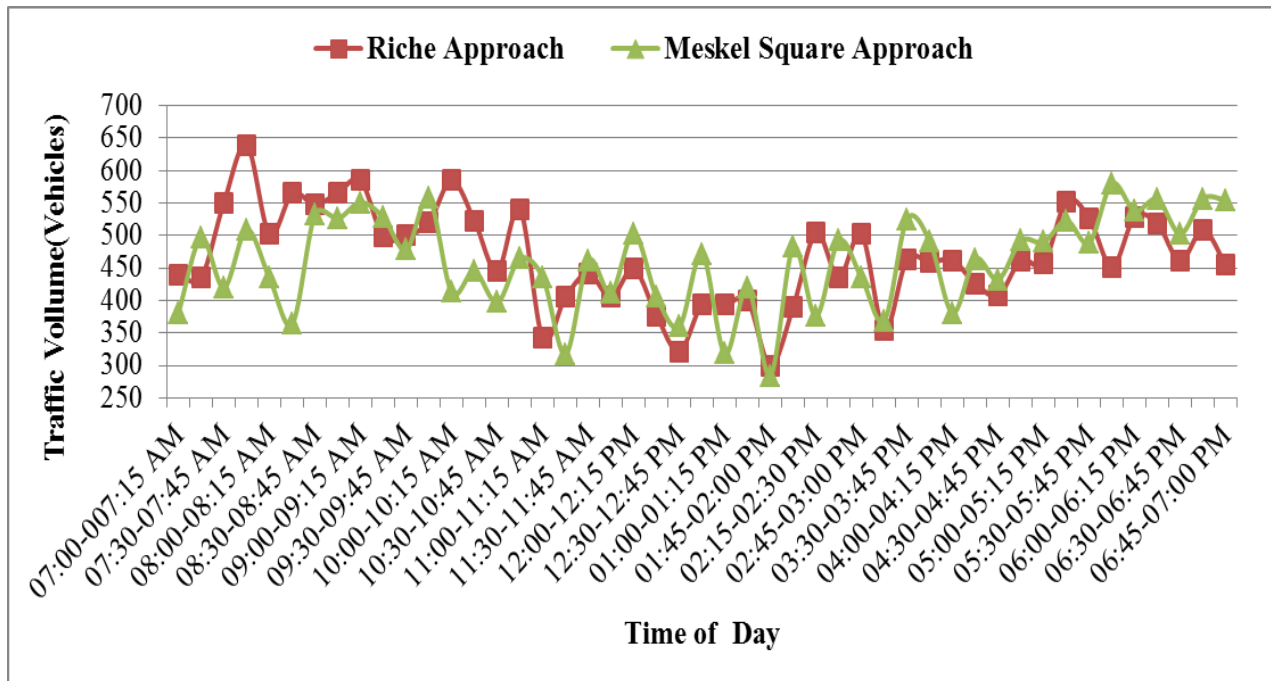


Figure 4-1: Traffic Volume at Meshualekiya intersection

4.1.2. Traffic Volume Analysis for Meskel Flower Intersection

This intersection is located between Global Hotel and Gotera interchange, which is the biggest interchange in Addis Ababa and it links traffic from Gotera, Kera, Wolosefer and Saris. Traffic volume is plotted for the four directions as shown in the figure 4-2 below.

As shown in the figure, in the morning peak period the highest traffic volume is occurred in Gotera approach, while in the evening peak period the highest traffic volume is occurred in Global approach. But in this intersection much vehicles are conflicting when there is no traffic police in the area due to misleading of railway piers found at the intersection.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

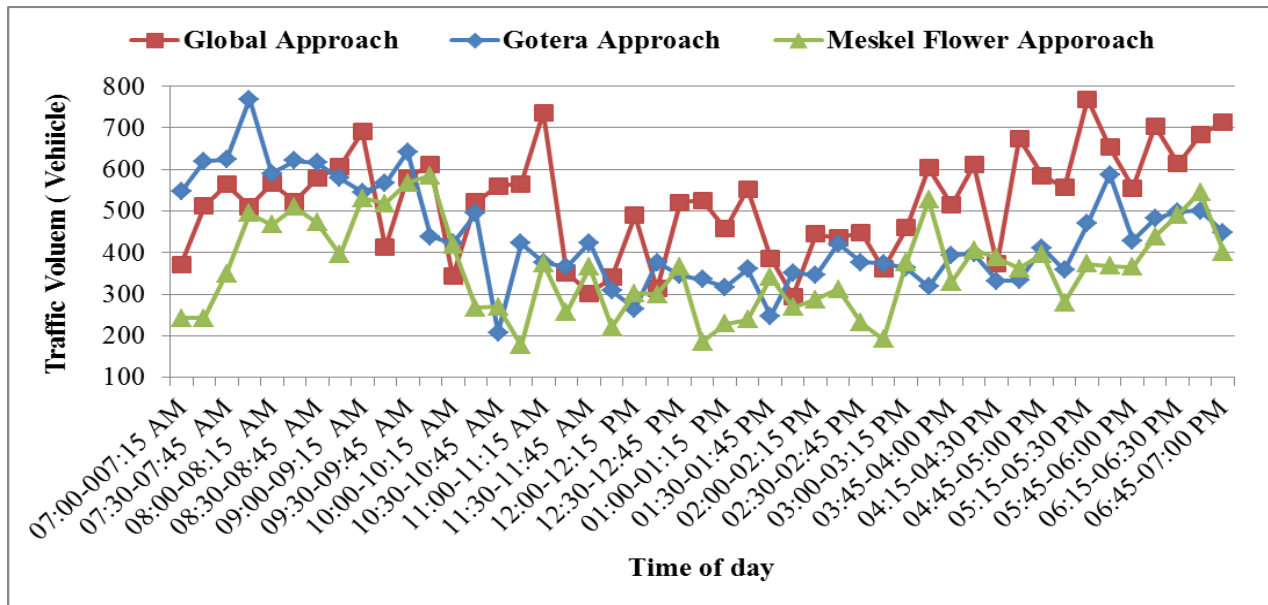


Figure 4-2: Traffic Volume at Meskel Flower intersection

4.1.3. Traffic Volume Analysis for Adey Abeba Intersection

As shown in the figure 4-3 below, the maximum traffic volume occurred on Saris approach in the morning peak period while during the evening peak period the highest traffic volume occurred on Nifas Silk approach. But, when we compare Addis Sefer and Bihere Tsigie approach, in the morning peak period the maximum traffic volume occurred from Bihere Tsigie approach whereas in the evening peak period the maximum traffic volume occurred towards Addis Sefer approach. At this intersection, Addis Sefer and Bihere Tsigie approaches and left turn approaches for Nifas Silk and Saris approaches are interrupted when AALRT crosses the area there is grade intersection with Addis Ababa Light Rail Transit. Figure 4-3 below shows traffic volume at Adey Abeba Intersection.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

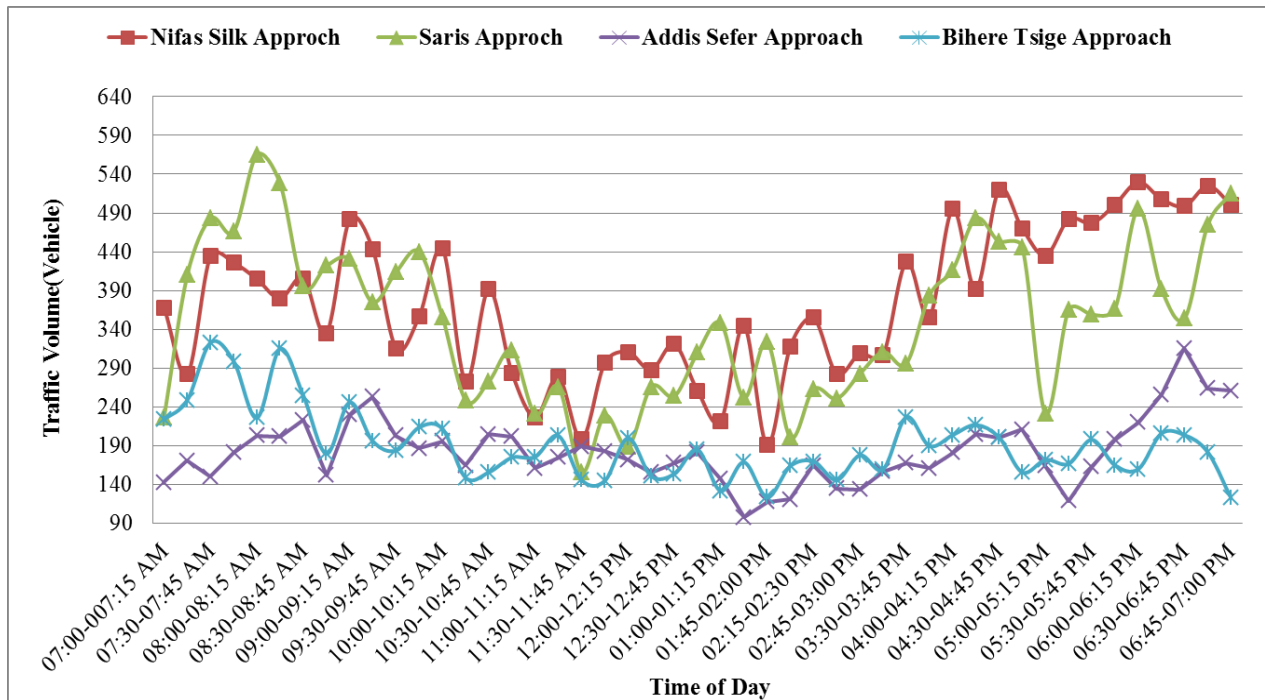


Figure 4-3: Traffic Volume at Adey Abeba intersection

4.1.4. Traffic Volume Analysis for Kality Intersection

This intersection connects two major road corridors of Addis Ababa which are, the North- South road corridor and Ring Road of Addis Ababa and all vehicles come from both the East, North and West part of Addis Ababa and converges at a single road corridor to South and exit of Addis Ababa and those which come from South part of it diverges to Hana Mariam, Fafa and Abo Saris exits. From figure 4-4, the Akaki approach has maximum traffic volume among the others throughout the day because it carries all vehicles coming from the Southern part of Addis Ababa mainly from Akaki Kility residents and condominiums. In addition, traffic flows from East and South of Ethiopia to Addis Ababa. Both Hana Mariam and Saris Abo approaches have peak volumes in the morning and evening peak times while the Fafa approach has maximum traffic volume in the evening peak period. Figure 4-4 below illustrates the traffic volume at Kality Intersection.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

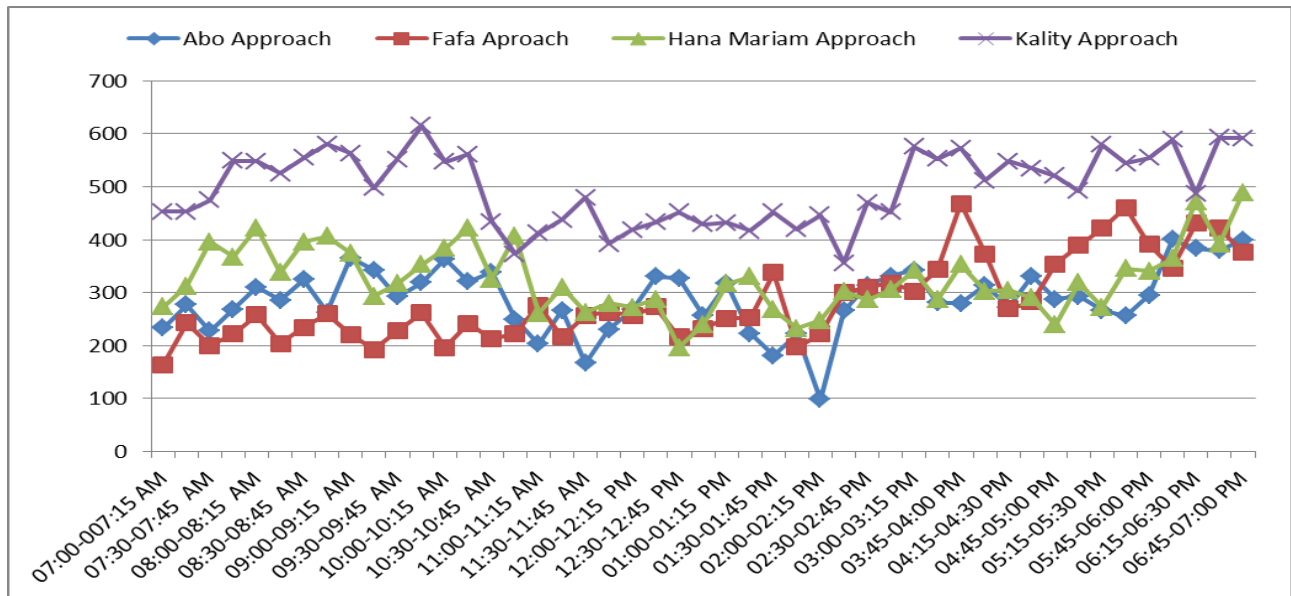


Figure 4-4: Traffic Volume at Kality intersection

4.2. Intersection Level of Service (LOS)

In order to determine congestion at intersections, level of service analyze at intersections were performed using SIDRA software. To calculate the level of service, the following data are necessary: Traffic volume, geometric characteristics of road, and pedestrian volume. Geometric data for the road is obtained from the Addis Ababa City Roads Authority; traffic volume is obtained using video camera and manual traffic volume count method. Those necessary data consist of; island diameter, circulatory width, number of circulatory lanes, entry lane number and average lane width at entry for roundabout junction; and number of lanes, lane width, configurations of lanes, grade, width of median, left turn moments, through moments, right turn moments, peak hour factor and heavy vehicle factor. In addition to these data, basic saturated flow is adjusted to 1200 tcu/hr instead of default value 1900 tcu/hr value because the default values are for an ideal road and traffic conditions. These values are tabulated in table 4-4 below and other parameters were used from the default values of the SIDRA software.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Table 4-1: Impute parameters for SIDRA intersection analysis software

Intersection	Geometric Data						Volume Data						
	Approach Leg	Number of Entry lanes	Number of Exit lanes	Lane Width (m)	Grade in the direction of flow	Median Width (m)	Total Traffic Volume			Peak Hour Factor	Heavy Vehicle Factor		
							LT	TH	RT		LT	TH	RT
Meshualekiya	Meskel Square Approach	3	3	3.5	2.14	15	157	1997	0	95.28	2.84	7.95	0
	Teb Menja Yaji	3	3	3.5	-2.14	15	294	1955	0	93.5	4.9	10.5	0
Meskel Flower	Global Approach	3	3	3.5	2.5	15	784	1998	0	91.48	3.84	9.74	0
	Gotera Approach	3	3	3.5	-2.5	15	514	1781	821	86.62	2.14	9.21	6.28
	Meskel Fower	3	3	3.5	-1.05	0	1251	0	950	96.83	0.84	0.00	1.58
Adey Abeba	Nifas Silk Approach	3	3	3.5	-2.5	15	278	1612	398	94.29	4.21	9.20	8.47
	Saris Approach	3	3	3.5	2.5	15	254	1700	367	92.09	2.50	8.40	5.14
	Biheretsigie Approach	3	3	3.5	-0.68	0	284	489	342	86.21	0.35	1.24	1.48
	Addis Sefer Approach	3	3	3.5	-1.24	0	288	546	384	87.24	1.24	2.01	0.84
Kality Interchange	Abo Approach	2	2	3.5	4.5	0	348	0	189	93.6	15.7	0.0	6.9
	Abo Approach Free flow	2	2	3.5	-3.25	0	0	1127	0	93.6	0.0	8.5	0.0
	Fafa Approach	3	3	3.5	-1.65	0	133	1437	185	92.83	12.05	21.83	4.25
	Hanamariam Approach	2	2	3.5	4.84	0	973	0	106	85.22	15.85	0.00	6.58
	Hanamariam Approach Free Flow	2	2	3.5	-2.5	0	0	709	0	85.22	0.00	4.51	0
	Kality Approach	3	3	3.5	0.95	0	488	1616	756	93.60	18.45	22.50	20.5

Note: LT: left turn, TH: Through, and RT: Right turn

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Level of service analysis is done using SIDRA software in conjunction with HCM 2000 right hand rule. Level of analysis for the intersections indicates that most of the intersections are performing above their capacity and have almost LOS F which indicates vehicles are moving at extremely low speeds, occurrence of high delays and high volumes. Table 4-2 below presents the Level of service results obtained from SIDRA software.

Table 4-2: LOS and Delay Output results from SIDRA intersection analysis software

Intersection	Approach legs	Delay(sec.)			LOS		
		LT	TH	RT	LT	TH	RT
Meshualekiya	Meskel Square Approach	68.9	69.0	-	F	F	-
	Riche Approach	50.1	50.7	-	F	F	-
Meskel Flower	Global Approach	52.7	42.6	-	F	F	-
	Gotera Approach	85.5	80.1	79.2	F	F	E
	Meskel Flower	54.0	-	55.9	F	F	E
Adey Abeba	Nifas Silk Approach	88.7	46.0	46.7	F	E	E
	Saris Approach	79.7	47.9	46.9	F	E	E
	Addis Sefer Approach	86.0	39.4	39.4	E	F	F
	Bihere Tsigie Approach	86.1	25.4	25.4	F	F	D
Kality	Abo Approach	465.1	0.1	24.5	F	A	C
	Fafa Approach	49.4	417.4	403.5	D	F	F
	Hana Mariam Approach	269.1	0.0	59.6	E	A	F
	Akaki Approach	418.8	431.9	174.8	F	F	F

Note: LT: left turn, TH: Through, and RT: Right turn

4.3. Analysis of Traffic Congestion

Congestion can be evaluated in various ways that can result at different estimates of costs and the benefits of specific congestion reduction strategies. So, in this research, travel time approach is used to analyze congestion and its economic costs. The following parameters were used to calculate the congestion performance measures for each urban roadway section: travel time, traffic volume data, average travel speed, threshold travel speed, travel rate, travel time, travel time index, delay, delay rate, delay ratio, total segment delay, vehicle volume, and vehicle occupancy.

4.3.1. Travel Time

Travel time is the time required to traverse a route between any points. The travel time for the selected road segments is calculated to analyze congestion levels.

4.3.1.1. Travel Time for Riche- Meshualekiya Road Segment

For this road segment the maximum travel time occurred in the morning peak periods whereas the minimum travel time occurred in the midday because most people come to the central business centers like Merkato, México, Piazza, Arat kilo, Amist kilo and Sidist kilo at the morning hours. Figure 4-5 below shows average travel time for Riche- Meshualekiya.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

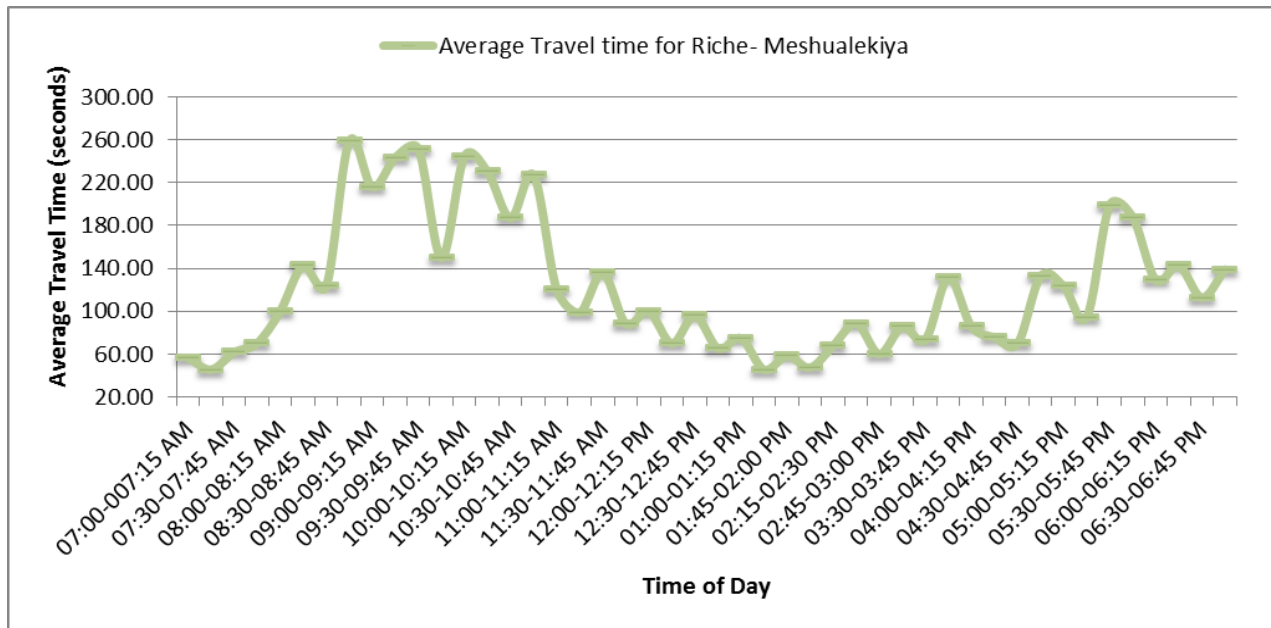


Figure 4-5: Average Travel Time for Riche- Meshualekiya Road Segment

4.3.1.2. Travel Time for Gobal – Meskel Flower Road Segment

Regarding Global- Meskel Flower road segment, the maximum travel time is in the evening due to persons who are working in the central parts: Merkato, México, Piazza, Arat kilo, Amist kilo and Sidist kilo return to their homes in the southern part of the city. Figure 4-6 below illustrates the average travel time for global- Meskel Flower.

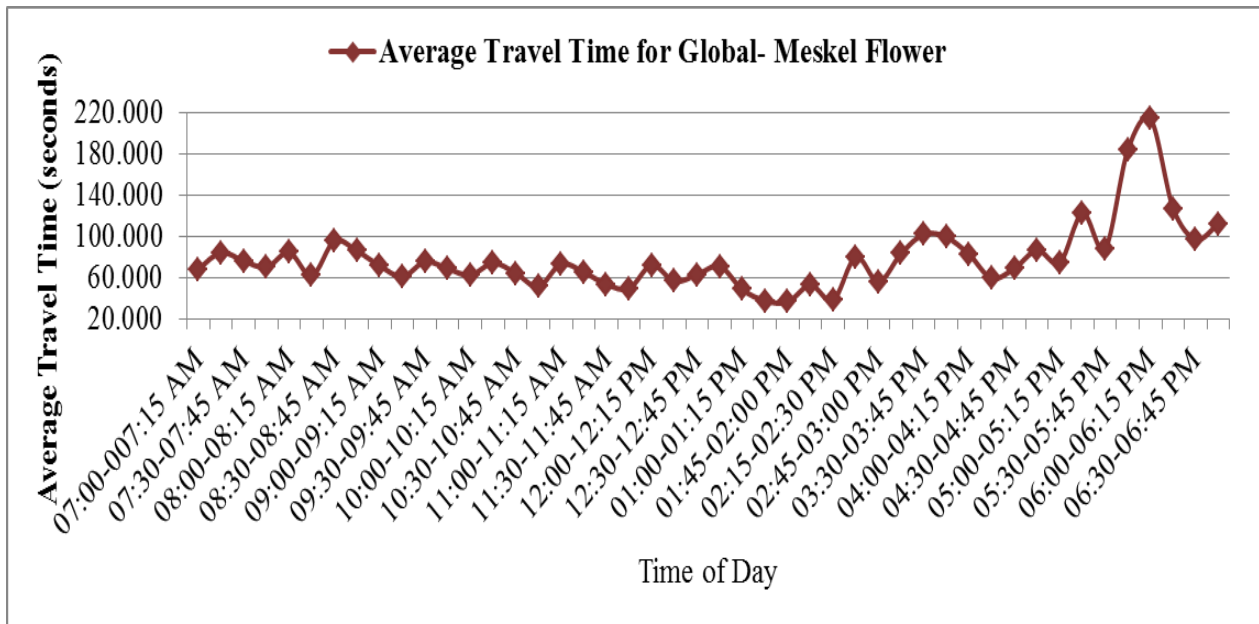


Figure 4-6: Average Travel Time for Nifas Silk- Adey Abeba Road Segment

4.3.1.3. Travel Time for Nifas Silk- Adey Abeba Road Segment

This road segment is found in Saris in which different trade activities are carried out especially agricultural products at Adey Abeba market and different manufactured goods and electronics. This road segment has different travel time from others due to the fact that there is movement in both directions to the market. So, the travel time for this road segment is the maximum during the morning and the evening peak period due to high movement of commuters and customers in that vicinity in both directions. Figure 4-7 below illustrates average travel time for Nifas Silk- Adey Abeba road segment.

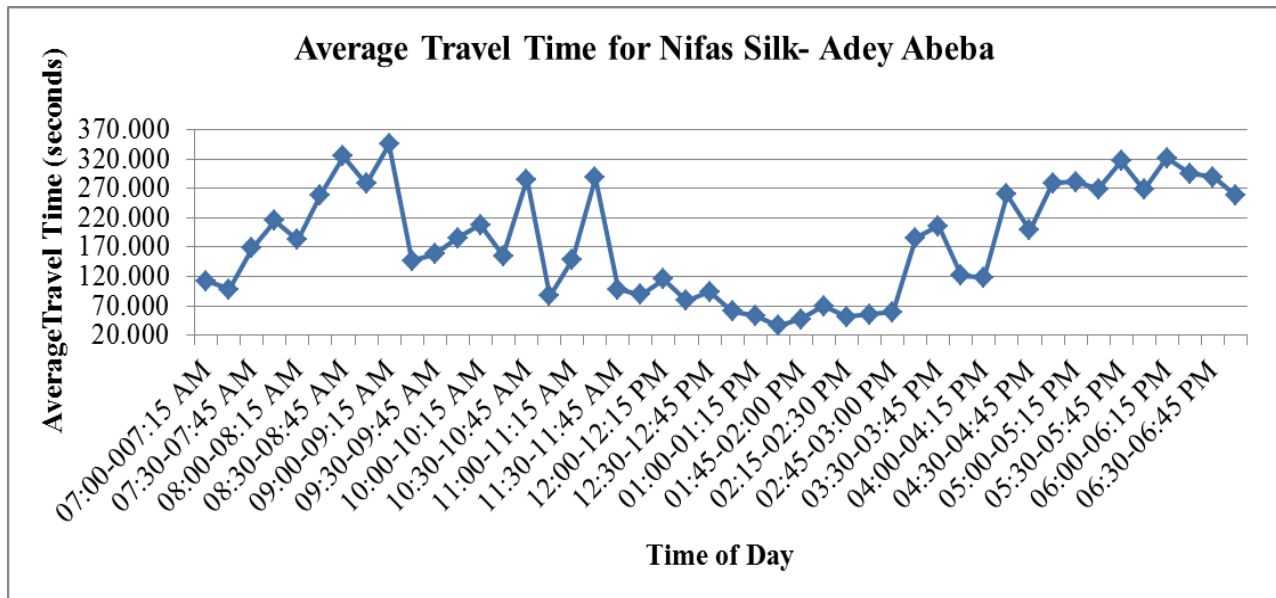


Figure 4-7: Average Travel Time for Nifas Silk- Adey Abeba Soad Segment

4.3.1.4. Travel Time for Akaki- Kality Road Segment

This road segment is also very congested because it accommodates vehicles which come from the Southern part of Addis Ababa to Eastern, Western, Northern and central part of city and additionally, due to the entry for Eastern and Southern part of the Country which are the trade center of the whole nation. In addition, there are more numbers of large vehicles unloading and other activities Customer Warehouse which is located near Kality intersection and the road condition is poor due to neglected maintenance which increases the travel time. Figure 4-8 illustrates the observed average travel time for Akaki- Kality road segment.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetlegna Interchange)

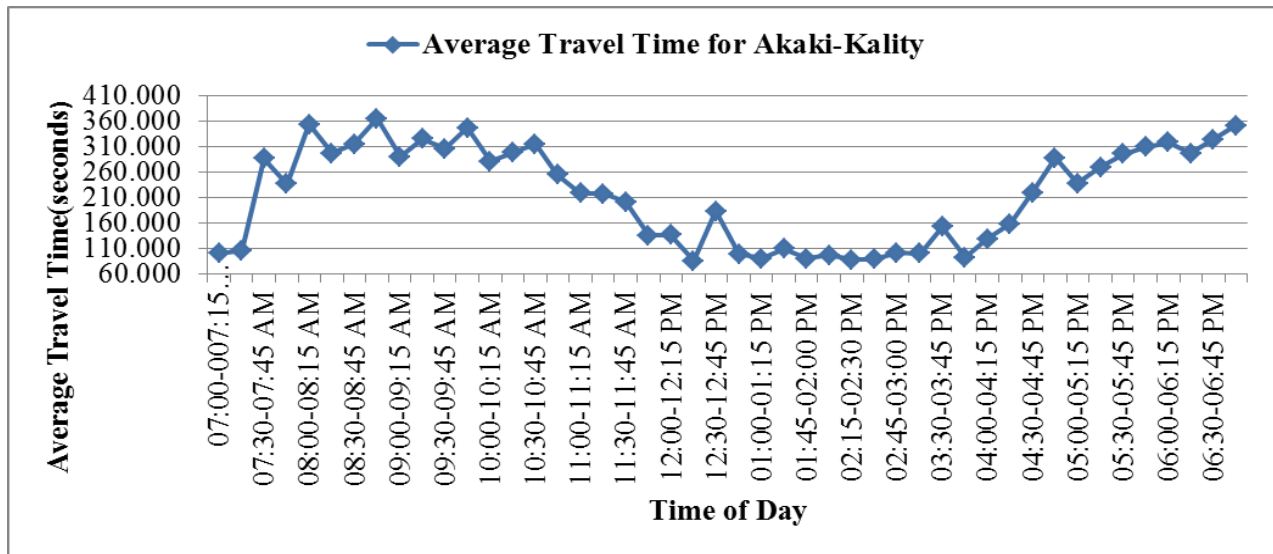


Figure 4-8: Average Travel Time for Akaki- Kality Road Segment

In order to compare the average travel time for these intersections, it was found necessary to convert average travel time per km. So, after converting all travel times to the same length, figure 4-9 was developed as shown below. So, when comparing the travel time for the four road segments, Akaki- Kality has the maximum travel time among those road segments in the morning while Nifas Silk- Adey Abeba has maximum value in the morning peak travel time next to Akaki- Kality whereas in the evening peak periods Nifas Silk- Adey Abeba has the maximum travel time than the rest even though it has less volume as compared to Akaki- Kality due to at this intersection pedestrian movements is very enormous and due to interference of the Light Rail Transit with left turn movements. As presented in figure 4-9 the travel time for Global- Meskel Flower road segment is the minimum as compared to the rest and it is almost constant throughout the day, except at the peak evening period.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

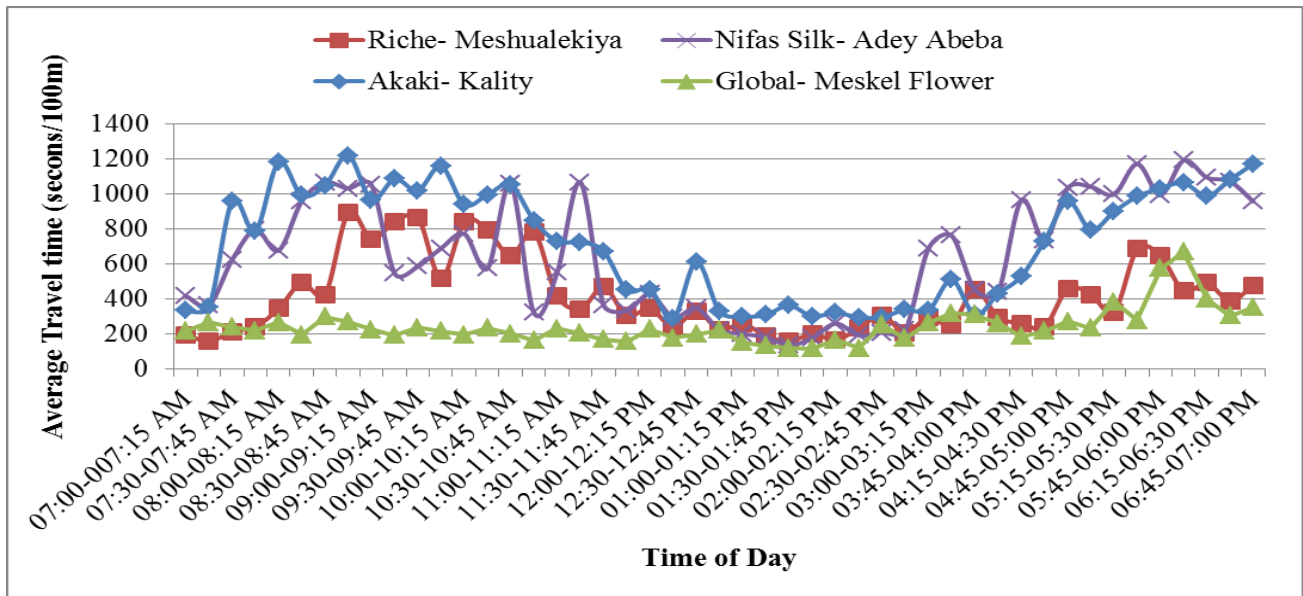


Figure 4-9: Average Travel Time in seconds

4.3.2. Travel Speed

Average travel speeds for the road segments are shown in figure 4-10 below. The results show that during the morning peak periods average travel speeds on Akaki- Kality Masetegna and Nifas Silk- Adey Abeba segment is almost below 5 Km/hr till mid-day and Global- Meskel Flower has average travel speed above 10 km/hr except at the evening peak period. Moreover, average travel speed on Global- Meskel Flower segment is the maximum among the selected road segments whereas the average travel speed for Akaki- Kality Masetegna and Nifas Silk- Adey Abeba segments are the minimum value which indicates Akaki- Kality Masetegna and Nifas Silk-Adey Abeba are the most congested corridor whereas the Global-Meskel Flower is with the minimum traffic congested corridor from the selected segments.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

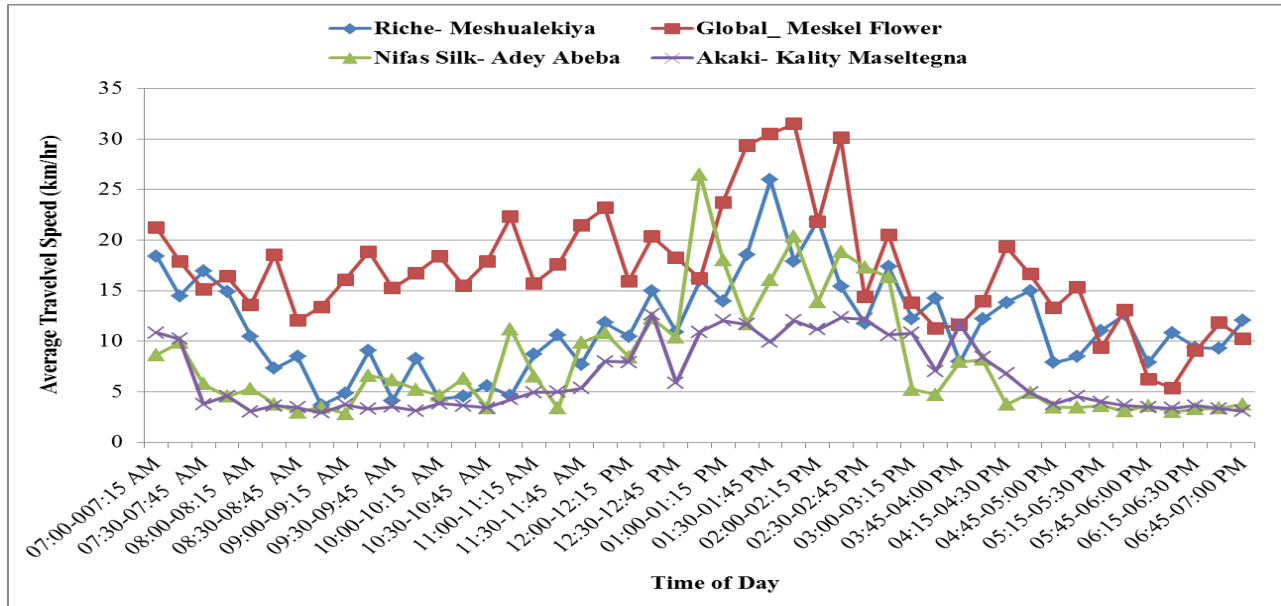


Figure 4-10: Average Travel Speed (Km/hr.)

4.3.3. Travel Rate, Travel Time Index

Travel rate is the inverse of travel speed has paramount practical significance to understand the level of congestion on the selected corridor since it expresses travel time for a unit segment length. To compare travel rates on the road segments the Global- Meskel Flower road segment has the minimum travel rate for the whole day; whereas, the Nifas Silk-Adey Abeba and the Akaki- Kality Masetegna road segments have the maximum travel rate for the whole day. In the morning peak period, the Nifas Silk- Adey Abeba, Riche- Meshualekiya and Akaki- Kality Masetegna road segments have maximum travel rate but in the mid-day Nifas Silk- Adey Abeba and Riche- Meshualekiya have low value as that of the Global- Meskel Flower while the Akaki- Kality Masetegna has even higher travel rate in the mid-day than the Global- Meskel Flower peak morning time. Figure 4-11 below presents the travel rate.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetlegna Interchange)

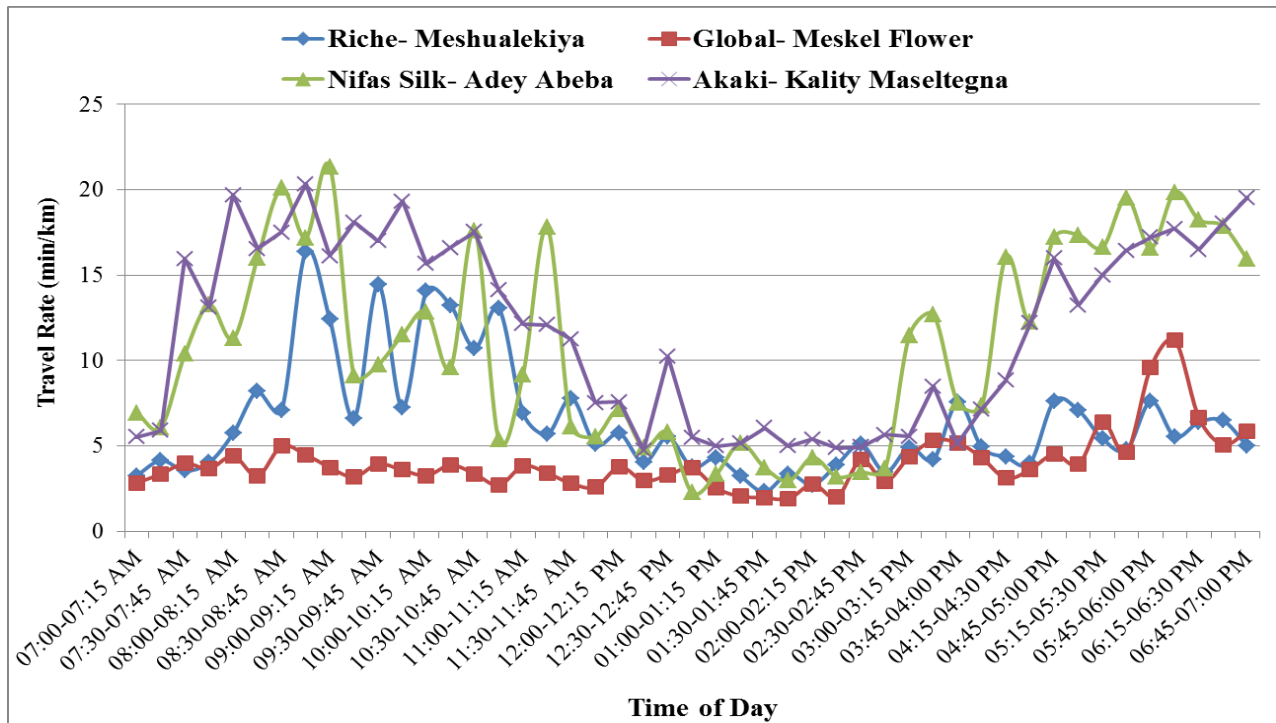


Figure 4-11: Travel Rate (min/km)

Travel time index is defined as the ratio between travel time during peak period and the free-flow travel time, which is also a measure of congestion pattern. It compares maximum congested travel time to the free flow travel time. Travel time index has similar trend as that of travel rate. Travel time index for all road segments in mid- day has values of less than three. Further investigation indicates that the morning peak period has the maximum value for the three road segments; Riche- Meshualekiya, Nifas Silk- Adey Abeba and Akali- Kality. Figure 4-12 below presents the indexes for the three road segments.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetlegna Interchange)

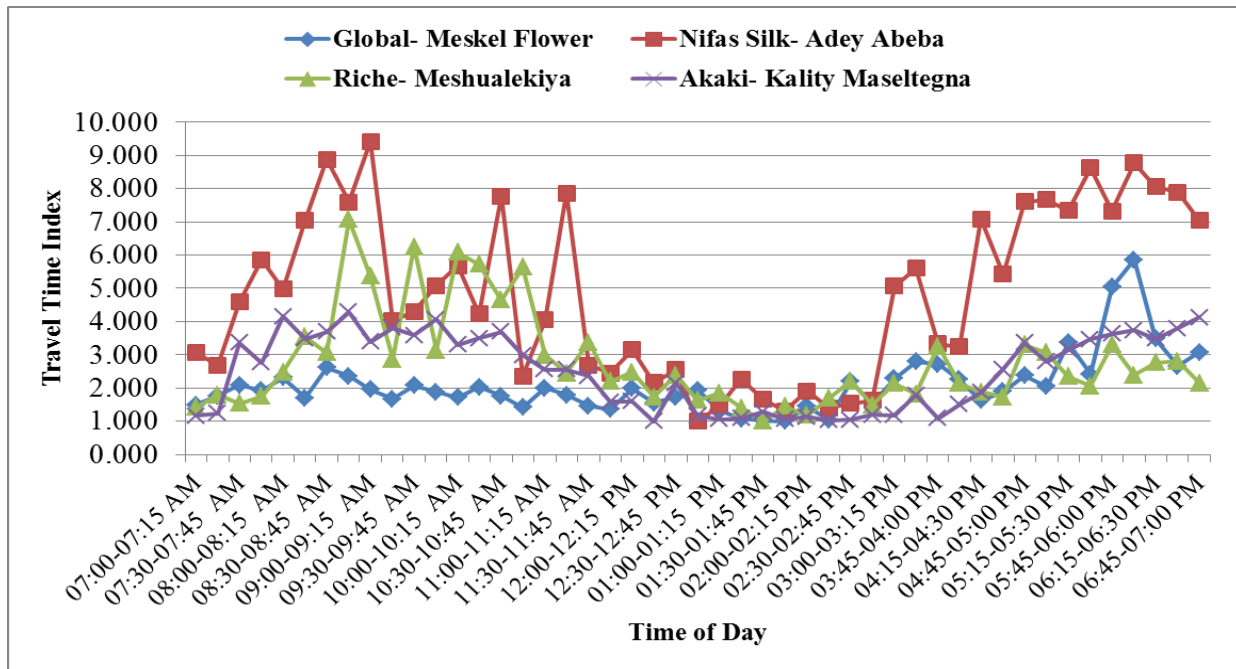


Figure 4-12: Travel Time Indexes for Road Segments

4.3.4. Delay, Delay Rate, Delay Ratio and Percent of Daily Delay

Delay is the amount of extra time spent traveling due to congestion on the road and its calculation is based on the baseline speed which is recorded on lowest travel time throughout the day. Figure 4-13 below shows maximum delay occurred in the morning and evening peak periods; however, the length of each segment is different. So, it is difficult to interpret delay directly from the figure before converting to the same unit length. But even the Nifas Silk- Adey Abeba road segment is the shortest one but the delay on this segment is the maximum because there is large number of pedestrians and interference of Light Rail Transit for left turn movements in the road segment. In addition, the Global- Meskel Flower is the longest segment; but its delay value is the minimum.

Delay rate is the amount of delay in minutes per kilometer of road segment. It expresses delay in terms of a unit length than that of delay so it is much better to express congestion and to compare congestion level at road segments than delay. From Figure 4-14 the Global- Meskel Flower road

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

segment has the minimum delay rate whereas the Nifas Silk- Adey Abeba and Akaki- Kality Masetegna road segments have the maximum delay rate both during the morning and evening peak periods.

Delay ratio is the ratio of delay rate to actual travel rate which also expresses congestion pattern of road segments. In the same way as that of delay rate, the Nifas Silk- Adey Abeba and Akaki- Kality Masetegna road segments have the maximum value and the Global- Meskel Flower road segment has the lowest value of delay ratio.

Percent of daily delay is the percent from total daily delay at the specified time interval of the day and it is a good indicator of congestion intensity for daily traffic. Figure 4-16 below shows the mid-day low percentage of delay that occurred for all segments, in the morning peak periods at Riche- Meshualekiya, Nifas Silk- Adey Abeba and Akaki- Kality road segments with the maximum percentage of daily delay but in the evening peak period, the Global- Meskel Flower, Nifas Silk- Adey Abeba and Akaki- Kality road segments have the maximum value. Figure 4-13, 4-14, 4-15 and 4-16 below illustrates delay in seconds; delay rates for the road segments in min/km; delay ratio for road segments; and percent of daily delays respectively.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

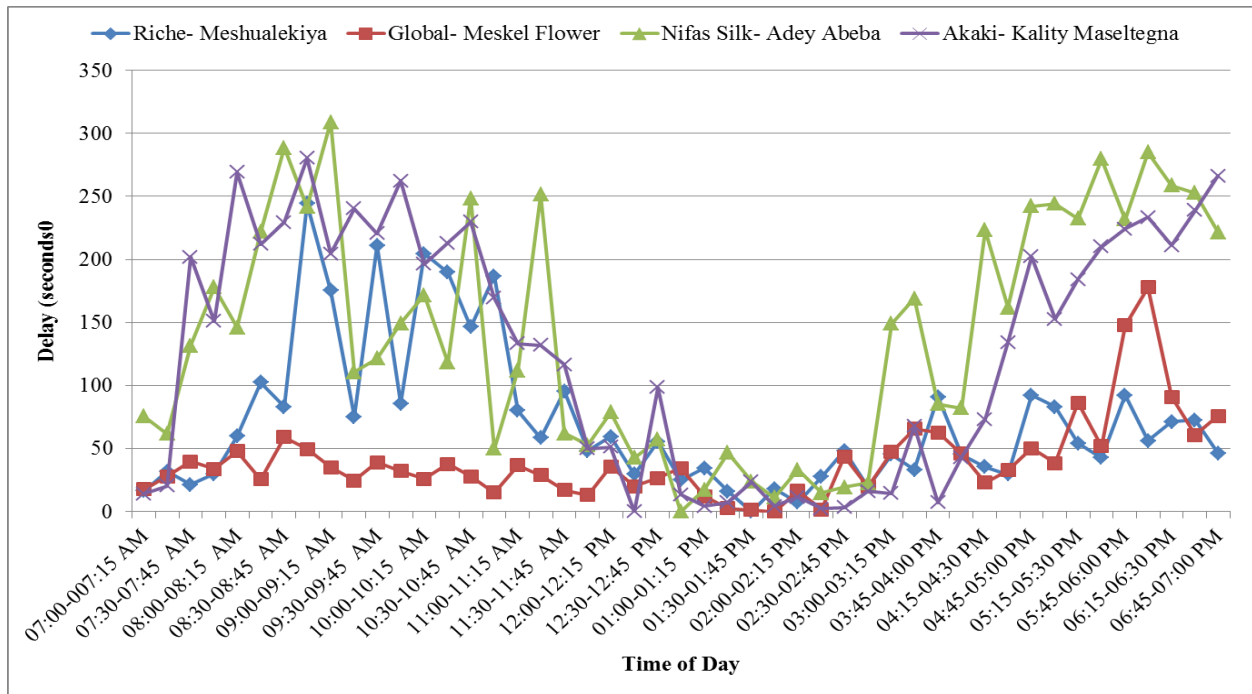


Figure 4-13: Delay for Road Segments in seconds

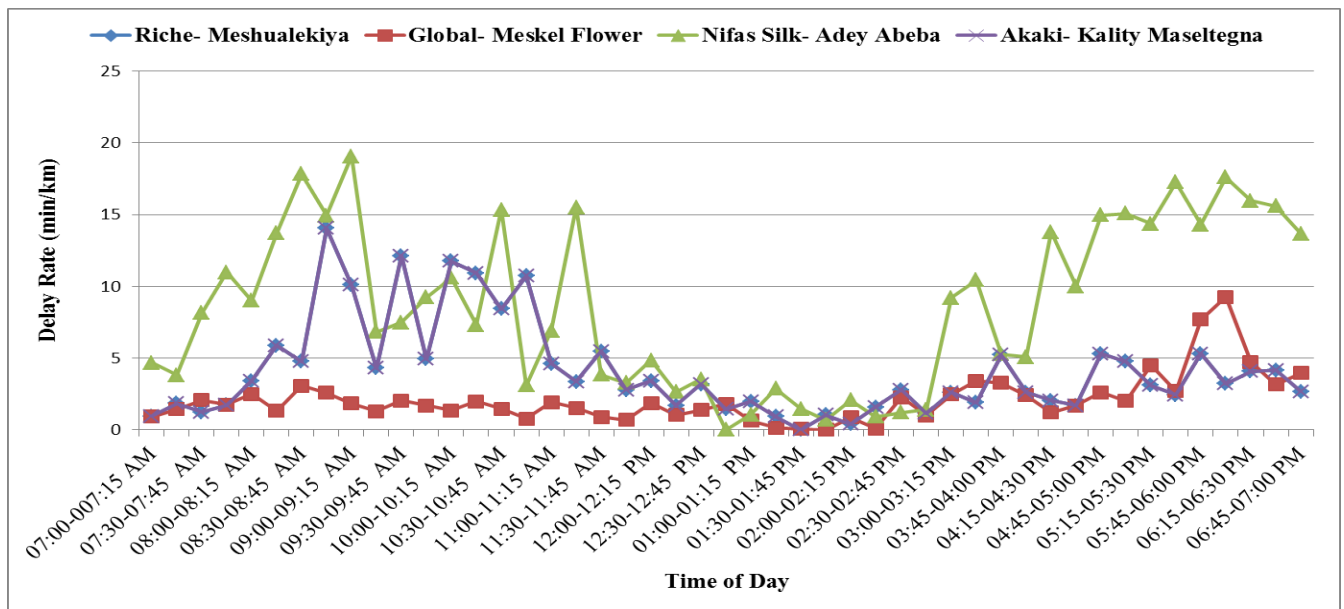


Figure 4-14: Delay Rate for Road Segments min/km

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

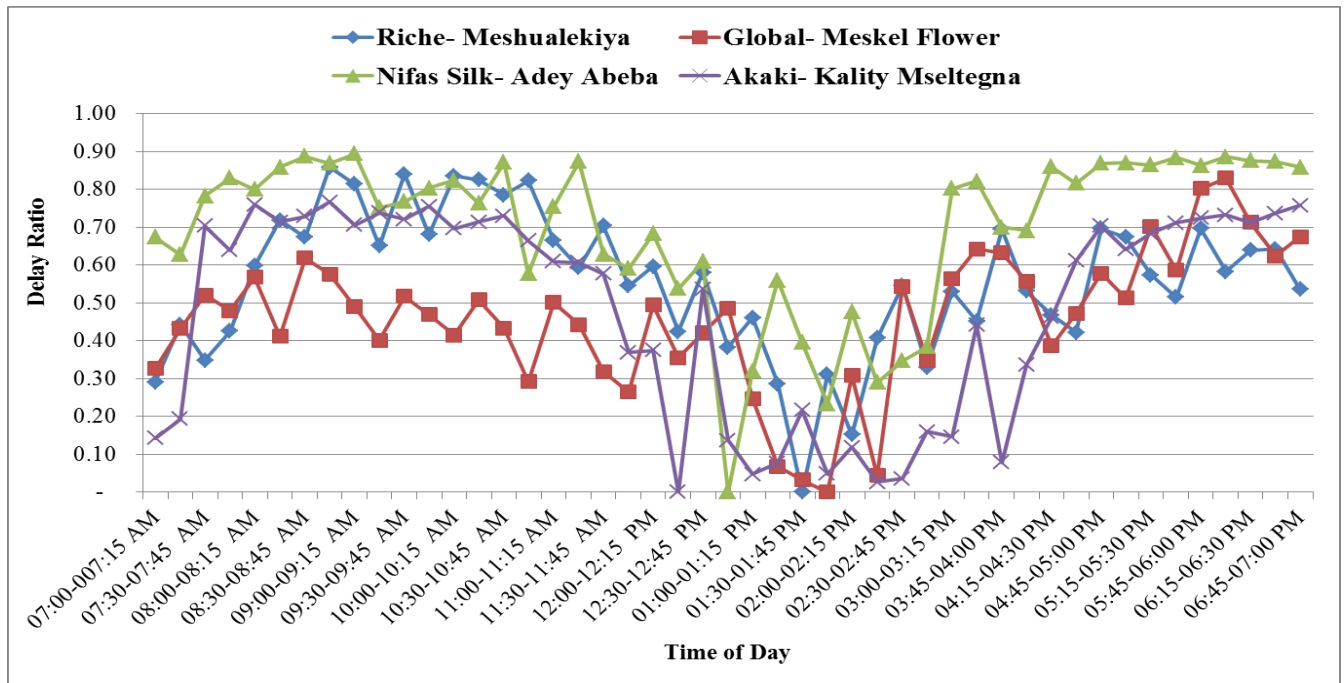


Figure 4-15 Delay Ratio for Road Segments

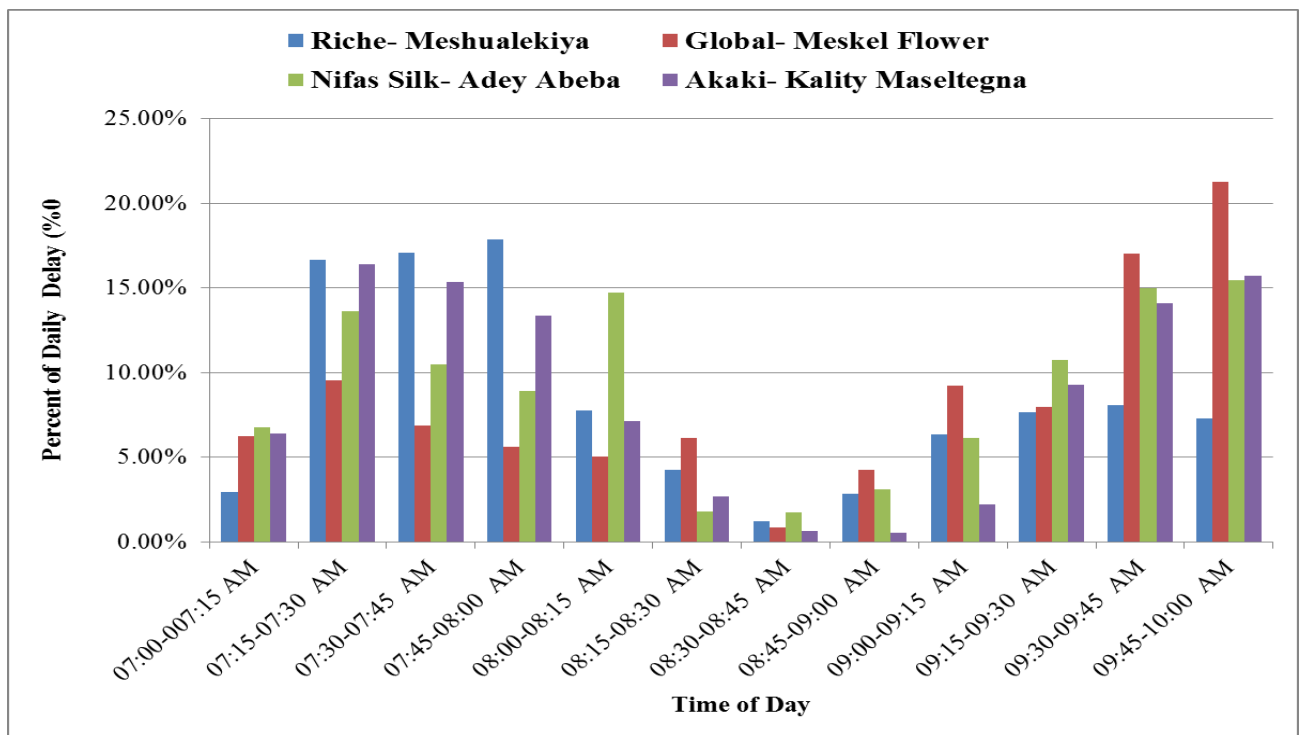


Figure 4-16: Percent of Daily Delay of Road Segments

4.3.5. Total Segment Delays (person minutes, vehicle minutes)

Total segment delay is also a useful measure to estimate the total duration of congestion of a road segment in urban areas, to perform economic analysis and it is easy for the public and policymakers to comprehend and to implement cost- effective decisions.

Total segment delay is used to analyze the intensity of congestion on people in the selected corridors because it shows how much total segment vehicles/person time is spent due to congestion on that road corridor.

As shown in Figure 4-17 below, there is maximum delay of vehicles/person in the morning and evening peak periods. During the morning peak period, the Akaki- Kality Masetlegna, Nifas Silk-Adey Abeba and Riche- Meshualekiya road segments have the maximum total delay while the Akaki- Kality Masetlegna and Nifas Silk- Adey Abeba have also the maximum value in the evening peak period. Figure 4-17 and 4-18 below illustrates total segment delays in vehicle-min and person- min respectively.

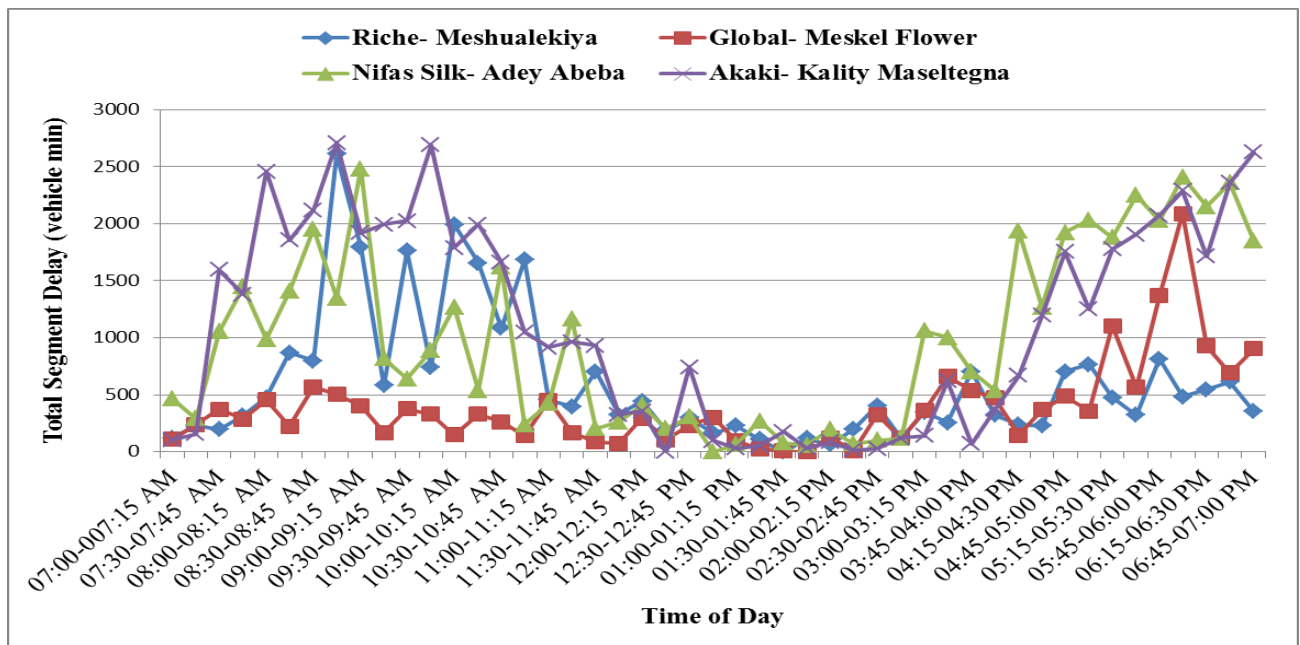


Figure 4-17: Total Segment Delay (vehicle min)

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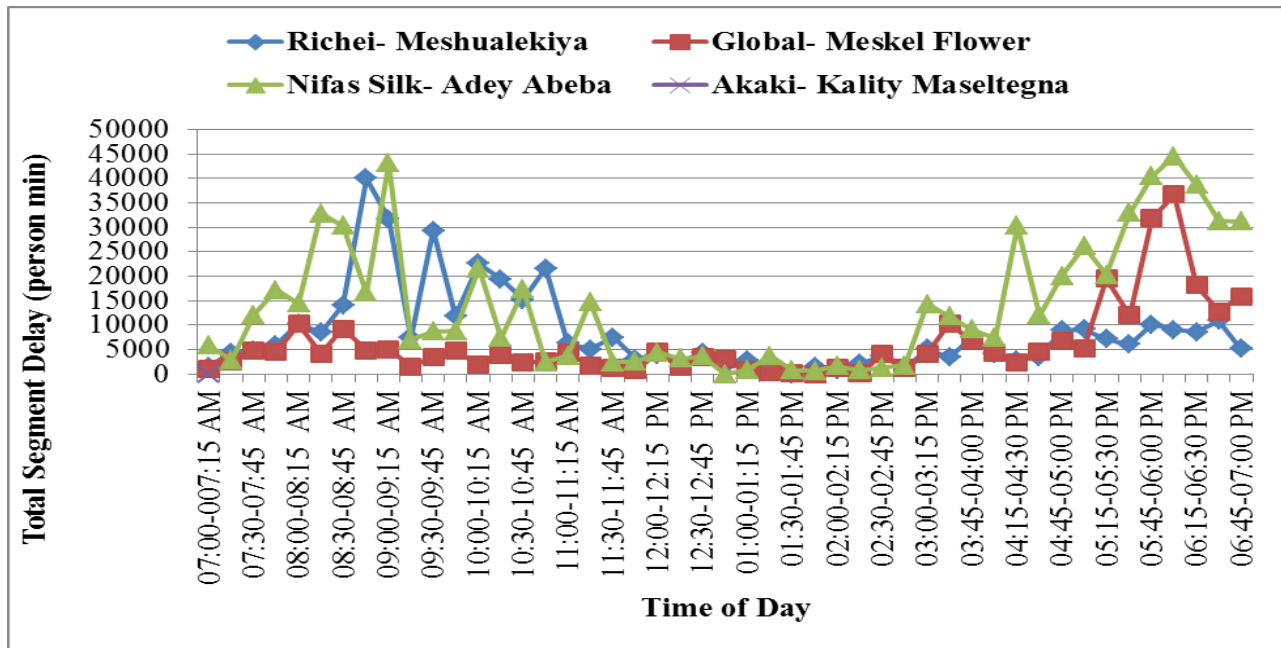


Figure 4-18: Total Segment Delay (person min)

4.4. Congestion Economic Cost Analysis

There is a great concern to measure traffic congestion economic cost throughout the world. To measure the economic cost of traffic congestion, there is no single rule and it differs depending on economic profile of areas and unique pattern of congestion.

This paper presents procedures to analyze the economic cost of traffic congestion based on the travel time approach. It provides an overview of the economic cost of congestion in Addis Ababa especially at the Meskel Square- Kality interchange which incorporates passenger car delay costs, passenger car excess fuel consumption due to congestion, truck vehicle delay cost and excess fuel consumption due to congestion, cargo delays, vehicle delay costs that include; operators’ costs, operating cost of vehicles excluding fuel cost.

To calculate the total congestion costs, the following parameters need to be known: Total segment delay (Vehicle min), vehicle occupancy, total segment delay (person min), delay per

traveler (annual hrs.), passenger car fuel economy (liter/km), passenger car fuel economy (liter/km) at FFC, truck fuel economy (liter/km), truck fuel economy (liter/km) at FFC, annual fuel wasted by passenger cars, annual fuel wasted by trucks, annual fuel consumed in FFC of passenger cars, annual fuel consumed in FFC of trucks, annual passenger vehicle delay cost, annual passenger fuel cost, annual truck delay cost, annual truck fuel cost, annual congestion cost, Percentage of commodities carried by truck, sensitivity of commodities, emission of CO₂ and other parameters are necessary.

4.4.1. Total Congestion Cost due to Delay of Vehicles

As the road segment becomes more congested, most vehicles travel below the free flow speeds which occur at low volume of the segment. So, to express in terms of costs, the following equations were used in the thesis.

4.4.1.1. Passenger Delay Cost

Passenger delay cost is the cost of passengers incurred due to traffic congestion and it was calculated using the following formula:

$$\text{Annual Passenger Delay Cost} = \frac{\text{Daily Passenger Vehicle Hours of Delay}}{\text{of Delay}} \times \frac{\text{Value of Person time}}{\left(\frac{\text{Birr}}{\text{hr}}\right)} \times \frac{\text{Vehicle Occupancy}}{\left(\frac{\text{person}}{\text{vehicle}}\right)} \times \text{Annual Conversation Factor}$$

Daily passenger vehicles hours of delay is obtained from the previous section 4.3.5 and value of person time is equal to 19 birr/hr. Vehicle occupancy data is obtained by multiplying the capacity of each vehicles by their number and dividing by the total number of vehicles moving on the road segment. Annual conversation factor is a factor multiplying the daily passenger vehicles hours of delay to annual passenger vehicles hours of delay. On Sundays and holidays, there is no congestion. There are 52 Sundays and 11 holidays per year in Ethiopia. So, annual conversation factor is equals to be 365 minus 63 which are 302.

4.4.1.2. Truck/ Commercial Vehicle Delay Cost

In the case of trucks the value of truck congestion cost is highly governed by delay cost because trucks do not carry passengers but only cargos. Truck vehicle delay cost is calculated using the following formula:

$$\text{Annual Commercial Delay Cost} = \text{Daily commercial Vehicle Hours of Delay} \times \text{Value of Commercial Vehicles} \times \text{Annual Conversation Factor}$$

Value of commercial vehicles includes vehicle operation costs, operators' costs, lease or purchase values, truck repair and maintenance, insurance premiums and other spare parts of vehicles

4.4.2. Total Congestion Costs due to Wasted Fuel

To calculate total congestion cost due to wasted fuel, it is important to determine the vehicles fuel economy, fuel wasted at the free flow condition and congested condition and fuel cost. Fuel economy is obtained from the Urban Mobility Report (2011) and was converted to the metric system as shown in the equation below. The current market price of diesel fuel is about Birr 17.45 /liter i.e. averaging the price of naphtha Birr 16.35/liter and Benzene Birr18.54 /liter.

4.4.2.1. Passenger Car Fuel Economy (liter)

Passenger car fuel economy in liters is calculated as follows:

$$\text{Passenger Car Fuel Economy (lit/km)} = ((-0.0066 \times (\text{speed})^2 \times 0.823 \times (\text{speed}) + 6.1577) \times \left(\frac{1.6093}{4.5461}\right))$$

4.4.2.2. Truck/ Commercial Fuel Efficiency

In the same way truck fuel economy in liters is calculated as follows:

$$\text{Truck Fuel Efficiency} \left(\frac{\text{lt}}{\text{km}} \right) = (1.4898 \times \ln(\text{speed}) - 0.2554 \times \left(\frac{1.6093}{4.5461} \right))$$

Then, after calculating the fuel economy for passenger and cargo vehicles, the next step is to calculate the fuel wasted at free flow condition and congested conditions.

4.4.2.3. Annual Fuel wasted

Annually wasted fuel at different congested and free flow conditions is calculated by multiplying travel time by average travel speed and dividing the result by fuel economy and converts each value annually by multiplying using annual conversation factor.

$$\text{Annual fuel Wasted in Congestion} = \frac{\text{Travel time (Vehicle hours)} \times \frac{\text{Average Hourly Speed}}{\text{Average Fuel Efficiency}} \times \text{Annual Conversation Factor}}$$

$$\text{Annual Fuel Consumed in FFC (lt)} = \frac{\text{Travel Time} \times \frac{\text{Free Flow Speed}}{\text{Average Fuel Efficiency}} \times \text{Annual Conversation Factor}}$$

Therefore, the fuel which is wasted due to congestion is the difference of fuel wasted at the different congested conditions and its free flow speed.

$$\text{Annual Fuel Wasted due to Congestion} = \frac{\text{Annual Fuel Consumed in Congestion}}{\text{Annual Fuel Consumed in Free Flow Speed}}$$

So, after calculating annual fuel wasted due to congestion, the next step is converting wasted fuel into monetary value.

$$\text{Annual Fuel Cost (Birr)} = \frac{\text{Annual Fuel Wasted due to Congestion (lt)} \times \text{Fuel Cost (Birr/lt)}}$$

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Therefore, total congestion cost is the sum of delay and wasted fuel due to congestion. From Table 4-4 below, the total congestion cost in the morning and evening peak period on the Akaki-Kality Masetegna road segment is higher than others because the percentage of trucks on this road segment is very high as compared to other road segments. The Riche- Meshualekiya has maximum total congestion costs in the morning peak period while the Nifas Silk- Adey Abeba and the Goter- Meskel Flower road segments have maximum costs in the evening peak period. The total congestion costs due to delays and fuel wastages are presented in Annex E. Figure 4-19 illustrates total costs in this respect.

Table 4-3: Total Annual Congestion Costs (Birr)

Time	Total Annual Congestion Cost in ETB			
	Riche-Meshualekiya	Global- Meskel Flower	Nifas Silk-Adey Abeba	Akaki-Kality Masetegna
07:00-008:00AM	1,681,010.20	1,091,032.42	3,254,380.57	6,234,055.06
08:00-09:00 AM	3,473,259.99	1,991,742.48	8,007,890.75	17,368,830.85
09:00-10:00 AM	7,124,410.09	1,282,410.57	5,762,482.06	14,733,951.18
10:00 - 11:00AM	6,429,194.42	903,387.95	4,172,236.96	10,485,819.43
11:00- 12:00 AM	2,482,744.04	699,107.96	2,081,047.67	4,344,271.98
12:00-01:00 PM	1,410,746.42	1,052,966.87	966,305.24	1,690,103.75
01:00-02:00 PM	611,656.54	100,411.22	509,320.01	393,415.77
02:00-03:00PM	914,329.53	562,869.90	467,461.20	310,135.13
03:00-04:00 PM	2,241,792.69	2,199,615.54	3,645,750.26	1,542,411.07
04:00-05:00 PM	2,708,090.44	1,595,758.34	7,524,458.18	7,814,578.25
05:00- 06:00 PM	3,414,099.81	8,421,415.19	13,131,020.59	12,632,044.26
06:00- 07:00 PM	3,482,948.58	7,044,151.96	8,496,096.18	15,109,877.46
Total	35,974,282.75	26,944,870.39	58,018,449.65	92,659,494.18
Per km	124,049,250.85	84,202,719.97	214,883,146.85	308,864,980.58
Ratio	0.17	0.13	0.27	0.43

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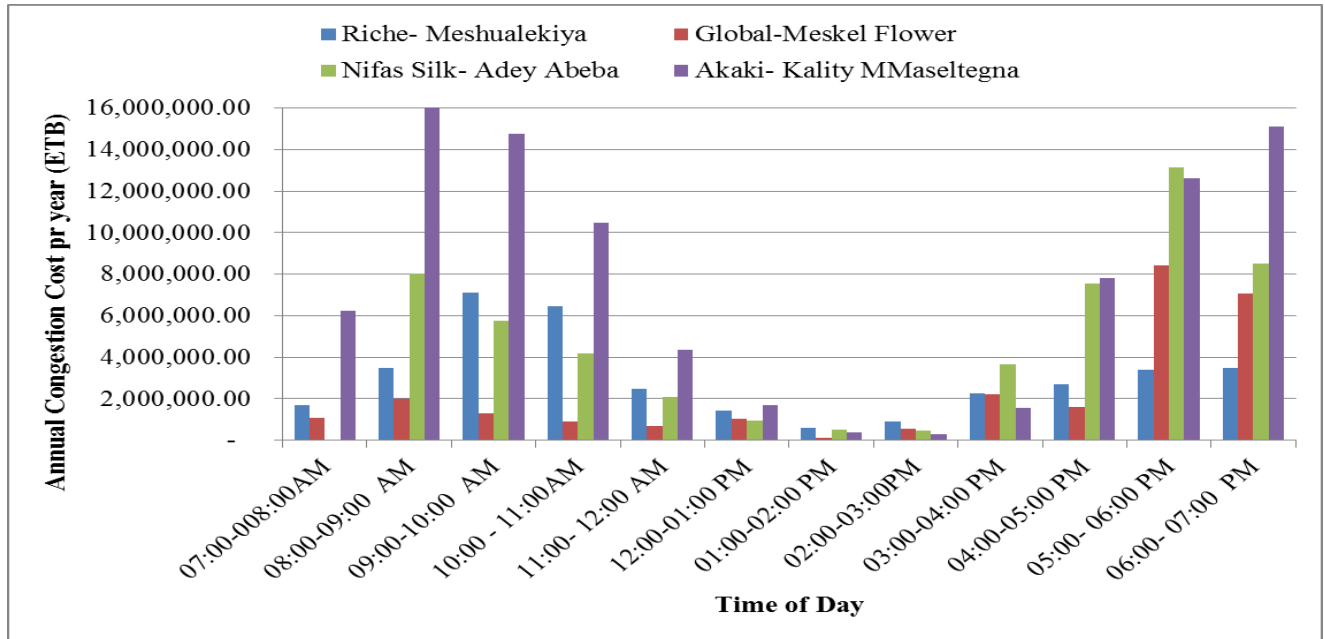


Figure 4-19: Cost per year in ETB

Another very important thing that is shown from Figure 4-20 to figure 4-23 is the relationship between average travel speed and fuel consumption. The graphs show that as the average travel speed increases, fuel consumption decreases for both passenger and truck vehicles. So, when traffic congestion reduces and average travel speed increases fuel consumption is reduced. According to Litman (2013), when average travel speed increases above 65-80 km/hr this relationship is not maintained because above 65-80 km/hr vehicles consume extra fuel to maintain its speed.

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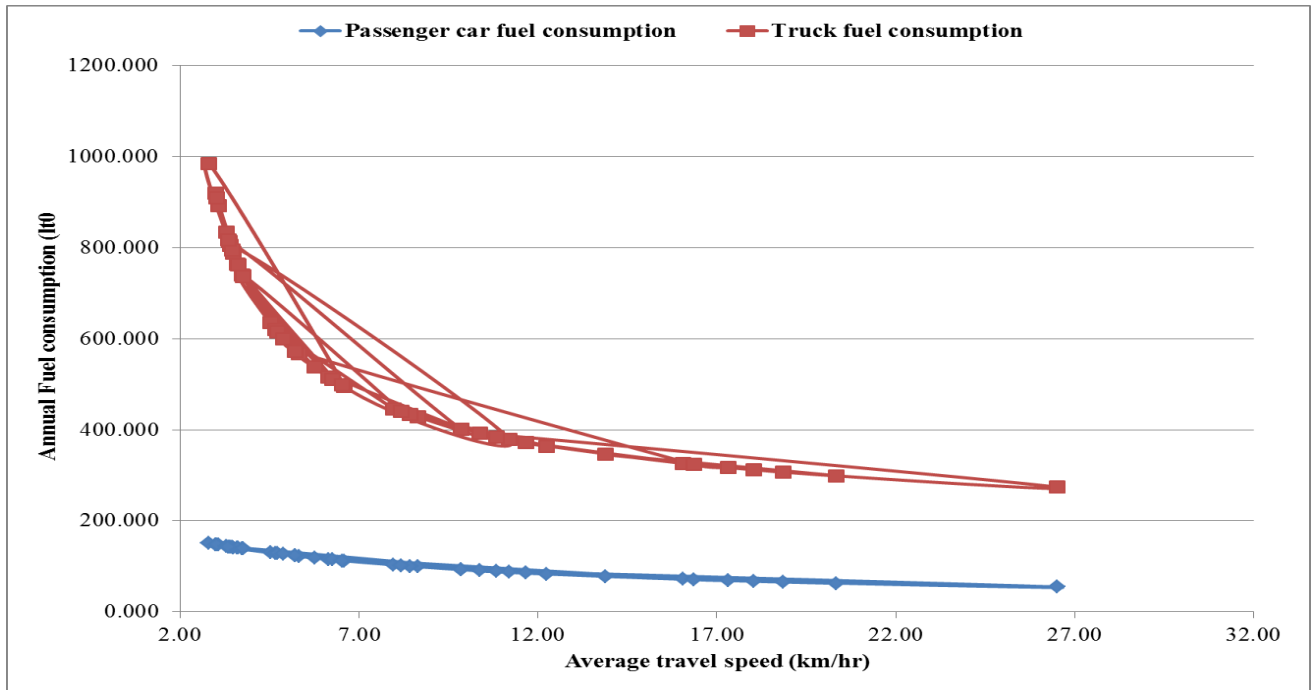


Figure 4-20: Relationship of Annual Fuel Consumption and Average Travel Speed for Nifas Silk- Adey Abeba Road Segment

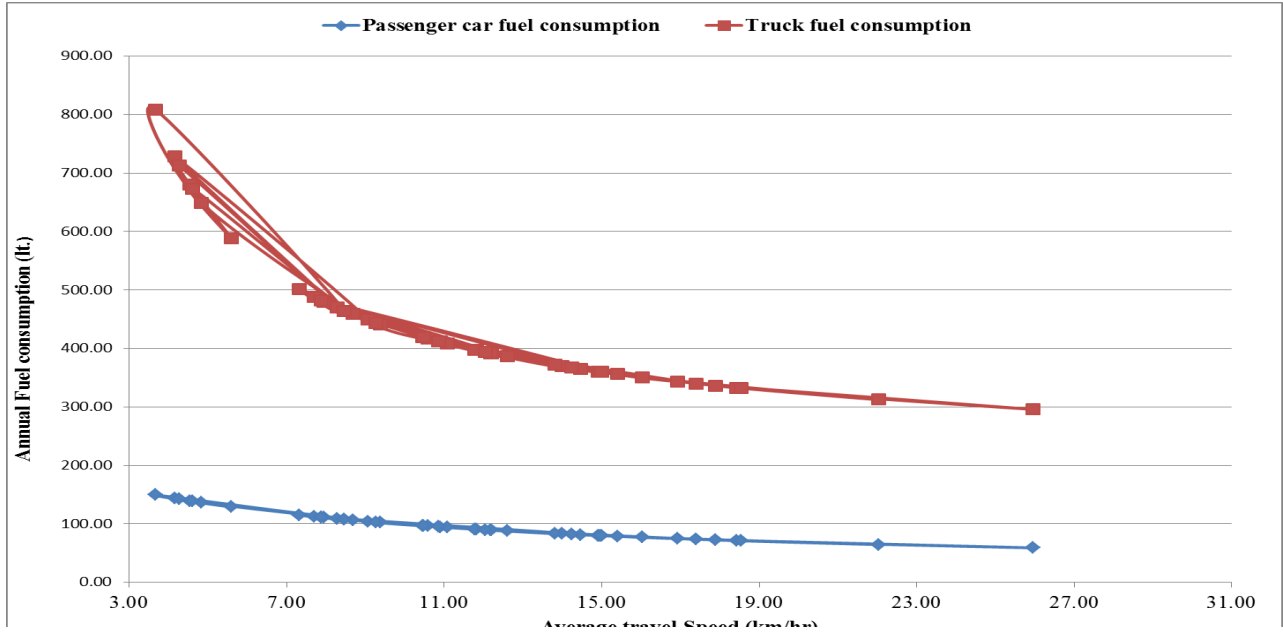


Figure 4-21: Relationship of Annual Fuel Consumption and Average Travel Speed Riche-Meshualekiya Road Segment

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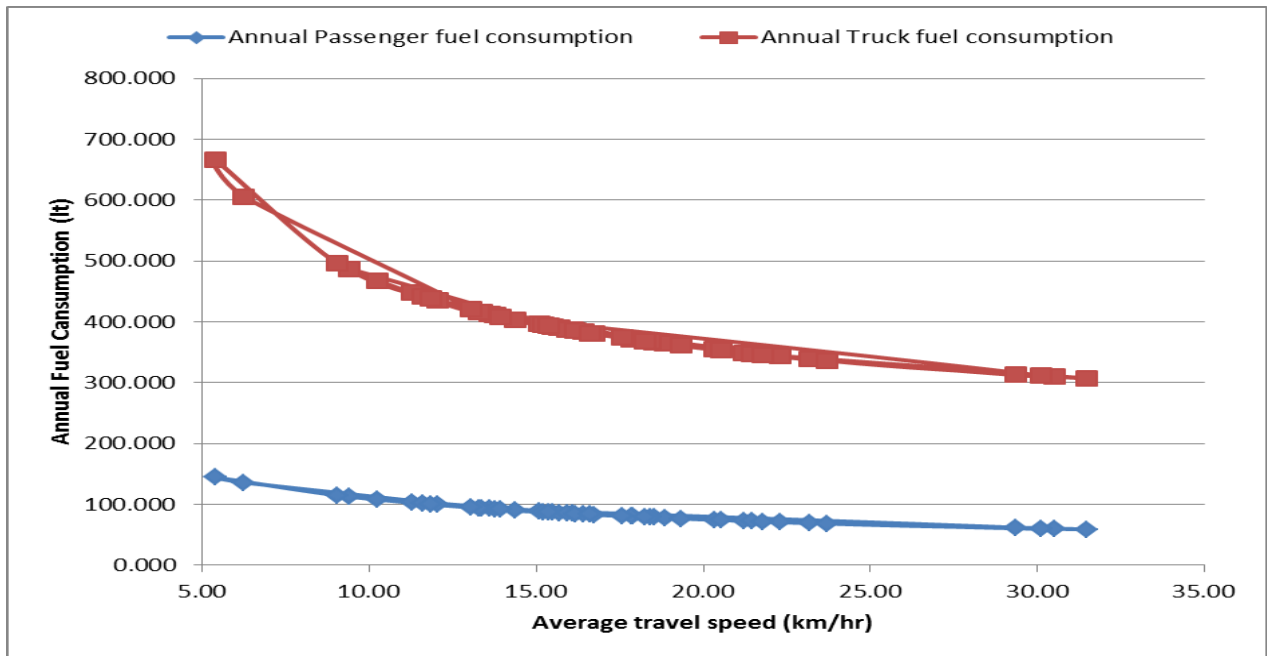


Figure 4-22: Relationship of annual fuel consumption and average travel speed for Global-Meskel Flower road segments

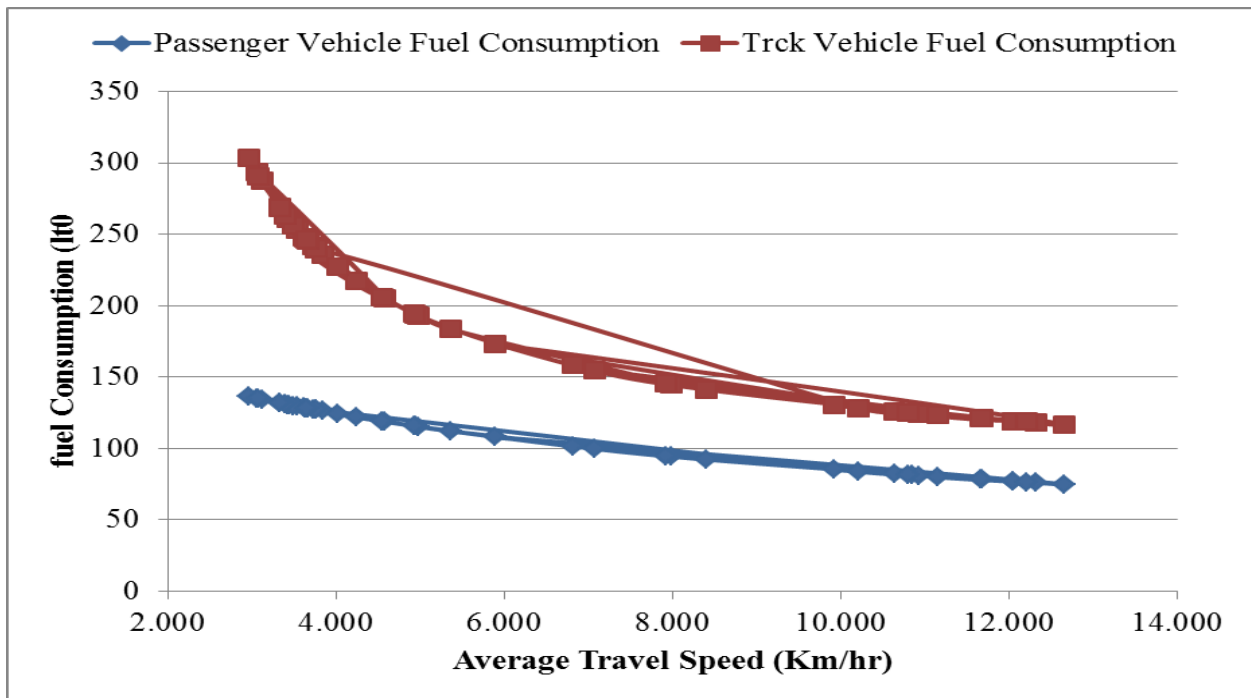


Figure 4-23: Relationship of Annual Fuel Consumption and Average Travel Speed for Akaki- Kality Masetegna

4.5. Commercial Costs of Traffic Congestion

Traffic congestion affects business activities due to delay of goods at the time of requirement which affects just in time logistics; forcing business companies to hold greater inventory, decreases value of perceivable commodities because it increases depreciation. In addition, for some commodities, such as fresh fruits and vegetables, due to delays perishability occurs. Therefore, traffic congestion affects each commodity moved by trucks even though its effect is differing from commodity to commodity. According to Gillett (2011), to evaluate commodities moved by trucks three time sensitivities are used: highly time sensitive (HTS), moderately time sensitive (MTS), and low time sensitive (LTS). Each sensitivity group includes various types of commodities based on their perishability and use. So according to Gillett (2011), highly time sensitive goods are those commodities that are at risk of high obsolescence costs due to the shipments; perishable nature which includes agricultural produce or fresh produce. Moderately time sensitive goods are those with lower time sensitivities such as bulk liquids and building materials and these are considered moderately time sensitive which are not at the same risk level to deteriorate in transit. Instead, many of the goods moved in this category have higher time sensitivities due to scheduling by receivers. Finally, the least time sensitive goods tend to be household products or other similar goods.

As provided by the Addis Ababa Chamber of Commerce (2009), commodities carried by trucks in Ethiopia are summarized in Table 4-4 below together with corresponding percentages in Figure 4-24.

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Table 4-4: Total Percentage Commodities carried by Trucks in Ethiopia

Commodities Carried	Percentage
Agricultural products including coffee and tea	22.3
Perishable foodstuffs	17.8
Construction materials	16.7
Machinery and equipment	8.5
Oil products	6.8
Processed foods and drinks	6.7
Other commodities	21.2

Source: Addis Ababa Chamber of Commerce, 2009

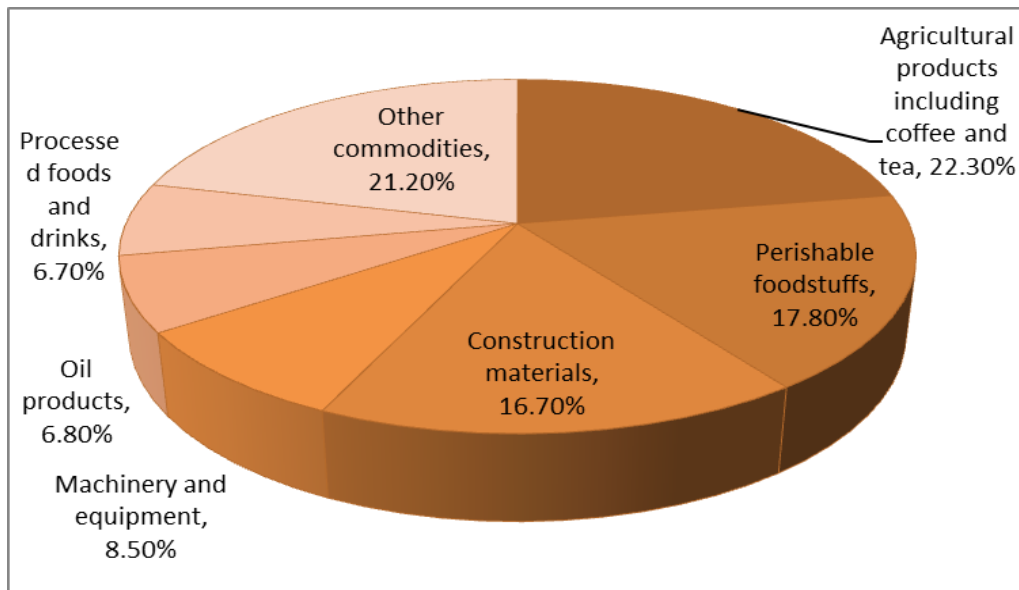


Figure 4-24: Graphical percentage of Commodities carried by trucks in Ethiopia

Classification of each commodity and their percentages are shown in Table 4-5 below. To calculate the total delay cost for commodities due to traffic congestion, user delay cost per (hour m³) is necessary. So, based on questionnaire interviews of stake holders they were found as

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follows: For highly time sensitive commodities Birr 20 / (hr m³), for moderately time sensitive Birr 10 / (hr m³) and low time sensitive Birr 5 / (hr m³) is used. Therefore, the total commodity delay costs were calculated using delay cost of each commodities by their respective percentages and then finally adding up to obtain total cost.

Table 4-5: Total Business Cost per year due to Traffic Congestion

Sensitivity group	Commodities	Percentage (%)	User Delay cost/hr.	Total Cost
Highly time Sensitive	Agricultural products (Perishable foodstuffs)	40.10	20	8,999,428.39
Moderately time sensitive	Construction materials Machinery and equipment Oil products Processed foods and drinks	38.70	10	4,342,616.94
Low time sensitive	Other commodities	21.20	5	1,189,450.63
Total		100	-	14,531,495.96

4.6. Traffic Congestion and its Effects on the Environment

Transportation has negative effects on the environment as a source of greenhouse gases such CO₂, CO, HC, NO_x. Greenhouse gas emissions make a significant contribution to atmospheric changes and climate disruptions, which are harmful to the natural environments and create a threat to human health and welfares. Among greenhouse gases emitted by vehicles, CO₂ contributes the major part because burned fuels are mainly converted to CO₂ after combustion. According to Litman (2013), when the traffic volume increases and the travel time decreases

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nearly below on average in between of 65 to 80 km/hr. the average fuel consumption of vehicles increases and in the same way the greenhouse emission increases because greenhouse emission is directly related to fuel consumption. The vehicular pollution is majorly caused due to the combustion of fuel. So, emission of CO₂ due to traffic congestion is calculated by multiplying wasted fuel due to congestion by conversion factor from liters of fuel to grams of CO₂. DEFRA (Department for Environment, Food and Rural Affairs of America) (2015), greenhouse gas conversion factor repository proposes 3.1643 (g CO₂)/ (g diesel), and it is this emission conversion factor that is used in this study. Figure 4-24 below shows the emission of CO₂ due to traffic congestion for those selected road segments.

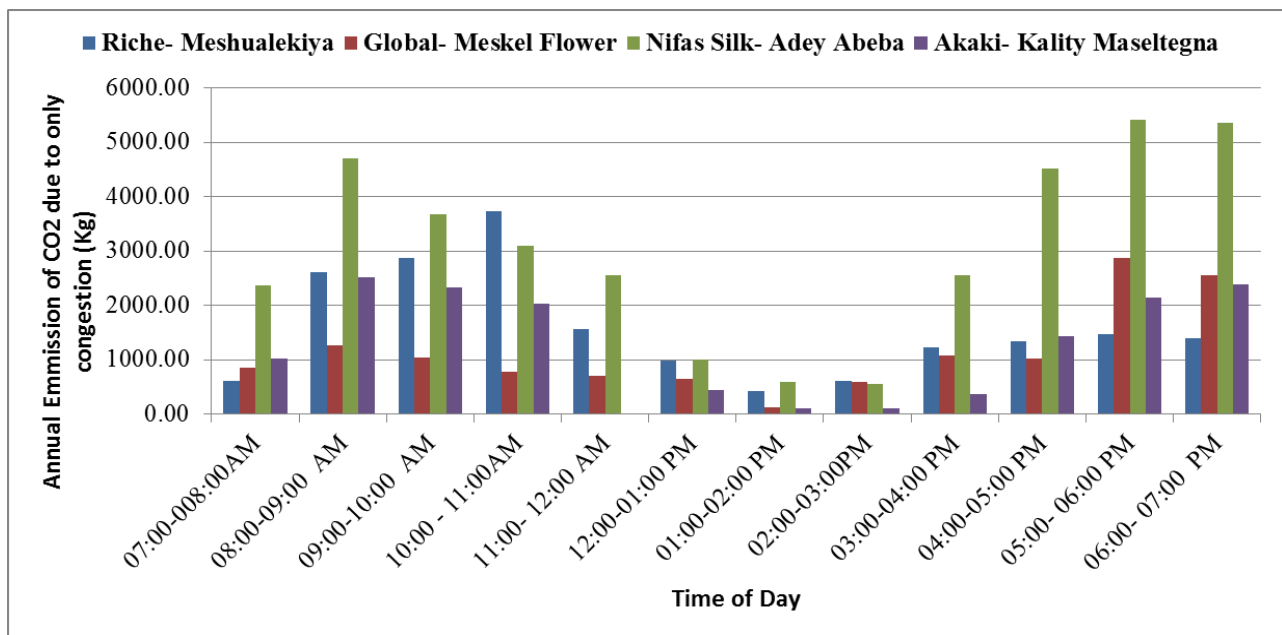


Figure 4-24: Annual Total Emission of CO₂ due to Congestion only in Kg.

Figure 4-24 shows that the Nifas Silk- Adey Abeba road segment has the maximum emission of CO₂ throughout the day than the rest. Similarly, the Riche- Meshualekiya road segment has also the maximum value next to the Nifas Silk-Adey Abeba road segment in the morning peak period. The Global- Meskel Flower road segment has the maximum value in the evening. The Akaki- Kality Masetegna road segment has the maximum value during both the morning and evening

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peak. In mid-day the minimum emission value occurs because congestion at mid-day has low value.

Then, after converting the wasted fuel due to congestion into CO₂ emission the next step is converting CO₂ emission into Birr. According to Tol (2005), atmospheric damage costs were estimated in the range from \$10 to \$50 per ton of carbon-dioxide, though some estimates are as high as \$300 or more per ton. So, in this paper, atmospheric damage cost of \$50 was accounted for equivalent to Birr1350 /1000kg or Birr1.3 /kg of CO₂. Table 4-6 below shows the estimated environmental cost of congestion.

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Table 4-6: Environmental Cost of Traffic Congestion

Duration	Corridor Name											
	Riche- Meshualekiya			Nifas Silk- Adey Abeba			Global- Meskel Flower			Akaki- KalityMasetegna		
	Wated Fuel Due to Congestion(lt)	Kilo gram of CO2	Environme ntal Cost(Birr)	Wasted Fuel Due to Congestion (lt)	Kilo gram of CO2	Environme ntal Cost (Birr)	Wasted Fuel Due to Congestion (lt)	Kilo gram of CO2	Environm ental Cost (Birr)	Wasted Fuel Due to Congestion (lt)	Kilo gram of CO2	Environm ental Cost (Birr)
12:30-12:45	125.46	317.60	412.88	128.04	324.13	421.37	67.46	195.07	253.59	89.00	257.34	256.04
12:45-01:00	60.28	152.58	198.36	0.00	0.00	0.00	85.99	248.63	323.21	13.71	39.63	38.33
01:00-01:15	81.25	205.67	267.37	42.69	108.06	140.48	31.94	92.34	120.05	4.39	12.70	11.40
01:15-01:30	39.95	101.13	131.47	106.90	270.62	351.80	7.34	21.22	27.59	7.36	21.27	19.97
01:30-01:45	0.00	0.00	0.00	57.99	146.80	190.84	3.30	9.55	12.41	23.42	67.71	66.41
01:45-02:00	44.64	113.00	146.91	28.13	71.20	92.56	0.00	0.00	0.00	4.43	12.79	11.49
02:00-02:15	18.32	46.38	60.30	78.72	199.27	259.05	42.81	123.77	160.90	11.72	33.88	32.58
02:15-02:30	66.26	167.73	218.05	37.22	94.22	122.49	4.62	13.35	17.35	2.36	6.82	5.52
02:30-02:45	110.67	280.16	364.21	47.85	121.14	157.48	106.09	306.75	398.78	3.27	9.46	8.16
02:45-03:00	48.53	122.85	159.71	55.48	140.44	182.57	50.81	146.92	191.00	16.37	47.33	46.03
03:00-03:15	104.37	264.22	343.48	304.27	770.25	1001.33	113.57	328.39	426.91	14.79	42.78	41.48
03:30-03:45	78.40	198.45	257.99	343.31	869.06	1129.78	152.50	440.95	573.24	63.04	182.26	180.96
03:45-04:00	194.92	493.42	641.45	183.18	463.70	602.82	146.64	424.01	551.22	7.46	21.56	20.26
04:00-04:15	104.58	264.73	344.15	176.79	447.53	581.78	111.43	322.20	418.85	41.68	120.51	119.21
04:15-04:30	83.18	210.57	273.74	456.02	1154.38	1500.70	59.17	171.09	222.42	67.98	196.55	195.25
04:30-04:45	70.24	177.82	231.17	329.52	834.17	1084.42	81.83	236.61	307.59	118.38	342.30	341.00
04:45-05:00	197.47	499.87	649.83	498.45	1261.80	1640.34	119.97	346.87	450.94	175.22	506.65	505.35
05:00-05:15	179.53	454.48	590.82	503.32	1274.13	1656.36	94.61	273.55	355.62	133.65	386.44	385.14
05:15-05:30	122.36	309.74	402.66	476.25	1205.60	1567.28	193.52	559.55	727.41	159.84	462.17	460.87
05:30-05:45	98.66	249.76	324.68	588.97	1490.94	1938.23	123.55	357.23	464.40	182.16	526.71	525.41
05:45-06:00	197.39	499.68	649.58	474.51	1201.19	1561.55	311.00	899.25	1169.02	194.55	562.53	561.23
06:00-06:15	126.33	319.79	415.72	602.71	1525.73	1983.45	368.34	1065.04	1384.56	202.78	586.33	585.03
06:15-06:30	156.30	395.65	514.35	537.25	1360.00	1768.01	202.43	585.31	760.90	183.04	529.25	527.95
06:30-06:45	158.87	402.18	522.84	522.86	1323.58	1720.66	142.39	411.71	535.22	208.15	601.84	600.54
06:45-01:00	106.60	269.86	350.82	452.05	1144.35	1487.65	172.89	499.91	649.88	233.76	675.90	674.60

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CO₂ has also a relationship with average travel speed because as the average speed decreases nearly from 65- 80 km/hr. fuel consumption and emission rate of CO₂ increases, because at very low average speeds there is stop and go driving and vehicles do not travel far engines running which consumes more fuel and emits more CO₂. Therefore, the emission rate per kilometer is very high. Whereas when vehicles travel at much higher speed like above 80 km/hr they demand very high engine and requires more fuel which leads to high CO₂ emission rate. So, congestion mitigation for this scenario is also used for reduction of CO₂. Figure 4-25 below illustrates relationship of annual emission of CO₂ and average travel speed.

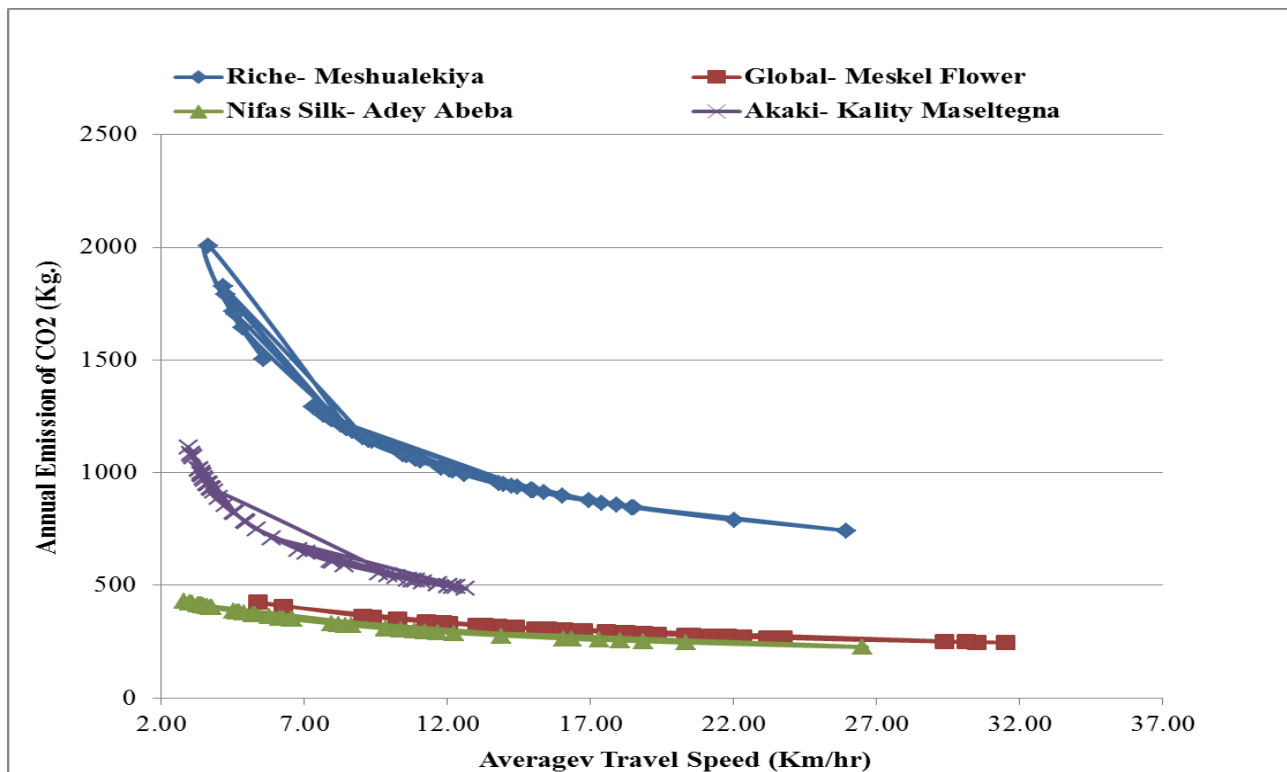


Figure 4-25: Relationship of Annual Emission of CO₂ and Average Travel Speed

4.7. Questionnaires Respond

Questionnaires were distributed to different classes of road users such as taxi drivers, bus drivers, commuters and students to assess the impact of congestion on individual person. The responses are summarized in Table 4-7 below. From the total distributed questionnaires among various causes of traffic congestion in the city, 90% of the respondents put lack of good mass transport, imbalance of vehicle volume and road capacity, bottlenecks, poor traffic management, illegal on street parking, inflexible work zone and informal on street trade are the major causes of traffic congestion. But the rest emphasize traffic accidents, pedestrian interference with vehicles and special events like road construction and maintenance as major contributors to traffic congestion.

Table 4-7: Questionnaire Response

Questionnaire		Frequency	Percent (%)
	Distributed	100	100.00
	Returned	90	90.00
Age	Below 20	18	20.00
	20-30	23	25.56
	30-40	20	22.22
	40-50	15	16.67
	Above 50	14	15.56
Sex	Male	58	64.44
	Female	32	35.56
Mode of transport	private vehicle	14	15.56
	Public	66	73.33
	Freight vehicle	5	5.56
	Others	5	5.56
Average distance travelled	1 km- 5 km	11	12.22
	6 km- 10 km	17	18.89
	11 km- 15 km	38	42.22
	above 16 km	24	26.67

4.8. Causes of Traffic Congestion

Traffic congestion is a multi-dimensional problem and the increase in traffic congestion is essentially a function of demand for road use increasing at a faster rate than the capacity, combined with ineffective traffic management. So, this mismatching are caused by various factors depending on the features of the road geometry, character of traffic flow, behavior of road users and those external factors.

On the selected road corridors, the causes of traffic congestion are identified based on site visit and questionnaires gathered. For the whole stretch from the Meskel Square to Kality interchange, the common causes of traffic congestion are: shortage of mass transport, poor traffic management, imbalance of vehicle volume and road capacity, especially at intersections, parking of passenger cars for loading and unloading of passengers near intersection entry and exit, on street parking on walkways and road ways which forces passengers to use roadways and conflict with vehicles, inflexible work zone and to some extent, traffic accidents are the major causes of traffic congestion.

All the above causes of traffic congestion but, especial conditions for each road segment and intersection are also causes of traffic congestion. For example, at the Adey Abeba intersection, pedestrian movements have great impact on traffic flow, because, the area is business center and many people come to the area for either buying or selling and to cross the intersection. For the Meskel Flower intersection, in addition to the above causes due to the presence of pier for the overpassing LRT, there is conflicting of vehicles in the absence of traffic police. At the Meshualekiya intersection, during the morning peaks, a number of vehicles come from the central area and so there is significant delays at the Meskel Square and creates long queues up to the intersection. In the afternoon, due to a large number of vehicles returning to their homes creates congestion and also parking at the exit and entry of intersection creates big problem.

4.9. Measures to Minimize Traffic Congestion

As traffic congestion is dynamic in nature, mitigation measures differ from place to place and time to time. From the questionnaires distributed the following are the basic congestion measures in decreasing order.

- ✚ Improve LRT (Light rail transit) by increasing their current number;
- ✚ Improve mass transportation system;
- ✚ Improve geometric design especially upgrading those at grade intersection to grade separated intersection;
- ✚ Increase road capacity;
- ✚ Improve traffic management strategies;
- ✚ Improve parking management;
- ✚ Mitigate illegal on street trade; and
- ✚ Flexible work schedule.

As observed during the study, parking of passenger cars for loading and unloading purposes on the road way creates serious problems. So, parking management strategies need to be addressed either by creating bay lane for parking especially at the exit and entry of intersections. Pedestrian cross movement is also another factor, especially at the Adey Abeba intersection and can be solved by constructing pedestrian bridge.

Among the different measures required, increasing the capacity of LRT is found to be important. For instance, if we increase the LRT capacity beyond its current capacity to accommodate about 25 percent of passenger who are moving by truck mode using the road segments, the following improvements can be achieved assuming that those 25 percent of passengers shift their mode of transport from truck to LRT. Similarly, assuming average travel speed increased by 25 percent,

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average travel time and traffic volume decreased by 25 percent and the flow continuous as previous pattern the following out puts are obtained:

Meskel Flower intersection:

- ✚ For both the Global- Meskel Flower and the Gotera- Meskel Flower road segments LOS changes from F to E;
- ✚ 10,640 vehicle minutes of total segment delay;
- ✚ 161,563 person minutes of total segment delay;
- ✚ 980,149 person hours of delay annual;
- ✚ 3,282 liters of fuel is saved or in general about ETB 16,630,320.78 is saved per year and about 9490 kg emission of CO₂ is reduced.

Adey Abeba Intersection:

- ✚ For both the Nifas Silk- Adey Abeba and the Saris- Adey Abeba road segments the LOS changes from LOS F to C;
- ✚ 22,490 vehicle minutes of total segment delay;
- ✚ 317,540 person minutes of total segment delay;
- ✚ 1,926,411 person hours of delay annual;
- ✚ 6008 liters of fuel is saved or in general about ETB 32,189,876.15 is saved per year and about 15,210 kg emission of CO₂ is reduced.

Meshualekiya Intersection

- ✚ For both Meskel Square and Riche approaches the LOS changes from F to A;

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- ✚ 15,141 vehicle minutes of total segment delay;
- ✚ 212,289 person minutes of total segment delay;
- ✚ 1,287,886 person hours of delay annual;
- ✚ 3,612 liters of fuel is saved or in general about ETB 27,789,552.34 is saved per year and about 9,144 kg emission of CO₂ is reduced.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Based on the results of the study the following major conclusions are formulated:

- ✚ Traffic flow is very congested on the selected road corridor because it is a crucial link with trade centers in the eastern and southern part of the country to Addis Ababa and it also links trade centers of Addis Ababa to the residential area in the South.
- ✚ Traffic volume in the morning period is high from the direction Kality to Meskel Square due to the fact that people commute to the city center for their day to day working and business activities; but traffic volume from the Bihere Tsige and the Addis Sefer approaches at the Adey Abeba is almost constant throughout the day with the evening peak period having the highest traffic volume.
- ✚ At Meskel Flower intersection occasionally even during mid-day traffic congestion occurs when there is no traffic police due to LRT piers which hamper smooth flow of traffic movements.
- ✚ From the four analyzed road segments for travel time, the Akaki- Kality Masetegna and Nifas Silk- Adey Abeba and Riche- Meshualekiya have the maximum travel time in the morning whereas Riche- Meshualekiya has maximum travel time in the morning peak period. But, the Global-Meskele Flower road segment has minimum value than other road segments.
- ✚ The total segment delay is very high and the result shows that about 17,241, 11,624 and 28,418 and 53,275 vehicle-min are lost on the Riche-Meshualekiya, Global-Meskel Flower, Nifas Silk-Adey Abeba and Akaki- Kality Masetegna road segments respectively.

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- ✚ In the case of the Adey Abeba intersection, another reason for traffic congestion is the interaction of LRT because of at grade intersection with LRT and large number of pedestrians crossing at the junction.
- ✚ Based on the LOS analysis, most intersections are performing above their capacities.
- ✚ From field observation and questionnaires, the following are major reasons for traffic congestion: lack of good mass transport, imbalance of vehicle volume and road capacity, bottlenecks, poor traffic management, interference of pedestrians at junctions, on street parking and informal on street trade and traffic accidents.
- ✚ Traffic congestion has different costs to road users and non-users. In this study; delay costs, vehicle fuel costs and cargo delay costs are incurred by road users and non-users and environmental cost is included.
- ✚ Total congestion costs including delay costs and wasted fuel costs of passenger and truck vehicles at the road segments were calculated at ETB 42,940,309.52, 24,265,882.55, 56,517,437.03 and 89,244,561.02 respectively in respect of the Riche-Meshualekya, Global-Meskel Flower, Nifas Silk-Adey Abeba and Akaki-Kality Masetegna road segments.
- ✚ Congestion has also environmental due to emission different pollutants. Of different pollutants, CO₂ is the major one.
- ✚ Total environmental cost of CO₂ was at ETB 104,263.07 generated from the Riche-Meshualekya, Global-Meskel Flower and Nifas Silk-Adey Abeba road segments respectively.
- ✚ When the average travel speed increases, fuel consumption and emission of pollutants decreases. So, reduction of congestion reduces emission of CO₂ pollutant.
- ✚ From the questionnaires gathered from different road users, the following can be solutions for traffic congestion: Improve LRT (Light rail transit), use mass transport,

proper maintenance of intersections, increase road capacity, improve traffic management strategies, improve parking management, mitigate illegal on street trade and use flexible work schedule.

- ✚ Among the various traffic congestion mitigation measures, improving current status of LRT has better importance. For instance if LRT is improved to accommodate about 25 percent more the cost of reduction in congestion would be Birr 25,538,295.70 and CO2 emission reduction would be 11,281.20 kg.

5.2.Recommendation

Traffic congestion needs to be properly addresses by policy makers and should be minimized by implementing timely and economical traffic management strategies. High quality, timely and complete traffic data are essential for the provision of current and accurate traffic information and for the deployment of traffic management measures. In Addis Ababa, the vast majority of data are collected manually and not properly. The data must be collected at the right places using the correct techniques and the data collected must be well organized and be available; be available for any research works in electronic forms. In addition, more integration is needed among Addis Ababa City Transport Authority, Addis Ababa City Roads Authority, Addis Ababa City Traffic Management Office and the like. Moreover, it is clear that Addis Ababa continues to develop; it would have to exert more researches and efforts and ensuring that its status will not be affected by problems brought about by its transportation and traffic system.

6. PROPOSED FUTURE RESEARCH AREAS

To better traffic congestion mitigation schemes in order to generate economic cost in Addis Ababa, further researches have to be done in the whole Addis Ababa to minimize congestion costs and enhance safe, economical and convenient traffic flow since this thesis only dealt with the North-South corridor of Addis Ababa. Furthermore, further researches have to be done on the on Light Rail Transient as a means of traffic mitigation by incorporating vehicles age and grade separated and at grade intersections; environmental costs traffic congestion and its mitigation methods; improving public transportation system to minimize traffic congestion in Addis Ababa; comparative analysis of economic cost of traffic congestion cost and constructions cost of Light Rail Transient, Modeling of Bus Rapid Transient as means of traffic congestion mitigation.

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ANNEXES

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ANNEX A: AVERAGE TRAVEL TIME

AVERAGE TRAVEL TIME AT CONGESTED SEGEMENTS (in sec)				
Time	Average Travel Time in sec			
	Meshualekiya Intersection(290 m)	Adey Abeba Intersection(270 m)	Meskel Flower Intersection (320 m)	Kality Interchange (300m)
	Riche-Meshualekiya	Nifas Silk- Adey Abeba	Global- Meskel Flower	Akaki- Kality Masetegna
07:00-007:15 AM	56.67	112.257	68.545	99.541
07:15-07:30 AM	45.56	98.467	84.546	105.847
07:30-07:45 AM	61.67	168.326	76.360	287.141
07:45-08:00 AM	70.00	214.689	70.264	236.254
08:00-08:15 AM	99.82	182.667	84.649	354.541
08:15-08:30 AM	142.65	258.694	62.111	297.540
08:30-08:45 AM	123.25	287.710	95.674	314.874
08:45-09:00 AM	258.64	278.389	86.087	365.871
09:00-09:15 AM	215.56	283.871	71.667	289.980
09:15-09:30 AM	243.27	147.222	61.111	325.641
09:30-09:45 AM	251.29	158.000	75.654	305.874
09:45-10:00 AM	149.65	186.111	68.848	347.570
10:00-10:15 AM	244.61	208.333	62.548	281.647
10:15-10:30 AM	230.00	154.889	74.364	298.511
10:30-10:45 AM	186.67	285.111	64.541	315.358
10:45-11:00 AM	226.89	86.667	51.667	254.641
11:00-11:15 AM	120.33	148.587	73.333	218.587
11:15-11:30 AM	98.66	288.000	65.555	217.384
11:30-11:45 AM	135.58	98.685	53.648	201.872
11:45-12:00 AM	88.40	89.616	49.698	135.240
12:00-12:15 PM	99.65	115.326	72.365	136.445
12:15-12:30 PM	69.82	79.360	56.667	85.412
12:30-12:45 PM	95.82	93.748	63.111	183.744
12:45-01:00 PM	65.15	60.556	71.155	98.871
01:00-01:15 PM	74.65	53.889	48.574	89.641
01:15-01:30 PM	54.59	48.784	42.466	92.542
01:30-01:45 PM	45.32	36.667	37.778	108.852
01:45-02:00 PM	58.32	47.778	36.587	89.674
02:00-02:15 PM	47.40	69.954	52.891	96.870
02:15-02:30 PM	67.82	51.567	38.254	87.674
02:30-02:45 PM	88.58	56.111	80.214	88.554
02:45-03:00 PM	60.00	59.444	56.146	101.572
03:00-03:15 PM	85.55	185.656	83.667	99.971
03:30-03:45 PM	73.33	205.655	102.257	152.854
03:45-04:00 PM	131.25	122.000	99.398	92.640
04:00-04:15 PM	85.64	118.667	82.674	128.540
04:15-04:30 PM	75.54	259.987	59.610	158.640
04:30-04:45 PM	69.61	198.649	69.324	219.541
04:45-05:00 PM	132.59	278.889	86.649	287.567
05:00-05:15 PM	123.25	281.000	75.000	238.140
05:15-05:30 PM	94.29	269.111	122.778	269.570
05:30-05:45 PM	198.87	316.222	88.333	295.540
05:45-06:00 PM	187.57	268.333	184.254	309.541
06:00-06:15 PM	128.87	321.540	214.364	318.655
06:15-06:30 PM	142.54	295.384	127.333	296.544
06:30-06:45 PM	112.61	289.354	97.333	324.514
06:45-07:00 PM	138.75	258.175	112.357	351.540

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ANNEX B. LEVEL OF SERVICE ANALYSIS

Level of Service Analysis for Meshualekiya Roundabout

i. Impute Data

Meshualekiya Intersection Analysis

Intersection Parameters	
Title	Meshualekiya Intersection Analysis
Intersection ID	Meshualeki
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes

Geometry - Approach Data						
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	Riche Approach	Two-way	3	3	15.00	0.0
North	Meskel Square Approach	Two-way	3	3	15.00	0.0

Geometry - Roundabout Data								
Location	Name	Island Diameter m	Circ. Width m	Circ. Lanes	Entry Radius m	Entry Angle degrees	Env. Factor	Entry/Circ. Flow Adjust.
South	Riche Approach	70.00	10.50	3	35.0	42.5	1.2000	None
North	Meskel Square Approach	70.00	10.50	3	30.0	42.5	1.2000	None

Geometry - Approach Lane Data						
Lane Number	Lane Type	Lane Discip.	Basic Satn Flow touch	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
South Riche Approach						
App. Lane 1	Slip (Giveway/Yield)	LT	1200	-	-	0.0
App. Lane 2	Normal	T	1200	-	-	0.0
App. Lane 3	Normal	T	1200	-	-	0.0
North Meskel Square Approach						
App. Lane 1	Slip (Giveway/Yield)	LT	1200	-	-	0.0
App. Lane 2	Normal	T	1200	-	-	0.0
App. Lane 3	Normal	T	1200	-	-	0.0

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Geometry - Approach & Exit Lane Data				
Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South Riche Approach				
App. Lane 1	3.50	500.0	-2.14	-
App. Lane 2	3.50	200.0	2.14	-
App. Lane 3	3.50	200.0	-2.14	-
Exit Lane 1	3.50	200.0	-2.14	-
Exit Lane 2	3.50	200.0	-2.14	-
Exit Lane 3	3.50	200.0	-2.14	-
North Meskel Square Approach				
App. Lane 1	3.50	500.0	2.14	-
App. Lane 2	3.50	500.0	2.14	-
App. Lane 3	3.50	500.0	2.14	-
Exit Lane 1	3.50	500.0	2.14	-
Exit Lane 2	3.50	500.0	2.14	-
Exit Lane 3	3.50	500.0	2.14	-

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

Geometry - Movement Definitions		
To Approach	Movement Banned	Turn Desig.
From: South Riche Approach		
South	No	L
North	No	T
From: North Meskel Square Approach		
North	No	L
South	No	T

Volumes						
To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South Riche Approach						
South	294.0	4.87	93.5	1.20	100.00	2.00
North	1955.0	10.50	93.5	1.20	100.00	2.00
From: North Meskel Square Approach						
North	157.0	2.84	95.3	1.20	100.00	2.00
South	1997.0	7.95	95.3	1.20	100.00	2.00

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Geometry - Approach & Exit Lane Data				
Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South Teb Menja Yaji				
App. Lane 1	3.50	500.0	-2.14	-
App. Lane 2	3.50	290.0	2.14	-
App. Lane 3	3.50	290.0	-2.14	-
Exit Lane 1	3.50	290.0	-2.14	-
Exit Lane 2	3.50	290.0	-2.14	-
Exit Lane 3	3.50	290.0	-2.14	-
North Meskel Square				
App. Lane 1	3.50	500.0	2.14	-
App. Lane 2	3.50	500.0	2.14	-
App. Lane 3	3.50	500.0	2.14	-
Exit Lane 1	3.50	500.0	2.14	-
Exit Lane 2	3.50	500.0	2.14	-
Exit Lane 3	3.50	500.0	2.14	-

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

Geometry - Movement Definitions		
To Approach	Movement Banned	Turn Desig.
From: South Teb Menja Yaji		
South	No	L
North	No	T
From: North Meskel Square		
North	No	L
South	No	T

Volumes						
To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South Teb Menja Yaji						
South	294.0	4.87	93.5	1.20	100.00	2.00
North	1955.0	10.50	93.5	1.20	100.00	2.00
From: North Meskel Square						
North	157.0	2.84	95.3	1.20	100.00	2.00
South	1997.0	7.95	95.3	1.20	100.00	2.00

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

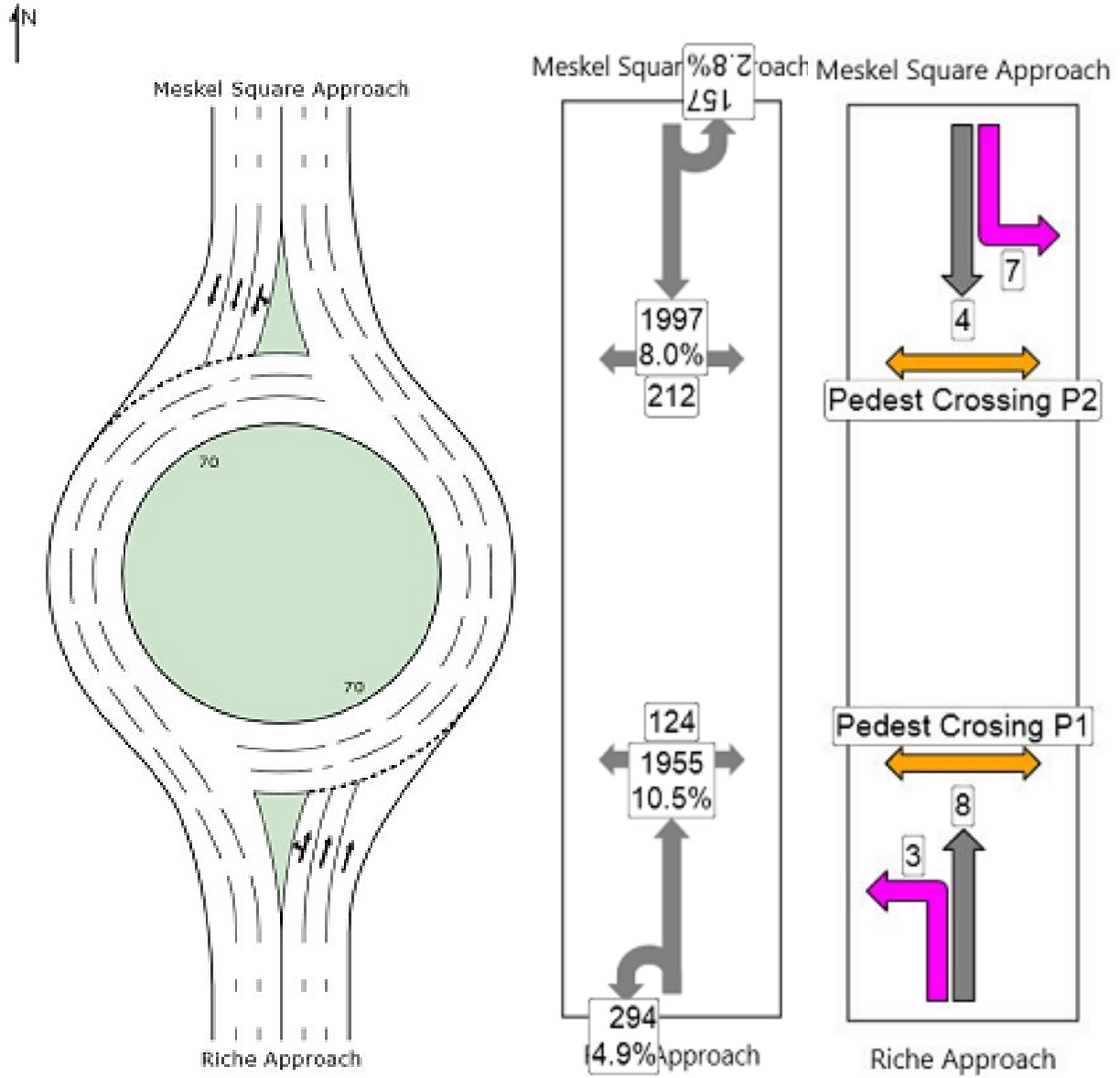


Figure B-1: Lay Out, Moment IDS and Volume Summary for Meshualekiya Intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ii. Out Put Data

Meshualekiya Intersection Analysis
Roundabout

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Riche Approach											
3	L	314	4.9	0.986	50.1	LOS F	16.0	129.8	0.68	1.00	18.9
8	T	2091	10.5	0.986	50.7	LOS F	16.0	132.6	0.67	1.02	17.5
Approach		2405	9.8	0.986	50.6	LOS F	16.0	132.6	0.67	1.02	17.7
North: Meskel Square Approach											
7	L	165	2.8	1.043	68.9	LOS F	27.4	219.8	1.00	2.50	16.6
4	T	2096	8.0	1.043	69.0	LOS F	27.4	219.8	1.00	2.50	15.2
Approach		2261	7.6	1.043	69.0	LOS F	27.4	219.8	1.00	2.50	15.4
All Vehicles		4666	8.7	1.043	59.5	LOS F	27.4	219.8	0.83	1.74	16.5

Level of Service (LOS) Method: Delay & v/c (HCM 2010).

Roundabout LOS Method: Same as Sign Control.

Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement

LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).

Intersection and Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).

Roundabout Capacity Model: US HCM 2010.

HCM Delay Model used. Geometric Delay not included.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

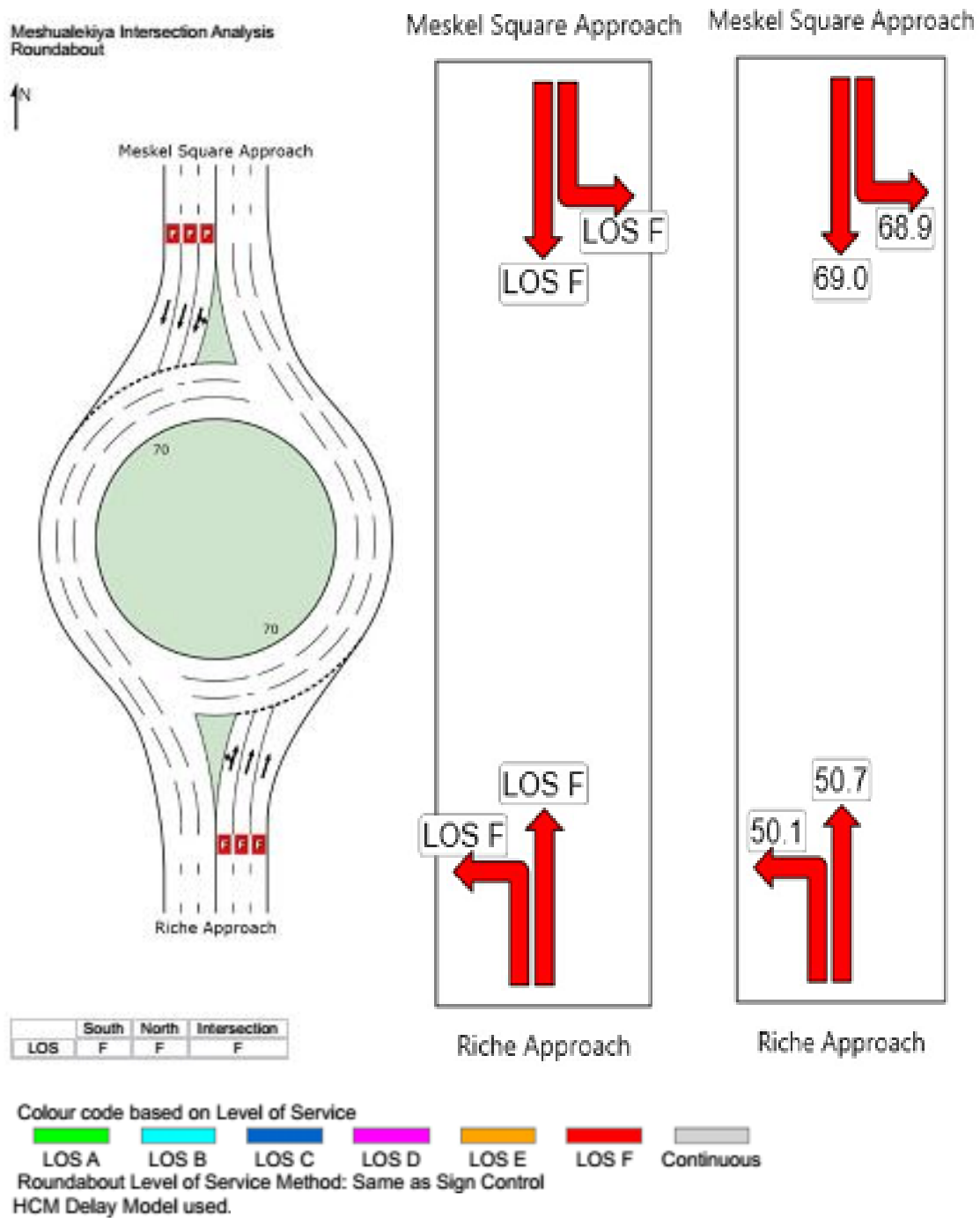


Figure B-2: LOS and Delay Summary for Meshualekiya intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Level of Service Analysis for Meskel Flower Intersection

i. Impute Data

Meskel Flower Intersection LOS Analysis

Intersection Parameters	
Title	Meskel Flower Intersection LOS Analysis
Intersection ID	Mes Flower
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes

Geometry - Approach Data						
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	Gotera Approach	Two-way	3	3	15.00	0.0
East	Meskel Flower Approach	Two-way	2	2	-	0.0
North	Gotera Approach	Two-way	3	3	15.00	0.0

Geometry - Approach Lane Data						
Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
South Gotera Approach						
App. Lane 1	Normal	LT	1200	-	-	0.0
App. Lane 2	Normal	T	1200	-	-	0.0
App. Lane 3	Normal	TR	1200	-	-	0.0
East Meskel Flower Approach						
App. Lane 1	Normal	L	1200	-	-	0.0
App. Lane 2	Normal	LR	1200	-	-	0.0
North Gotera Approach						
App. Lane 1	Slip (Giveaway/Yield)	L	1200	-	-	0.0
App. Lane 2	Slip (Giveaway/Yield)	LT	1200	-	-	0.0
App. Lane 3	Normal	T	1200	-	-	0.0

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Geometry - Approach & Exit Lane Data				
Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South Gotera Approach				
App. Lane 1	3.50	500.0	-2.50	-
App. Lane 2	3.50	500.0	-2.50	-
App. Lane 3	3.50	500.0	-2.50	-
Exit Lane 1	3.50	500.0	-2.50	-
Exit Lane 2	3.50	500.0	-2.50	-
Exit Lane 3	3.50	500.0	-2.50	-
East Meskel Flower Approach				
App. Lane 1	3.50	500.0	-1.05	-
App. Lane 2	3.50	500.0	-1.05	-
Exit Lane 1	3.50	500.0	-1.05	-
Exit Lane 2	3.50	500.0	-1.05	-
North Gotera Approach				
App. Lane 1	3.50	500.0	2.50	-
App. Lane 2	3.50	500.0	2.50	-
App. Lane 3	3.50	500.0	2.50	-
Exit Lane 1	3.50	500.0	2.50	-
Exit Lane 2	3.50	500.0	2.50	-
Exit Lane 3	3.50	500.0	2.50	-

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

Geometry - Movement Definitions		
To Approach	Movement Banned	Turn Desig.
From: South Gotera Approach		
South	No	L
North	No	T
East	No	R
From: East Meskel Flower Approach		
East	Yes	-
South	No	L
North	No	R
From: North Gotera Approach		
North	Yes	-
East	No	L
South	No	T

Volumes						
To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South Gotera Approach						
South	514.0	2.14	86.6	1.20	100.00	2.00
North	1781.0	9.21	86.6	1.20	100.00	2.00
East	821.0	6.28	86.6	1.20	100.00	2.00
From: East Meskel Flower Approach						
South	1251.0	0.84	96.8	1.20	100.00	2.00
North	950.0	1.58	96.8	1.20	100.00	2.00
From: North Gotera Approach						
East	784.0	3.84	91.5	1.20	100.00	2.00
South	1998.0	9.74	91.5	1.20	100.00	2.00

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

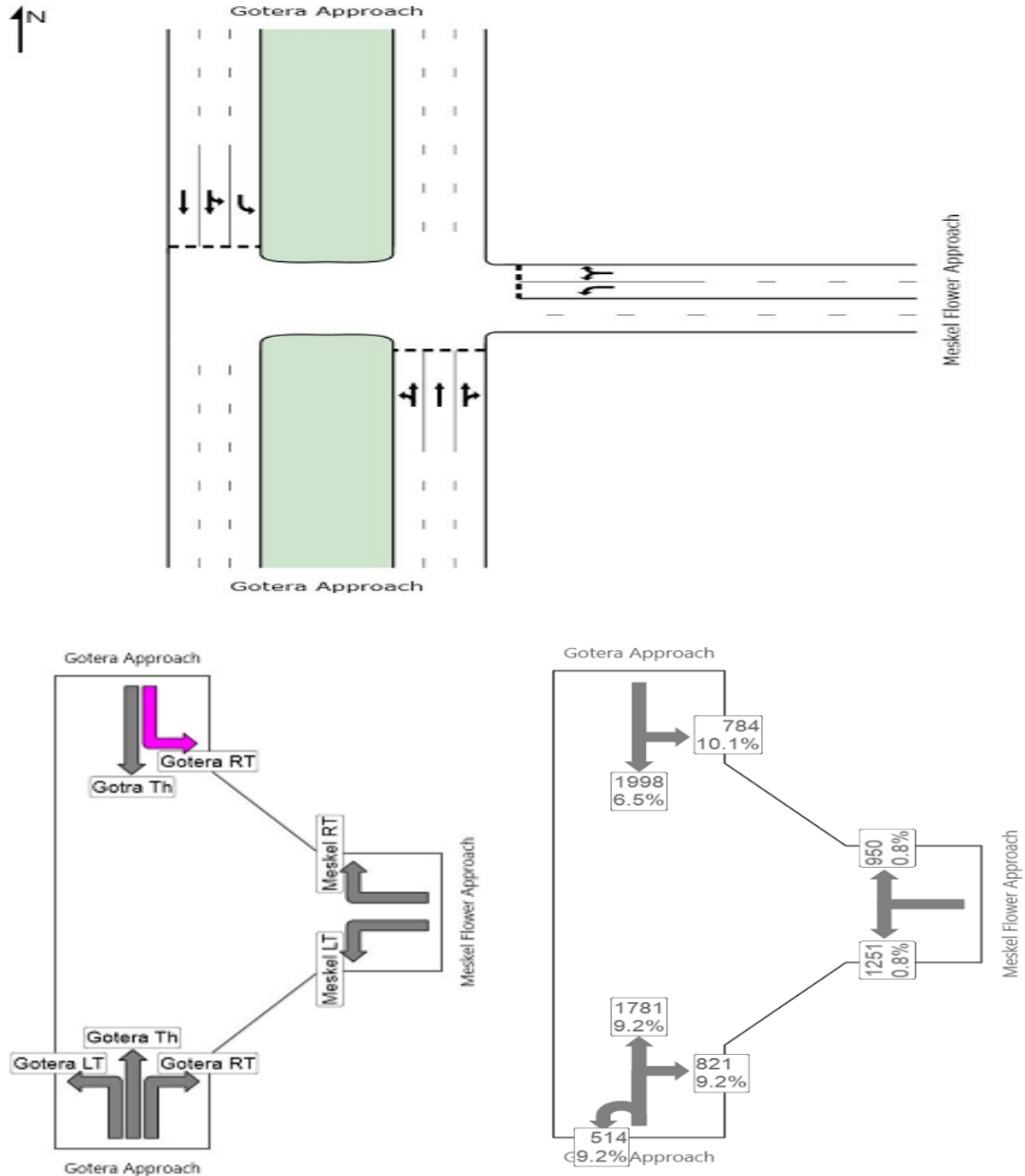


Figure: B-3: Meskel Flower intersection Lay Out, Movement IDS and Volume Summary
Meskel Flower intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ii. Out Put Data

Meskel Flower Intersection LOS Analysis

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Gotera Approach											
Gotera	L	593	2.1	1.124	85.5	LOS F	53.4	425.9	1.00	4.72	13.0
	LT										
Gotera	T	2056	9.2	1.124	80.1	LOS F	53.4	425.9	1.00	0.00	13.1
	Th										
Gotera	R	948	6.3	1.124	79.2	LOS F	39.2	315.1	1.00	0.00	13.2
	RT										
Approach		3597	7.3	1.124	80.8	LOS F	53.4	425.9	1.00	0.78	13.1
East: Meskel Flower Approach											
Meskel	L	1292	0.8	1.057	54.0	LOS F	21.1	161.9	1.00	0.00	16.3
	LT										
Meskel	R	981	1.6	1.057	55.9	LOS F	18.9	145.8	1.00	0.00	15.7
	RT										
Approach		2273	1.2	1.057	54.8	LOS F	21.1	161.9	1.00	0.00	16.0
North: Gotera Approach											
Gotera	L	857	3.8	1.000 [*]	52.7	LOS F	79.2	651.2	1.00	2.11	16.4
	RT										
Gotera	T	2184	9.7	1.000 [*]	42.6	LOS E	79.2	651.2	0.50	0.09	21.7
	Th										
Approach		3041	8.1	1.000	45.5	LOS E	79.2	651.2	0.64	0.66	19.8
All Vehicles		8911	6.0	1.124	62.1	NA	79.2	651.2	0.88	0.54	15.6

Level of Service (LOS) Method: Delay & v/c (HCM 2010).

Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement

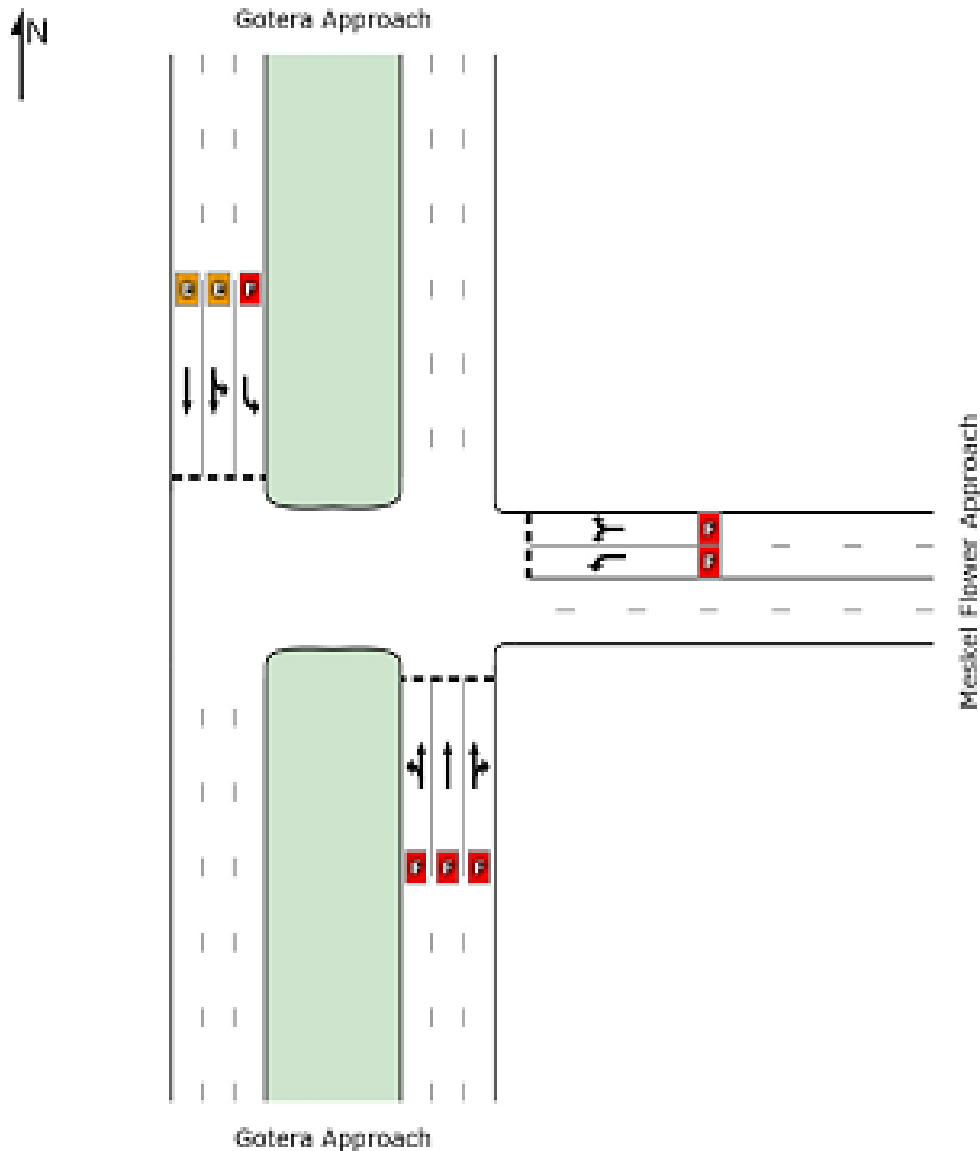
LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).

Minor Road Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).

NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road movements.

HCM Delay Model used. Geometric Delay not included.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)



	South	East	North	Intersection
LOS	F	F	E	NA

Level of Service (LOS) Method: Delay & v/c (HCM 2010).

Lane LOS values are based on average delay and v/c ratio (degree of saturation) per lane.

LOS F will result if v/c > irrespective of lane delay value (does not apply for approaches and intersection).

Minor Road Approach LOS values are based on average delay for all lanes (v/c not used as specified in HCM 2010).

NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road lanes.

HCM Delay Model used. Geometric Delay not included.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

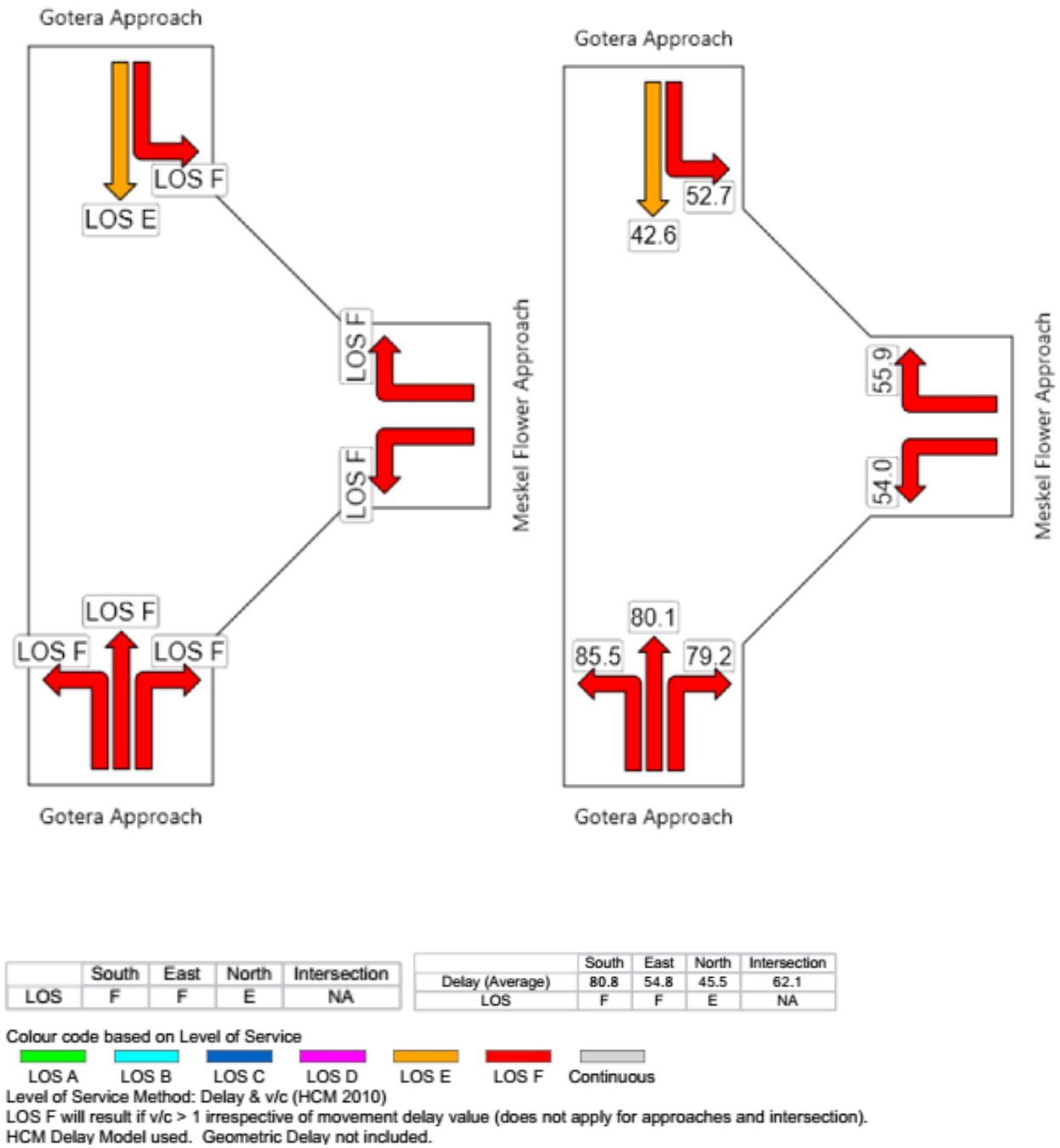


Figure B-4: LOS and Delay Summary for Meskel Flower intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Level of Service Analysis for Adey Abeba Intersection

i. Impute Data

Adey Abeba Intersection

Intersection Parameters	
Title	Adey Abeba Intersection
Intersection ID	Adey
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes

Geometry - Approach Data						
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %
South	Saris Approach	Two-way	3	3	15.00	0.0
East	Addis Sefer Approach	Two-way	2	2	-	0.0
North	Nifas Silk Approach	Two-way	3	3	15.00	0.0
West	Bihere Tsigie Approach	Two-way	2	2	-	0.0

Geometry - Approach Lane Data						
Lane Number	Lane Type	Lane Discip.	Basic Satn Flow tcu/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %
South Saris Approach						
App. Lane 1	Normal	LT	1200	-	-	0.0
App. Lane 2	Normal	T	1200	-	-	0.0
App. Lane 3	Normal	TR	1200	-	-	0.0
East Addis Sefer Approach						
App. Lane 1	Normal	LT	1200	-	-	0.0
App. Lane 2	Normal	TR	1200	-	-	0.0
North Nifas Silk Approach						
App. Lane 1	Normal	LT	1200	-	-	0.0
App. Lane 2	Normal	T	1200	-	-	0.0
App. Lane 3	Normal	TR	1200	-	-	0.0
West Bihere Tsigie Approach						
App. Lane 1	Normal	LT	1200	-	-	0.0
App. Lane 2	Normal	TR	1200	-	-	0.0

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Volumes						
To Approach	Total veh	HV %	Peak Flow Factor %	Vehicle Occupancy pers/veh	Flow Scale %	Growth Rate %/year
From: South Saris Approach						
West	254.0	2.50	92.1	1.20	100.00	2.00
North	1708.0	8.40	92.1	1.20	100.00	2.00
East	367.0	5.14	92.1	1.20	100.00	2.00
From: East Addis Sefer Approach						
South	288.0	1.24	87.2	1.20	100.00	2.00
West	546.0	2.01	87.2	1.20	100.00	2.00
North	384.0	0.84	87.2	1.20	100.00	2.00
From: North Nifas Silk Approach						
East	278.0	4.21	94.3	1.20	100.00	2.00
South	1612.0	9.20	94.3	1.20	100.00	2.00
West	398.0	8.47	94.3	1.20	100.00	2.00
From: West Bihere Tsigie Approach						
North	284.0	0.35	86.2	1.20	100.00	2.00
East	489.0	1.24	86.2	1.20	100.00	2.00
South	342.0	1.48	86.2	1.20	100.00	2.00

Geometry - Approach & Exit Lane Data				
Lane Number	Lane Width m	Lane Length m	Grade %	SL Type
South Saris Approach				
App. Lane 1	3.50	500.0	2.50	-
App. Lane 2	3.50	500.0	2.50	-
App. Lane 3	3.50	500.0	2.50	-
Exit Lane 1	3.50	500.0	0.00	-
Exit Lane 2	3.50	500.0	0.00	-
Exit Lane 3	3.50	500.0	0.00	-
East Addis Sefer Approach				
App. Lane 1	3.50	500.0	-1.24	-
App. Lane 2	3.50	500.0	-1.24	-
Exit Lane 1	3.50	500.0	-1.24	-
Exit Lane 2	3.50	500.0	-1.24	-
North Nifas Silk Approach				
App. Lane 1	3.50	500.0	-2.50	-
App. Lane 2	3.50	500.0	-2.50	-
App. Lane 3	3.50	500.0	-2.50	-
Exit Lane 1	3.50	500.0	-2.50	-
Exit Lane 2	3.50	500.0	-2.50	-
Exit Lane 3	3.50	500.0	-2.50	-
West Bihere Tsigie Approach				
App. Lane 1	3.50	500.0	-0.68	-
App. Lane 2	3.50	500.0	-0.68	-
Exit Lane 1	3.50	500.0	-0.68	-
Exit Lane 2	3.50	500.0	-0.68	-

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

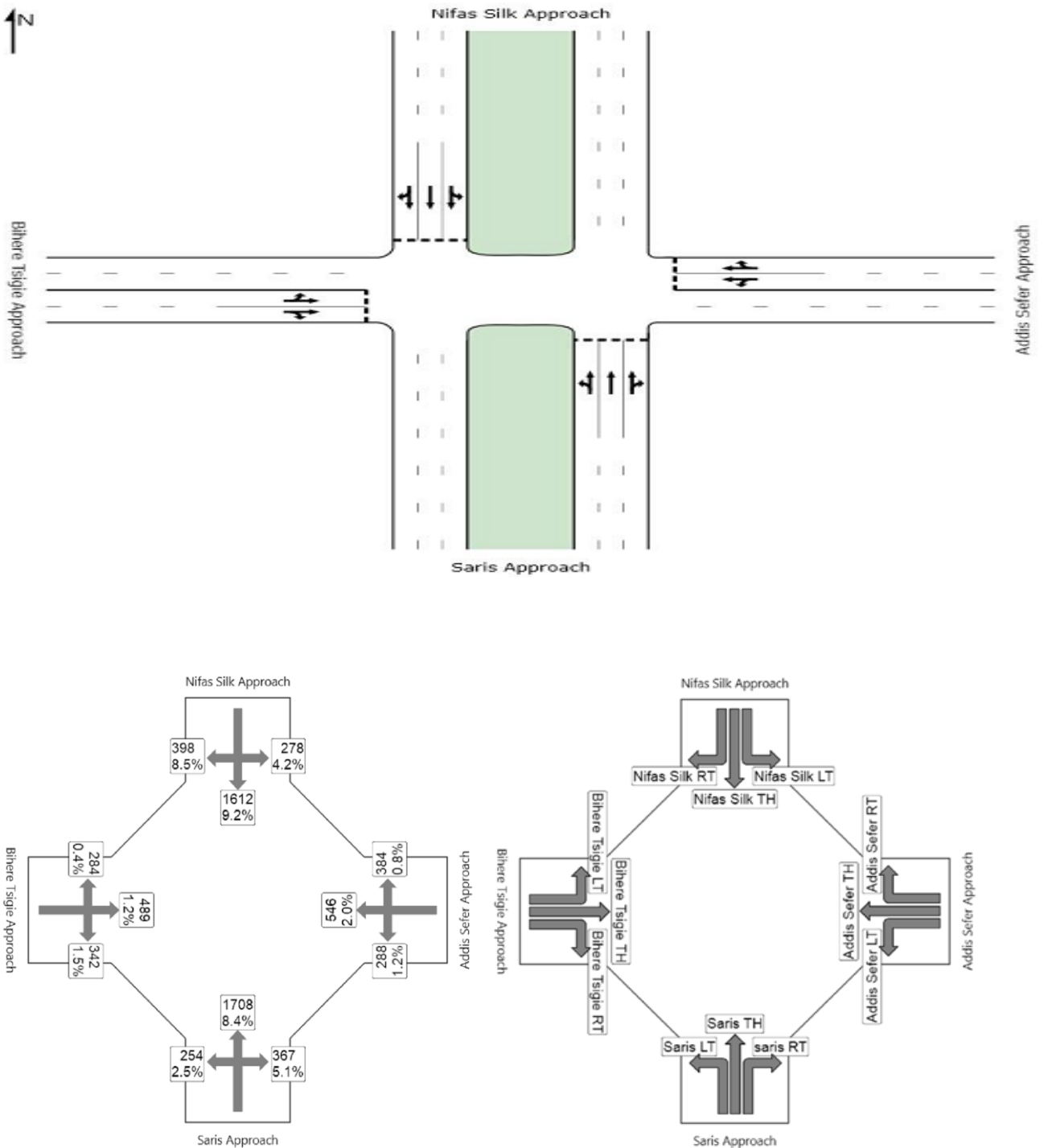


Figure B-5: Lay Out, Movement IDS and Voume Summery for Adey Abeba intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ii. Out Put Data

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Queue Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Saris Approach											
Saris	L	276	2.5	0.996	79.7	LOS F	14.9	117.0	1.00	2.61	13.8
LT											
Saris	T	1855	8.4	0.997	47.9	LOS E	14.9	117.0	0.05	0.17	27.8
TH											
saris	R	399	5.1	0.996	46.9	LOS E	0.0	0.0	0.00	0.41	28.9
RT											
Approach		2529	7.2	0.997	51.2	LOS F	14.9	117.0	0.15	0.47	25.2
East: Addis Sefer Approach											
Addis Sefer	L	330	1.2	1.000 ⁴	86.0	LOS F	21.9	168.4	1.00	3.99	13.3
LT											
Addis Sefer	T	626	2.0	0.967	39.4	LOS E	0.0	0.0	0.00	0.22	29.3
TH											
Addis Sefer	R	440	0.8	0.967	39.4	LOS E	0.0	0.0	0.00	0.41	28.9
RT											
Approach		1396	1.5	1.000	50.4	LOS F	21.9	168.4	0.24	1.17	22.7
North: Nifas Silk Approach											
Nifas	L	295	4.2	0.996	88.7	LOS F	14.4	113.6	1.00	3.02	13.0
Silk LT											
Nifas	T	1709	9.2	0.994	46.0	LOS E	14.4	113.6	0.00	0.17	29.4
Silk TH											
Nifas	R	422	8.5	0.995	46.7	LOS E	0.0	0.0	0.00	0.41	28.9
Silk RT											
Approach		2426	8.5	0.995	51.3	LOS F	14.4	113.6	0.12	0.56	25.4
West: Bihere Tsigie Approach											
Bihere Tsigie	L	329	0.4	1.001	86.1	LOS F	22.5	171.8	1.00	4.30	13.3
LT											
Bihere Tsigie	T	567	1.2	0.873	25.4	LOS D	0.0	0.0	0.00	0.22	29.3
TH											
Bihere Tsigie	R	397	1.5	0.872	25.4	LOS D	0.0	0.0	0.00	0.41	28.9
RT											
Approach		1293	1.1	1.000	40.9	LOS F	22.5	171.8	0.25	1.32	22.3
All Vehicles		7645	5.5	1.000	49.4	NA	22.5	171.8	0.17	0.77	24.2

Level of Service (LOS) Method: Delay & v/c (HCM 2010).

Vehicle movement LOS values are based on average delay and v/c ratio (degree of saturation) per movement

LOS F will result if v/c > 1 irrespective of movement delay value (does not apply for approaches and intersection).

Minor Road Approach LOS values are based on average delay for all movements (v/c not used as specified in HCM 2010).

NA: Intersection LOS and Major Road Approach LOS values are Not Applicable for two-way sign control since the average delay is not a good LOS measure due to zero delays associated with major road movements.

HCM Delay Model used

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

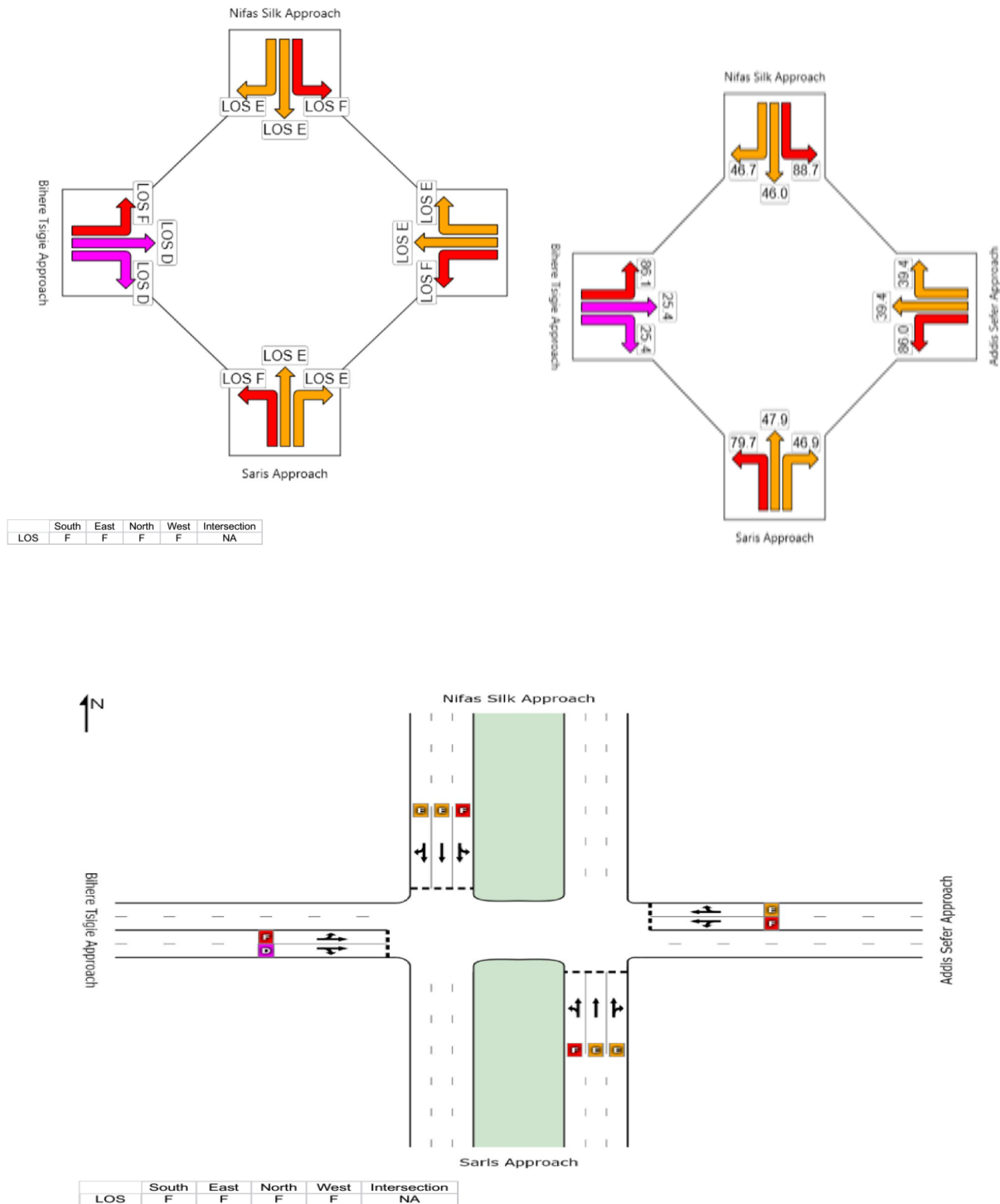


Figure B-6: LOS and Delay Summary for Adey Abeba intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Level of Service Analysis for Kality intersection Intersection

i. Inputs Data

Intersection Parameters	
Title	Kality Interchange
Intersection ID	Kality
Unit Time (for volumes)	60 minutes
Peak Flow Period (for performance)	15 minutes
Signal Analysis Method	Fixed Time

Geometry - Approach Data							
Location	Name	Type	No. of App. Lanes	No. of Exit Lanes	Median Width m	Extra Bunching %	
South	Akaki Approach	Two-way	3	3	-	0.0	
East	Abo Approach	Two-way	2	1	-	0.0	
North	Fafa Approach	Two-way	3	3	-	0.0	
West	Hanamarlam Approach	Two-way	2	1	-	0.0	

Geometry - Approach Lane Data - Signalised												
Lane Number	Lane Type	Lane Discp.	Basic Satn Flow veh/h	Utilisation Ratio %	Saturation Speed km/h	Capacity Adjustment %	Buses Stopping veh/h	Parking Man. veh/h	SL Green Constraint	Free Queue L veh	T veh	R veh
South Akaki Approach												
App. Lane 1	Normal	L	1200	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1950	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Slip (Giveway/Yield)	TR	1950	-	-	0.0	-	-	No	0	2	3
East Abo Approach												
App. Lane 1	Normal	L	1200	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Slip (Giveway/Yield)	R	1950	-	-	0.0	-	-	No	0	0	0
North Fafa Approach												
App. Lane 1	Normal	L	1800	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Normal	T	1950	-	-	0.0	-	-	No	0	0	0
App. Lane 3	Slip (Giveway/Yield)	TR	1950	-	-	0.0	-	-	No	0	2	3
West Hanamarlam Approach												
App. Lane 1	Normal	L	1800	-	-	0.0	-	-	No	0	0	0
App. Lane 2	Slip (Giveway/Yield)	R	1950	-	-	0.0	-	-	No	0	0	0

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

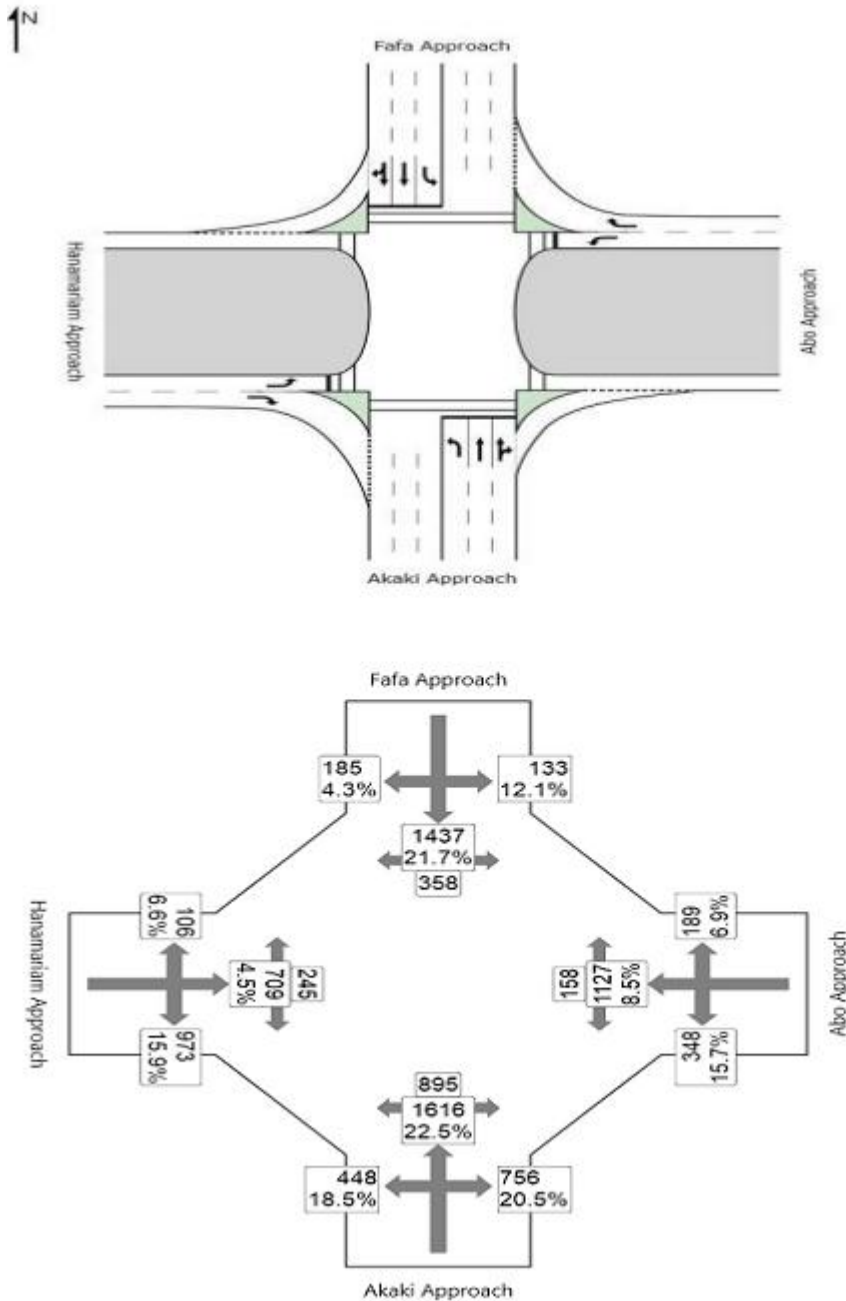


Figure B-7: Lay Out , Movement IDS and Voume Summery for Kaliy intersection

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

iii. Outputs

Movement Performance - Vehicles											
Mov ID	Turn	Demand Flow veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate per veh	Average Speed km/h
South: Akaki Approach											
10	L	479	18.5	1.194	174.8	LOS F	58.7	476.0	1.00	1.35	9.2
11	T	1726	22.5	1.807	431.9	LOS F	209.1	1746.4	1.00	2.30	4.3
12	R	808	20.5	1.806	418.8	LOS F	197.8	1636.9	1.00	2.01	4.5
Approach		3013	21.3	1.807	387.5	LOS F	209.1	1746.4	1.00	2.07	4.7
East: Abo Approach											
1	L	372	15.7	1.824	465.1	LOS F	64.6	512.7	1.00	1.78	4.0
2	T	1204	8.5	0.182	0.1	NA ^a	NA ^a	NA ^a	NA ^a	0.00	60.0
3	R	202	6.9	0.255	24.5	LOS C	8.6	63.7	0.62	0.75	27.8
Approach		574	12.6	1.824	310.0	LOS F	64.6	512.7	0.28	0.46	28.1
North: Fafa Approach											
4	L	142	12.1	0.317	49.4	LOS D	9.6	74.2	0.83	0.78	20.8
5	T	1548	21.7	1.783	417.4	LOS F	146.3	1214.4	1.00	2.15	4.4
6	R	198	4.3	1.779	403.5	LOS F	124.8	1007.0	1.00	1.86	4.6
Approach		1888	19.1	1.782	388.3	LOS F	146.3	1214.4	0.99	2.02	4.7
West: Hanamarlam Approach											
7	L	124	6.6	0.385	59.9	LOS E	9.4	69.5	0.91	0.79	18.8
8	T	832	4.5	0.123	0.0	NA ^a	NA ^a	NA ^a	NA ^a	0.00	60.0
9	R	1142	15.9	1.504	269.1	LOS F	142.5	1133.0	1.00	1.68	6.6
Approach		1266	14.9	1.504	248.5	LOS F	142.5	1133.0	0.60	0.96	18.1
All Vehicles		8776	14.4	1.824	272.7	LOS F	209.1	1746.4	0.76	1.47	9.6

Level of Service (LOS) Method: Delay (HCM 2000).

Vehicle movement LOS values are based on average delay per movement

Intersection and Approach LOS values are based on average delay for all vehicle movements.

SIDRA Standard Delay Model used.

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

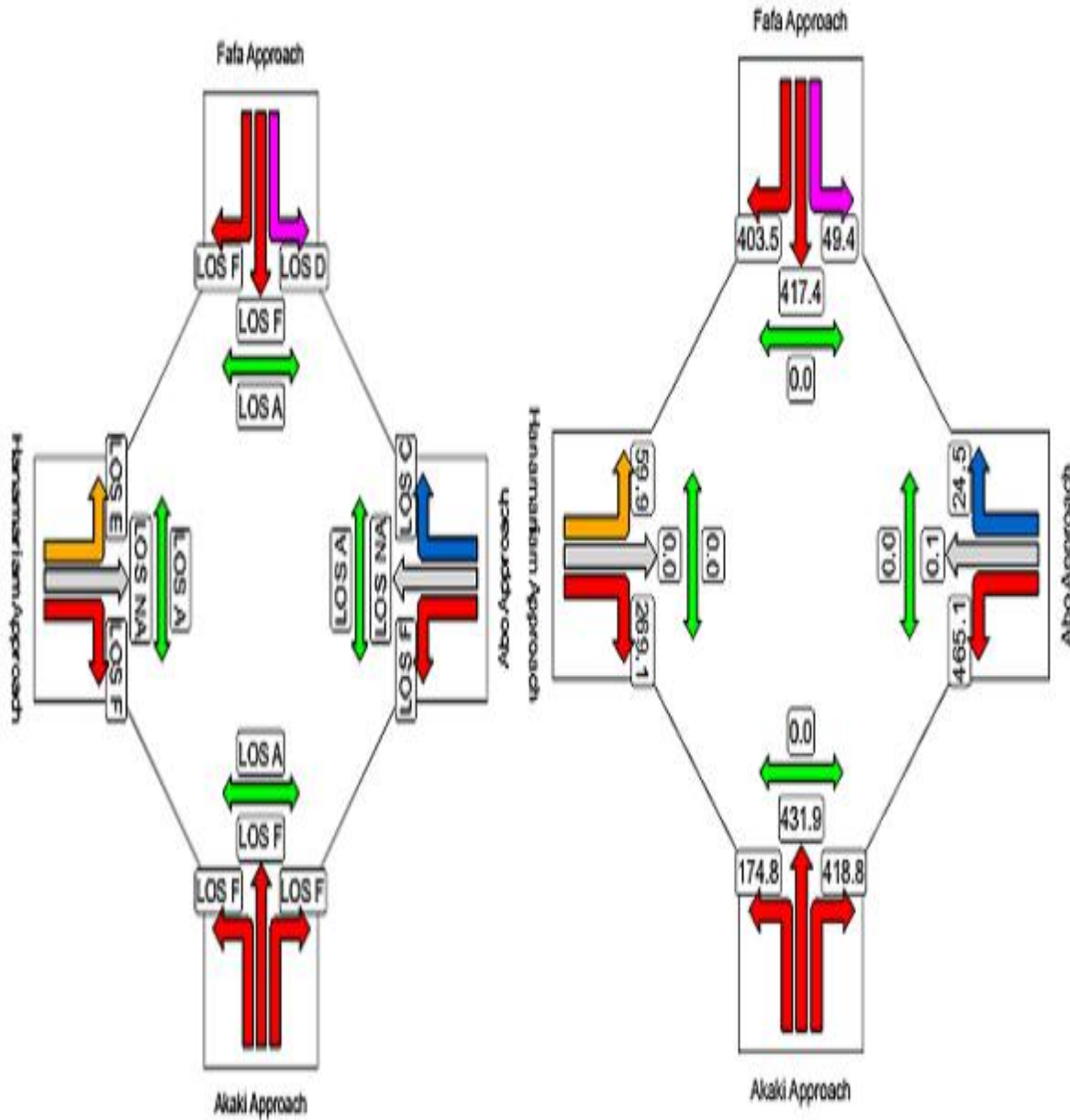


Figure B-8: LOS and Delay Summary for Kality intersection

ANNEX C: QUESTIONNARY

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

The aim of the research is to collect valuable information about the Traffic Congestion under the title “Analysis of Traffic Congestion and its Economic Cost in Addis Ababa a Case Study on Meskel Square to Kality Masetegna Interchange)”. The researcher hopes to gather relevant data that will provide useful information about the overall traffic congestion, its causes, solutions and effects in the city. The data gathered from you will only be used for academic purpose, for M.Sc. thesis in Civil and Environmental Engineering under Road and Transport Engineering. Therefore your definite data and answers will be highly appreciated and will be kept confidential.

Thank you for your cooperation

Instruction: Please answer all questions by putting an “X” mark on your choice and write your opinion for others. Write your opinions on some of the questions you are requested. You do not need to write your name.

Part I: General Information about the respondents

1. Sex Male Female
2. Education level
Degree Diploma (10+2)
Grade twelve complete Below grade 12 Other
3. Age Below 20 20-30 30-40 40-50 Above 50

Par II Interview Question

1. What is the mode of travel you most often use in your day to day activity?
Personal/private vehicle Public transport
Freight Vehicles Other
2. How long you travel average distance from home to work?

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

- 1- 5 km 6-10 km 11-15 km greater than or equal 16 m
3. Is there vehicle congestion along the street?
4. How do you see the current vehicle traffic flow along the street?
- Very high congested Congested
- Low congestion No congestion
5. Rank the major causes of congestion
- Imbalance of vehicle volume and road capacity Inflexible work schedule
- Illegal in street vehicle parking Un- availability of mass transport
- Un- integrated land use In-formal on street trading
- Poor vehicle condition Poor traffic management
- Bottlenecks Bad weather condition
- Traffic accidents Special events Lack of good mass transport
- Pedestrian interference with vehicles
6. What is the negative effect of congestion on your day to day activity?
7. If you are a business man how much commodities delay costs per hour on your business activity?
8. What do you suggest to minimize congestion along the street?
- Improve the road capacity
- Improve parking management
- Use mass transport
- Flexible work schedule
- Mitigate street on street trade
- Introduce HOV lane
- Improve traffic management strategy
- Improve light rail way transportation
- Any other measure
9. What do you have taken to minimize congestion?
10. Anything you want to say?
11. Thank you very much!!

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ANNEX D: CONGESTION ANALYSIS

Congestion Analysis Sheet															
Corridor Name: Riche- Meshualekiya															
Segment Length: 290 m															
Duration	Travel time (sec)	Average travel speed (km/hr)	Travel Rate (min/km)	Delay (sec)	Persent of Daily Delay	Delay Rate(min/km)	Travel Time Index	Traffic Volume (Veh)	Average Vehicle Occupancy(persons/veh)	Travel Time(person min)	Total Segment Delay (Veh min)	Total Segment Delay(per min)	Delay per traveler(annual hrs)	Annual Person-hours of Delay	Delay Ratio
07:00-07:15 AM	56.67	18.42	3.26	16.43	0.00	0.94	1.41	439.00	12.54	5199.22	120.23	1507.62	1.67	9146.24	0.29
07:15-07:30 AM	72.16	14.47	4.15	31.93	0.01	1.83	1.79	435.00	18.84	9856.61	231.47	4360.91	3.24	26456.18	0.44
07:30-07:45 AM	61.67	16.93	3.54	21.43	0.01	1.23	1.53	551.00	24.65	13959.43	196.81	4851.47	2.17	29432.24	0.35
07:45-08:00 AM	70.00	14.91	4.02	29.77	0.01	1.71	1.74	640.00	18.65	13925.33	317.49	5921.25	3.02	35922.25	0.43
08:00-08:15 AM	99.82	10.46	5.74	59.58	0.02	3.42	2.48	478.00	21.64	17208.32	474.67	10271.86	6.04	62315.93	0.60
08:15-08:30 AM	142.65	7.32	8.20	102.41	0.03	5.89	3.55	509.00	9.71	11750.12	868.78	8435.84	10.38	51177.41	0.72
08:30-08:45 AM	123.25	8.47	7.08	83.01	0.02	4.77	3.06	575.00	17.66	20862.93	795.51	14051.95	8.42	85248.50	0.67
08:45-09:00 AM	284.51	3.67	16.35	244.28	0.07	14.04	7.07	641.00	15.35	46657.28	2609.72	40059.18	24.77	243025.66	0.86
09:00-09:15 AM	215.56	4.84	12.39	175.33	0.05	10.08	5.36	615.00	17.65	38987.17	1797.12	31710.22	17.78	192375.35	0.81
09:15-09:30 AM	115.22	9.06	6.62	74.99	0.02	4.31	2.86	464.00	12.64	11262.90	579.90	7329.95	7.60	44468.37	0.65
09:30-09:45 AM	251.29	4.15	14.44	211.05	0.06	12.13	6.25	501.00	16.64	34914.88	1762.29	29324.46	21.40	177901.75	0.84
09:45-10:00 AM	125.93	8.29	7.24	85.69	0.03	4.92	3.13	520.00	15.94	17396.73	742.68	11838.40	8.69	71819.60	0.68
10:00-10:15 AM	244.61	4.27	14.06	204.38	0.06	11.75	6.08	585.00	11.31	26974.03	1992.68	22537.22	20.72	136725.79	0.84
10:15-10:30 AM	230.00	4.54	13.22	189.77	0.06	10.91	5.72	523.00	11.68	23416.45	1654.12	19320.10	19.24	117208.61	0.83
10:30-10:45 AM	186.67	5.59	10.73	146.43	0.04	8.42	4.64	445.00	13.99	19364.22	1086.03	15190.37	14.85	92154.91	0.78
10:45-11:00 AM	226.89	4.60	13.04	186.65	0.06	10.73	5.64	541.00	12.84	26267.83	1683.00	21609.67	18.92	131098.65	0.82
11:00-11:15 AM	120.33	8.68	6.92	80.10	0.02	4.60	2.99	342.00	13.64	9355.68	456.56	6227.49	8.12	37780.08	0.67
11:15-11:30 AM	98.66	10.58	5.67	58.43	0.02	3.36	2.45	405.00	12.81	8531.23	394.40	5052.21	5.92	30650.07	0.59
11:30-11:45 AM	135.58	7.70	7.79	95.35	0.03	5.48	3.37	442.00	10.54	10527.37	702.40	7403.34	9.67	44913.60	0.70
11:45-12:00 AM	88.40	11.81	5.08	48.16	0.01	2.77	2.20	405.00	9.52	5680.39	325.09	3094.89	4.88	18775.67	0.54

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Duration	Travel time (sec)	Average travel speed (km/hr)	Travel Rate (min/km)	Delay (sec)	Persent of Daily Delay	Delay Rate(min/km)	Travel Time Index	Traffic Volume (Veh)	Average Vehicle Occupancy(persons/veh)	Travel Time(person min)	Total Segment Delay (Veh min)	Total Segment Delay(per min)	Delay per traveler(annual hrs)	Annual Person-hours of Delay	Delay Ratio
12:00-12:15 PM	99.65	10.48	5.73	59.41	0.02	3.41	2.48	449.00	8.94	6666.55	444.61	3974.79	6.02	24113.72	0.60
12:15-12:30 PM	69.82	14.95	4.01	29.58	0.01	1.70	1.74	377.00	12.58	5518.64	185.87	2338.29	3.00	14185.62	0.42
12:30-12:45 PM	95.82	10.90	5.51	55.58	0.02	3.19	2.38	321.00	14.64	7504.77	297.36	4353.40	5.64	26410.65	0.58
01:00-01:15 PM	65.15	16.03	3.74	24.91	0.01	1.43	1.62	394.00	9.74	4166.66	163.58	1593.26	2.53	9665.77	0.38
01:15-01:30 PM	74.65	13.99	4.29	34.41	0.01	1.98	1.86	393.00	12.65	6185.15	225.41	2851.38	3.49	17298.34	0.46
01:30-01:45 PM	56.32	18.54	3.24	16.09	0.00	0.92	1.40	400.00	11.35	4261.85	107.26	1217.40	1.63	7385.57	0.29
01:45-02:00 PM	40.24	25.95	2.31	0.00	0.00	0.00	1.00	300.00	13.25	2665.57	0.00	0.00	0.00	0.00	0.00
02:00-02:15 PM	58.32	17.90	3.35	18.09	0.01	1.04	1.45	390.00	11.51	4363.51	117.58	1353.33	1.83	8210.19	0.31
02:15-02:30 PM	47.40	22.03	2.72	7.16	0.00	0.41	1.18	504.00	11.97	4767.45	60.18	720.55	0.73	4371.34	0.15
02:30-02:45 PM	67.82	15.39	3.90	27.58	0.01	1.59	1.69	436.00	10.58	5213.92	200.43	2120.59	2.80	12864.94	0.41
02:45-03:00 PM	88.58	11.79	5.09	48.35	0.01	2.78	2.20	502.00	8.95	6631.09	404.52	3619.24	4.90	21956.72	0.55
03:00-03:15 PM	60.00	17.40	3.45	19.76	0.01	1.14	1.49	354.00	9.78	3462.06	116.61	1140.42	2.00	6918.56	0.33
03:30-03:45 PM	85.55	12.20	4.92	45.31	0.01	2.60	2.13	464.00	14.59	9650.18	350.41	5111.42	4.59	31009.31	0.53
03:45-04:00 PM	73.33	14.24	4.21	33.10	0.01	1.90	1.82	459.00	13.54	7595.94	253.20	3428.36	3.36	20798.71	0.45
04:00-04:15 PM	131.25	7.95	7.54	91.02	0.03	5.23	3.26	462.00	10.57	10682.70	700.85	7408.01	9.23	44941.93	0.69
04:15-04:30 PM	85.64	12.19	4.92	45.41	0.01	2.61	2.13	426.00	12.54	7625.24	322.40	4042.95	4.60	24527.25	0.53
04:30-04:45 PM	75.54	13.82	4.34	35.31	0.01	2.03	1.88	408.00	11.86	6092.47	240.10	2847.60	3.58	17275.44	0.47
04:45-05:00 PM	69.61	15.00	4.00	29.38	0.01	1.69	1.73	462.00	15.32	8214.14	226.22	3466.62	2.98	21030.81	0.42
05:00-05:15 PM	132.59	7.87	7.62	92.35	0.03	5.31	3.30	457.00	12.65	12774.87	703.41	8898.19	9.36	53982.37	0.70
05:15-05:30 PM	123.25	8.47	7.08	83.01	0.02	4.77	3.06	553.00	11.87	13483.45	765.09	9081.66	8.42	55095.43	0.67
05:30-05:45 PM	94.29	11.07	5.42	54.05	0.02	3.11	2.34	527.00	14.93	12364.34	474.76	7088.12	5.48	43001.25	0.57
05:45-06:00 PM	82.82	12.61	4.76	42.58	0.01	2.45	2.06	452.00	18.84	11754.05	320.78	6043.58	4.32	36664.37	0.51
06:00-06:15 PM	132.55	7.88	7.62	92.31	0.03	5.31	3.29	529.00	12.42	14514.29	813.88	10108.44	9.36	61324.54	0.70
06:15-06:30 PM	96.24	10.85	5.53	56.01	0.02	3.22	2.39	518.00	18.62	15471.48	483.54	9003.60	5.68	54621.82	0.58
06:30-06:45 PM	111.30	9.38	6.40	71.06	0.02	4.08	2.77	461.00	15.64	13374.38	546.00	8539.45	7.20	51806.00	0.64
06:45-07:00 PM	112.61	9.27	6.47	72.38	0.02	4.16	2.80	509.00	17.65	16861.79	614.02	10837.37	7.34	65746.70	0.64
06:45-01:00 PM	86.62	12.05	4.98	46.38	0.01	2.67	2.15	455.00	14.68	9642.60	351.74	5163.51	4.70	31325.30	0.54

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Analysis Sheet															
Corridor Name:Global – Meskel Flower															
Segment Length:320m															
Duration	Travel Time(Sec)	Average travel speed (km/hr)	Travel Rate (min/km)	Delay (Sec)	Persent of Daily Delay	Delay Rate (min/km)	Travel Time Index	Traffic Volume(Veh)	Average Vehicle Occupancy (persons/veh)	Travel Time (person min)	Total Segment Delay(Veh min)	Total Segment Delay(per min)	Delay per traveler (annual hrs)	Annual Person-hours of Delay	Delay Ratio
07:00-07:15 AM	54.29	21.22	2.83	17.70	0.95%	0.92	1.48	371.00	9.54	3202.48	109.46	1044.25	1.79	6335.10	0.33
07:15-07:30 AM	64.35	17.90	3.35	27.77	1.48%	1.45	1.76	512.00	10.51	5771.69	236.95	2490.37	2.82	15108.27	0.43
07:30-07:45 AM	76.36	15.09	3.98	39.77	2.13%	2.07	2.09	564.00	12.54	9000.99	373.86	4688.26	4.03	28442.10	0.52
07:45-08:00 AM	70.26	16.40	3.66	33.68	1.80%	1.75	1.92	510.00	15.64	9340.91	286.26	4477.03	3.41	27160.67	0.48
08:00-08:15 AM	84.65	13.61	4.41	48.06	2.57%	2.50	2.31	566.00	22.54	17998.69	453.38	10219.29	4.87	61997.06	0.57
08:15-08:30 AM	62.11	18.55	3.23	25.52	1.36%	1.33	1.70	523.00	18.54	10037.59	222.49	4124.88	2.59	25024.24	0.41
08:30-08:45 AM	95.67	12.04	4.98	59.09	3.16%	3.08	2.61	579.00	16.25	15006.57	570.19	9267.86	5.99	56225.02	0.62
08:45-09:00 AM	86.09	13.38	4.48	49.50	2.65%	2.58	2.35	607.00	9.65	8404.32	500.78	4832.48	5.02	29317.04	0.57
09:00-09:15 AM	71.67	16.07	3.73	35.08	1.88%	1.83	1.96	690.00	12.54	10335.05	403.42	5058.84	3.56	30690.29	0.49
09:15-09:30 AM	61.11	18.85	3.18	24.52	1.31%	1.28	1.67	412.00	8.65	3629.80	168.40	1456.65	2.49	8837.01	0.40
09:30-09:45 AM	75.65	15.23	3.94	39.07	2.09%	2.03	2.07	580.00	9.36	6845.17	377.65	3534.78	3.96	21444.35	0.52
09:45-10:00 AM	68.85	16.73	3.59	32.26	1.72%	1.68	1.88	611.00	14.65	10271.15	328.52	4812.88	3.27	29198.16	0.47
10:00-10:15 AM	62.55	18.42	3.26	25.96	1.39%	1.35	1.71	343.00	12.64	4519.64	148.41	1875.91	2.63	11380.50	0.42
10:15-10:30 AM	74.36	15.49	3.87	37.78	2.02%	1.97	2.03	522.00	11.54	7466.01	328.66	3792.75	3.83	23009.32	0.51
10:30-10:45 AM	64.54	17.85	3.36	27.95	1.49%	1.46	1.76	560.00	8.95	5391.32	260.90	2335.09	2.83	14166.22	0.43
10:45-11:00 AM	51.67	22.30	2.69	15.08	0.81%	0.79	1.41	565.00	17.45	8489.91	142.00	2477.90	1.53	15032.61	0.29
11:00-11:15 AM	73.33	15.71	3.82	36.75	1.96%	1.91	2.00	737.00	9.52	8575.40	451.37	4297.02	3.73	26068.58	0.50
11:15-11:30 AM	65.56	17.57	3.41	28.97	1.55%	1.51	1.79	351.00	10.35	3969.19	169.46	1753.94	2.94	10640.57	0.44
11:30-11:45 AM	53.65	21.47	2.79	17.06	0.91%	0.89	1.47	302.00	14.65	3955.91	85.87	1258.05	1.73	7632.17	0.32
11:45-12:00 AM	49.70	23.18	2.59	13.11	0.70%	0.68	1.36	341.00	9.80	2768.01	74.51	730.24	1.33	4430.12	0.26

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Duration	Travel Time(Sec)	Average travel speed(km/hr)	Travel Rate (min/km)	Delay (Sec)	Persent of Daily Delay	Delay Rate (min/km)	Travel Time Index	Traffic Volume(V eh)	Average Vehicle Occupancy(persons/veh)	Travel Time (person min)	Total Segment Delay(Veh min)	Total Segment Delay(per min)	Delay per traveler (annual hrs)	Annual Person-hours of Delay	Delay Ratio
12:00-12:15 PM	72.37	15.92	3.77	35.78	1.91%	1.86	1.98	490.00	15.32	9053.83	292.19	4476.30	3.63	27156.25	0.49
12:15-12:30 PM	56.67	20.33	2.95	20.08	1.07%	1.05	1.55	313.00	13.21	3905.02	104.75	1383.73	2.04	8394.65	0.35
12:30-12:45 PM	63.11	18.25	3.29	26.52	1.42%	1.38	1.72	520.00	15.32	8380.02	229.88	3521.92	2.69	21366.34	0.42
01:00-01:15 PM	48.57	23.72	2.53	11.99	0.64%	0.62	1.33	457.00	8.74	3233.57	91.30	797.98	1.22	4841.11	0.25
01:15-01:30 PM	39.25	29.35	2.04	2.66	0.14%	0.14	1.07	553.00	10.25	3707.87	24.53	251.46	0.27	1525.54	0.07
01:30-01:45 PM	37.78	30.49	1.97	1.19	0.06%	0.06	1.03	386.00	12.64	3071.99	7.66	96.83	0.12	587.44	0.03
01:45-02:00 PM	36.59	31.49	1.91	0.00	0.00%	0.00	1.00	294.00	16.65	2984.95	0.00	0.00	0.00	0.00	0.00
02:00-02:15 PM	52.89	21.78	2.75	16.30	0.87%	0.85	1.45	445.00	9.50	3726.61	120.92	1148.75	1.65	6969.10	0.31
02:15-02:30 PM	38.25	30.11	1.99	1.67	0.09%	0.09	1.05	435.00	8.80	2440.63	12.09	106.38	0.17	645.37	0.04
02:30-02:45 PM	80.21	14.36	4.18	43.63	2.33%	2.27	2.19	449.00	12.64	7587.40	326.48	4126.66	4.42	25035.06	0.54
02:45-03:00 PM	56.15	20.52	2.92	19.56	1.05%	1.02	1.53	360.00	9.60	3234.00	117.35	1126.59	1.98	6834.65	0.35
03:00-03:15 PM	83.67	13.77	4.36	47.08	2.52%	2.45	2.29	460.00	11.51	7383.03	360.94	4154.47	4.77	25203.76	0.56
03:30-03:45 PM	102.26	11.27	5.33	65.67	3.51%	3.42	2.79	604.00	15.64	16099.61	661.08	10339.26	6.66	62724.84	0.64
03:45-04:00 PM	99.40	11.59	5.18	62.81	3.36%	3.27	2.72	514.00	12.46	10609.81	538.08	6704.49	6.37	40673.89	0.63
04:00-04:15 PM	82.67	13.93	4.31	46.09	2.46%	2.40	2.26	611.00	9.40	7913.83	469.32	4411.60	4.67	26763.71	0.56
04:15-04:30 PM	59.61	19.33	3.10	23.02	1.23%	1.20	1.63	373.00	15.64	5796.17	143.13	2238.64	2.33	13581.07	0.39
04:30-04:45 PM	69.32	16.62	3.61	32.74	1.75%	1.71	1.89	675.00	12.32	9608.31	368.29	4537.35	3.32	27526.58	0.47
04:45-05:00 PM	86.65	13.29	4.51	50.06	2.68%	2.61	2.37	585.00	13.64	11523.50	488.11	6657.80	5.08	40390.64	0.58
05:00-05:15 PM	75.00	15.36	3.91	38.41	2.05%	2.00	2.05	557.00	14.66	10207.03	356.60	5227.77	3.89	31715.11	0.51
05:15-05:30 PM	122.78	9.38	6.39	86.19	4.61%	4.49	3.36	769.00	17.64	27758.34	1104.68	19486.53	8.74	118218.27	0.70
05:30-05:45 PM	88.33	13.04	4.60	51.75	2.77%	2.70	2.41	653.00	21.25	20428.92	563.17	11967.42	5.25	72602.33	0.59
05:45-06:00 PM	184.25	6.25	9.60	147.67	7.89%	7.69	5.04	555.00	23.31	39735.20	1365.92	31845.05	14.97	193193.32	0.80
06:00-06:15 PM	214.36	5.37	11.16	177.78	9.50%	9.26	5.86	704.00	17.58	44217.29	2085.92	36670.42	18.02	222467.20	0.83
06:15-06:30 PM	127.33	9.05	6.63	90.75	4.85%	4.73	3.48	614.00	19.54	25461.49	928.64	18145.58	9.20	110083.16	0.71
06:30-06:45 PM	97.33	11.84	5.07	60.75	3.25%	3.16	2.66	683.00	18.45	20442.19	691.50	12758.10	6.16	77399.12	0.62
06:45-07:00 PM	112.36	10.25	5.85	75.77	4.05%	3.95	3.07	714.00	17.54	23451.83	901.66	15815.17	7.68	95945.36	0.67

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Analysis Sheet															
Corridor Name:Nifas Silk- Adey Abeba															
Segment Length:270m															
Duration	Travel Time(Sec)	Average travel speed (km/hr)	Travel Rate (min/km)	Delay (sec)	Persent of Daily Delay	Delay Rate (min/km)	Travel Time Index	Traffic Volume (Veh)	Average Vehicle Occupancy (persons/veh)	Travel Time(pers on min)	Total Segment Delay (Veh min)	Total Segment Delay(per min)	Delay per traveler (annual hrs)	Annual Person-hours of Delay	Delay Ratio
07:00-07:15 AM	112.26	8.66	6.93	75.59	0.01	4.67	3.06	368.00	12.54	8633.90	463.62	5813.79	7.66	35270.32	0.67
07:15-07:30 AM	98.47	9.87	6.08	61.80	0.01	3.81	2.69	282.00	9.54	4415.04	290.46	2770.98	6.27	16810.63	0.63
07:30-07:45 AM	168.33	5.77	10.39	131.66	0.02	8.13	4.59	479.00	11.54	15507.52	1051.08	12129.50	13.35	73585.66	0.78
07:45-08:00 AM	214.69	4.53	13.25	178.02	0.03	10.99	5.86	488.00	11.87	20726.65	1447.91	17186.75	18.05	104266.29	0.83
08:00-08:15 AM	182.67	5.32	11.28	146.00	0.02	9.01	4.98	405.00	14.64	18051.12	985.50	14427.72	14.80	87528.17	0.80
08:15-08:30 AM	258.69	3.76	15.97	222.03	0.03	13.71	7.06	380.00	23.35	38256.53	1406.17	32834.14	22.51	199193.79	0.86
08:30-08:45 AM	325.29	2.99	20.08	288.62	0.04	17.82	8.87	406.00	15.54	34205.36	1953.01	30349.72	29.26	184121.61	0.89
08:45-09:00 AM	278.39	3.49	17.18	241.72	0.04	14.92	7.59	335.00	12.32	19149.45	1349.62	16627.27	24.51	100872.12	0.87
09:00-09:15 AM	345.54	2.81	21.33	308.87	0.05	19.07	9.42	482.00	17.35	48160.93	2481.29	43050.39	31.32	261172.36	0.89
09:15-09:30 AM	147.22	6.60	9.09	110.56	0.02	6.82	4.02	443.00	8.64	9391.60	816.27	7052.56	11.21	42785.53	0.75
09:30-09:45 AM	158.00	6.15	9.75	121.33	0.02	7.49	4.31	316.00	13.65	11358.62	639.02	8722.65	12.30	52917.43	0.77
09:45-10:00 AM	186.11	5.22	11.49	149.44	0.02	9.22	5.08	357.00	9.87	10929.65	889.19	8776.35	15.15	53243.18	0.80
10:00-10:15 AM	208.33	4.67	12.86	171.67	0.03	10.60	5.68	444.00	16.97	26162.08	1270.33	21557.56	17.41	130782.51	0.82
10:15-10:30 AM	154.89	6.28	9.56	118.22	0.02	7.30	4.22	273.00	13.75	9687.42	537.91	7394.13	11.99	44857.70	0.76
10:30-10:45 AM	285.11	3.41	17.60	248.44	0.04	15.34	7.78	391.00	10.65	19787.42	1619.03	17242.67	25.19	104605.50	0.87
10:45-11:00 AM	86.67	11.22	5.35	50.00	0.01	3.09	2.36	284.00	9.84	4036.59	236.67	2328.80	5.07	14128.05	0.58
11:00-11:15 AM	148.59	6.54	9.17	111.92	0.02	6.91	4.05	227.00	8.69	4885.12	423.43	3679.62	11.35	22323.05	0.75
11:15-11:30 AM	288.00	3.38	17.78	251.33	0.04	15.51	7.85	279.00	12.64	16927.49	1168.70	14772.37	25.48	89619.03	0.87
11:30-11:45 AM	98.69	9.85	6.09	62.02	0.01	3.83	2.69	198.00	11.62	3784.18	204.66	2378.15	6.29	14427.47	0.63
11:45-12:00 AM	89.62	10.85	5.53	52.95	0.01	3.27	2.44	297.00	9.50	4214.21	262.10	2489.96	5.37	15105.76	0.59

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Duration	Travel Time(Sec)	Average travel speed (km/hr)	Travel Rate (min/km)	Delay (sec)	Persent of Daily Delay	Delay Rate (min/km)	Travel Time Index	Traffic Volume (Veh)	Average Vehicle Occupancy (persons/veh)	Travel Time(pers on min)	Total Segment Delay (Veh min)	Total Segment Delay(per min)	Delay per traveler (annual hrs)	Annual Person-hours of Delay	Delay Ratio
12:00-12:15 PM	79.36	12.25	4.90	42.69	0.01	2.64	2.16	288.00	15.36	5852.56	204.93	3148.50	4.33	19100.88	0.54
12:15-12:30 PM	93.75	10.37	5.79	57.08	0.01	3.52	2.56	321.00	11.65	5843.08	305.39	3557.74	5.79	21583.60	0.61
12:30-12:45 PM	36.67	26.51	2.26	0.00	0.00	0.00	1.00	185.00	15.98	1806.63	0.00	0.00	0.00	0.00	0.00
01:00-01:15 PM	53.89	18.04	3.33	17.22	0.00	1.06	1.47	222.00	12.31	2454.48	63.72	784.42	1.75	4758.82	0.32
01:15-01:30 PM	83.33	11.66	5.14	46.67	0.01	2.88	2.27	345.00	13.84	6631.67	268.33	3713.73	4.73	22529.98	0.56
01:30-01:45 PM	60.56	16.05	3.74	23.89	0.00	1.47	1.65	191.00	9.40	1812.02	76.05	714.84	2.42	4336.67	0.39
01:45-02:00 PM	47.78	20.34	2.95	11.11	0.00	0.69	1.30	318.00	9.80	2481.58	58.89	577.11	1.13	3501.14	0.23
02:00-02:15 PM	69.95	13.89	4.32	33.29	0.01	2.05	1.91	355.00	8.30	3435.34	196.95	1634.70	3.38	9917.21	0.48
02:15-02:30 PM	51.57	18.85	3.18	14.90	0.00	0.92	1.41	283.00	9.80	2383.58	70.28	688.73	1.51	4178.28	0.29
02:30-02:45 PM	56.11	17.32	3.46	19.44	0.00	1.20	1.53	309.00	12.84	3710.40	100.14	1285.78	1.97	7800.42	0.35
02:45-03:00 PM	59.44	16.35	3.67	22.78	0.00	1.41	1.62	307.00	14.64	4453.17	116.55	1706.35	2.31	10351.88	0.38
03:00-03:15 PM	185.66	5.24	11.46	148.99	0.02	9.20	5.06	427.00	13.46	17784.02	1060.30	14271.71	15.11	86581.68	0.80
03:30-03:45 PM	205.65	4.73	12.69	168.99	0.03	10.43	5.61	356.00	11.78	14374.17	1002.66	11811.37	17.13	71655.64	0.82
03:45-04:00 PM	122.00	7.97	7.53	85.33	0.01	5.27	3.33	495.00	12.98	13064.37	704.00	9137.92	8.65	55436.71	0.70
04:00-04:15 PM	118.67	8.19	7.33	82.00	0.01	5.06	3.24	392.00	13.65	10582.69	535.73	7312.76	8.31	44364.08	0.69
04:15-04:30 PM	259.99	3.74	16.05	223.32	0.03	13.79	7.09	520.00	15.65	35271.93	1935.44	30297.44	22.64	183804.47	0.86
04:30-04:45 PM	198.65	4.89	12.26	161.98	0.02	10.00	5.42	470.00	9.40	14627.18	1268.86	11927.29	16.42	72358.91	0.82
04:45-05:00 PM	278.89	3.49	17.22	242.22	0.04	14.95	7.61	476.00	10.45	23120.82	1921.63	20081.03	24.56	121824.91	0.87
05:00-05:15 PM	281.00	3.46	17.35	244.33	0.04	15.08	7.66	499.00	12.85	30030.24	2032.04	26111.70	24.77	158410.98	0.87
05:15-05:30 PM	269.11	3.61	16.61	232.44	0.04	14.35	7.34	485.00	10.80	23493.40	1878.93	20292.40	23.57	123107.22	0.86
05:30-05:45 PM	316.22	3.07	19.52	279.56	0.04	17.26	8.62	483.00	14.65	37292.88	2250.42	32968.69	28.34	200010.02	0.88
05:45-06:00 PM	268.33	3.62	16.56	231.67	0.04	14.30	7.32	525.00	19.94	46817.46	2027.08	40420.04	23.49	245214.92	0.86
06:00-06:15 PM	321.54	3.02	19.85	284.87	0.04	17.58	8.77	508.00	18.45	50227.76	2411.93	44500.06	28.88	269967.05	0.89
06:15-06:30 PM	295.38	3.29	18.23	258.72	0.04	15.97	8.06	499.00	17.96	44108.50	2151.67	38633.22	26.23	234374.86	0.88
06:30-06:45 PM	289.35	3.36	17.86	252.69	0.04	15.60	7.89	560.00	13.25	35783.44	2358.42	31249.00	25.62	189577.27	0.87
06:45-07:00 PM	258.18	3.76	15.94	221.51	0.03	13.67	7.04	501.00	16.84	36307.33	1849.59	31150.87	22.46	188981.95	0.86

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Analysis Sheet														
Corridor Name: Akaki- Kality Masetegna														
Segment Length: 300m														
Duration	Travel Time(Sec)	Average travel speed(km/hr)	Travel Rate(min/km)	Delay(Sec)	Percent of Daily Delay	Delay Rate(min/km)	Travel Time Index	Delay Ratio	Traffic Volume(Veh)	Average Vehicle Occupancy (persons/veh)	Travel Time(person min)	Total Segment Delay (Veh min)	Total Segment Delay (per min)	Annual Person-hours of Delay
07:00-07:15 AM	112.541	9.597	6.252	27.129	0.45%	1.507	1.318	0.241	453	11.86	604070.01	204.60	2426.94	12215.60
07:15-07:30 AM	105.847	10.203	5.880	20.435	0.34%	1.135	1.239	0.193	453	19.64	940720.77	154.11	3026.95	15235.66
07:30-07:45 AM	287.141	3.761	15.952	201.729	3.33%	11.207	3.362	0.703	475	17.82	2430641.39	1597.02	28460.52	143251.26
07:45-08:00 AM	236.254	4.571	13.125	150.842	2.49%	8.380	2.766	0.638	549	18.54	2404831.59	1380.20	25590.37	128804.85
08:00-08:15 AM	354.541	3.046	19.697	269.129	4.44%	14.952	4.151	0.759	548	21.75	4224822.17	2458.04	53450.43	269033.84
08:15-08:30 AM	297.54	3.630	16.530	212.128	3.50%	11.785	3.484	0.713	525	18.91	2953902.74	1856.12	35099.23	176666.12
08:30-08:45 AM	314.8741	3.430	17.493	229.4621	3.79%	12.748	3.687	0.729	555	16.51	2883131.63	2120.61	35017.67	176255.61
08:45-09:00 AM	365.871	2.952	20.326	280.459	4.63%	15.581	4.284	0.767	580	15.94	3382550.57	2711.10	43214.99	217515.46
09:00-09:15 AM	289.98	3.724	16.110	204.568	3.38%	11.365	3.395	0.705	563	16.81	2744705.94	1919.53	32271.13	162431.37
09:15-09:30 AM	325.641	3.317	18.091	240.229	3.97%	13.346	3.813	0.738	498	17.65	2862935.37	1993.90	35200.32	177174.96
09:30-09:45 AM	305.874	3.531	16.993	220.462	3.64%	12.248	3.581	0.721	552	13.35	2252679.73	2026.41	27060.72	136205.63
09:45-10:00 AM	347.57	3.107	19.309	262.158	4.33%	14.564	4.069	0.754	616	15.33	3278467.06	2689.30	41213.59	207441.72
10:00-10:15 AM	281.647	3.835	15.647	196.235	3.24%	10.902	3.298	0.697	547	13.57	2089836.23	1789.01	24267.91	122148.47
10:15-10:30 AM	298.511	3.618	16.584	213.099	3.52%	11.839	3.495	0.714	562	12.85	2154174.18	1994.25	25630.12	129004.94
10:30-10:45 AM	315.358	3.425	17.520	229.946	3.80%	12.775	3.692	0.729	434	16.64	2277439.79	1663.28	27676.91	139307.13
10:45-11:00 AM	254.641	4.241	14.147	169.229	2.79%	9.402	2.981	0.665	373	15.87	1505708.78	1050.63	16677.70	83944.43
11:00-11:15 AM	218.587	4.941	12.144	133.175	2.20%	7.399	2.559	0.609	412	11.84	1065350.63	913.36	10817.82	54449.69
11:15-11:30 AM	217.384	4.968	12.077	131.972	2.18%	7.332	2.545	0.607	438	12.01	1142407.27	962.30	11559.10	58180.79
11:30-11:45 AM	201.872	5.350	11.215	116.46	1.92%	6.470	2.364	0.577	479	11.11	1074493.60	929.74	10331.26	52000.67
11:45-12:00 AM	135.24	7.986	7.513	49.828	0.82%	2.768	1.583	0.368	392	10.59	560650.06	325.13	3442.78	17328.65

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Duration	Travel Time(Sec)	Average travel speed(km/hr)	Travel Rate (min/km)	Delay (Sec)	Percent of Daily Delay	Delay Rate(min/km)	Travel Time Index	Delay Ratio	Traffic Volume(Veh)	Average Vehicle Occupancy (persons/veh)	Travel Time (person min)	Total Segment Delay (Veh min)	Total Segment Delay (per min)	Annual Person-hours of Delay
12:00-12:15 PM	136.445	7.915	7.580	51.033	0.84%	2.835	1.597	0.374	419	13.84	791296.27	356.38	4932.66	24827.73
12:15-12:30 PM	85.412	12.645	4.745	0	0.00%	0.000	1.000	0.000	433	9.99	369464.13	0.00	0.00	0.00
12:30-12:45 PM	183.744	5.878	10.208	98.332	1.62%	5.463	2.151	0.535	452	11.00	913409.06	740.77	8146.96	41006.38
12:45-01:00 PM	98.871	10.923	5.493	13.459	0.22%	0.748	1.158	0.136	430	11.88	504417.38	96.34	1144.41	5760.21
01:00-01:15 PM	89.641	12.048	4.980	4.229	0.07%	0.235	1.050	0.047	432	9.89	383066.83	30.45	301.20	1516.04
01:15-01:30 PM	92.542	11.670	5.141	7.13	0.12%	0.396	1.083	0.077	417	10.13	390723.89	49.55	501.73	2525.37
01:30-01:45 PM	108.852	9.922	6.047	23.44	0.39%	1.302	1.274	0.215	452	12.00	590413.25	176.58	2118.98	10665.51
01:45-02:00 PM	89.674	12.044	4.982	4.262	0.07%	0.237	1.050	0.048	420	11.12	418926.44	29.83	331.84	1670.28
02:00-02:15 PM	96.87	11.149	5.382	11.458	0.19%	0.637	1.134	0.118	446	10.68	461332.53	85.17	909.46	4577.60
02:15-02:30 PM	87.674	12.318	4.871	2.262	0.04%	0.126	1.026	0.026	356	7.89	246324.66	13.42	105.92	533.13
02:30-02:45 PM	88.554	12.196	4.920	3.142	0.05%	0.175	1.037	0.035	470	8.26	343543.34	24.59	203.16	1022.55
02:45-03:00 PM	101.572	10.633	5.643	16.16	0.27%	0.898	1.189	0.159	452	10.02	460207.29	121.74	1220.31	6142.22
03:00-03:15 PM	99.971	10.803	5.554	14.559	0.24%	0.809	1.170	0.146	576	11.74	675326.00	139.65	1639.15	8250.41
03:30-03:45 PM	152.854	7.066	8.492	67.442	1.11%	3.747	1.790	0.441	553	9.01	761248.84	621.03	5597.95	28176.35
03:45-04:00 PM	92.64	11.658	5.147	7.228	0.12%	0.402	1.085	0.078	573	8.95	474516.67	68.97	617.05	3105.81
04:00-04:15 PM	128.54	8.402	7.141	43.128	0.71%	2.396	1.505	0.336	512	12.01	789767.50	367.67	4416.41	22229.25
04:15-04:30 PM	158.64	6.808	8.813	73.228	1.21%	4.068	1.857	0.462	548	12.96	1125211.71	668.21	8656.60	43571.56
04:30-04:45 PM	219.541	4.919	12.197	134.129	2.21%	7.452	2.570	0.611	535	13.57	1593621.77	1195.98	16227.11	81676.43
04:45-05:00 PM	287.567	3.756	15.976	202.155	3.34%	11.231	3.367	0.703	520	14.66	2191881.68	1752.01	25680.96	129260.84
05:00-05:15 PM	238.14	4.535	13.230	152.728	2.52%	8.485	2.788	0.641	492	15.60	1825352.82	1251.10	19511.11	98205.90
05:15-05:30 PM	269.57	4.006	14.976	184.158	3.04%	10.231	3.156	0.683	580	14.56	2274970.91	1778.66	25902.62	130376.50
05:30-05:45 PM	295.54	3.654	16.419	210.128	3.47%	11.674	3.460	0.711	544	16.84	2707590.89	1905.16	32084.81	161493.54
05:45-06:00 PM	309.541	3.489	17.197	224.129	3.70%	12.452	3.624	0.724	555	11.87	2036685.99	2071.33	24578.35	123711.02
06:00-06:15 PM	318.6545	3.389	17.703	233.2425	3.85%	12.958	3.731	0.732	589	12.58	2360358.01	2289.66	28794.81	144933.89
06:15-06:30 PM	296.544	3.642	16.475	211.132	3.49%	11.730	3.472	0.712	488	15.65	2263038.10	1715.45	26853.79	135164.06
06:30-06:45 PM	324.514	3.328	18.029	239.102	3.95%	13.283	3.799	0.737	593	15.46	2972949.01	2361.13	36507.83	183756.06
06:45-07:00 PM	351.54	3.072	19.530	266.128	4.39%	14.785	4.116	0.757	592	17.56	3654857.32	2625.80	46114.23	232108.31

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

ANNEX E: CONGESTION COST ANALYSIS

Traffic Cost Calculation															
Corridor Name:Riche- Meshualekiya															
Segment Length:290m															
Time	Passenger car Fuel Economy(lt)	Passenger car Fuel Economy(lt) at FFC	Truck Fuel Economy	Truck Fuel Economy at FFC	Annual Fuel wated in (pc)	Annual Fuel Consumed in FFC of pc	Annual Fuel wated in (Truck)	Annual Fuel Consumed in FFC of trucks	Annual Fuel Wasted in congestion of pc	Annual Fuel Wasted in congestion of truck	Annual pc veh delay cost	Annual pc fuel cost	Annual truck delay cost	Annual truck fuel cost	Annual Congestion Cost
07:00-07:15 AM	6.75	8.17	1.45	1.63	58.95	48.75	275.31	244.74	10.19	30.56	122552.07	151.18	45384.95	80.00	168168.20
07:15-07:30 AM	5.91	8.17	1.32	1.63	67.42	48.75	301.92	244.74	18.66	57.18	354491.02	276.81	87380.21	149.67	442297.70
07:30-07:45 AM	6.44	8.17	1.40	1.63	61.80	48.75	284.07	244.74	13.05	39.32	394367.79	193.50	74297.34	102.93	468961.56
07:45-08:00 AM	6.01	8.17	1.33	1.63	66.30	48.75	298.29	244.74	17.55	53.55	481328.60	260.24	119853.73	140.17	601582.74
08:00-08:15 AM	4.97	8.17	1.15	1.63	80.09	48.75	346.94	244.74	31.33	102.19	834982.16	464.75	179187.90	267.49	1014902.30
08:15-08:30 AM	4.19	8.17	0.96	1.63	95.09	48.75	415.03	244.74	46.34	170.29	685735.05	687.31	327963.76	445.72	1014831.84
08:30-08:45 AM	4.48	8.17	1.04	1.63	88.87	48.75	384.16	244.74	40.12	139.41	1142259.57	595.02	300306.33	364.91	1443525.84
08:45-09:00 AM	3.22	8.17	0.60	1.63	123.75	48.75	668.93	244.74	74.99	424.18	3256343.59	1112.35	985168.64	1110.30	4243734.88
09:00-09:15 AM	3.54	8.17	0.74	1.63	112.60	48.75	536.90	244.74	63.84	292.16	2577671.10	946.96	678413.65	764.72	3257796.44
09:15-09:30 AM	4.63	8.17	1.07	1.63	86.04	48.75	371.44	244.74	37.28	126.69	595839.50	552.96	218912.70	331.61	815636.77
09:30-09:45 AM	3.35	8.17	0.66	1.63	118.85	48.75	602.62	244.74	70.10	357.87	2383736.86	1039.75	665263.55	936.73	3050976.89
09:45-10:00 AM	4.43	8.17	1.03	1.63	89.78	48.75	388.42	244.74	41.03	143.67	962323.46	608.56	280363.51	376.06	1243671.59
10:00-10:15 AM	3.38	8.17	0.67	1.63	117.77	48.75	589.94	244.74	69.02	345.19	1832012.88	1023.69	752236.94	903.55	2586177.06
10:15-10:30 AM	3.45	8.17	0.71	1.63	115.27	48.75	562.85	244.74	66.51	318.10	1570498.82	986.56	624429.64	832.64	2196747.66
10:30-10:45 AM	3.74	8.17	0.82	1.63	106.57	48.75	487.05	244.74	57.81	242.30	1234799.83	857.49	409978.16	634.22	1646269.71
10:45-11:00 AM	3.47	8.17	0.71	1.63	114.71	48.75	557.19	244.74	65.96	312.45	1756613.84	978.29	635330.95	817.83	2393740.91
11:00-11:15 AM	4.53	8.17	1.05	1.63	87.86	48.75	379.54	244.74	39.11	134.80	506221.89	580.04	172351.59	352.83	679506.35
11:15-11:30 AM	5.00	8.17	1.15	1.63	79.61	48.75	345.09	244.74	30.86	100.35	410685.69	457.72	148884.40	262.67	560290.47
11:30-11:45 AM	4.28	8.17	0.99	1.63	92.93	48.75	403.76	244.74	44.17	159.02	601805.28	655.16	265157.62	416.23	868034.29
11:45-12:00 AM	5.29	8.17	1.21	1.63	75.20	48.75	328.59	244.74	26.44	83.85	251578.46	392.20	122722.80	219.47	374912.92

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Time	Passenger car Fuel Economy(lt)	Passenger car Fuel Economy(lt) at FFC	Truck Fuel Economy	Truck Fuel Economy at FFC	Annual Fuel wated in pc)	Annual Fuel Consumed in FFC of pc	Annual Fuel wated in Truck)	Annual Fuel Consumed in FFC of trucks	Annual Fuel Wasted in congestion of pc	Annual Fuel Wasted in congestion of truck	Annual pc veh delay cost	Annual pc fuel cost	Annual truck delay cost	Annual truck fuel cost	Annual Congestion Cost
12:00-12:15 PM	4.98	8.17	1.15	1.63	80.02	48.75	346.67	244.74	31.26	101.92	323103.98	463.72	167839.25	266.78	491673.74
12:15-12:30 PM	6.01	8.17	1.34	1.63	66.20	48.75	297.99	244.74	17.45	53.24	190075.65	258.83	70167.27	139.36	260641.11
12:30-12:45 PM	5.08	8.17	1.17	1.63	78.43	48.75	340.54	244.74	29.67	95.79	353881.00	440.08	112254.80	250.74	466826.62
12:45-01:00 PM	6.25	8.17	1.37	1.63	63.72	48.75	290.06	244.74	14.96	45.31	129513.37	221.93	61751.05	118.61	191604.96
01:00-01:15 PM	5.80	8.17	1.30	1.63	68.68	48.75	306.07	244.74	19.92	61.32	231783.53	295.50	85090.44	160.52	317329.99
01:15-01:30 PM	6.78	8.17	1.45	1.63	58.75	48.75	274.70	244.74	9.99	29.96	98960.50	148.22	40490.65	78.41	139677.78
01:30-01:45 PM	8.17	8.17	1.63	1.63	48.75	48.75	244.74	244.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01:45-02:00 PM	6.65	8.17	1.43	1.63	59.91	48.75	278.23	244.74	11.15	33.49	110009.82	165.40	44385.88	87.66	154648.77
02:00-02:15 PM	7.46	8.17	1.54	1.63	53.35	48.75	258.47	244.74	4.59	13.73	58572.35	68.12	22716.54	35.94	81392.94
02:15-02:30 PM	6.11	8.17	1.35	1.63	65.15	48.75	294.61	244.74	16.40	49.86	172379.61	243.21	75663.94	130.52	248417.28
02:30-02:45 PM	5.29	8.17	1.21	1.63	75.28	48.75	328.89	244.74	26.53	84.15	294202.00	393.44	152706.29	220.26	447521.99
02:45-03:00 PM	6.54	8.17	1.42	1.63	60.86	48.75	281.17	244.74	12.11	36.42	92703.03	179.58	44019.37	95.34	136997.32
03:00-03:15 PM	5.39	8.17	1.23	1.63	73.90	48.75	323.97	244.74	25.15	79.22	415499.15	373.04	132279.61	207.37	548359.16
03:30-03:45 PM	5.85	8.17	1.31	1.63	68.01	48.75	303.88	244.74	19.26	59.14	278685.55	285.66	95583.85	154.79	374709.85
03:45-04:00 PM	4.35	8.17	1.00	1.63	91.54	48.75	396.87	244.74	42.79	152.13	602184.83	634.65	264571.80	398.20	867789.48
04:00-04:15 PM	5.38	8.17	1.23	1.63	73.95	48.75	324.13	244.74	25.19	79.38	328644.98	373.70	121707.74	207.78	450934.20
04:15-04:30 PM	5.76	8.17	1.29	1.63	69.13	48.75	307.56	244.74	20.37	62.81	231476.68	302.14	90638.20	164.41	322581.43
04:30-04:45 PM	6.02	8.17	1.34	1.63	66.10	48.75	297.64	244.74	17.34	52.90	281795.47	257.25	85398.57	138.47	367589.76
04:45-05:00 PM	4.33	8.17	1.00	1.63	91.97	48.75	398.99	244.74	43.22	154.25	723319.21	641.03	265538.94	403.74	989902.92
05:00-05:15 PM	4.48	8.17	1.04	1.63	88.87	48.75	384.16	244.74	40.12	139.42	738233.41	595.03	288822.96	364.92	1028016.33
05:15-05:30 PM	5.12	8.17	1.18	1.63	77.77	48.75	338.08	244.74	29.02	93.34	576181.30	430.44	179220.67	244.31	756076.72
05:30-05:45 PM	5.48	8.17	1.25	1.63	72.64	48.75	319.52	244.74	23.88	74.78	491272.39	354.26	121096.11	195.73	612918.50
05:45-06:00 PM	4.33	8.17	1.00	1.63	91.96	48.75	398.93	244.74	43.21	154.18	821698.32	640.84	307241.26	403.58	1129983.99
06:00-06:15 PM	5.07	8.17	1.17	1.63	78.61	48.75	341.22	244.74	29.85	96.48	731887.32	442.75	182538.00	252.53	915120.60
06:15-06:30 PM	4.71	8.17	1.09	1.63	84.59	48.75	365.21	244.74	35.83	120.46	694157.76	531.46	206115.27	315.32	901119.80
06:30-06:45 PM	4.68	8.17	1.08	1.63	85.08	48.75	367.30	244.74	36.32	122.55	880951.58	538.74	231790.73	320.78	1113601.83
06:45-07:00 PM	5.35	8.17	1.22	1.63	74.39	48.75	325.71	244.74	25.64	80.96	419733.14	380.29	132781.00	211.92	553106.35

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Cost Analysis Sheet															
Corridor Name:Global – Meskel Flower															
Segment Length:320m															
Time	Passenger car Fuel Economy (lt)	Passenger car Fuel Economy (km/lt) at FFC	Truck Fuel Economy (km/hr)	Truck Fuel Economy at FFC (km/hr)	Annual Fuel wated in pc(lt)	Annual Fuel wated in Truck (lt)	Annual Fuel Consumed in FFC of pc(lt)	Annual Fuel Consumed in FFC of trucks (lt)	Annual Fuel Wasted in congestion of pc(lt)	Annual Fuel Wasted in congestion of truck (lt)	Annual pc veh delay cost(Birr)	Annual pc fuel cost(Birr)	Annual truck delay cost (Birr)	Annual truck fuel cost(Birr)	Annual Congestion Cost(Birr)
07:00-07:15 AM	7.31	9.04	1.52	1.73	72.64	349.17	58.76	307.14	13.88	42.03	102592.90	272.55	29964.63	145.65	132975.74
07:15-07:30 AM	6.65	9.04	1.43	1.73	79.89	371.06	58.76	307.14	21.13	63.92	244668.81	414.95	64865.81	221.49	310171.06
07:30-07:45 AM	6.04	9.04	1.34	1.73	87.86	396.02	58.76	307.14	29.10	88.89	460601.87	571.48	102345.36	307.99	563826.69
07:45-08:00 AM	6.33	9.04	1.38	1.73	83.91	383.47	58.76	307.14	25.15	76.34	439849.90	493.77	78362.40	264.51	518970.58
08:00-08:15 AM	5.71	9.04	1.29	1.73	92.96	412.75	58.76	307.14	34.20	105.62	1004003.14	671.56	124114.11	365.96	1129154.77
08:15-08:30 AM	6.78	9.04	1.45	1.73	78.32	366.27	58.76	307.14	19.56	59.13	405251.78	384.10	60905.31	204.89	466746.09
08:30-08:45 AM	5.35	9.04	1.22	1.73	99.27	434.56	58.76	307.14	40.51	127.43	910528.72	795.39	156089.39	441.54	1067855.04
08:45-09:00 AM	5.66	9.04	1.28	1.73	93.81	415.62	58.76	307.14	35.05	108.49	474770.90	688.29	137087.16	375.91	612922.26
09:00-09:15 AM	6.26	9.04	1.37	1.73	84.83	386.38	58.76	307.14	26.07	79.25	497009.83	511.97	110435.18	274.58	608231.56
09:15-09:30 AM	6.84	9.04	1.46	1.73	77.61	364.12	58.76	307.14	18.85	56.98	143109.84	370.19	46099.20	197.44	189776.66
09:30-09:45 AM	6.07	9.04	1.35	1.73	87.41	394.58	58.76	307.14	28.66	87.44	347277.62	562.66	103381.05	302.99	451524.32
09:45-10:00 AM	6.40	9.04	1.40	1.73	82.96	380.52	58.76	307.14	24.20	73.39	472845.82	475.20	89933.59	254.28	563508.88
10:00-10:15 AM	6.75	9.04	1.45	1.73	78.63	367.20	58.76	307.14	19.87	60.07	184300.07	390.15	40627.34	208.13	225525.70
10:15-10:30 AM	6.13	9.04	1.35	1.73	86.59	391.94	58.76	307.14	27.83	84.80	372621.42	546.43	89970.89	293.84	463432.58
10:30-10:45 AM	6.64	9.04	1.43	1.73	80.02	371.45	58.76	307.14	21.26	64.32	229412.94	417.49	71422.47	222.86	301475.76
10:45-11:00 AM	7.51	9.04	1.55	1.73	70.66	343.28	58.76	307.14	11.91	36.14	243443.68	233.77	38872.55	125.22	282675.24
11:00-11:15 AM	6.18	9.04	1.36	1.73	85.92	389.82	58.76	307.14	27.16	82.68	422164.14	533.34	123561.84	286.50	546545.82
11:15-11:30 AM	6.58	9.04	1.42	1.73	80.72	373.60	58.76	307.14	21.96	66.47	172317.29	431.24	46390.44	230.30	219369.28
11:30-11:45 AM	7.36	9.04	1.53	1.73	72.16	347.74	58.76	307.14	13.40	40.60	123598.14	263.13	23507.93	140.68	147509.88
11:45-12:00 AM	7.68	9.04	1.57	1.73	69.16	338.79	58.76	307.14	10.40	31.65	71742.94	204.23	20398.26	109.68	92455.10

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Time	Passenger car Fuel Economy(lt)	Passenger car Fuel Economy(Truck Fuel Economy(km /hr)	Truck Fuel Economy at FFC(km/hr)	Annual Fuel wated in	Annual Fuel wated in	Annual Fuel Consumed	Annual Fuel Consumed in FFC of	Annual Fuel Wasted in	Annual Fuel Wasted in congestion of	Annual pc veh delay cost(Birr)	Annual pc fuel cost(Birr)	Annual truck delay cost (Birr)	Annual truck fuel cost(Birr)	Annual Congestion Cost(Birr)
12:00-12:15 PM	6.226	9.037	1.369	1.729	70.569	320.884	48.616	254.123	21.953	66.76	363,871.36	325.61	16,545.09	174.75	380,916.81
12:15-12:30 PM	7.137	9.037	1.498	1.729	61.558	293.261	48.616	254.123	12.941	39.14	112,481.38	191.95	5,931.41	102.44	118,707.18
12:30-12:45 PM	6.719	9.037	1.441	1.729	65.384	304.819	48.616	254.123	16.768	50.70	286,291.37	248.71	13,016.71	132.70	299,689.49
12:45-01:00 PM	6.284	9.037	1.378	1.729	69.912	318.814	48.616	254.123	21.295	64.69	236,040.64	315.86	17,127.56	169.33	253,653.39
01:00-01:15 PM	7.775	9.037	1.579	1.729	56.505	278.171	48.616	254.123	7.889	24.05	64,866.84	117.01	5,170.01	62.95	70,216.80
01:15-01:30 PM	8.718	9.037	1.692	1.729	50.393	259.686	48.616	254.123	1.777	5.56	20,440.96	26.35	1,389.18	14.56	21,871.06
01:30-01:45 PM	8.891	9.037	1.712	1.729	49.412	256.630	48.616	254.123	0.795	2.51	7,871.22	11.79	433.79	6.56	8,323.36
01:45-02:00 PM	9.037	9.037	1.729	1.729	48.616	254.123	48.616	254.123	0.000	0.00	0.00	0.00	0.00	0.00	0.00
02:00-02:15 PM	7.417	9.037	1.534	1.729	59.234	286.311	48.616	254.123	10.617	32.19	93,380.19	157.48	6,847.17	84.25	100,469.09
02:15-02:30 PM	8.834	9.037	1.705	1.729	49.730	257.625	48.616	254.123	1.113	3.50	8,647.46	16.51	684.52	9.17	9,357.66
02:30-02:45 PM	5.882	9.037	1.315	1.729	74.692	334.138	48.616	254.123	26.075	80.02	335,449.18	386.76	18,486.71	209.44	354,532.09
02:45-03:00 PM	7.174	9.037	1.503	1.729	61.241	292.311	48.616	254.123	12.624	38.19	91,578.72	187.25	6,645.13	99.96	98,511.05
03:00-03:15 PM	5.748	9.037	1.293	1.729	76.429	339.883	48.616	254.123	27.813	85.76	337,709.68	412.53	20,438.46	224.48	358,785.14
03:30-03:45 PM	5.165	9.037	1.187	1.729	85.053	370.189	48.616	254.123	36.437	116.07	840,461.21	540.45	37,433.54	303.80	878,739.00
03:45-04:00 PM	5.243	9.037	1.202	1.729	83.802	365.582	48.616	254.123	35.186	111.46	544,996.66	521.89	30,468.83	291.74	576,279.13
04:00-04:15 PM	5.786	9.037	1.299	1.729	75.934	338.236	48.616	254.123	27.318	84.11	358,611.71	405.19	26,575.20	220.17	385,812.27
04:15-04:30 PM	6.938	9.037	1.471	1.729	63.328	298.584	48.616	254.123	14.711	44.46	181,975.21	218.20	8,104.53	116.38	190,414.32
04:30-04:45 PM	6.376	9.037	1.392	1.729	68.905	315.664	48.616	254.123	20.288	61.54	368,833.47	300.93	20,854.49	161.08	390,149.98
04:45-05:00 PM	5.640	9.037	1.274	1.729	77.894	344.811	48.616	254.123	29.278	90.69	541,201.35	434.26	27,639.14	237.38	569,512.13
05:00-05:15 PM	6.104	9.037	1.350	1.729	71.980	325.367	48.616	254.123	23.364	71.24	424,956.39	346.55	20,192.51	186.48	445,681.93
05:15-05:30 PM	4.708	9.037	1.090	1.729	93.323	402.936	48.616	254.123	44.707	148.81	1,584,027.40	663.11	62,552.42	389.52	1,647,632.44
05:30-05:45 PM	5.582	9.037	1.264	1.729	78.707	347.580	48.616	254.123	30.090	93.46	972,811.43	446.32	31,889.65	244.63	1,005,392.02
05:45-06:00 PM	3.910	9.037	0.876	1.729	112.362	501.381	48.616	254.123	63.746	247.26	2,588,631.29	945.51	77,345.21	647.20	2,667,569.20
06:00-06:15 PM	3.678	9.037	0.796	1.729	119.450	551.634	48.616	254.123	70.833	297.51	2,980,877.11	1,050.64	118,115.04	778.73	3,100,821.52
06:15-06:30 PM	4.624	9.037	1.071	1.729	95.005	410.163	48.616	254.123	46.388	156.04	1,475,023.66	688.06	52,584.10	408.44	1,528,704.25
06:30-06:45 PM	5.301	9.037	1.213	1.729	82.883	362.245	48.616	254.123	34.266	108.12	1,037,084.42	508.25	39,155.95	283.01	1,077,031.64
06:45-07:00 PM	4.921	9.037	1.137	1.729	89.272	386.361	48.616	254.123	40.656	132.24	1,285,588.73	603.03	51,056.67	346.13	1,337,594.56

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Cost Analysis Sheet															
Corridor Name:Nifas Silk- Adey Abeba															
Segment Length:270m															
Time	Passenger car Fuel Economy(km/lt)	Passenger car Fuel Economy(km/lt) at FFC	Truck Fuel Economy(km/lt)	Truck Fuel Economy at FFC(km/lt)	Annual Fuel wasted in pc (lt)	Annual Fuel wated in Truck(lt)	Annual Fuel Consumed in FFC of pc(lt)	Annual Fuel Consumed in FFC of trucks(lt)	Annual Fuel Wasted in congestion of pc(lt)	Annual Fuel Wasted in congestion of truck(lt)	Annual pc veh delay cost(Birr)	Annual pc fuel cost(Birr)	Annual truck delay cost (Birr)	Annual truck fuel cost(Birr)	Annual Congestion Cost
07:00-07:15 AM	4.527	8.261	1.048	1.638	81.879	353.717	44.872	226.295	37.008	127.423	472,593.27	548.92	28,535.28	333.529	502,011.00
07:15-07:30 AM	4.828	8.261	1.117	1.638	76.778	331.830	44.872	226.295	31.907	105.535	225,248.55	473.25	23,329.45	276.238	249,327.50
07:30-07:45 AM	3.784	8.261	0.834	1.638	97.956	444.296	44.872	226.295	53.085	218.001	985,987.14	787.38	49,701.55	570.618	1,037,046.68
07:45-08:00 AM	3.451	8.261	0.706	1.638	107.417	525.037	44.872	226.295	62.545	298.742	1,397,082.30	927.70	67,203.43	781.957	1,465,995.39
08:00-08:15 AM	3.664	8.261	0.791	1.638	101.173	468.508	44.872	226.295	56.301	242.213	1,172,805.29	835.09	55,115.00	633.993	1,229,389.37
08:15-08:30 AM	3.241	8.261	0.608	1.638	114.358	609.995	44.872	226.295	69.486	383.701	2,669,032.65	1,030.66	83,815.32	1004.337	2,754,882.96
08:30-08:45 AM	3.029	8.261	0.487	1.638	122.360	761.347	44.872	226.295	77.488	535.052	2,467,077.77	1,149.35	108,954.65	1400.498	2,578,582.27
08:45-09:00 AM	3.169	8.261	0.569	1.638	116.991	651.480	44.872	226.295	72.119	425.185	1,351,603.34	1,069.71	91,250.18	1112.922	1,445,036.14
09:00-09:15 AM	2.981	8.261	0.455	1.638	124.357	814.643	44.872	226.295	79.485	588.348	3,499,494.40	1,178.97	116,600.06	1540.002	3,618,813.43
09:15-09:30 AM	4.001	8.261	0.905	1.638	92.639	409.611	44.872	226.295	47.767	183.316	573,290.83	708.50	41,734.72	479.830	616,213.88
09:30-09:45 AM	3.884	8.261	0.868	1.638	95.448	427.200	44.872	226.295	50.577	200.905	709,049.93	750.18	45,803.33	525.869	756,129.31
09:45-10:00 AM	3.638	8.261	0.781	1.638	101.904	474.415	44.872	226.295	57.032	248.121	713,414.78	845.93	56,415.28	649.456	771,325.44
10:00-10:15 AM	3.488	8.261	0.722	1.638	106.269	513.510	44.872	226.295	61.397	287.215	1,752,377.82	910.68	64,804.17	751.785	1,818,844.44
10:15-10:30 AM	3.916	8.261	0.878	1.638	94.658	422.098	44.872	226.295	49.787	195.803	601,056.17	738.46	44,628.89	512.515	646,936.03
10:30-10:45 AM	3.146	8.261	0.556	1.638	117.833	666.213	44.872	226.295	72.962	439.918	1,401,627.53	1,082.20	93,787.78	1151.485	1,497,648.99
10:45-11:00 AM	5.153	8.261	1.184	1.638	71.931	312.970	44.872	226.295	27.059	86.675	189,304.26	401.36	18,875.00	226.871	208,807.49
11:00-11:15 AM	3.986	8.261	0.900	1.638	93.006	411.825	44.872	226.295	48.134	185.531	299,110.50	713.95	42,249.93	485.626	342,560.01
11:15-11:30 AM	3.136	8.261	0.551	1.638	118.187	672.640	44.872	226.295	73.316	446.345	1,200,821.16	1,087.45	94,878.33	1168.309	1,297,955.25
11:30-11:45 AM	4.823	8.261	1.116	1.638	76.864	332.177	44.872	226.295	31.992	105.883	193,316.25	474.52	23,411.92	277.148	217,479.83
11:45-12:00 AM	5.065	8.261	1.167	1.638	73.188	317.704	44.872	226.295	28.316	91.409	202,404.78	420.00	19,988.52	239.264	223,052.58

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Time	Passenger car Fuel Economy(km/ltr)	Passenger car Fuel Economy(km/ltr) at FFC	Truck Fuel Economy(km/ltr)	Truck Fuel Economy at FFC(km/ltr)	Annual Fuel wasted in pc (ltr)	Annual Fuel wated in Truck(ltr)	Annual Fuel Consumed in FFC of pc(ltr)	Annual Fuel Consumed in FFC of trucks(ltr)	Annual Fuel Wasted in congestion of pc(ltr)	Annual Fuel Wasted in congestion of truck(ltr)	Annual pc veh delay cost(Birr)	Annual pc fuel cost(Birr)	Annual truck delay cost (Birr)	Annual truck fuel cost(Birr)	Annual Congestion Cost
12:00-12:15 PM	4.469	8.261	1.034	1.638	82.941	358.586	44.872	226.295	38.069	132.291	351,645.92	564.66	29,694.07	346.272	382,250.93
12:15-12:30 PM	5.398	8.261	1.231	1.638	68.676	301.159	44.872	226.295	23.804	74.864	255,936.04	353.08	16,116.65	195.957	272,601.72
12:30-12:45 PM	4.949	8.261	1.143	1.638	74.897	324.311	44.872	226.295	30.025	98.017	289,202.48	445.35	21,548.20	256.558	311,452.59
12:45-01:00 PM	8.261	8.261	1.638	1.638	44.872	226.295	44.872	226.295	0.000	0.000	0.000	0.000	0.000	0.000	0.000
01:00-01:15 PM	6.675	8.261	1.435	1.638	55.537	258.318	44.872	226.295	10.666	32.024	63,764.23	158.20	6,501.39	83.822	70,507.63
01:15-01:30 PM	5.260	8.261	1.205	1.638	70.472	307.598	44.872	226.295	25.600	81.303	301,883.17	379.71	17,616.67	212.811	320,092.36
01:30-01:45 PM	6.254	8.261	1.373	1.638	59.270	269.887	44.872	226.295	14.398	43.592	58,107.76	213.56	9,018.06	114.103	67,453.49
01:45-02:00 PM	7.140	8.261	1.498	1.638	51.918	247.376	44.872	226.295	7.047	21.081	46,912.39	104.52	4,194.44	55.179	51,266.53
02:00-02:15 PM	5.777	8.261	1.297	1.638	64.168	285.716	44.872	226.295	19.297	59.421	132,882.44	286.22	12,566.12	155.535	145,890.31
02:15-02:30 PM	6.841	8.261	1.458	1.638	54.184	254.203	44.872	226.295	9.313	27.908	55,985.51	138.13	5,624.75	73.050	61,821.44
02:30-02:45 PM	6.525	8.261	1.414	1.638	56.806	262.212	44.872	226.295	11.934	35.918	104,519.17	177.02	7,340.28	94.015	112,130.48
02:45-03:00 PM	6.319	8.261	1.383	1.638	58.663	267.982	44.872	226.295	13.792	41.687	138,706.68	204.56	8,598.61	109.115	147,618.97
03:00-03:15 PM	3.641	8.261	0.783	1.638	101.808	473.632	44.872	226.295	56.936	247.337	1,160,123.11	844.51	56,243.34	647.405	1,217,858.37
03:30-03:45 PM	3.505	8.261	0.729	1.638	105.773	508.701	44.872	226.295	60.901	282.406	960,126.56	903.31	63,793.02	739.197	1,025,562.09
03:45-04:00 PM	4.353	8.261	1.004	1.638	85.164	369.181	44.872	226.295	40.292	142.886	742,806.26	597.63	32,213.33	374.004	775,991.23
04:00-04:15 PM	4.409	8.261	1.019	1.638	84.068	363.886	44.872	226.295	39.196	137.591	594,442.05	581.38	30,955.00	360.145	626,338.57
04:15-04:30 PM	3.236	8.261	0.605	1.638	114.539	612.647	44.872	226.295	69.667	386.352	2,462,828.42	1,033.34	84,303.47	1011.276	2,549,176.51
04:30-04:45 PM	3.549	8.261	0.747	1.638	104.437	496.252	44.872	226.295	59.565	269.958	969,549.78	883.50	61,148.30	706.614	1,032,288.20
04:45-05:00 PM	3.167	8.261	0.568	1.638	117.054	652.565	44.872	226.295	72.183	426.270	1,632,353.41	1,070.65	91,438.89	1115.762	1,725,978.71
05:00-05:15 PM	3.160	8.261	0.564	1.638	117.321	657.166	44.872	226.295	72.450	430.871	2,122,576.52	1,074.61	92,235.83	1127.805	2,217,014.77
05:15-05:30 PM	3.202	8.261	0.587	1.638	115.782	631.636	44.872	226.295	70.911	405.341	1,649,535.35	1,051.78	87,747.78	1060.981	1,739,395.89
05:30-05:45 PM	3.053	8.261	0.502	1.638	121.408	738.729	44.872	226.295	76.537	512.434	2,679,969.47	1,135.23	105,532.22	1341.295	2,787,978.22
05:45-06:00 PM	3.204	8.261	0.588	1.638	115.679	629.998	44.872	226.295	70.807	403.703	3,285,677.77	1,050.24	87,454.17	1056.692	3,375,238.87
06:00-06:15 PM	3.039	8.261	0.493	1.638	121.971	751.907	44.872	226.295	77.099	525.613	3,617,335.94	1,143.58	107,539.68	1375.791	3,727,395.00
06:15-06:30 PM	3.113	8.261	0.538	1.638	119.071	689.341	44.872	226.295	74.199	463.047	3,140,429.99	1,100.55	97,665.94	1212.024	3,240,408.51
06:30-06:45 PM	3.132	8.261	0.549	1.638	118.352	675.673	44.872	226.295	73.480	449.378	2,540,179.11	1,089.89	95,389.47	1176.247	2,637,834.72
06:45-07:00 PM	3.244	8.261	0.609	1.638	114.285	608.934	44.872	226.295	69.414	382.639	2,532,202.43	1,029.58	83,619.39	1001.559	2,617,852.96

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Congestion Cost Analysis Sheet															
Corridor Name: Akaki- Kality Masetegna															
Segment Length: 300m															
Time	Passenger car Fuel Economy (lt)	Passenger car Fuel Economy(lt) at FFC	Truck Fuel Economy	Truck Fuel Economy at FFC	Annual Fuel wated in pc)	Annual Fuel Consumed in FFC of pc	Annual Fuel wated in Truck)	Annual Fuel Consumed in FFC of trucks	Annual Fuel Wasted in congestion of pc	Annual Fuel Wasted in congestion of truck	Annual pc delay cost	Annual pc fuel cost	Annual truck delay cost	Annual truck fuel cost	Annual Congestion Cost
07:00-07:15 AM	4.760	5.490	3.114	3.525	86.520	75.022	132.282	116.859	11.499	15.423	185677.089	160.520	102980.930	53.826	288872.365
07:15-07:30 AM	4.909	5.490	3.205	3.525	83.899	75.022	128.511	116.859	8.877	11.652	231582.027	123.925	77570.692	40.666	309317.311
07:30-07:45 AM	3.243	5.490	1.718	3.525	127.023	75.022	239.714	116.859	52.001	122.855	2177419.188	725.939	803834.029	428.764	2982407.920
07:45-08:00 AM	3.463	5.490	2.009	3.525	118.944	75.022	205.035	116.859	43.922	88.176	1957833.749	613.152	694702.831	307.735	2653457.467
08:00-08:15 AM	3.046	5.490	1.404	3.525	135.237	75.022	293.343	116.859	60.215	176.485	4089314.341	840.606	1237215.916	615.931	5327986.793
08:15-08:30 AM	3.207	5.490	1.665	3.525	128.450	75.022	247.343	116.859	53.429	130.484	2685325.029	745.863	934247.067	455.391	3620773.349
08:30-08:45 AM	3.152	5.490	1.581	3.525	130.689	75.022	260.542	116.859	55.667	143.684	2679085.201	777.111	1067374.828	501.455	3747738.595
08:45-09:00 AM	3.019	5.490	1.357	3.525	136.409	75.022	303.473	116.859	61.387	186.614	3306235.022	856.963	1364588.846	651.282	4672332.112
09:00-09:15 AM	3.232	5.490	1.704	3.525	127.419	75.022	241.776	116.859	52.398	124.917	2468956.882	731.471	966163.299	435.962	3436287.615
09:15-09:30 AM	3.120	5.490	1.531	3.525	131.998	75.022	269.068	116.859	56.976	152.209	2693059.375	795.384	1003596.686	531.210	3697982.655
09:30-09:45 AM	3.179	5.490	1.624	3.525	129.547	75.022	253.611	116.859	54.526	136.752	2070325.645	761.181	1019961.319	477.266	3091525.411
09:45-10:00 AM	3.063	5.490	1.434	3.525	134.490	75.022	287.290	116.859	59.468	170.431	3153114.094	830.174	1353616.422	594.805	4508155.495
10:00-10:15 AM	3.263	5.490	1.747	3.525	126.242	75.022	235.765	116.859	51.220	118.906	1856656.765	715.029	900467.905	414.981	2758254.680
10:15-10:30 AM	3.203	5.490	1.660	3.525	128.580	75.022	248.066	116.859	53.559	131.208	1960875.044	747.677	1003773.242	457.914	2965853.878
10:30-10:45 AM	3.150	5.490	1.579	3.525	130.749	75.022	260.920	116.859	55.727	144.061	2117468.415	777.950	837182.287	502.773	2955931.425
10:45-11:00 AM	3.373	5.490	1.897	3.525	122.095	75.022	217.102	116.859	47.073	100.243	1275955.333	657.142	528817.121	349.850	1805779.445
11:00-11:15 AM	3.562	5.490	2.125	3.525	115.624	75.022	193.860	116.859	40.602	77.002	827635.239	566.804	459723.799	268.736	1288194.579
11:15-11:30 AM	3.570	5.490	2.133	3.525	115.386	75.022	193.113	116.859	40.365	76.254	884348.023	563.489	484355.569	266.128	1369533.209
11:30-11:45 AM	3.672	5.490	2.243	3.525	112.180	75.022	183.618	116.859	37.158	66.759	790410.247	518.731	467968.630	232.989	1259130.598
11:45-12:00 AM	4.357	5.490	2.840	3.525	94.524	75.022	145.032	116.859	19.502	28.173	263395.409	272.254	163647.609	98.324	427413.595

Analysis of Traffic Congestion and its Economic Cost in Addis Ababa (Case of Meskel Square to Kality Masetegna Interchange)

Time	Passenger car Fuel Economy (lt)	Passenger car Fuel Economy(lt) at FFC	Truck Fuel Economy	Truck Fuel Economy at FFC	Annual Fuel wated in pc)	Annual Fuel Consumed in FFC of pc	Annual Fuel wated in Truck)	Annual Fuel Consumed in FFC of trucks	Annual Fuel Wasted in congestion of pc	Annual Fuel Wasted in congestion of truck	Annual pc delay cost	Annual pc fuel cost	Annual truck delay cost	Annual truck fuel cost	Annual Congestion Cost
12:00-12:15 PM	4.339	5.490	2.827	3.525	94.915	75.022	145.710	116.859	19.893	28.851	377381.513	277.705	179378.160	100.690	557138.067
12:15-12:30 PM	5.490	5.490	3.525	3.525	75.022	75.022	116.859	116.859	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12:30-12:45 PM	3.811	5.490	2.383	3.525	108.062	75.022	172.818	116.859	33.040	55.959	623297.023	461.239	372853.092	195.298	996806.653
12:45-01:00 PM	5.083	5.490	3.307	3.525	81.024	75.022	124.563	116.859	6.002	7.704	87555.199	83.788	48493.151	26.889	136159.026
01:00-01:15 PM	5.351	5.490	3.453	3.525	76.976	75.022	119.296	116.859	1.954	2.437	23043.772	27.281	15325.896	8.505	38405.453
01:15-01:30 PM	5.262	5.490	3.405	3.525	78.279	75.022	120.958	116.859	3.258	4.099	38385.628	45.478	24941.928	14.306	63387.341
01:30-01:45 PM	4.840	5.490	3.163	3.525	85.092	75.022	130.205	116.859	10.070	13.347	162115.791	140.578	88879.271	46.579	251182.219
01:45-02:00 PM	5.350	5.490	3.452	3.525	76.991	75.022	119.315	116.859	1.969	2.456	25388.246	27.490	15016.447	8.571	40440.754
02:00-02:15 PM	5.138	5.490	3.337	3.525	80.170	75.022	123.426	116.859	5.149	6.567	69579.551	71.877	42869.470	22.920	112543.819
02:15-02:30 PM	5.414	5.490	3.486	3.525	76.075	75.022	118.164	116.859	1.053	1.306	8103.595	14.705	6755.337	4.556	14878.193
02:30-02:45 PM	5.385	5.490	3.471	3.525	76.480	75.022	118.671	116.859	1.458	1.812	15542.739	20.355	12375.029	6.324	27944.447
02:45-03:00 PM	5.013	5.490	3.266	3.525	82.155	75.022	126.095	116.859	7.133	9.236	93361.728	99.580	61275.129	32.233	154768.670
03:00-03:15 PM	5.054	5.490	3.290	3.525	81.487	75.022	125.187	116.859	6.466	8.329	125406.200	90.259	70288.021	29.067	195813.547
03:30-03:45 PM	4.122	5.490	2.658	3.525	99.930	75.022	154.986	116.859	24.909	38.127	428280.506	347.727	312584.303	133.064	741345.600
03:45-04:00 PM	5.259	5.490	3.404	3.525	78.323	75.022	121.014	116.859	3.301	4.155	47208.381	46.086	34713.474	14.502	81982.442
04:00-04:15 PM	4.463	5.490	2.916	3.525	92.293	75.022	141.266	116.859	17.271	24.407	337884.532	241.108	185058.654	85.182	523269.476
04:15-04:30 PM	4.055	5.490	2.602	3.525	101.575	75.022	158.283	116.859	26.553	41.424	662287.783	370.682	336330.102	144.570	999133.137
04:30-04:45 PM	3.556	5.490	2.118	3.525	115.811	75.022	194.454	116.859	40.789	77.595	1241481.733	569.419	601978.404	270.808	1844300.363
04:45-05:00 PM	3.241	5.490	1.716	3.525	127.083	75.022	240.022	116.859	52.061	123.163	1964764.844	726.774	881845.033	429.840	2847766.491
05:00-05:15 PM	3.453	5.490	1.997	3.525	119.281	75.022	206.251	116.859	44.259	89.392	1492729.672	617.854	629718.756	311.979	2123378.261
05:15-05:30 PM	3.310	5.490	1.812	3.525	124.452	75.022	227.270	116.859	49.431	110.412	1981722.817	690.053	895258.540	385.336	2878056.746
05:30-05:45 PM	3.213	5.490	1.675	3.525	128.181	75.022	245.860	116.859	53.159	129.001	2454701.752	742.103	958930.802	450.213	3414824.870
05:45-06:00 PM	3.168	5.490	1.606	3.525	130.018	75.022	256.414	116.859	54.996	139.556	1880407.515	767.746	1042567.173	487.049	2924229.482
06:00-06:15 PM	3.140	5.490	1.563	3.525	131.155	75.022	263.506	116.859	56.133	146.647	2202995.152	783.622	1152464.150	511.799	3356754.723
06:15-06:30 PM	3.210	5.490	1.670	3.525	128.316	75.022	246.604	116.859	53.295	129.745	2054493.709	743.995	863441.908	452.809	2919132.421
06:30-06:45 PM	3.124	5.490	1.536	3.525	131.863	75.022	268.163	116.859	56.842	151.304	2793092.139	793.510	1188436.566	528.053	3982850.268
06:45-07:00 PM	3.053	5.490	1.417	3.525	134.918	75.022	290.721	116.859	59.896	173.862	3528046.332	836.150	1321650.788	606.780	4851140.049