



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY

**ASSESSMENT OF SMOKE EMISSIONS GENERATED FROM FREIGHT VEHICLES
AT IDLING CONDITIONS IN THE CITY OF ADDIS ABABA**

BY
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JUNE, 2016
ADDIS ABABA, ETHIOPIA

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Assessment of Smoke Emissions Generated From Freight Vehicles
at Idling Conditions in the City of Addis Ababa

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A Thesis Submitted to School of Graduate Studies in

Partial Fulfillment of the Requirement for Degree of

Master of Science

In

Road and Transport Engineering

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Prof. Girma Gebresenbet and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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DEDICATION

To my father and my mother whom I
love very much

ACKNOWLEDGMENTS

First and for most, praise and glory be to God who loved and saved the world through Christ and by whose grace I do all things.

I would like to give my deepest thanks and love to my parents (Abi and Mama) who have always been with me and who have contributions in every single thing that I do. I would also like to thank my gentle brothers, my wise and lovely sister (Miny), and all my family, for all of you are part of this.

I thank the Ethiopian Roads Authority (ERA), the Addis Ababa Institute of Technology (AAiT) and the Linneaus-Program of the Swedish University of agricultural sciences who made the masters study and the research possible.

I appreciate my advisor Professor Girma Gebresenbet, for his dynamism and his wisdom in believing in his students and would like to give my sincere and heartfelt thanks for his great suggestions, critical comments and fatherly support.

I give my warmest thanks to Derebew Shankute, President and Chief Engineer of Vehicular-Smogless Air for Ethiopia, without whose help this research paper would not have been produced. I would also like to thank his colleague Shemsu for his help in execution of tests at site.

I thank Elshaday Woldehawariat who has also been doing her research and shared the stay in Sweden with me.

I would like to give my deepest respect and thanks for Dr. Samuel Aradom and Dr. Fufa Sorri who have been giving us their fatherly and important advices in our stay in Sweden. I would also like to thank the staffs of Energy and Technology Department of the Swedish University of Agricultural Sciences, who in one way or another have comforted our stay.

I also thank Dr. Bikila Teklu from the Addis Ababa Institute of Technology, for having helped in my data collection. Many thanks goes also to Ato Tesfaye from Size and Weight control station of the Ethiopian Roads Authority (ERA, Mojo site) for his willingness in giving data.

Finally it is my pleasure to give many thanks to my friends who in many ways have been with me. My brother Dolche, My sister Miny, Dere and Geni, you have actually parts in this work, thank you.

Abstract

Vehicles are the major sources of air pollution. In the developing world old aged vehicles are one of the main reasons why vehicles emit pollutant gases to the environment. The poor transport planning and traffic management systems leading to traffic congestion and hence idling, on the other hand, is the other major reason aggravating emission from vehicles. Vehicle related emissions are known to cause stroke, cancers including childhood leukaemia, lower IQ levels in children and adverse reproductive outcomes, low birth weight and premature birth and respiratory diseases (Suglia et al., 2007).

The objective of this research was to quantify the smoke emissions from tailpipes of diesel powered freight vehicles when they idle because of congestion & red light traffic stopping in the city of Addis Ababa; and the relation of these emissions with vehicles age. Considering the patterns of freight movements in the city of Addis Ababa, freight vehicles that entered through the Djibouti Mojo corridor during the year 2015 were used for the analysis as 95% of import commodities is through this route.

The major freight destinations in the city were identified to assess and analyze the idling situation on the routes from the entry point to the different freight destinations in the city. An empirical model was developed that combined data of Average Annual Daily Traffic of Freight Vehicles, freight destinations of the vehicles, idling times spent by vehicles on the selected freight routes of Addis Ababa and smoke densities of smoke emissions from freight vehicles.

For the completion of analysis, two types of field measurements were performed. One was to quantify the idle times on the different routes towards the major freight destinations and another was to simulate actual road traffic idling at a measurement site and measure the smoke produced from sample freight vehicles per idle situations; referred as 'stop and go' scenarios, by the use of a smoke measuring instrument called opacity meter .

It was found that the age of the freight vehicles in the city of Addis Ababa is a major factor for the emission of smoke from tailpipes. Vehicles' age was correlated with smoke emission with a high correlation constant of -0.8. Average opacity values of 80%, 73% 21 % and 8% were obtained for the model year groups of 1959-1991, 1991-2000, 2000-

2010 and 2010-2014 respectively from which the opacity values for the vehicles of pre 1991 vehicles resulted in much higher values than the standards of the US Environmental Protection Agency i.e. 50 %. The computed average smoke density from the freight vehicles resulted in a value of 7.6 meter⁻¹ which is very much higher than the threshold set by the standard of the European Union (EU VI). The result from the smoke emission due to idling on each of the routes to the freight destination computed by the empirical model was found to have increased with 93% from the calculated value on the empirical model using the threshold set by the standard of the European Union (EU VI). It was concluded that the level of smoke emissions from freight vehicles in the city of Addis Ababa is very high to cause deleterious impacts on the health of the city dwellers and also on the environment. To tackle the problem, old aged vehicles should be banned from import, optimized traffic management systems should be effected, integrated traffic and environmental laws should be formulated and implemented and stringent laws on smoke emissions should also be formulated and executed.

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LIST OF ABBREVIATIONS

A.A.	Addis Ababa
AADT	Annual Average Daily Traffic
AAEPA	Addis Ababa Environmental Protection Authority
CO	Carbon mono-oxide
CO ₂	Carbon dioxide
CRC	Children's Right Council
CFC	Chlorofluorocarbons
CNG	Compressed Natural Gas
CRGE	Climate Resilient Green Economy
EPA	Environmental Protection Agency
Eq.	Equation
ERA	Ethiopian Roads Authority
EPA	Environmental Protection Agency
HC	Hydro Carbons
I/R	Inspection and Repair
Km	Kilometer
O ₂	Oxygen Molecule
OD	Origin-Destination
O-D	Origin-Destination
PM	Particulate Matter
US	The United States of America
WHO	World Health Organization
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
SCR	Selective Catalytic Reduction
IDI	Indirect Injection
DI	Direct Injection
THC	Total Hydrocarbon

PM	Particulate Matter
CO	Carbon monoxides
NOx	Nitrogen Oxides
EGR	Exhaust Gas Recirculation
RPM	Revolution Per Minute
Gg	Giga Gram
Proc.	Proclamation
ETH-EPA	Ethiopian Environmental Protection Authority

Definitions

For the purpose of this research paper, the following words and terms shall have the meanings hereinafter ascribed to them.

A “stop and go scenario” is to represent a vehicles pattern of movement from the point it stops till the point it starts to accelerate.

“The Corridor” means the route from Djibouti-Mojo.

“The City” means the city of Addis Ababa.

The term “diesel-powered freight vehicles” is interchangeably used with “heavy duty freight vehicles”.

“Commodity” and “Freight” could be seen interchangeably used.

“Soot” and “Black smoke” are used interchangeably because soot is the fine powder consisting chiefly of carbon that colors smoke.

1 Introduction

1.1 General Background

The world's 700 million cars are a major source of air pollution. The emissions from vehicles include hydrocarbons, Nitrous oxides, Carbon monoxide, and toxic fine particles called particulate matter. Vehicle emissions are linked to a number of health effects, including respiratory and cardiovascular diseases such as asthma and lung cancer (UNEP,1996).As cited by the UNEP (1996),the World Health Organization estimates that approximately 460,000 people die prematurely each year as a result of exposure to particulate matter. The US Environmental Protection Agency has estimated that 60 percent of the annual US cancer cases related to air pollution is due to automotive emissions.

Transport accounts for two thirds of greenhouse gas emission in the globe, road transport taking the largest share (United Nations, 2004).

According to the WHO (2015), the transportation sector accounts for approximately 16 percent of the global annual mean emission black carbon. The vast majority of which is from diesel-fueled vehicles. According to Bond et al. (2013) as cited by WHO (2014), after CO₂, black carbon (smoke) is the second most important emission in the present-day atmosphere in terms of its climate forcing.

The black carbon exhausted from diesel powered vehicles is the soot which we see as a black smoke when exhausted through the tail pipes of diesel vehicles. Black carbon from diesel powered vehicles is known to cause of environmental and health hazards. Diesel emissions contribute to the development of cancer, cardiovascular and respiratory health effects pollute born of air, water, and soil, reductions in visibility and global climate change (Lloyd et al., 2001).

Urbanization is inducing freight transportation leading to widespread traffic congestion in the city of Addis Ababa. Traffic congestions lead vehicles to idle unnecessarily in which vehicle's engines are kept on when the vehicle is not in motion. At idling, engines are

forced to produce several pollutants due to the consumption of non-utilizable fuel which makes idling one of the aggravating factors for vehicular emission.

Another most important factor affecting vehicular emissions is vehicle's age. As the vehicle's age increases the efficiency of the engines decreases and therefore the fuel combustion efficiency of a vehicle decreases, resulting in excess unburnt hydrocarbons from fuel. This leads to the formation and emission of pollutant gases from the engine to the environment.

This research is focused on the smoke (black carbon) that is emitted from diesel powered freight vehicles in the city of Addis Ababa when they *idle* while delivering goods to the different freight destinations in the city. It also extends to the relation between the age of freight vehicles in the city and the level of smoke emission.

1.2 Road transport in Addis Ababa

The rapid urbanization of Addis Ababa is necessitating growth in the need of transportation in the city. In his study, Birhanu (2003) defined the transportation system of the city as the most complex in the country due to the rapid rate of urbanization initiated movements in the city. Until the mid of 2015 all passenger and freight mobility in the city was ensured through roads. It was only recently that a Light Rail Transport (LRT) for passenger transport began construction (in 2011) and was opened for public use on November 2015.

Though massive road construction and improvement works have been going on in the city and has contributed to the efficiency of transport mobility has changed the image of the city as well as facilitated other socio-economic developments, there is a huge work to be done in the road infrastructure as a whole. The class and quality of roads have great influences on the efficient and effective mobility of vehicles in the road transportation system. The widths of the roads in Addis Ababa are claimed to be not sufficient for the daily commuting 180,000 vehicles in the city (Asegid , 2010).

The quality of the road pavement does also affect the mobility of vehicles. Road quality in Addis Ababa is labelled as poor and insufficient for the mobility of the road traffic that

it accommodates; for which, the major reason is the frequent deterioration of both the constructed and rehabilitated roads due to surface and pavement drainage systems.

Impediment of the traffic flow due to insufficient widths and poor quality of roads affects the operation modes of vehicles' by decreasing their speed and allowing vehicles to cruise and hence idle. The idling creates unnecessary fuel consumption of the vehicle which then will increase the potential of exhaust emission from vehicles.

Vehicle ownership is low in Addis Ababa (below 100 vehicles per 1000 of population), though rapidly increasing mainly due to economic growth and the introduction of low cost private cars into the local market (Yared, 2010). There are about 403,711 vehicles where most of them are old more than 15 years of age with an annual average growth rate of 10% (Tsehaynesh, 2010). More than 70% of registered vehicles in the country are found in Addis Ababa (The transport policy of Addis Ababa). According to the Road Transport Authority of Addis Ababa (2013) of the registered freight vehicles in the city 55% of them have an age more than 10 years.

The engine efficiency of vehicles decrease as the vehicle ages which affects the combustion processes of vehicles and therefore exhausts emissions.

The other major important factor in the road mobility in the city of Addis Ababa is the behavior of drivers. The driving norm in the city of Addis Ababa can be labelled as *chaotic*. There could possibly be many interrelated factors that could be a reason for the observable problem. Among the many factors, the non-existence of stringent laws and also enforcement of these laws can be taken as the very root causes for the problem.

Until 2014, the Addis Ababa City Transport Bureau was the authority engaged with the city's traffic management systems, public and freight transport systems and drivers & vehicles Inspection and control systems. After 2014, the bureau was divided into three autonomous bodies under it, so that accountabilities could be distributed and to mitigate the lack of enforceability of transport laws.

In his study of models relating traffic safety with road environment and traffic flows on arterial roads in Addis Ababa, Birhanu (2003) concluded that the traffic management system in Addis Ababa, unlike many modern cities, is growing without adequate plan and control, which led to the existing mixed-up land uses. He labeled the city's road

networks inadequately planned to meet the traffic demand. Road hierarchies are not well established and arterial roads are not access controlled. He also states that the traffic management system in the city is inadequate to cope with the rapidly increasing motor and pedestrian traffic. Traffic controls, signs, and markings as well as pedestrian facilities are not in place. The rapidly increasing traffic on the undeveloped road infrastructure coupled with the unsafe behavior of road users results in a highly conflicting traffic that consequently leads to the occurrence of many road accidents in the city.

The absence of coordination and symbiosis in implementing the laws and regulations pertinent to environment protection and transport sectors, as well as gaps in improving quality of fuel used in the transportation sector is also a main problem. The city widely suffers from high levels of traffic congestion leading to ambient air and noise pollution due to vehicular emissions (Transport Policy of Addis Ababa, 2011).

1.2.1 Freight Transportation in Ethiopia, Addis Ababa

The need to satisfy personal household and industrial needs in the city of Addis Ababa is demanding the increase of commodity movement in the city and hence travels demand. Road transport is one of the most important modes for freight transport in Ethiopia. Road freight transport is recognized as the backbone for the economic development of the country, assuring more than 90% of freight movement (Tadesse, 2006). Also according to the study made by the Nathan Association (2014), of the total transport of goods, 95 % of them are transported through roads.

Commodity movements in Addis Ababa are mainly, from other cities of the country to the city, within the city for local distribution of goods, from the city to other cities, from other cities to other cities passing through the city of Addis Ababa, from the port of Djibouti to the city in the case of imports through roads and from the city to the port of Djibouti in the case of exports through roads.

Prior to 1999, the port of Assab served about 85% of Ethiopia's external trade with Djibouti accounting for about 15%. Ethiopia stopped using the port of Assab due to the poor relations between Eritrea and Ethiopia .Since then the Djibouti Corridor has

become Ethiopia's main outlet to overseas markets. Around 95% of the Ethiopian imports and exports cargo is served through the Djibouti-Mojo Corridor (Nathan Associations, 2014).

There are five major gates to the city of Addis Ababa through which freight transportation to and outside the city are passed. These are the Ambo Gate through the Ambo Road, the Bishoftu Gate through Kality, the Dessie Gate through Lege Tafo, The Gojjam Gate through Entoto, the Jimma Gate through Sebeta. The Kality gate (Figure 2) is the gate through which freight vehicles from the Djibouti – Mojo corridor enter and exit to and from the city. According to the Data from the Ethiopian Roads Authority a total of 50786 ,45917,47300 freight vehicles of different carrying capacities entered the city of Addis Ababa on the years 2013,2014, and 2015 through the Mojo weight and size control station, through the gate of Kality to Addis Ababa.

From this Corridor, the freight vehicles distribute the goods to the different market areas and production zones in the city. According to the study made by Kebede (2013) the major freight destinations in the city of Addis Ababa are Kality, Kera, Merkato, Megenagna and CMC at which the goods from the import-freight vehicles entering the city are distributed (Figure 6). According to Debela (2013) more than 146 warehouses are available where 59% of the warehouses are located within and surrounding of the main city center attracting huge freight vehicles to the city, operating at a poor level of service.

For this research paper freight vehicles that entered the city of Addis Ababa from this corridor on the year 2015, through the Bishoftu (Kality) gate are considered.

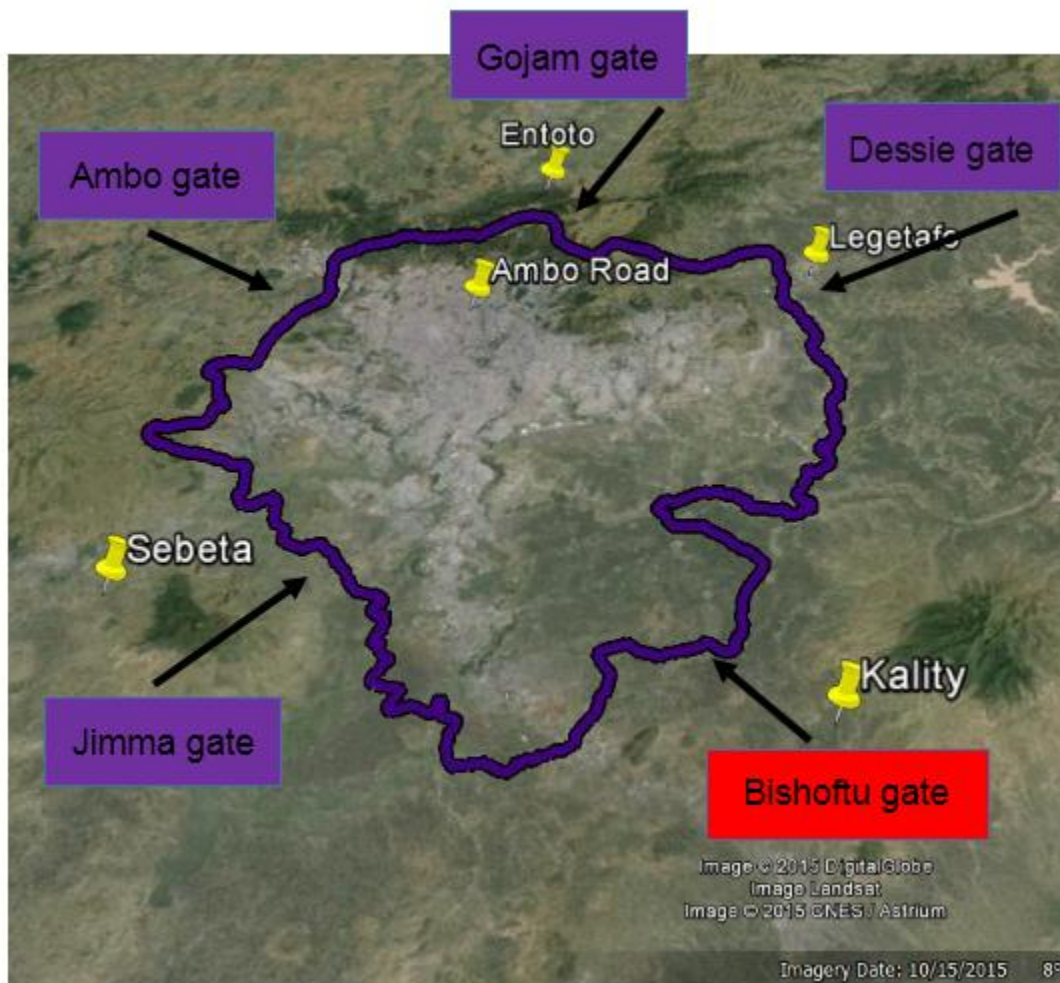


Figure 1: Route directions to the five different gates to the city of Addis Ababa

The Ethiopian logistics system in general is characterized by poor logistics management system, lack of coordination of goods transport, low level of development of logistics infrastructure and inadequate fleets of freight vehicles in number and age, damage and quality deterioration of goods while handling, transporting and in storage (Debela, 2013).

1.2.1.1 Freight Vehicles in Ethiopia

Availability and utilization of vehicles are the key characteristics of efficient and effective management of the transport system (Debela, 2013). According to the latest available transport authority data the dry cargo vehicle size in Ethiopia is about 65,534 of which 56,686 are public commercials and the remaining 8,848 private commercial. (Afro Consult & Trading PLC, 2010)

The combined stock of freight transport vehicles in Ethiopia have an average age of over 15 years and commercial freight transport vehicle share the same age spectrum. (Asnake, 2006). Source of energy for all freight vehicles is fossil fuel (Debela, 2013). International highways link Addis Ababa with neighboring countries such as Djibouti, Eretria, Kenya and Sudan which made Addis Ababa to accumulate 77% of the registered vehicles in Ethiopia. Ethiopian logistics system is characterized by poor fleets of freight vehicles in number and age. According to the study of Debela (2013), the status of the dry freight vehicles age is very startling and about 60% are older than 10 years. The report on status of fuel quality and vehicle emission standards sub saharan Africa of the United Nations Environment Program (2012) stated that there is no import restriction of vehicles on age basis in Ethiopia.

The share of freight movement in the city seems less as compared to other activity movements .The share of freight vehicles driven within the city is only 7.53% but these vehicles cause severe congestions due to their big size and difficulty of maneuverability (Debela, 2013).

The combination of the facts that freight vehicles in the city are old aged and the congestions that they create due to their poor maneuverability, makes the freight transportation in the city prone to exhaust pollution from which the most observable is the emission of smoke from diesel powered freight vehicles.

The emission control technologies of mid 1990s diesel vehicles in the country are mostly Diesel Oxidation Catalyst (DOC) and those after 2000 mostly have Diesel Particulate Filters (DPF) (Redda, 2012).

1.2.1.2 Idling due to traffic congestion and red light stopping in the city of Addis Ababa

Despite the lower car ownership levels, traffic congestion is becoming a more serious problems in a day to day activity of all people in all parts the city of Addis Ababa especially during the morning and evening peak hours. (Yared, 2010).

Lack of proper management of traffic in the city, insufficient capacity of the roads to cope up with the existing traffic volume, inadequate public transport, fixed working time, and poor land-use or lack of integration between transport and land-use planning and illegal on-street parking habit are the major causes that create traffic congestion in the city. (Yared, 2010).The other major reason for traffic congestions in the city of Addis Ababa is the behavior of drivers which is attributed to the lack of stringent traffic laws and law enforcement in the city and in the country as a whole.



Figure 2: Traffic Congestion in the City of Addis Ababa (Lindsay Prossnitz , 2015)

The highly observable congestion in the city is causing long periods of both cruise and stop idling of vehicles at roads during which vehicles consume fuel under no engine load and emit exhaust pollutant gases from tailpipes which is one of the causes for air pollution in the city affecting the health of city dwellers and also the climate of the city.

Yared,(2010) suggest that increase of capacity of roads, improved public transport, adequate parking arrangements and improvement in land-use planning would reduce the discernible traffic congestion in the city.

Second to traffic congestions, vehicle traffic movement at junctions in Addis Ababa are the major causes of idling. Traffic movement at junctions is regulated either by traffic polices or by traffic light in the city. There occurs a case also where neither of the two exists and drivers by themselves manage the traffic flow and traffic jams reach their peaks.

Traffic lights management systems in the city of Addis Ababa are by non-automatic traffic light management systems and the implementation of intelligent transport system is not yet executed in the city. Even though there could not been found studies on estimation of the amount of time spent and wasted on traffic lights in the city of Addis Ababa, It is observed that there is a significant time wasted through idling at traffic lights in the city.

1.3 Objectives of the research

The general objective of this research was to assess the level of smoke emission from freight vehicles at idling conditions in the city of Addis Ababa.

The specific objectives were to:

- Identify the major freight entry and major freight destinations in the city of Addis Ababa.
- Estimate the idling time in relation to the total travel time, on the routes to the major freight destinations in the city of Addis Ababa.
- Study the amount of smoke from the tailpipes of diesel powered freight vehicles.
- Develop an empirical model for the determination of smoke density of diesel powered freight vehicles at idling.
- Study the relationship between the age of freight vehicles and smoke emission.

2 Literature Review

2.1 Environmental Pollution

The dictionary definition of environmental pollution is the introduction of contaminants in to the natural environment that causes adverse change. Pollutants are waste materials that pollute air, water or soil. Pollutants can be either foreign substances like chemical substances, forms of energies such as heat, light or noise, or naturally occurring contaminants.

Among the many forms of pollution, the major ones are air pollution, noise pollution, light pollution, soil contamination, thermal pollution and water pollution (Bradford, 2015). Air pollution is one of the most crucial concerns in the world. It is the release of chemicals and particulates into the atmosphere. Common gaseous pollutants include carbon monoxide, sulfur dioxide, chlorofluorocarbons (CFCs), nitrogen oxides and Particulate matter (smoke, aerosols, smoke, fumes, dust, ash and pollen) (Pure earth et al., 2015).

The four main sources of air pollution are (a) *Stationary sources* such as power plants, oil refineries, industrial facilities, and factories, (b) *Area sources such as* agricultural areas and wood burning fireplaces, (c) *Natural sources* such as wind-blown dust, wildfires, and volcanoes and (d) *Mobile sources* which includes any air pollution emitted by motor vehicles, airplanes, locomotives, and other engines and equipment that can be moved from one location to another (US EPA, 2015).

2.2 Road transport and vehicular emission

Motor vehicles in the road transport systems are the most vital means of movement through which both passenger and good transportations are ensured. On the other hand, road transportation is becoming the victim of its own success and faces considerable challenges and is one of the most polluting modes of transportation. (European Union, 2012).

Road transport is an important source of greenhouse gas emissions (United Nations, 2004). The combustion of fossil fuels in vehicles for the reason of transportation is the

single largest source of human-made greenhouse gases (EPA, 2013). Emissions from fossil fuels can be from gasoline fuels or diesel fuels. Black smoke belching out of diesel buses and trucks has come to shape the public image of air pollution in many cities in the world (WHO, 2002).

2.3 Formation of Vehicular Emission

A vehicle is moved by burning fuel in an engine and its by-products are released in the combustion process into the surrounding environment. Currently, the majority of motor vehicles worldwide are powered by gasoline or diesel fuels. Other energy sources include ethanol, biodiesel, propane, compressed natural gas (CNG), electric batteries charged from an external source, and hydrogen. (Perry, 1997)

Diesel and Gasoline engines are both internal combustion engines which convert fuel into energy through a series of small explosions or combustions. They differ in their way of explosions for combustion. In a gasoline engine, fuel is mixed with air, compressed by pistons and ignited by sparks from spark plugs. In diesel engines, however, the air is compressed first, and then the fuel is injected. Because, air heats up when it's compressed, and the fuel ignites (US Department of Energy 2013).

A perfect combustion is said to occur when oxygen in the air would convert all of the hydrogen in fuel to water and all of the carbon in the fuel to carbon dioxide (carbon mixed with oxygen) (US EPA, 1994).

FUEL (Hydrocarbons (HC)) + AIR (Oxygen (O₂) and nitrogen (N)) = CARBON DIOXIDE (CO₂) + WATER (H₂O) + NITROGEN (N)

Perfect combustion is an ideal combustion that it does not occur in almost all of combustion processes in vehicle engines. Imperfect combustion is the typical real-world engine combustion process in which fuel is only partially burned and unburned hydrocarbons, Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO₂) and Water (H₂O) from the fuel are released. More specifically, incomplete combustion occurs when the air to fuel ratio of the combustion is either less or more than the right

amount. Air–fuel ratio (AFR) is the mass ratio of air to fuel present in a combustion process. It is an important measure for anti-pollution.

The typical incomplete combustion is:

Hydrocarbon (HC) + Oxygen (O₂) → Remnants of Hydrocarbon + Carbon dioxide (CO₂) + Carbon monoxide (CO) + Carbon + Water (H₂O)

The carbon is the black carbon containing soot which we see as a black smoke when exhausted thorough the tail pipes of diesel powered vehicles. Depending on the way they are emitted there are different types of emissions from vehicles. The two common types are tail pipe emissions and evaporative emissions. Tail pipe emission is an exhaust emission from the burnt fuel that an engine produces, which passes through the engines exhaust system and is exhausted through the tail pipe. Evaporative emissions are the result of fuel vapors escaping from the vehicle's fuel system.

2.3.1 Smoke emission from diesel engine vehicles

Almost all freight vehicles in the world are diesel powered (Christie-Joy et al., 2011). The transportation sector accounts for approximately 16 percent of the global annual mean anthropogenic radiative forcing of black carbon, the vast majority of which is from diesel-fueled vehicles (WHO 2014; Koch et al. 2007). The exhaust of a typical diesel engine contains elemental carbon (soot or smoke), semi-volatile organic hydrocarbons, sulfates (primarily sulfuric acid), and water vapor (The Lubrizol Corporation, 2015). Elemental carbon (soot or smoke) is one of the most hazardous diesel tail pipe exhaust emissions (Herron, 2015). Smoke is a general term used to describe the cloudy, hazy, emanations that result from the burning of organic substances.

It consists of solid and/or liquid particles or droplets that are so small that they tend to remain suspended in air for extended periods of times (Environmental Systems Products Holdings, USA, 2015). The carbon particle or soot (Smoke) content of diesel emission varies from 60% to 80% depending on the fuel used and the type of engine, most contaminants being adsorbed onto the soot (The Lubrizol Corporation, 2015). Smoke from diesel engines can be white, blue or black in color. Blue smoke contains mainly oil and un-burnt fuel indicating a poorly serviced engine. White smoke contains

water droplets and un-burnt fuel which is produced when the engine is started from cold and disappears when the engine warms up (Health and Safety Executive, Great Britain, 1999). Black smoke from vehicles is caused by an unbalanced air-to-fuel ratio, when either insufficient amount of oxygen is available (Lean Mix) or when there is too much Hydrocarbon of the fuel (Rich mix) (Hickey, 2014). Although smoke is often visible to the human eye, much of it is not. The black smoke from a diesel engine is an exhaust consisting of carbon and soot or particulate matter of size 2.5 micrometers and 10 micrometers from incomplete combustion of diesel fuel and traces of engine lubricant.

2.3.2 Impacts from emission of smoke from diesel vehicles

Researches have indicated that traffic-related exposures cause stroke; cancers, including childhood leukaemia, lower IQ levels in children (Suglia et al., 2007) and adverse reproductive outcomes, low birth weight and premature birth (Suglia et al., 2007). Large particle emissions from older diesels pose a greater health risk from today's modern diesel vehicle (Kittleson, CRC, 2002).

According to Bond et al. (2013) as cited by WHO (2014), after CO₂, black carbon (smoke) is the second most important emission in the present-day atmosphere in terms of its climate forcing.

Recent epidemiological studies show elevated risks of non-allergic respiratory morbidity, cardiovascular morbidity, cancer, allergic illnesses, adverse pregnancy and birth outcomes, and diminished male fertility for drivers, commuters and individuals living near roadways (Zhang, 2010).

This black carbon has a deleterious effect on health. In their research, Garcidueñas et al. (2015) stated that children exposed to concentrations above the standards for ozone, and fine particulate matter (PM_{2.5}) which is 15-65 µg/ m³ are vulnerable to neuron-inflammation, damages to the neurovascular unit, and the production of auto antibodies to neural and tight-junction proteins and may constitute significant risk factors for the development of Alzheimer's disease later in life. According to Lloyd et al. (2001) diesel emissions contribute to the development of cancer; cardiovascular and respiratory health effects; pollution of air, water, and soil, reductions in visibility and global climate

change. In their research Brodrick et al. also stated that diesel smoke is responsible for the human respiratory health problems. The studies of US EPA (2009) and the WHO (2005) also confirm that exposures to PM (including black carbon) could cause cardiopulmonary disease such as asthma or congestive heart disease on children and persons with lower socioeconomic status (US EPA, 2009). Therefore, emission in general and smoke (black carbon) emission from vehicles in particular are hazardous both to the environment to human health.

2.4 Factors affecting the emissions from vehicles

Factors such as fuel, engine technology, engine type and operating conditions influence the characteristics of diesel exhaust, causing significant variation in the mix of exhaust gases and the size and composition of the particulate matter (WHO 2014; Mauderly et al. ,1994).The parameters that most heavily affect the emissions from diesel powered vehicles include vehicle class and weight, driving cycle, vehicle vocation, fuel type, engine exhaust after treatment, vehicle age, and the terrain travelled (Clark et al. , 2002).

2.4.1 Fuel and emission

Diesel exhaust is produced regardless of the fuel type. It rather is mostly dependent on the timing of injection of fuel and the engine efficiency to burn all of the hydrocarbons in the fuel. But the amount of diesel emissions can be affected by the fuel quality; the main factors being fuel density, sulfur content, and certain distillation characteristics. Variations in fuel density (and viscosity) result in variations in engine power and, consequently, in fuel consumption and engine emissions. It is expected that higher Sulphur levels in a fuel could potentially increase PM (Black Carbon) by a small amount (Orbital Australia Pty Ltd, 2010).

2.4.2 Engine technology, engine repair and smoke emission

Particulate Matter (PM) containing smoke and NO_x emissions are more challenging to control and are the main focus of diesel emissions control research, as well as the main source of technology costs (Burgess et al. 2009).

Emission Reduction Technologies can basically be divided in to two; In-cylinder control and after treatment control (Burgess et al. 2009). In-Cylinder emission control systems are control systems applied prior to the air to fuel mixture and combustion process.

The severity of Particulate Matter is tightening laws for emission levels in the world. It is therefore difficult to meet the stringent laws only with in-cylinder emission reduction strategies, requiring after treatment control in most engines. After treatment control systems are control systems applied after air to fuel mixture and combustion process. The main after treatment devices for diesel powered vehicles are diesel oxidation catalysts (DOC) and Diesel Particulate Filters (DPF). Diesel oxidation catalysts (DOC) promote chemical oxidation of CO and HC (Majewski, 2012).

Engine Technologies would of course require initial investments in that, freight Vehicles with emission reduction technologies cost more than engines with no emission control technologies. The use of diesel particle filter (DPF) is one of the leading after-treatment techniques for PM with about 98% efficiencies (Johnson, 2009).

2.4.3 Engine operating condition and emission

The speed characteristics of vehicles can be divided into four operating modes. These are acceleration, *cruise*, deceleration and *Idling*. The general emission characteristics of vehicles of each of the operating modes are different. The proportion of a trip spent in these different stages will depend on the driver's behavior (aggressive vs. mild driving habits), the roadway type (freeway vs. arterial), and the level of traffic congestion (Mathew Barth). Emission rates are generally higher at lower average speeds, less sensitive for mid-range speeds, and higher as speeds increase (Hallmark, 2004).

2.4.3.1 Idling at traffic congestions and red light stopping at traffic light and emission

The two basic reasons why a vehicle idles and hence emits pollutants to the environment are traffic congestion and red light stopping at traffic lights (Guttikunda, 2009) in which both are categorized as 'stop and go scenarios'.

Urbanization and hence the induction of transportation is leading to widespread traffic congestion in cities (Zaroso, 2008). Traffic congestion can be of two types; recurrent and non-recurrent traffic congestions. Recurrent congestions are congestions that the traffic faces on every day travel commuting while non-recurrent traffic congestions are congestions caused by traffic incidents as accidents and car breakages. Traffic congestion directly affects commuters with an increased travel time, excessive delay in a queue, increased fuel cost, delay for important appointment and job, loss in productive hours; and it indirectly affects the living standard and the environment as well. Therefore, traffic congestion cause upon road users and cities to incur a significant amount of money for both economic and social costs (Wondossen, 2011).

Indirectly, traffic congestion is one of the major reasons for vehicle idling impacting fuel consumption and therefore vehicular emission and air pollution (European Conference on ministries of Transport, 2007).It increases vehicle emissions of particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO₂), volatile organic compounds (VOCs) or hydrocarbons (HCs), nitrogen oxides (NO_x), and other pollutants associated with vehicles (Zhang, 2011). Emissions are further increased as vehicles spend more time in congestion, idling or crawling, and undergoing numerous acceleration and deceleration events (Zhang, 2011).

Impacts of Idling

Idling increases the duration of exposure of people to exhaust gases from vehicles impacting the environment and health. The impacts from vehicular exhausts can be categorized in to three major categories; health impacts of idling, climate impacts of idling and economic costs of idling. Idling of cars and trucks is an unnecessary source of roadside pollution.

According to Burgess et al. (2009), the exposure of people, to exhausts, due to idling increases childhood respiratory consequences, cancer risks, heart disease, and asthma and lung cancer from diesel and lower IQ levels.

Idling does also have economic impacts. Burgess et.al. (2009) state that idling adds to the financial cost of a driving and estimated that idling for more than 10 seconds wastes more fuel than turning the engine off and on. According to the emissions research and measurement division, Environment Canada (2000) idling approximately wastes 0.39-1.65 gal/hr. (1.48-6.25 lit/ hr.) for trucks.

Although turning off the engine is the quickest, most effective way to cut fuel costs and reduce pollution from idling, a number of anti-idling technologies provide alternatives when auxiliary power is needed (Burgess et al., 2009). Among the suggestions towards idling in cities, Burgess et al. (2009) suggest that idling of trucks in cities can be improved by, a combination of better enforcement, outreach to individual drivers and sharing successful business and truck fleet strategies.

Burgess et al. (2009) suggest that advertising can play a critical role in public education they suggest to use banners, signs and posters to remind drivers to shut off their engines.

2.5 City logistics and transport emission

Rodrigue et al., (2015) define city logistics as “the means over which freight distribution can take place in urban areas as well as the strategies that can improve its overall efficiency while mitigating congestion and environmental externalities. It includes the provision of services contributing to efficiently managing the movements of goods in cities and providing innovative responses to customer demands.”

One of the critical impediment factors to city logistics is urban traffic congestion resulting pollutant emissions (Taylor, 2015). European Commission (2011) states that urban congestion is not only causing the increase in environmental pollution but also energy consumption .Urban mobility accounts for 40% of all CO₂ emissions of road transport and up to 70% of other pollutants from transport (European Commission, 2015).

Urban commodity movement is ensured by freight vehicles. Freight vehicles are mostly diesel powered and are known to emit soot particles in the form of smoke. In their research WBCPB (2012), of the diesel freight vehicles in the Calcutta, India, 72% of them were found to emit black smoke. All these facts directly relate to public health as traffic emissions are responsible for 70% of the cancerous and other dangerous substances (Schliwa et al. 2014; Silva & Ribero, 2009).

Sustainable city logistics solutions are therefore required to address these problems in city centres (Russo & Comi, 2012). According to Russo and Comi (2012), three elements are essential for promoting city logistics; application of innovative ICT, change in mind-sets of logistics managers, and public-private partnerships; from public utility point of view, the most important aspect is to promote a sustainable development strategy.

2.6 Measurements, estimations and analyses of smoke emission from freight vehicles

Among the measurements of emissions from vehicles the two ways of emission measurements from vehicles are common; Mobile emission measurements which measures instantaneous or second by second emissions from vehicles which varies depending on the speed of vehicles , and road side measurements which are performed on vehicles while they are at no engine load or at an idle state.

WHO (2002) stated that the lack of a relatively inexpensive and quick method for measuring particulate emissions makes the study of PM (Black carbon) difficult. One of the most common methods of measurements of smoke (component of Particulate matter) for diesel powered vehicles is by the use of opacity meter.

2.6.1 The Snap/Free Acceleration Smoke Test

The most common procedure for testing emissions from in-use diesel vehicles is the snap acceleration test (also called snap idle test) defined according to the Society of Automotive Engineers' SAE J1667 (in North America) or ECE R24 (in Europe)

(WHO,2002). The snap acceleration test is executed by the use of an instrument called opacity meter.

Opacity meter is an instrument which measures optical properties of diesel smoke, providing an indirect way of measuring of diesel particulate emissions. It detects and measures the amount of light blocked in a sample of smoke emitted by diesel engines from cars, trucks, ships, buses, motorcycles, locomotives and large stacks from industrial operations (SAE J1667).

There are two groups of instruments: *opacity meters*, which evaluate smoke in the exhaust gas, and *smoke number meters*, which optically evaluate soot collected on paper filters.

The opacity meter consists of an *optical unit* mounted inside a *measuring head* consisting of a *light source*, a *photodiode*, and a *separate electronic control unit*. To quantify the visible black smoke emission, these instruments use a physical phenomenon. This phenomenon works with the extinction of a light beam, by scattering and absorption.

Beam from the light-source (SLED) is absorbed and scattered by the particulate exhaust emissions. A photodiode determines the light intensity of the attenuated beam and the corresponding opacity value is transmitted to a separate remote display.

The opacity meter used in this research paper is in compliance with the instrument specification in Society of Automotive Engineers (SAE) J1667 test procedure.

The procedure for the test is, with the transmission in neutral, the throttle pedal of a diesel vehicle should be pushed rapidly but not abruptly to its full-throttle position, accelerating the engine from low idle to its maximum governed speed.

This is repeated several times and the average of the maximum exhaust gas opacity in each test is computed. Slight differences in the time taken to accelerate the engine from low idle to maximum governed speed can lead to very different exhaust opacity readings. Therefore, the rate of acceleration for each engine type needs to be more precisely defined. Each instantaneous reading of the opacity meter should be corrected for gas temperature, pressure, humidity and altitude, as required in the SAE J1667 standard. Any dilution of the exhaust gases with clean air will lower smoke readings.

Furthermore, it is extremely difficult to get rpm readings from diesel engines, particularly the older ones, yet accurate rpm readings are essential to add to the controls as well. The smoke opacity measurement is the only relatively low-cost and widely available method to measure smoke emissions from trucks in the field.

There have not been found many studies made directly on opacity indications of smoke. Rather many studies are made on measurements of Particulate matter (Containing soot or smoke).

McCormick et al. (2003) has quantified smoke opacities of freight vehicles at idling based inspection and maintenance program. Twenty six vehicles have been tested of which seventeen of them were pre-1991 and nine of them were post 1991, engine years ranging 1986-1999 and gross vehicle weight from 11,000 to 80,000 lb. (4,990-36,288 Kg). The vehicles' model year of their study ranged from 1986-1999. Seventeen of them were pre 1991 and nine of them post 1991 later heavy duty vehicles. Their study resulted in average before and after opacity values of 54% (Marginal from US EPA's Standard) and 39% (Marginal from US EPA's Standard) for the pre 1991 vehicles respectively, and, average before and after opacity values of 66%(Failed by 10% increase from the US EPA's Standard) and 39%(Marginal from US EPA's Standard) for the post 1991 vehicles respectively.

In their study, McCormick et.al (2003) checked for the correlation between opacity and PM and found that they are poorly correlated. Also they suggested that a simple tail-pipe measurement of CO during a snap acceleration might be a more accurate predictor of PM (Black Carbon). Also in the research of Checkel et.al (2005), opacity measurements made with a commercial test instrument correlated very poorly with actual particulate matter emission rate.

In their study, Agarwal et al. (2014) tested six different vehicles for exhaust, of which three of them were diesel powered. Vehicles were tested at different engine speeds operating under no-load conditions to simulate the situation of a typical city traffic junction. A partial flow dilution tunnel was used for diluting the exhaust with pre-conditioned, heated and filtered air. When the exhaust exited the tailpipe, it was rapidly diluted at a dilution ratio of 20. Real-time measurements were performed at four engine

speeds: 1500, 2000, 2500, and 3000 RPM. Smoke opacity was measured using online instruments. Emission measurement was done using an exhaust gas emission analyzer (AVL: Di Gas 444), while a smoke opacity meter (AVL: 437) was used for determining the opacity of the engine exhaust gas. The engine of each vehicle was operated at an idle condition for at least 10 minutes to attain thermal stabilization. Total Particulate Matter (TPM) and trace metals were determined for the particulates collected (30 min sample duration) on 47-mm quartz filter papers. The research Agarwal et al. (2014) resulted in low opacity levels the maximum being 1.1 % or a smoke density 0.16/m which is very much below the standards of both the Environmental Protection Agency of the US and the European Union of Europe.

2.7 Environmental laws and standards of smoke/opacity

Ethiopia does not have a standard for specific smoke opacities (smoke densities). Only general environmental laws exist in the country. As cited by Gebreyes (2014), according to the constitution of the Federal Democratic Republic of Ethiopia 1996, Article 44 stipulates environmental rights and it states that “all persons have the right to a clean and healthy environment.” Article 92 stipulates the environmental objectives of the government and it states that “The government shall endeavor to ensure that all Ethiopians live in a clean and healthy environment. Environmental policy of Ethiopia and conservation strategy under proc. no 300/2002 states about environmental pollution control.

Reestablishment legislation of the federal transport authority under proclamation no.468/2005 states that “The Transport Authority shall prepare and submit and, upon approval, implement standards relating to smoke ,gas, vapor, and the like emitted from the exhaust pipes of vehicles and trains with the view to preventing pollution taking into account international criteria and capacity of the country” .

The Addis Ababa Administration Environmental Protection Authority has also been established by law with mandates of protecting and preserving ecosystem resources of Addis Ababa under proc.681/2010, to govern the vehicles identification, inspection and registration with a provision that an authorized inspector of an inspection station shall

inspect each vehicle presented for the purpose of establishing vehicle compliance with environmental pollution protection standards.

Specific standards for smoke opacity or smoke emission could not be found on the environmental law of the country.

Standards of the environmental protection agency of the USA

“Federal regulation of heavy-duty engine emissions in the United States began in 1974. More stringent regulations were phased-in beginning in 1988 and 2004, with the most recent set of standards phased-in between 2007 and 2010.”(EPA, 2010)

The emission standards include standards on CO, Nox, PM, HC and Smoke Opacity. Smoke Opacity standards of the US EPA are depicted in the table 1 below.

Table 1: US EPA standards of smoke opacities (2010)

Engine Model Year	Opacity,%
Post 1991	< 40
Pre 1991	< 50

Standards of the European Union

Europe first introduced heavy-duty vehicle emission standards in 1988. The "Euro" track was established beginning in 1992 with increasingly stringent standards implemented every few years. Since the establishment, six tiers have been formulated and many countries have since developed regulations that are aligned in large part with the European standards.

The emission standards include standards of smoke. The following table shows the standards for smoke from Tier I-Tier VI.

Table 2: European Union standards of smoke density

Tier	Smoke (meter ⁻¹)
Euro I	-
	-
Euro II	-
	-
Euro III	0.15
	0.8
Euro IV	0.5
Euro V	0.5
Euro VI	-

Standards on vehicle Idling

Laws on idling of vehicles do not exist in most countries and where there exists, they are not stringent. In the US, Idling is illegal in 42 states and most anti-idling laws are aimed at large trucks and commercial vehicles. The case of New Jersey is reviewed in this research paper.

New Jersey’s three minute Idling law for Diesel-Powered Vehicles

According to the New Jersey’s Department of Environmental Protection, New Jersey Administrative Code, Title 7, Chapter 27, Subchapter 14 (2009), no person shall cause, suffer, allow, or permit the engine of a diesel-powered motor vehicle to idle for more than three consecutive minutes if the vehicle is not in motion, except for :

- A motor vehicle that has been stopped for three or more hours may idle for up to 15 consecutive minutes when the ambient temperature is below 25 degrees Fahrenheit.
- A diesel bus while it is actively discharging or picking up passengers may idle for 15 consecutive minutes in a 60-minute period.

New York also has a more or less the same three minute idling limit laws which have been on the books since 1971 but has rarely been enforced. As a result, few drivers are

aware of the law, and even if they are, the chances of getting a ticket for idling are so low that it is not enough of a deterrent (Burgess, 2009).

2.8. Emission from Road Transport in Ethiopia-Addis Ababa

75% of the emissions in Ethiopia come from road transport, particularly freight and construction vehicles, and to a lesser extent private passenger vehicles. (Climate-Resilient Green Economy, CRGE, 2011).

CRGE (2012) states the rapidly growing economy will bring with it a strong need for freight transport, leading to steep growth in tonne-km of freight transported from 23 billion in 2010 to 279 billion in 2030. This will result in emissions rising from 2.0 Mt CO_{2e} in 2010 to 24.1 Mt CO_{2e} in 2030. CRGE (2012) also assumes that the average fuel efficiency of the freight vehicle fleet will improve by 3.3% from 2010 to 2030.

The Addis Ababa Greenhouse Gas Emission Inventory of 2012 shows that of the 4.8 million tons of carbon dioxide gas (CO₂) the city emits, transport vehicles account for 47% of the total emission (Getnet,2015).

Green House Gas Inventory has been carried out in Ethiopia, covering mainly the period from 1990 to 1995 which resulted in gross CO₂ emission of 2596Gg for 1994, of which 88% came from fossil fuel combustion in the energy and road transport sectors. Carbon monoxide (CO) emission was estimated to be about 7619 Gg of which 44% is from the energy and the transport sector. Nitrous Oxide (N₂O) emission has been estimated to be 24Gg, of which 12% was the contribution of the energy and the transport sector. Sulphur Dioxide (SO₂) has been about 13Gg, of which fossil fuel use in the manufacturing industries, construction and transport sub sectors are the main sources.

To this effect Ethiopia is working to contribute to the effort in reduction of global Green House Gas emission by promoting climate resilience green economy strategy (CRGE, 2012).

Kume et al. (2011) assessed CO concentration as a measure of traffic air pollution in Addis Ababa. They made tests on a total of 80 road side and 24 on-road daily traffic air samples during wet and dry seasons of 2007 and 2008. Their research resulted in mean

15 minute CO concentration of 2.1 ppm (GM=1.3) and 2.8 ppm (GM=2.2) for wet and dry seasons, respectively. The concentrations from season to season varied statistically. The CO temporal and spatial profiles among the two seasons were similar. The overall mean on-road CO concentration was 5.4 ppm (GM=5.3). Fifteen percent of roadside samples and all on-road samples exhibited more than 50% of the 8-hr CO WHO guideline. They concluded that the consistency in spatial and temporal profiles and the variation on both on-road and road side traffic lines imply that vehicles are the main source of traffic air pollution and that there is a concern that the CO 8-hr World Health Organization guideline might be exceeded in future.

The increased emissions are driven first by higher emissions from freight transport (+13% p.a.) and also by higher emissions from passenger transport (+9% p.a.) (CRGE, 2012).

Derebew et al. (2012) made vehicular exhaust tests on 782 passenger vehicles, and tests on ambient air quality, to investigate the level of air pollution from gasoline passenger vehicles. They measured tail pipe exhausts using Vehicle Gas Analyzers. From their research Derebew et al. (2012) concluded that both ambient and vehicular HC, CO and PM levels are well above worldwide standards for human and environmental health. This study has also found that improperly functioning motor vehicles are major contributors to Addis Ababa's air pollution. The situation is serious enough that urgent regulatory actions are strongly needed.

In his research, Worku (2012) selected twelve sites to measure 15minute, 30 minute, 1 hour and 8 hour ambient CO (ppm) concentration in in the city of Addis Ababa. And from the results he concluded that CO concentration level in the ambient air is below both the WHO and ETH-EPA guideline limits and the impact can be considered insignificant. Worku (2012) also measured the 24 hrs. Ambient PM ($\mu\text{g}/\text{m}^3$), at the twelve sites and found that $\text{PM}_{2.5}$ concentration levels in the ambient air are higher than the WHO guideline limits for all sites and except four of them all were also higher than the ETH-EPA guidelines.

In his study, to estimate the total amount of CO_2 and CO per day, Kebede (2013), considered two scenarios. For the first scenario the day and night time 24 hours total

traffic with their percentage distribution at the day and night time counted for two days and for the second scenario with the whole AADT shifted to night traffic.

For the first scenario estimates CO₂ were found to be 36.84 tons per day of CO₂ and 100 Kilogram per day of CO pollutant gases are released to the atmosphere of Addis Ababa City. The exhaust emission has share of 12% for night movement and 88% for the day time movement. These higher differences on exhaust emission percentage share showed most of the movements of freight vehicles take place at the day time.

For the second scenario, Kebede (2013), estimated amount CO₂ of per day of 29.18 tons and 90 Kilogram per day of CO pollutant gases are released to the atmosphere of Addis Ababa City. The exhaust emission has reduced 7.66 tons of CO₂ and 10 Kilogram CO per day compared to the first scenario.

As per the literatures reviewed, the levels of vehicular emissions are high and need quite an attention. Tsehaynesh (2011) suggests the introduction of stricter fuel efficiency standards for passengers and cargo transportation ,promotion of the purchase of hybrid and electric vehicles, construction of an electric rail network powered by renewable energy to substitute road freight transport ; to counter the low efficiency of the existing vehicle fleet and hence the emissions contributed by them.

Stricter environmental laws are the key stone in controlling vehicular emissions in Ethiopia. Under Proc. 468/2005, the Federal Transport Authority was established which empowers the city authorities and is responsible for the preparation and implementation of standards of the exhaust pipe emissions. The Addis Ababa Environmental Protection Authority has been established by law with mandates of protecting and preserving the ecosystem resources of Addis Ababa. Under the regulation, Regulation No.25/2007 of Addis Ababa City Government's Environmental Pollution air quality standards exists.

2.8 Summary

Vehicular emission is the most critical concerns of the environment in urban cities of the world. It has also become an issue in the city of Addis Ababa. Freight vehicles in particular are the major sources of smoke in the city most of them being diesel powered.

The major portion of diesel powered vehicular emission is soot (smoke). Even though a number of studies has been done to investigate both vehicular and ambient levels of exhausts of hydrocarbons (HC), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO₂), PM and SO₂ for the city of Addis Ababa, no study has been made on the smoke from diesel powered freight vehicles. Therefore this research paper will set a foundation in filling the gap of research on emission from diesel powered freight vehicles in the city of Addis Ababa and; also on the relation between traffic idling and traffic emission.

3 Methods

Parameters

The collected and analyzed data were used to quantify two main parameters; the total time that freight vehicles that enter the city of Addis Ababa idled when vehicles distributed goods to the main freight destinations of the city and the amount of smoke emissions that these freight vehicles emit on idling. The number of freight vehicles that have entered through the gate of Kality on the year 2015 was considered.

Under the data collection and analyses inputs for the two main parameters and the correlation between model year (vehicles' age) and smoke emission were assessed.

3.1 Determination of smoke emission on idling from freight vehicles entering the city of Addis Ababa through the gate of Kality

The analysis made under this section mainly deal with the amount of average smoke emissions (in terms of smoke density (meter^{-1})) that freight vehicles entering the city of Addis Ababa from the Djibouti-Mojo corridor through the gate of Kality produce per day, when they are idling towards reaching their destinations, at idling mainly due to traffic congestions and red light stopping at traffic lights.

To obtain the emission of smoke at idling, the idling situation was simulated by a road side smoke emission measurement test procedure called the Snap (Free) acceleration test discussed clearly in the following section.

3.1.1 The Snap (free) Acceleration Test (Snap Idle-Test)

The Snap Acceleration Test Procedure is a test procedure containing guidelines formulated by the Environmental Protection Agency (EPA) of the United States of America which has been used for an inspection and repair programs for heavy duty vehicles since 1996 .It is executed based on Society of Automotive Engineers (SAE) J1667 test procedures.

It is a non-moving vehicle test conducted along roadsides, in a truck depot, at a vehicle repair facility, or other test facilities. The test is intended to be used on heavy-duty

trucks and buses powered *by diesel engines*. The main objective of the test is to determine the *opacities* (the light blocking ability) of the smokes exhausted from the tail pipes of diesel powered heavy duty vehicles from which the amount of smoke produced is determined. (SAE J1667 test procedures).

The complete Snap-Acceleration process consists of five phases. (SAE J1667 test procedures)

- Vehicle preparation
- Test preparation and equipment set-up
- Driver familiarization and vehicle preconditioning
- Execution of the snap-acceleration test
- Calculation and reporting of final results

All of the above, except the last, procedures are discussed in the *Data Collection* part of section 3.1.3 and the last is discussed in the *Analysis* part of the same section.

The test is designed to be executed using an instrument called opacity meter or smoke meter using the light extinction principle of smoke measurement (SAE J1667 test procedures).

3.1.1.1 Opacity Meter / Smoke Meter

Opacity meter is an instrument which measures optical properties of diesel smoke, providing an indirect way of measuring of diesel particulate emissions (SAE J1667 test procedures). It detects and measures the amount of light blocked in a sample of smoke emitted by diesel engines from cars, trucks, ships, buses, motorcycles, locomotives and large stacks from industrial operations.

There are two groups of instruments: (a) Opacity meters, which evaluate smoke in the exhaust gas, and (b) smoke number meters, which optically evaluate soot collected on paper filters.

The opacity meter consists of an optical unit mounted inside a measuring head consisting of a light source, a photodiode, and a separate electronic control unit. To quantify the visible black smoke emission, these instruments use a physical phenomenon which works with the extinction of a light beam, by scattering and

absorption (Figure 4). The opacity meter used in this research paper is in compliance with the instrument specification in Society of Automotive Engineers (SAE) J1667 test procedure.



Figure 3: Opacity meter (Reading Monitor (Left) and tail pipe plug (Right))

In the execution of the test, beam of light is transmitted from the light source. Part of the light reaches the light detector and part of it is blocked by the smoke accumulated in the tail pipe. The percentage of light transmitted from a source which is prevented from reaching a light detector is termed as the Opacity (N). And, the fraction of light transmitted from a source which reaches a light detector is Transmittance (T).

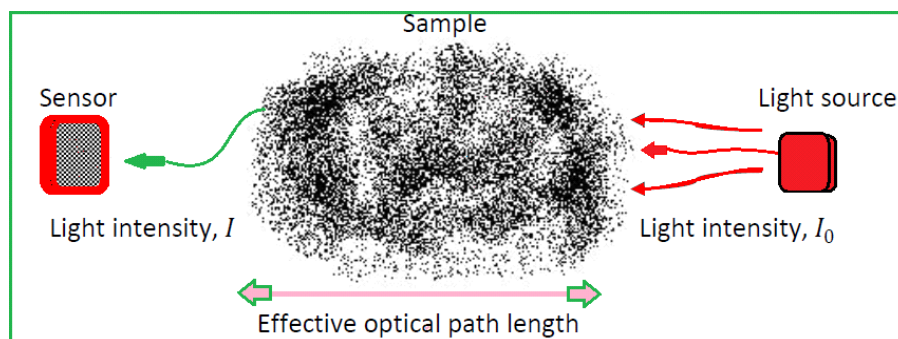


Figure 4: Light Transmission Process of the Opacity Meter (Lorenc Malka, 2015)

Opacity (N) - The percentage (%) of light transmitted from a source which is prevented from reaching a light detector.

Transmittance (T)-The fraction of light transmitted from a source which reaches a light detector.

Effective Optical Path Length (L) or (EOPL) is the length of the smoke obscured optical path between the smoke meter light source and detector. Portions of the total light source to detector path length which are not smoke obscured do not contribute to the effective optical path length.

Smoke Density (m-1) (K) - (also known as “light extinction coefficient” and “light absorption coefficient”) is a fundamental means of quantifying the ability of a smoke plume or smoke containing gas sample to obscure light. By convention, smoke density is expressed on a per meter basis (meter⁻¹).

Light Source - The light source is a lamp with a color temperature in the range of 2800 to 3250 °K, or a green light emitting diode.

Light Detector - The light detector is a photocell or a photodiode which detects the light scattered by the light source. A photodiode is a semiconductor device that converts light into current. The current is generated when photons are absorbed in the photodiode.

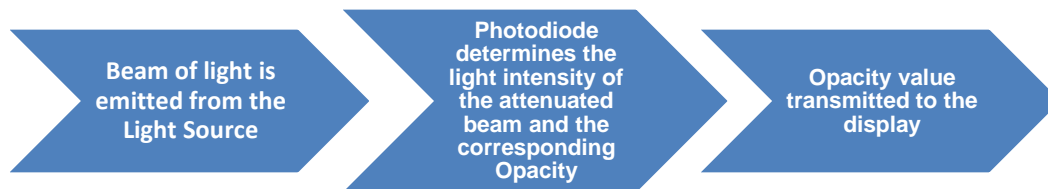


Figure 5: Opacity Measurement by the Light Extinction Principle

There are two significant drawbacks of the opacity meter (SAE J1667 test procedures). These are:

Insufficient resolution: for smoke levels of smokeless diesel. (Low emission), and

Insensitivity to small particles: a substantial portion of diesel particles have diameters below 200 nm. Particles of 200 nm diameter or greater block green light in proportion to their cross-section surface area. Particles of 50 nm diameters, however, block only




about 15% of their surface area (Jones, 2002). This means that opacity readings depend on particle sizes and will be underestimated if smaller particles are measured.

For the execution of the test:

- The opacity meter is turned on.
- The opacity meter is plugged on the tail pipes of vehicles.
- The throttle is set to the fully open position as rapidly as possible by accelerating the pedal.
- The throttle is held in the fully open position until the time the engine reaches its maximum governed speed, plus an additional 1 to 4 s.
- Upon completion of the 1 to 4 s with the engine at its maximum governed speed, the throttle is released to allow the engine to return to the low idle speed.
- Once the engine reached its low idle speed, the engine is allowed to remain at idle for a minimum of 5s, but no longer than 45s, before initiating the next snap-acceleration test cycle. The time period at low idle allows the engine's turbocharger (if so equipped) to decelerate to its normal speed at engine idle. This helps to reduce the smoke variability between snap-acceleration cycles.
- Opacity is read from the monitor of the opacity meter
- All the above steps were repeated three times per test to complete the snap-acceleration cycles; the three results of opacity values are then averaged to give one final accurate result.

The snap (free) acceleration test in this research paper is used to simulate the stop and go idle scenario of vehicles at traffic congestions and red light stopping at traffic lights. On Table 3, the common activities shared by the snap acceleration test and the stop and go scenario of vehicles at idling, which led to the simulation of the idling situation by the test is presented.

Table 3: Common activities shared by the snap acceleration test and the stop and go scenario of vehicles at idling

Idle(stop and go scenario) conditions (traffic congestion & red light stopping)		Snap acceleration test	
One Stop	Vehicles stop while the engine is running, after deceleration.		Vehicles are made to stop with engine running.
	Vehicles idle for some time (till the congestion is relieved or till traffic light turns from red to green).		Vehicles are intentionally made to idle.
	Vehicle accelerates to start moving.		Vehicle's engine is accelerated till it reaches maximum allowable speed.

To estimate the average smoke density (meter^{-1}) on each of the routes to the freight destinations per day on Idling, an empirical model was developed through empirical observations. The empirical model was developed based on the idea that ‘the freight diesel vehicles entering the city through the gate of Kality have specific destinations, face a number idling till they reach their destinations and during each stop and go scenario (idling) smoke emissions are produced.’

For the development of the model, input parameters were identified of which the data collection methods for the input parameters are presented.

The first input parameter was the Annual Average Daily Traffic (AADT) of freight vehicles entering the city through the corridor, which was done through secondary data collection method (Section 3.1.1.).The second input parameter was the percent share of the destinations (%) for receiving freight vehicles. To obtain this parameter, (a) the different destinations (section 3.1.2.- part A) of the freight vehicles through the gate of Kality and (b) the share of these destinations, both secondary and primary data collection methods are used.

The third parameter is the average numbers of idles or stops (number of stop and go scenarios) made on each of the routes for which a primary data collection was used to obtain the data (section 3.1.2. –Part B).

The fourth and the last parameter to the model is the average smoke density (meter⁻¹) per stop which was obtained by the conversion of the smoke opacity values measured at site to smoke densities(section 3.1.3.). Opacity (%) measurements obtained from field-data collection were measured by the use of opacity meter, with test conditions simulating idle vehicle conditions at road sides as discussed above. Smoke density values (meter⁻¹) were then determined from opacity values.

$$\text{ASD per day} = \frac{\text{AADT}}{\text{(I)}} \times \frac{\text{D (\%)}}{\text{(II)}} \times \frac{\text{S(No.)}}{\text{(III)}} \times \frac{\text{SD (meter}^{-1}\text{)}}{\text{(IV)}} \quad \text{Eq.1}$$

The input parameters are aggregated and used in an empirical model below

Where:

ASD per day - Average smoke density (meter⁻¹) per route, per day on idling

AADT- Average Annual Daily Traffic

D (%)-Percent share of the destination (%)

S (No.) - Average number of stops on the route

SD (meter⁻¹) -Weighted average value of smoke density per stop (meter⁻¹)

3.1.2 Determining Annual Average Daily Traffic of freight vehicles entering the city of Addis Ababa through the gate of Kality (I)

i. Data Collection

There is no trend of performing actual Annual Average Daily Traffic counts (AADTs) designed specifically for freight vehicles entering the city on regular basis (yearly, monthly etc). For this reason, another method than counting freight traffic was used on this research paper.

The Ethiopian Roads Authority (ERA) has established weigh bridges at nine different corners of Addis Ababa- entry in order to control the effect of overloaded vehicles on pavements structure damages. The weigh bridge stations are located at **Mojo**, Alemgena, Awash, Combolcha, Dengeno, Holeta, Jimma, Sendafa, Shashemene and Sululta.

According to the council of Ministers Regulations No.11/1990 of Ethiopia to amend vehicle size and weight regulations, in each of the nine transport warden, freight vehicles of gross vehicle weight greater than 5 tons must pass through the weigh-bridges and get checked for their load and if found overloaded, proper actions are taken. Therefore, these weight stations are found to give reliable actual number of freight vehicles entering the city of Addis Ababa from the different directions of the country. For this research paper data of the years 2013, 2014 and 2015 are collected from the Ethiopian Roads Authority, Mojo site.

At the weight station, origins and destinations of vehicles are recorded laterally with the number of vehicles that have passed through the weigh-bridge in a day through a particular origin-destination route.

Appendix A shows the data recording format showing origins and destinations of freight vehicles with total numbers of vehicles through the different O-D.

ii. Data Analysis

From the data, each month's number of vehicles, of the years 2013, 2014 and 2015, whose destinations were to Addis Ababa were collected and summed up. The data of the years 2013 and 2014 were collected and analyzed only for the purpose of seeing the freight vehicle entry growth trend. For the empirical model, only the data of the year 2015 were used.

Annual Average Daily Freight Vehicles were obtained by dividing the sum of the months total by 365 days to get the total number of vehicles entering Addis Ababa through the gate of Kality (AADT-Freight).

3.1.3 Determining percentage shares of different destinations in the city of Addis Ababa and idle time quantification along the routes to each of the destinations

A. Percentage shares of different destinations in the city of Addis Ababa from the corridor. (II)

It was discussed in chapter two, why among the five main gates of Addis, the gate of Kality (The Bishoftu gate) from the Djiboutti Mojo, was chosen (Figure 7).

To determine the main destinations of freight in the city, previous studies were referred, as secondary data; and also a field survey was executed as a primary data.

i. Data Collection

Two types of data collection methods were used for obtaining percentage shares of destinations. Data were gathered through secondary data collection and primary data collection methods. The secondary data was gathered from the research of Kebede (2013) which was obtained from a primary data collection method.

According to the research made by Kebede (2013), there are five main freight destinations from the gate of Kality to Addis Ababa to the different parts of the city.

These destinations are located in the different sub cities of the city. As discussed in chapter one, for ease of reference, in the analysis the different destinations are labeled from D₁-D₅. The data from the study of Kebede (2013) was done profoundly through a field data counting of 200 vehicles at the day time and night time. Therefore this data is used for further analysis.

These destinations are:

- **Kality** : from the Akaki Kality Sub-city, D₁
- **Merkato** : from Addis Ketema Sub-city, D₂
- **Kera** : from Kirkos Sub-city, D₃
- **Megenagna**: from Yeka Sub-city, D₄
- **CMC**: from Oromia Region, D₅

Figure 6 shows the route from Djibouti to Mojo (where freight vehicles are checked for overloading) and Figure 7 shows the different routes to the different freight destinations in the city of Addis Ababa.

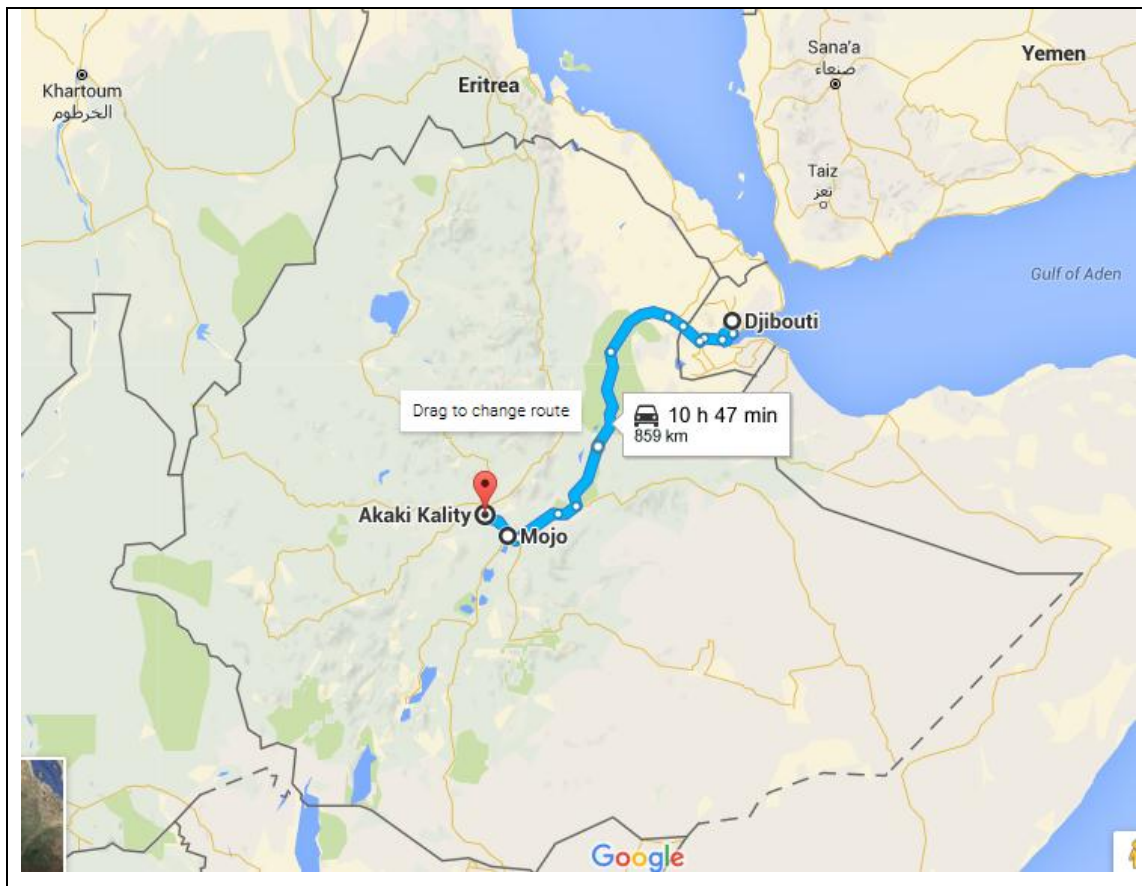


Figure 6: The route from Djibouti- Mojo to Akaki-Kality on google map (The entry route to the gate of Kality)

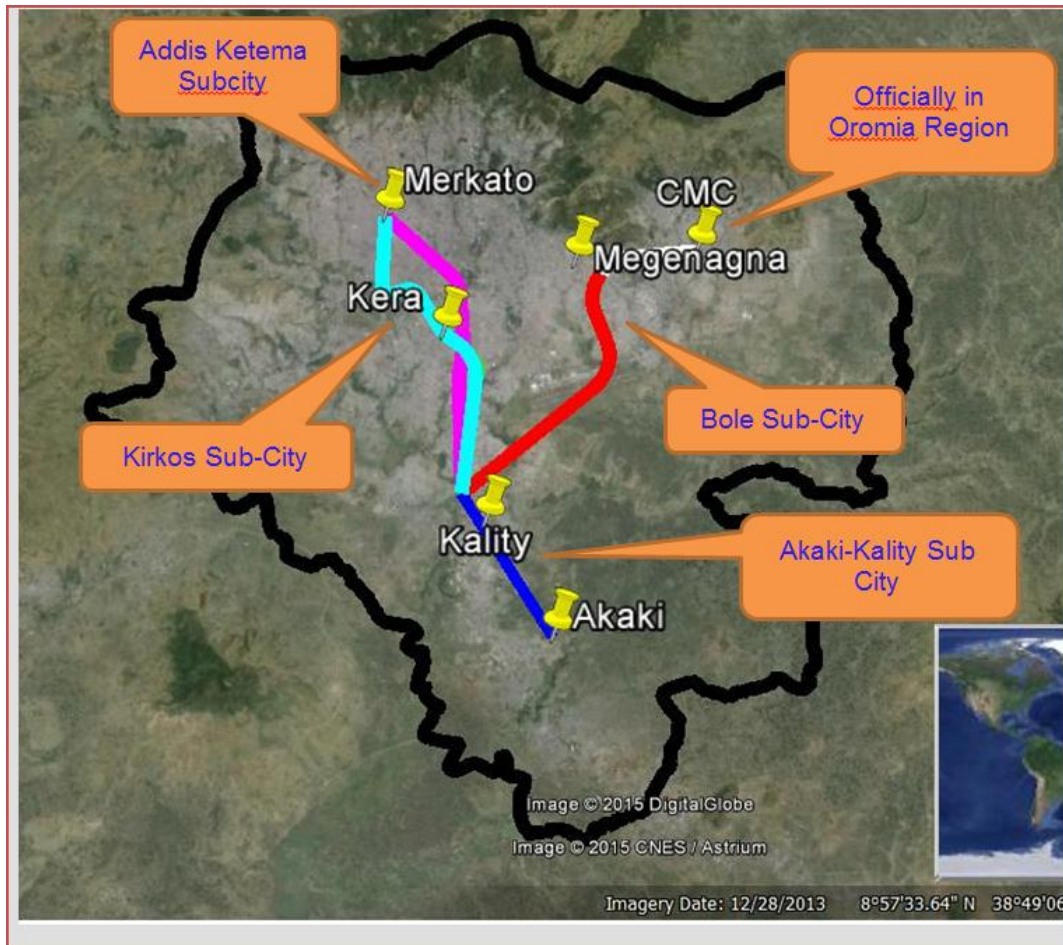


Figure 7: Freight destinations in the city of Addis Ababa plotted on google earth view.

Color Code	To Destination	Denotation	Routes
Blue	Kality	D ₁	All
Red	Megenagna	D ₂	R ₁
Cyan	Kera-	D ₄	R ₂ - R _{2E}
Magenta	Merkato	D ₅	R ₃

A primary data collection was also done in the field to support the data obtained from the secondary data collection. A site was chosen where all vehicles would cross and split to the different destinations of the city when they enter the city through the gate of Kality, and where it was convenient to stop vehicles without creating congestion in the traffic flow. Akaki was chosen as a vehicle stopping site. At this site vehicles were randomly stopped and drivers were interviewed about their destinations. The collection is made on Monday, which is a peak vehicle movement day from Mojo which was learnt from observations. The destinations of twenty freight vehicles from Akaki were recorded.

ii. Method Analysis

The percentage distributions to the different destinations of the city were obtained. These percentage shares were taken to the empirical model (Eq. 1)

The number of vehicles counted through the primary data collection to each of the destinations were summed up and divided to the total number of vehicles to get the percentage shares of each destination sub cities.

Due to its robustness, the data from the secondary source was found representative in telling the actual destinations of the freight vehicles therefore the results of the secondary data were taken to the empirical analysis made on section 3.1.5. The data from the primary data collection were used as a supporting data.

B. Determining average number of stop and go scenarios to the different destinations (III)

One of the most important input parameters to the empirical model (Eq. 1) is the number of stops made due to congestion and red light stopping from the entry point (the gate of Kality) to the destinations of freight in the city of Addis Ababa. Data collection for this section was based on the result of the analysis made on part A of this section. In part A of this section the data collection and the analysis methods for the determination

of the freight destinations were discussed. Here, the freight destinations obtained from part A were used to quantify the idle times experienced through each routes.

i. Data Collection

The location Akaki was chosen as an entry point splitting to the different destinations of the city. A data collection was assigned to count and record the idling times i.e. the number of stops and the time spent during each stop, while going to each of the destinations. To measure the average number of stops to each of the destinations, representative routes were chosen based on driver preferences and rough observations. Data collection time was set on peak traffic hours that is from 8:00 -10:00 a.m. in the morning and 4:00 – 6:00 p.m. in the afternoon.

For the first destination i.e. Kality D₁, since all drives necessarily had to pass through Kality, six idle stop measurements were made. For the next three destination routes i.e. D₂, D₃ , D₄ , idle time measurements were made two times, on the two peak hour collection times i.e. in the morning and in the afternoon. For the fifth destination i.e. Merkato D₅ two idle stop measurements were made for each of the routes chosen which totals to four, for all routes to Merkato.

The data collection format is presented on Appendix B. The contents of the data collected were:

- Numbers of stops on that route
- The times at which the vehicle reached and left each stop
- Locations at which stops are made (Name and Type: Four legged junction, Round about etc...)
- The reasons for which the vehicles stopped (congestion, red light stopping or other).

The selected routes with their respective Kilometer lengths are summarized on Table 4

Table 4: Routes Selected to the main freight destinations

Notation	Destination	Route	Total Length of Route
D ₁ (R _{AR})	Kality	Routes 1-4	7.7
D ₂ (R ₁)	Megenagna	Akaki-Kality--Saris-Rwanda Michael - Bole-Imperial Hotel-Megenagna	20.2
D ₃ (R _{1E})	CMC	Akaki-Kality-Bole-Imperial–Megenagna-Salite Mihret-CMC	25.1
D ₄ (R ₂)	Kera	Akaki –Kality--Saris-Adey Ababa- Kadisco - Gotera –Kera	15.3
D ₅ (R _{2E})	Merkato	Akaki-Kality--Saris-Gotera- Kera- Lideta-Merkato	20.5
D ₅ (R ₃)		Akaki-Kality -Saris-Stadium-Black Lion Hospital- Teklehaymanot – Merkato	20.9

ii. Descriptive Data Analysis

Descriptive data analyses were made to:

- compare average number of stops made on each of the freight routes.
- compare average time spent on idling for each route
- assess idling time per hour spent on each of the routes
- assess the share of idling from the total travel time
- assess the difference between the ideal travel time spent on each route and the actual travel time it took, from the measurements made.
- compare cruise idling and stop idling.

In this research paper, stop idling is to represent the condition of vehicles at zero kilometer per hour with the engine on and cruise idling represents the condition of vehicles with a speed of 20-30 Km/hr.

iii. Data Analysis for the input of the empirical model

The recorded number of stops for each route were averaged to give average number of stops made by vehicles towards reaching their freight destinations using the different selected routes which was later used in the Empirical model (Eq. 1)

3.1.4 Field data collection for determining smoke emissions (IV)

In this section data collection methods for the measurements of smoke opacity values are presented and the determination of average smoke density (meter^{-1}) from smoke opacities (%) measured, is discussed in the analysis section, which is later used by the empirical model (Eq. 1)

i. Data Collection

Both primary and secondary methods of data collection were used to obtain a data of opacity measurement results. The primary data collection was through the actual execution of opacity measurements at site using the opacity meter in a test procedure (Snap Acceleration Test Procedure), as discussed in section 3.1.1. And the secondary data was obtained from the Addis Ababa Environmental Protection Authority (AAEPA) which was executed by Engineer Derebew with the same test procedure.

The data from both were combined and analyzed to give results and final conclusions.

To execute measurements at site, a team was formed;

- A mechanic who also served as a driver from the Addis Ababa Environmental Protection Authority (AAEPA).
- Equipment handler from the Addis Ababa Environmental Protection Authority (AAEPA).
- An officer from Road Transport Authority to rightfully stop vehicles. Finding an available fleet of freight vehicles would have been very difficult and time consuming task.
- Data recorder.

An appropriate site was also selected at Kality, where it was convenient to stop freight vehicles without creating congestion and the site was prepared for test execution.

Measurement Set-up

- Traffic cones were put at the side of the road so that vehicles could be directed easily to the measurement site. The officer from the RTA wore a highlighted green uniform so that drivers could be stopped rightfully. Vehicles were randomly selected and were stopped by the officer from RTA.
- Drivers were briefed about the aim of measurement by the Mechanic (*Driver Familiarization and Vehicle Preconditioning*).

Execution of the Snap-Acceleration Test

The five phases discussed in section 3.1.1. were followed for the field data collection of this research paper.



Figure 8: Pre clearing of the tailpipe before measurement (left) and opacity meter plugged on tailpipe (right)

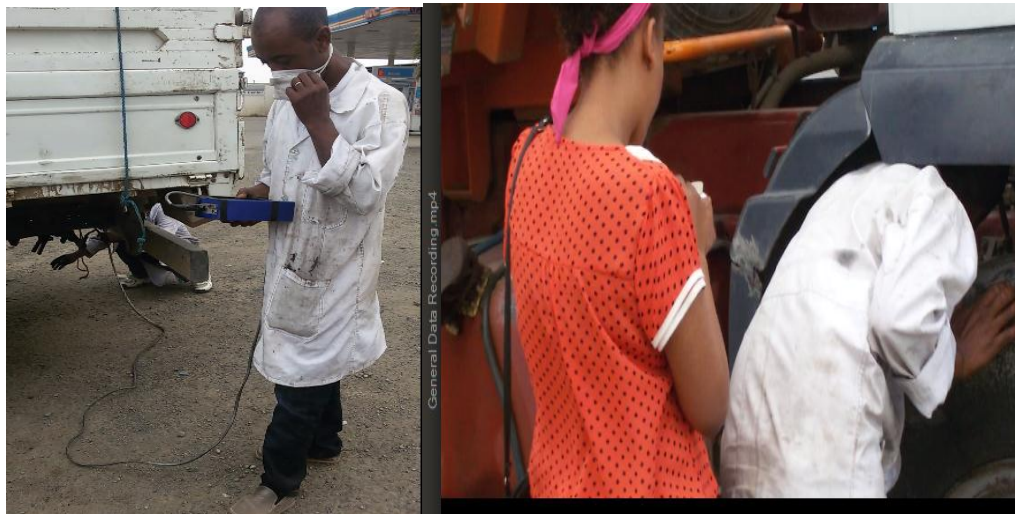


Figure 9: Opacity reading (left) and data recording (right)

While the snap acceleration test was being executed, the data recorder recorded the following data from the vehicles.

- Vehicles Model Year
- Vehicle Make
- Carrying Capacity
- Vehicle Model Name
- Vehicle License
- Odometer Reading

Data measurements for a total of 85 opacity measurement data were taken for further analysis. Appendix C shows the data collected with the above inputs and opacity results.

ii. Data analysis for the input of the Empirical model

From the measurement executed, opacity results were obtained. As stated in the objectives of this research paper. The measured data of opacities were not directly used as raw data but were first converted to transmittance (Eq. 2) and then to smoke density by a relationship called Beer Lambert relationship.



Figure 10: Data Processing

Opacity is converted to Transmittance by:

$$\text{Transmittance (\%)} = 100\% - \text{Opacity (\%)} \quad \text{Eq. 2}$$

After the transmittance of each of the opacity values were calculated; the Beer-Lambert law was used to calculate smoke density from Transmittance.

The Beer-Lambert Law is the relationship between Transmittance, Smoke Density, and Effective Optical Path Length as shown in Eq. 3 (Society of Automotive Engineers, 1996)

$$T = e^{-kL} \quad \text{Eq. 3}$$

Where:

T = Transmittance

K = Smoke density (meter⁻¹)

L = Effective optical length (EOPL)

iii. Descriptive Data Analysis

Descriptive analyses were made on the relationship between the data recorded (model year, vehicles' carrying capacity) with the opacity value measurements and also for the determined smoke density values and each of the vehicle parameters recorded. The vehicle parameters were grouped in ranges so that emission patterns are seen according to each group and each of the parameters are presented in Table 5.

Age Group

Table 5: Group for Model Year of vehicles tested

Group No.	Model year group
1	1959-1991
2	1991-2000
3	2000-2010
4	2010-2014

Descriptive statistical analysis is made to get statistical measures of central tendency, moments of statistical distribution and measures of dispersion, for the measured opacity and the calculated smoke density values classified by model year (age) groups as in Table 5.

As vehicles' age highly impacts the exhaust emissions from vehicles, a correlation coefficient was also determined for the relation between the vehicles age (model year group) & smoke density and vehicles age (model year group) & opacity is calculated. Best fit regression lines were fitted for the relations between the vehicles age (model year group) & smoke density and vehicles age (model year group) & opacity values.

Carrying Capacity

Vehicles were also classified with their carrying capacities which are presented on Table 6

Table 6: Group for carrying capacity of vehicles tested

Group No.	Carrying capacity ton group
1	1.5-3.5
2	3.6-7
3	7-12
4	12-20
5	20-30
6	>30

3.1.5 Empirical Analysis

As discussed on the above sections, the overall analysis was based on the empirical model (Eq. 1). All the results from Section 3.1.1. -3.1.3. were used as an input to this equation and average smoke density (meter⁻¹) per route, per day on idling were determined.

Assumptions

It was assumed that:

- Vehicles considered in this research have idled on all of their stops made during congestion and red light stopping, instead of turning off their engines, if the idling is not for more than five minutes. This assumption was made based on the observation made and from the usual trends of vehicles in the city.
- There was no difference in the time taken for accelerating the vehicle when the three consecutive measurements of opacity were made for a vehicle.
- Gas temperature, pressure, humidity and altitude, as required in the SAE J1667 standard were not needed.

- During the test, dilution of the exhaust gases with clean air might have occurred which could have lower smoke readings but no corrections were made for that.

4 RESULTS AND DISCUSSIONS

4.1. Opacity values, smoke densities and different vehicle parameters

i. Opacity, smoke density and age group (model year group)

Average values of opacity values (%) and smoke densities (meter⁻¹) were calculated for each of the vehicle model year group. The results are presented on Table 7 and Figure 11. Results from descriptive statistical analysis i.e. statistical measures of central tendency (mean, mode and median) and moments of statistical distribution (standard deviation) for the measured opacity and the calculated smoke density values classified by model year (age groups) are presented on Appendix D.

Table 7: Average values opacities (%) and smoke density (meter⁻¹) of the measured data

Group No.	Model Year Group	Average Opacity Value (%)	Average -smoke Density(Per meter)	Smoke density (per meter) standard in Euro (EU VI)	Smoke Opacity(%) Standard of The US EPA
1	1959-1991	80%	22,48	0,5	55%
2	1991-2000	73%	13,99		
3	2000-2010	21%	2,41		40%
4	2010-2014	8%	0,84		

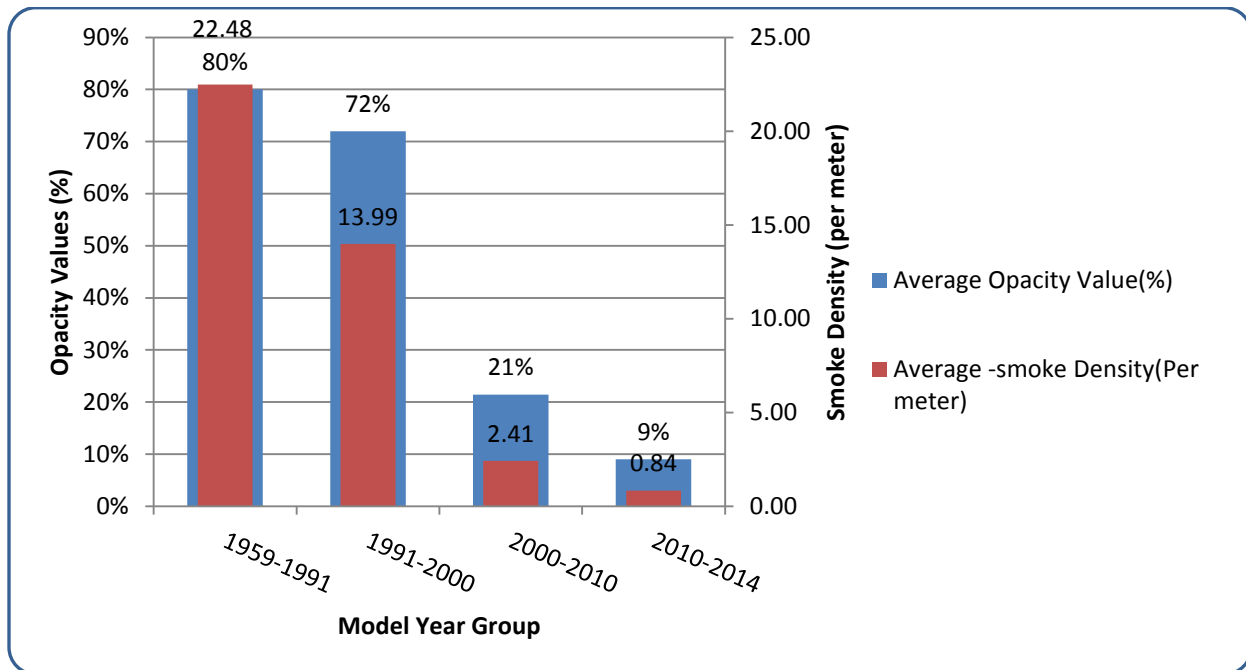


Figure 11: Model Year of Vehicles and Smoke Opacity (%) (Left Vertical Axis) and Model Year of Vehicles and Smoke density (per meter) (Right Vertical Axis).

The results of average smoke opacity values are higher for vehicles of, model year group 1959-1991 and 1991-2000 i.e. 80% and 73% with 95 % confidence intervals of 62%-98% and 60%-86% respectively as compared to the US EPA standards for pre-1991 vehicles of model year group i.e. 50%.

The result supports the hypothesis that older diesel vehicles in Addis Ababa emit high levels of smoke mainly due to excessive wear & damage of engine parts and also due to antiquated or malfunctioning pollution controls. The results obtained from the analysis in this research paper is higher than the average opacity values of the pre 1991 vehicles tested by Robert L. McCormick et al. (2003) which are 54%.

On the other hand, the average opacity values of the model years 2000-2010 and 2010-2014 are low 21% and 8% with 95 % confidence interval of 12%-31 % and 4%-14%

respectively which are low and also support the hypothesis that older diesel vehicles in Addis Ababa emit high levels of smoke.

Also, smoke densities (meter⁻¹) of vehicles of model year group 1959-1991 resulted in an average value of 22.48 meter⁻¹ with a 95 % confidence interval of 14.29-30.67 ,model year group 1991-2000 resulted in an average value of 13.98 with a 95 % confidence interval of 9.7-18.26, the model year group 2000-2010 resulted in an average value of 2.41 with a 95 % confidence interval of 1.09-3.73 and the model year group 2010-2014 resulted in average value of 0.84 with a 95% confidence interval of 0.32-1.35.

The model year groups of 1959-1991 and 1991-2000 resulted in a very high smoke density values as compared to the standards of the Euro EU (VI) i.e. 0.5 meter⁻¹ .

ii. Opacity, smoke density and carrying capacity

Opacity and smoke density values were categorized with their carrying capacity group as shown on Table 8. Results of average opacity values (%) and smoke densities (meter⁻¹) are presented for the carrying capacity group. The results are presented on Table 8 and Figure 12 .

Table 8 : Carrying capacity, smoke opacity and smoke density

Group No.	Carrying-Capacity Ton Group	Average-Opacity Value (%)	Average-smoke-Density(meter ⁻¹)
1	1.5-3.5	63	12.43
2	3.5-12	24	3.51
4	12-20	21	2.01
5	20-30	39	7.29
6	>30	39	11.58

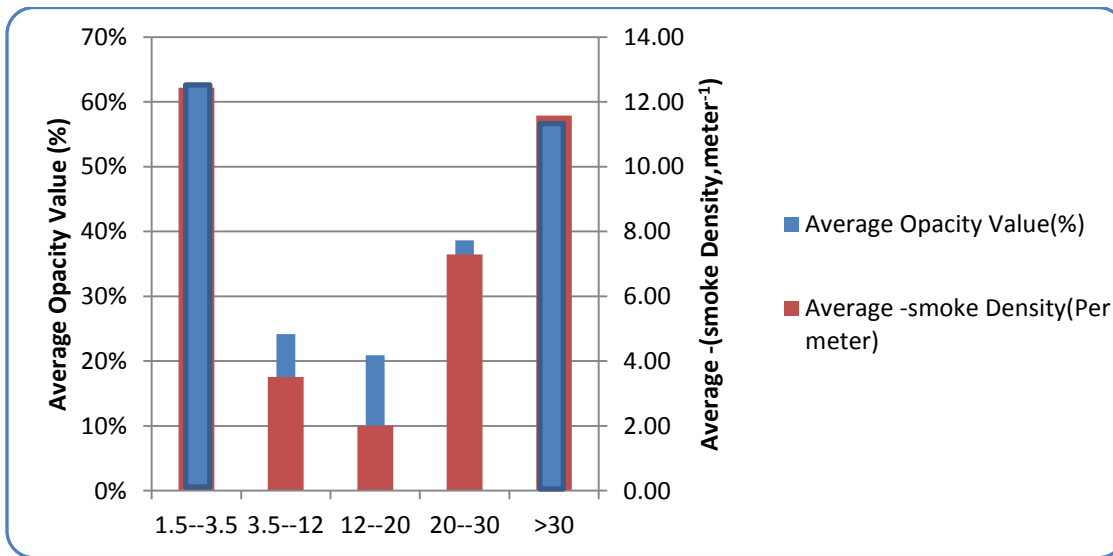


Figure 12: Opacity values vs. smoke densities vs. carrying capacity group

The estimated smoke opacities of the ton groups 1.5-3.5 ton are found to especially emit i.e. 63 %. But all values of smoke densities for all of the ton groups are found higher than the standards of the European Union- EU VI.

There is no correlational pattern found between loading capacities of vehicles and smoke densities or smoke opacities.

4.2. Regression analysis

A high negative coefficient of correlation of -0.8 between vehicles' model year and smoke density (smoke opacity) was obtained; the negative sign indicating that, the relation between vehicles' age (model year) and the smoke opacity are inversely related. The same was obtained for smoke density (meter⁻¹) with vehicles' age with a correlation coefficient of -0.75 with the same indication as the smoke opacity (%); the negative sign indicating the apparent relation between vehicles' age (model year) and smoke density (meter⁻¹) being an inverse one.

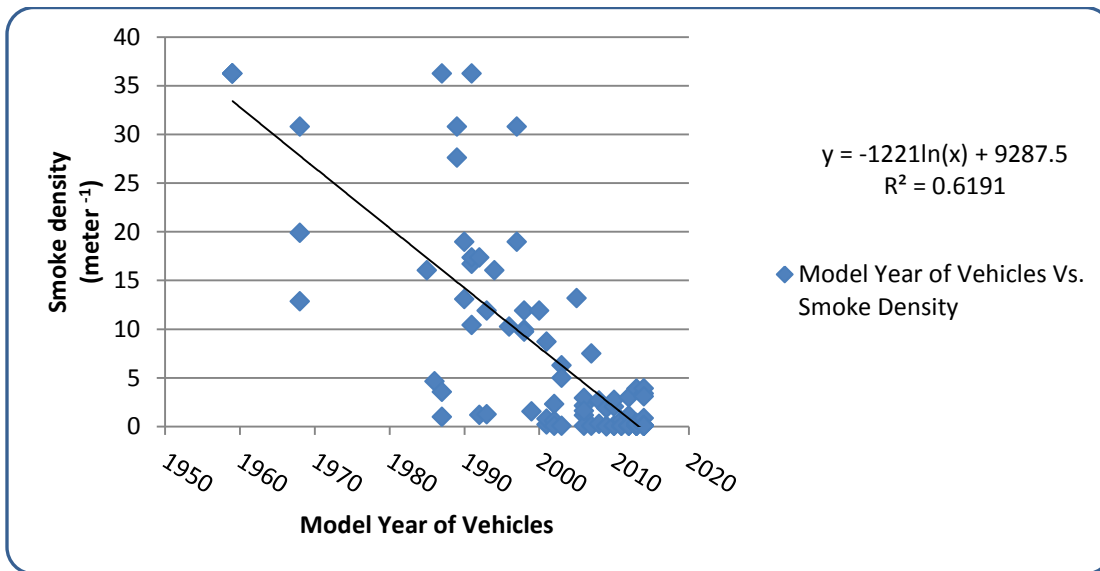


Figure 14: Model year of vehicles vs. smoke density (logarithmic relation)

The coefficient of determination obtained by fitting the relation between smoke densities and model year of vehicles are the same i.e. 0.62.

The obtained coefficient of determination actually shows a good correlation between vehicles' age and emitted smoke but it is not as high as it is expected to be as vehicles' age is expected to be one of the most influencing factors for emission since engines of old aged vehicles are not efficient enough to burn the fuel completely. It was tried to investigate the reasons for the lower coefficient of determination than the expected, and the probable reasons could be the existence of some outlying values of smoke opacity measurements. The outlying values could have resulted from the fact that smoke emissions could not solely be the results of excessive wear of engine emission control systems (DPF) even though a vehicle might be new.

Therefore, the coefficient of determination (R squared) values could be judged as a good fit for both linear and logarithmic relations.

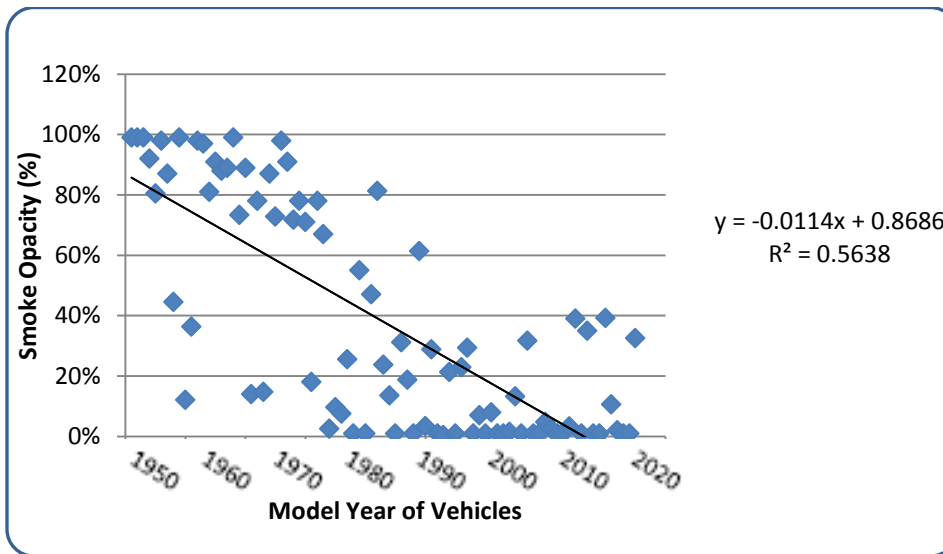


Figure 15: Model year of vehicles vs. opacity (linear relation)

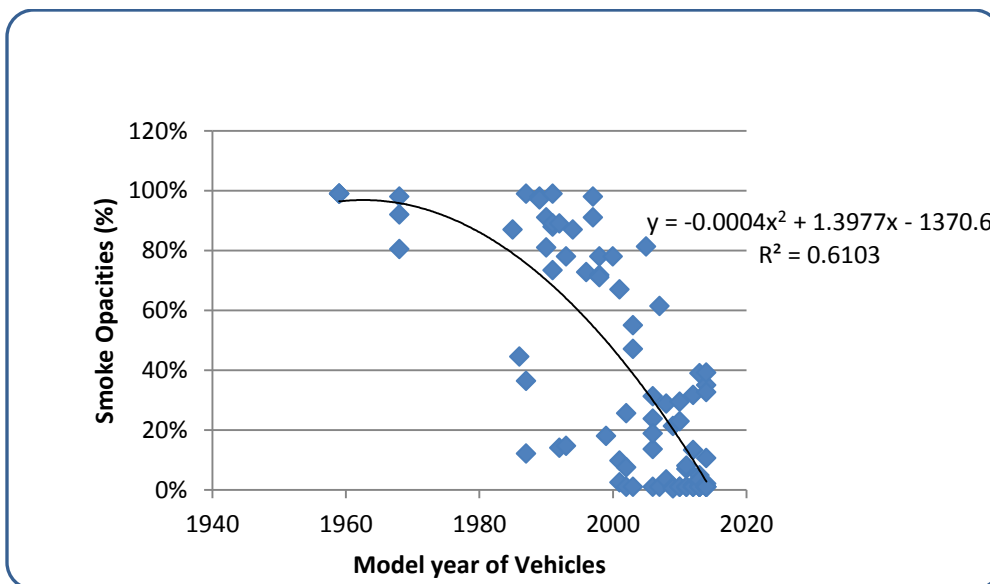


Figure 16: Model years of vehicles vs. opacities (second order polynomial relation)

The coefficient of determination obtained by fitting the relation between smoke opacities and model year of vehicles is found to be i.e. 0.56 for linear relation and 0.61 for second order polynomial relations as shown on Figure 15 and Figure 16. These values are slightly lower than the coefficient of determination obtained for the relation between

smoke densities and vehicles' age. This value also shows that both fits are not highly perfect from the expectation of the relations between vehicles' age and emissions in general but considering the same fact as for the relation of smoke densities and vehicle age, the R squared value for the relation of smoke opacities and model years could be judged as a good fit for both linear and second order polynomial relations.

The results from both correlations show the clear increase of emission of smoke with decrease in vehicles' age indicating that older freight vehicles in the city of Addis Ababa are emitting more smoke. The correlation also supports the hypothesis that as diesel freight vehicles are aged their potential of smoke emission is increased and the freight vehicles in the city of Addis Ababa.

4.3. Descriptive results on idling

Tables 10 -14 present the results of the measurements on idling and also calculated parameters of idling obtained from the measured parameters for the routes towards each of the chosen freight destinations.

On the tables, stop idling means that the vehicle has stopped without movement while the engine of the vehicle is on. While cruise idling means the vehicle is idling at slow movement at vehicles speed of 20-30 Km /hr. The ideal travel time is the time it ideally takes for a vehicle to reach to its destination had it travelled in a 'no idling' situation with an average speed of 50 Km/hr, the only stop being only due to red light traffic stop.

Two types of idling are calculated for ease of reference and discussing results; measured time at idling and un-measured time at Idling. Measured time at idling is the idling time actually measured at site while the un-measured time at idling is the time obtained by subtracting ideal travel time and measured idle time from the total travel time. The unmeasured idle time could be the idle time that is due to miscellaneous reasons but when totaled, has a significant share for idling time. The miscellaneous times could be the drivers' behavior of driving, pedestrian crossing, the quality of road affecting the speed of the vehicle etc... Total travel time at idling is therefore the sum of the measured and unmeasured times of idling.

4.3.1. Idling on the route to Kality

To reach to the freight destination at Kality three routes R₁, R₂ and R₃ were used and idling times were measured and calculated averaging the morning and afternoon peak hour results from these three routes.

Table 9: Field data measurement on idling from Akaki- Kality (D₁) through the routes R₁, R₂ and R₃

Average length of the Route=7.7 Km					
Average of morning and afternoon results					
A	No. of stop idling	3	F	Measured time at idling due to congestion (Min)	3
B	No. of cruise idling	1	G	Idling due to red light stop at traffic lights or by traffic polices(Min)	1
C	Total number of stops (no of idling times)(A+B)	4	H	Ideal total travel time(Min)	10
D	Percentage of stop idling from total Idling ,%	75%	I	Actual total travel time(Min)	22
E	Percentage of cruise Idling from total Idling (A/C), %	25%	J	Unmeasured time at Idling (Min) (I-H-F-G)	8
-	-	-	K	Total time at idling(F+I)	11
-	-	-	L	Percentage of idling from actual travel time (J/H),%	50%
			M	Idling per hour(min/hr)	11

From the total idling times measured it was found that 75% of the idling occurred as stop idling in which the test-vehicle stopped three times on average on the routes and 25% of the idling occurred as cruising in which the test-vehicle cruised and accelerated one time, in which the vehicle stopped for a total of four times. From the results it can be deduced that along the route to Kality, vehicles tend to completely stop and accelerate to start movement on most of their travel time. Figure 17 shows the estimated shares of

cruise and stop idling from the total idling time. The fact that the vehicles stop more than they cruise is an indication of the unnecessary fuel consumption during the idling situations at the stop and go scenarios. During each idling, fuel is unnecessarily consumed and smoke is released from the tailpipes, per each of the idle stop or cruise, to the environment.

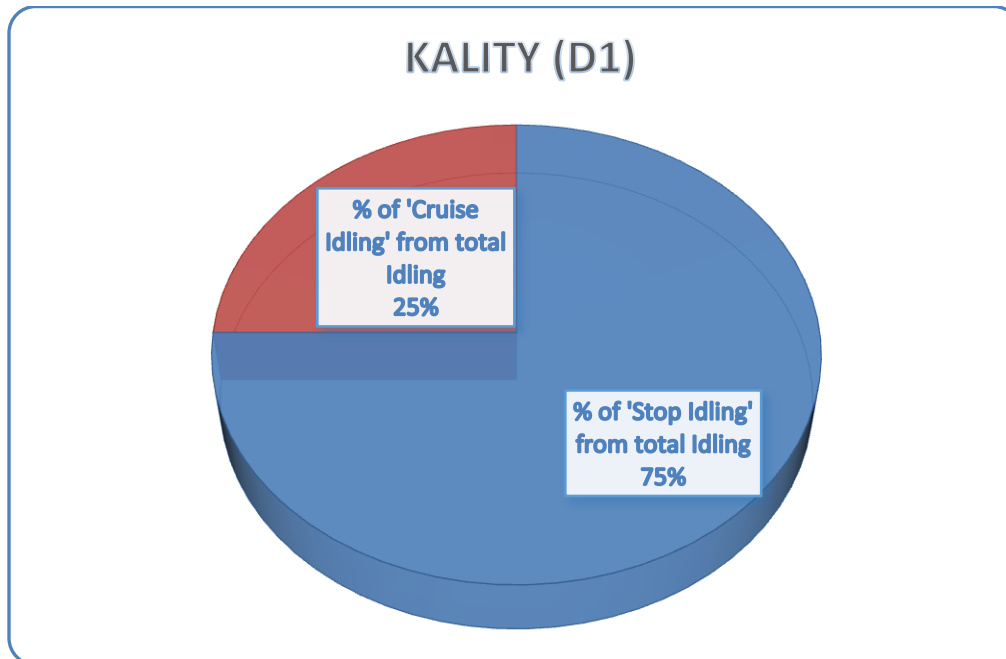


Figure 17 : Estimated percentage shares of cruise idling and stop idling from the total idling time for reaching the freight destination at Kality, %

The ideal travel time as discussed in section 4.3 is the time it ideally takes for a vehicle to reach to its destination had it travelled in a 'no idling' situation with an average speed of 50 Km/hr ,the only stop made being only due to traffic light. The estimated gap between the ideal and the actual travel times found on this route is found to be very large.

Figure 18 presents the comparison between the ideal travel time it should have taken and the actual time it took from Akaki to Kality.

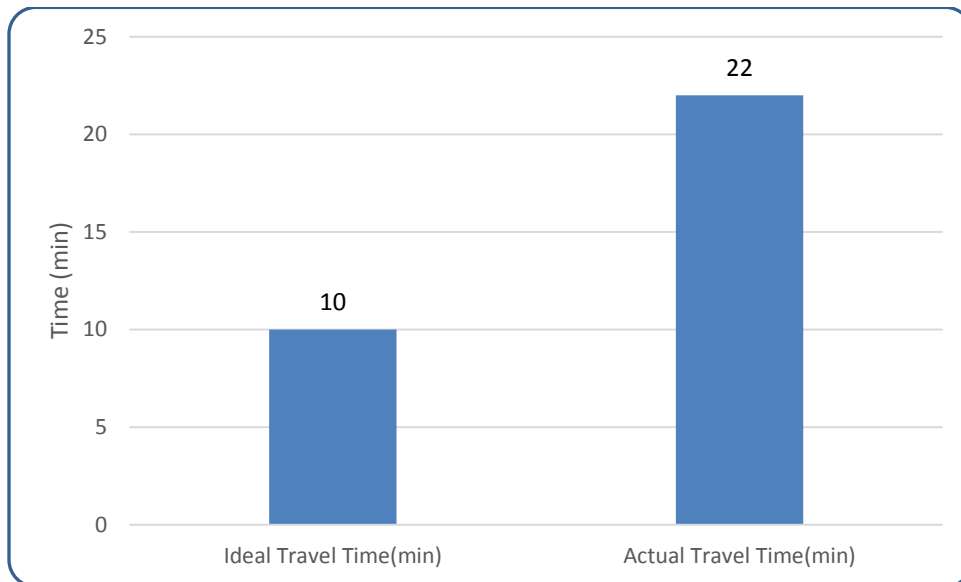


Figure 18: Ideal time versus average actual travel time (Akaki -Kality)

From Figure 18 it can be seen that the actual travel time measured at site is more than double the ideal time which shows that there is a high level of congestion from Akaki to Kality.

From the total travel time i.e. the measured and un-measured idling times to reach this destination, the test-vehicle idled 50% of the time which is half the time it actually traveled which indicates that there is a high level of idling on the route. The results are shown on Figure 19.

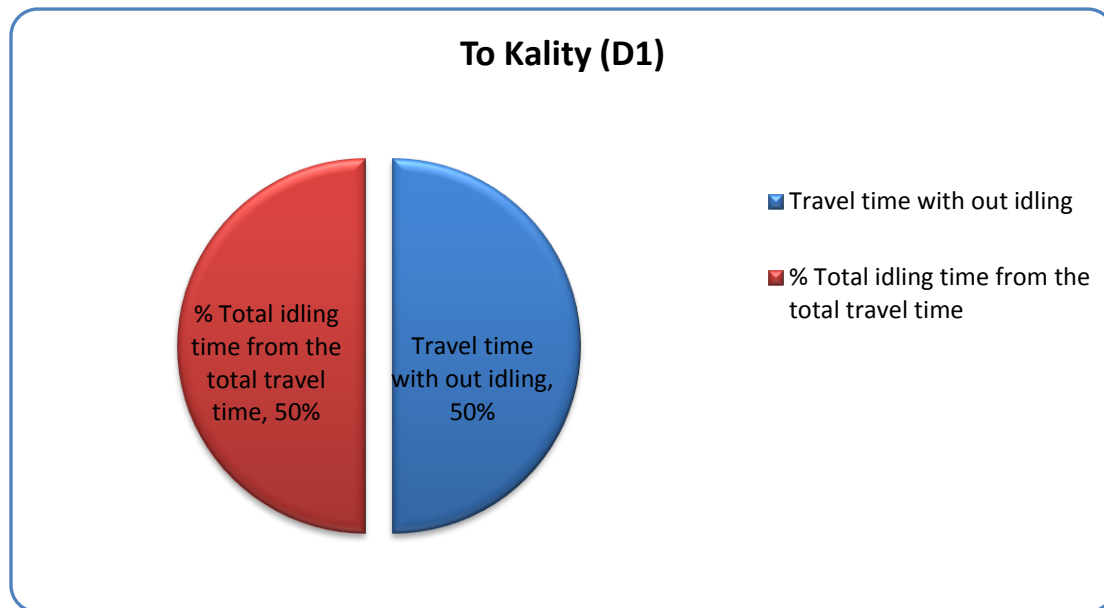


Figure 19: Estimated percentage shares of idling time and travel time without idling from the total travel time (Akaki-Kality), %

4.3.2. Idling on the route to Megenagna

The route used for the measurement of idling for reaching the freight destination Megenagna was R₁ (Akaki-Kality-Saris-Rwanda-Michael-Bole-Imperial hotel-Megenagna). Table 10 presents the measured and calculated parameters of the results of idling for this destination.

Table 10: Field data measurement on idling-towards Megenagna (D₂) through the route R₁

Average length of the Route=24.5 Km					
Average of morning and afternoon results					
A	No. of stop idling	7	F	Measured time at idling (Min)	27
B	No. of cruise idling	4	G	Idling due to red light stop at traffic lights or by traffic polices(Min)	1
C	Total number of stops (no of idling times)(A+B)	11	H	Ideal total travel time	29
D	Percentage of stop idling from total Idling ,%	64%	I	Actual total travel time(Min)	55
E	Percentage of cruise Idling from total Idling (A/C), %	36%	J	Unmeasured time at Idling (Min) (I-H-F-G)	0
-	-	-	K	Total time at idling(F+I)	28
-	-	-	L	Percentage of idling from actual travel time (J/H),%	50%
			M	Idling per hour(min/hr)	28

From the total idling times measured along the route to Megenagna, it was found that the test-vehicle stopped eleven times in which 64% (average number of stops=7) of the idling occurred as stop idling and 36% (average number of cruising =4) of the idling occurred as cruise idling. The number of stops to Megenagna is found also significantly high.

Figure 20 shows the estimated percentage shares of cruise idling and stop idling from the total idling time for reaching the freight destination at Megenagna.

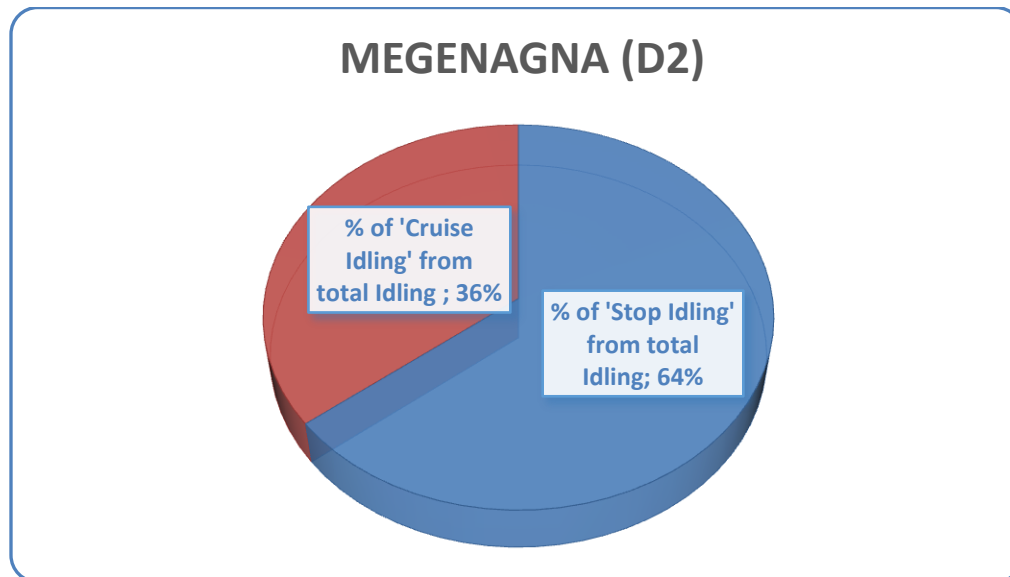


Figure 20: Estimated percentage shares of cruise idling and stop idling from the total idling time (Akaki-Kality), %

The road to Megenagna is a very congested road. The severe condition of congestion on the route to Megenagna is reflected on the results. The average travel time it took for the test vehicle to reach to this destination is double the time it must have taken, had everything been ideal and the vehicle traveled with no idling except at traffic lights, from Akaki to Megenagna.

Figure 21 presents the actual travel time it took for the test vehicles compared with the ideal travel time it must have taken for the test vehicle to reach from Akaki to Megenagna.

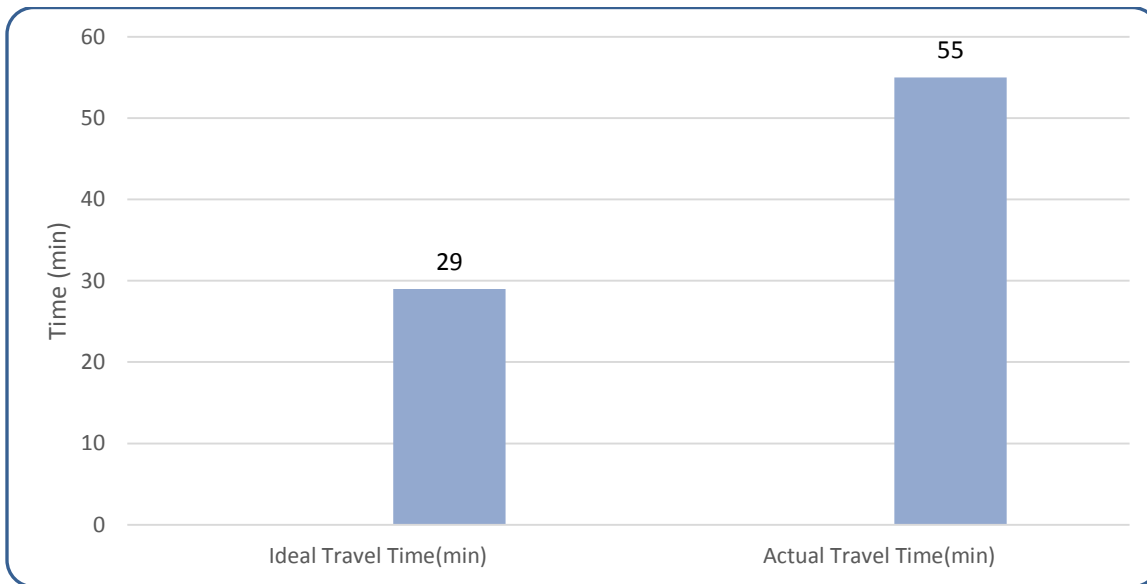


Figure 21: Ideal time versus average actual travel time (Akaki -Megenagna)

From the total travel time to reach this destination the test vehicle idled 50% of the time which is half of the time it actually traveled which indicates that there is a high level of idling on this route (shown on Figure 22).

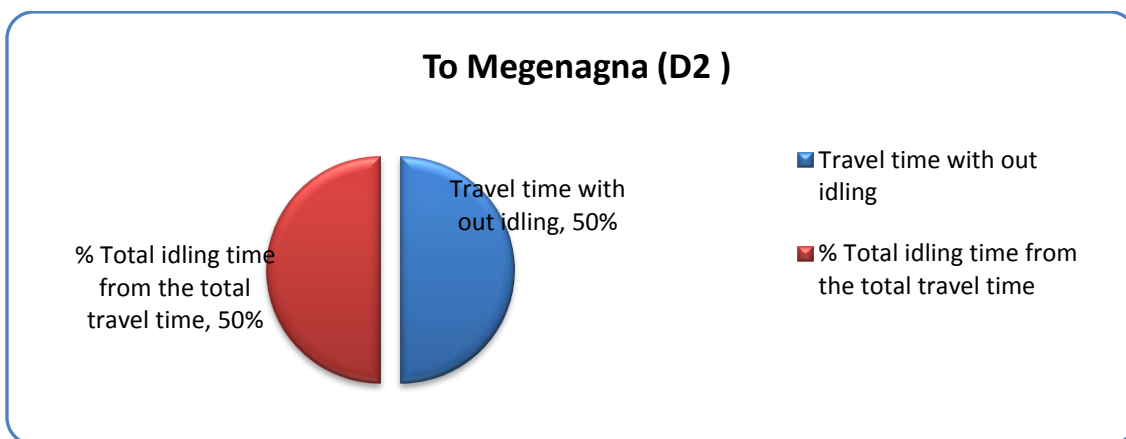


Figure 22: Estimated percentage shares of idling time and travel time without idling from the total travel time (Akaki-Megenagna)

4.3.3. Idling on the route to CMC

The route used for the measurement of idling for reaching the freight destination CMC was R_{1E} (Akaki-Kality-Saris-Rwanda Michael-Bole-Imperial Hotel-Megenagna-CMC).

Table 11 presents the measured and calculated parameters of the results of idling for this destination.

Table 11: Field data measurement on idling-Akaki-CMC (D₃) through the routes R_{1E}

Average length of the Route=25.1 Km					
Average of morning and afternoon Results					
A	No. of stop idling	10	F	Measured time at idling (Min)	26.5
B	No. of cruise idling	8	G	Idling due to traffic light or traffic police	1.0
C	Total number of stops (no of idling times)(A+B)	18	H	Ideal total travel time	30.0
D	Percentage of stop idling from total Idling ,%	55%	I	Actual total travel time(Min)	69
E	Percentage of cruise Idling from total Idling (A/C), %	45%	J	Unmeasured time at Idling (Min) (I-H-F-G)	15
-	-	-	K	Total time at idling(F+I)	42.5
-	-	-	L	Percentage of idling from actual travel time (J/H),%	62%
			M	Idling per hour(min/hr)	23

From the total idling times measured along the route to CMC, it was found that the test-vehicle stopped eighteen times in which 55% (Average number of stops=10) of the idling occurred as stop idling and 45% (Average number of cruising =8) of the idling

occurred as cruise idling with a total number of stops of 18. The test vehicle cruised and stopped almost for equal number of times from the total idle times which shows that vehicles experience a long line of congestion along the route in which they face both types of idling.

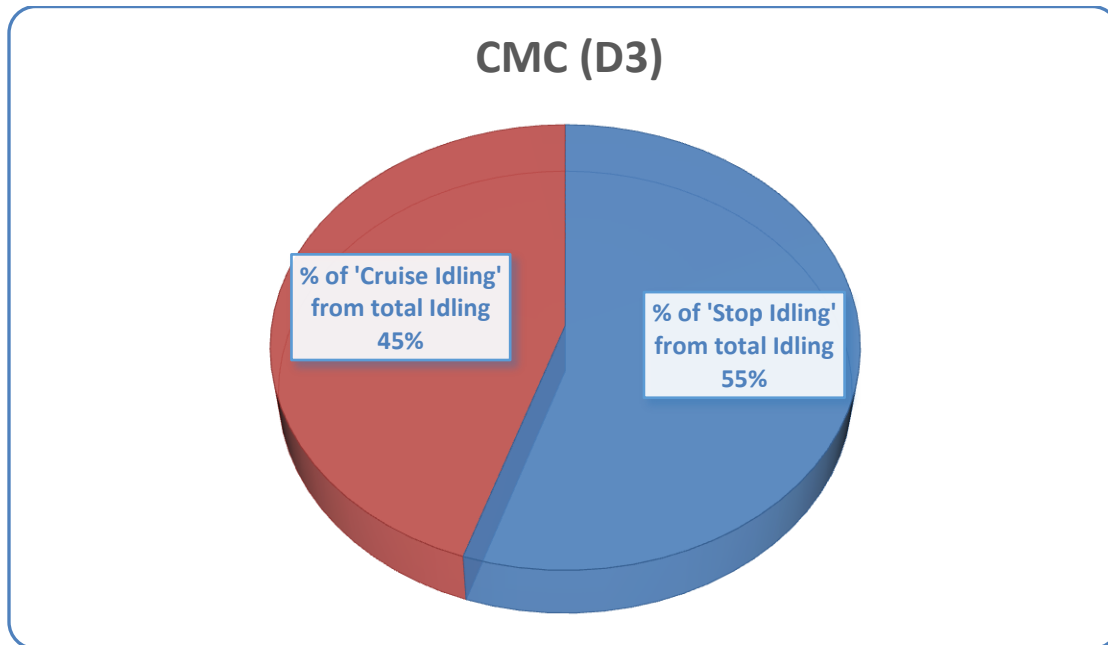


Figure 23: Estimated percentage shares of cruise idling and stop idling from the total idling time for reaching the freight destination at CMC

Since the route traveled by the test vehicle to Megenagna was extended to CMC, the result obtained for the comparison of the ideal travel time and the actual travel time to CMC signified the severity of the congestion from Megenagna to CMC. From the comparison of the ideal to actual travel time towards Megenagna it is found that the time difference is double but in the case towards CMC the relation got almost close to triple. This result could be a little puzzling as the route from Akaki to Megenagna is a more congested route than the route from Megenagna to CMC. The current road construction being undertaken at Megenagna and around its exits, is the main reason behind the observable high idling time from Megenagna to CMC than from Akaki to Megenagna.

It can be judged from previous trends of travel along that route that the road from Megenagna to CMC is not a congested route because of the adequate width of the road and also the less vehicle fleet towards CMC since CMC is a residential area currently going under development.

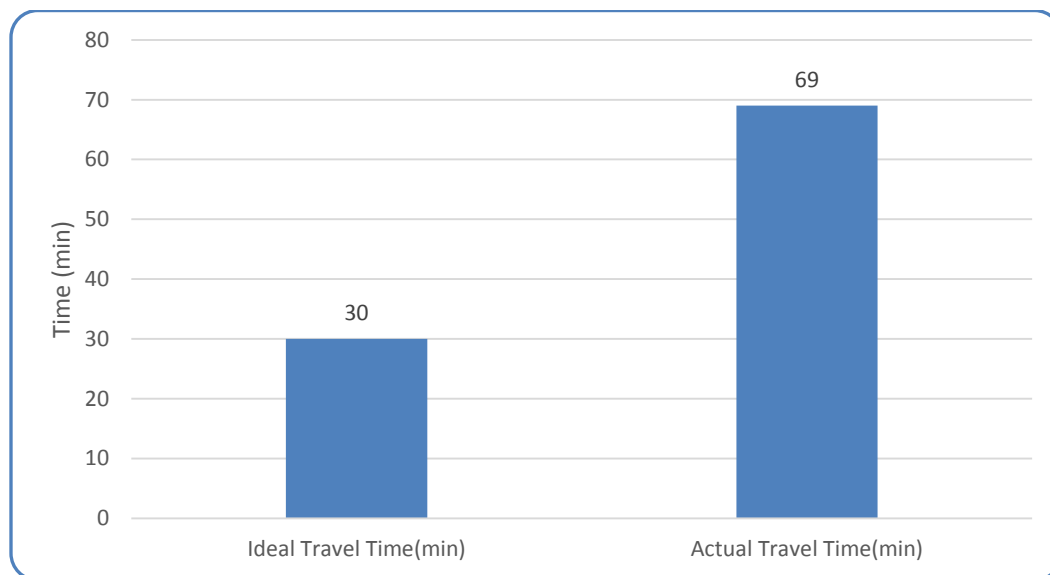


Figure 24: Ideal time versus average actual travel time (Akaki -CMC)

From the total travel time to reach this destination the test vehicle idled on average 62% of the time which is more than half of the time it actually traveled which indicates that there is a very high level of idling on this route.

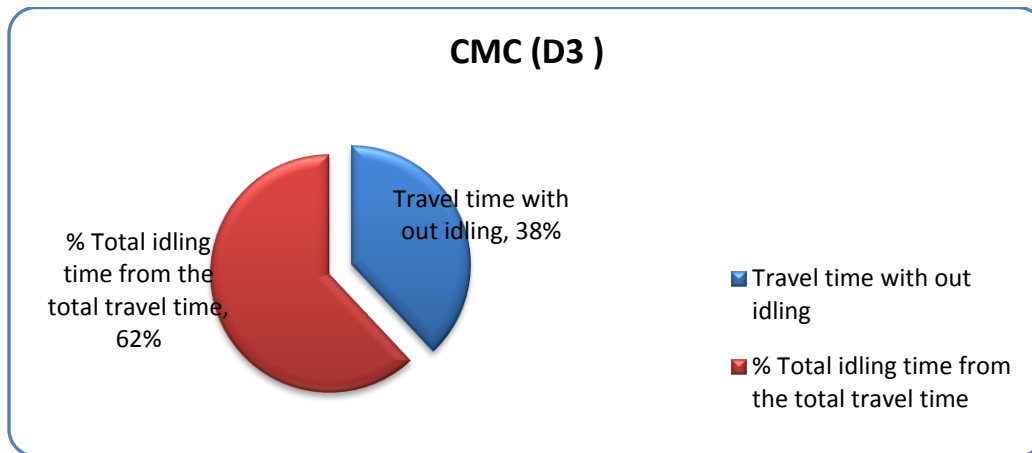


Figure 25: Estimated percentage shares of idling time and travel time without idling from the total travel time (Akaki- CMC)

4.3.4. Idling on the route to Kera

The route used for the measurement of idling for reaching the freight destination Kera is R₂ (Akaki-Kality--Saris-Gotera - Kera).

Table 12: Field data measurement on idling-toward Kera (D₄) through the routes R₂

Average length of the Route=15.3 Km					
Average of morning and afternoon results					
A	No. of stop idling	9	F	Measured time at idling (Min)	13.0
B	No. of cruise idling	1	G	Idling due to traffic light or traffic police	3.0
C	Total number of stops (no of idling times)(A+B)	10	H	Ideal total travel time	21.0
D	Percentage of stop idling from total Idling ,%	90%	I	Actual total travel time(Min)	38
E	Percentage of cruise Idling from total Idling (A/C), %	10%	J	Unmeasured time at Idling (Min) (I-H-F-G)	1
-	-	-	K	Total time at idling(F+I)	17
-	-	-	L	Percentage of idling from actual travel time (J/H),%	44%
			M	Idling per hour(min/hr)	19

From the total idling times measured along the route to Kera, the test-vehicle stopped ten times in which 92% (Average number of stops=9) of the idling occurred as stop idling and the test vehicle almost did not cruise with a total number of stops of 10.

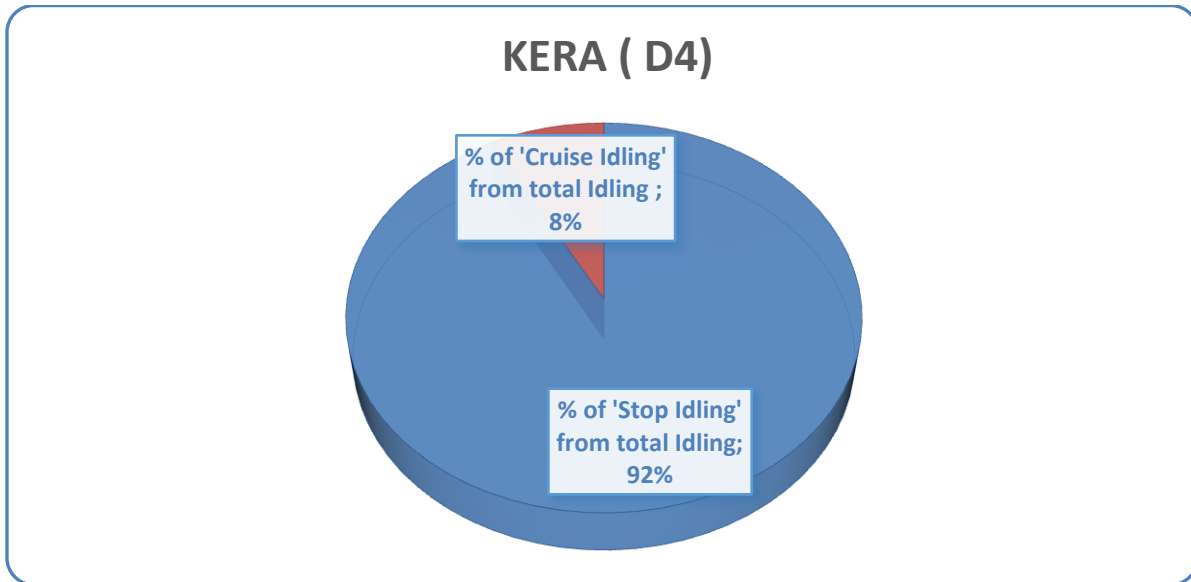


Figure 26: Estimated percentage shares of cruise idling and stop idling from the total idling time for reaching the freight destination at Kera

From the results, it can be observed that the time it actually took for the test vehicle to go from Akaki to Kera is almost double the time it must have taken in a no idling situation (except due to traffic lights) which, as the cases of the routes to Kality, Megenagna and CMC, shows the rough conditions of congestion on the route.

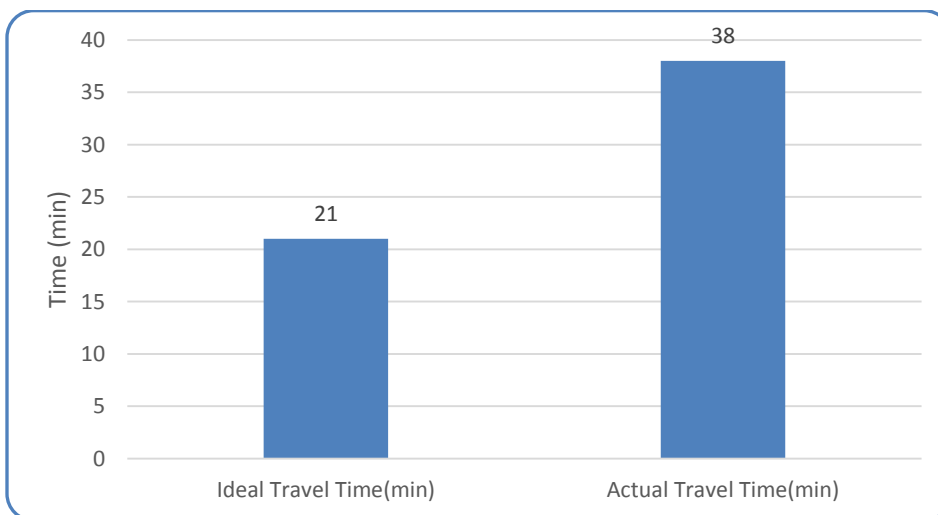


Figure 27: Ideal time versus average actual travel time (Akaki - Kera)

From the total travel time to reach this destination the test vehicle idled 44% of the time which is close to half of the time it actually traveled which can be actually considered as high level of idling on this route.

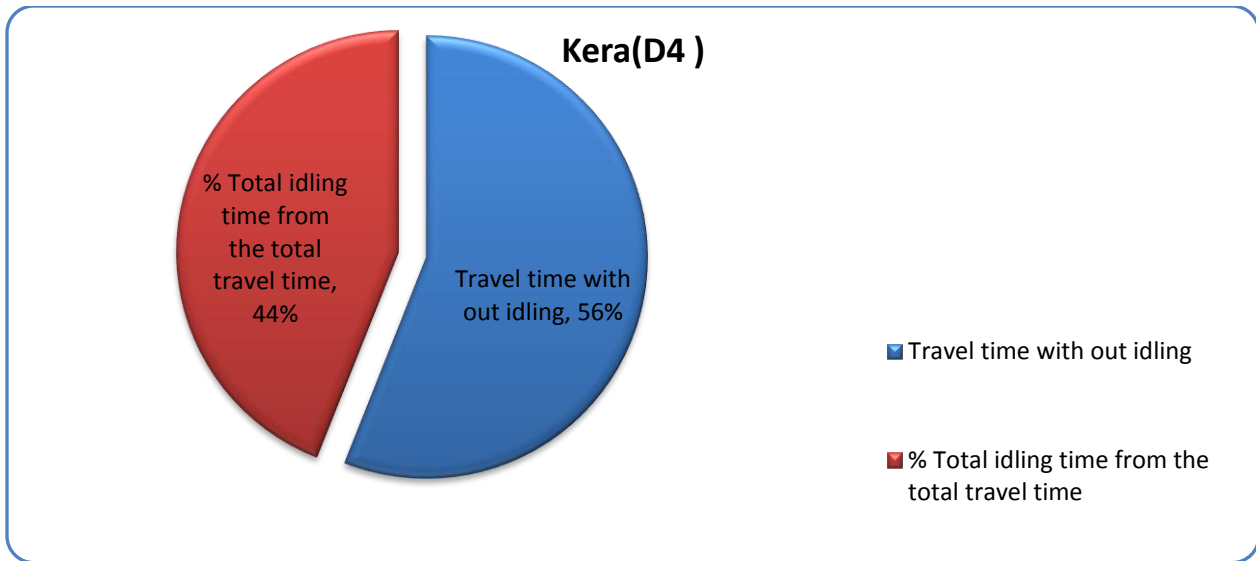


Figure 28: Estimated percentage shares of idling time and travel time without idling from the total travel time (Akaki- Kera)

4.3.5. Idling on the route to Merkato

Two routes are used for measuring idling times for reaching the freight destination at Merkato i.e. R_{2E} (Akaki-Kality-Saris-Gotera– Kera-Lideta-Merkato) and R_3 (Akaki-Kality-Saris- Stadium-Black Lion Hospital- Teklehaymanot – Merkato).

Table13 : Field data measurement on idling-towards Merkato (D₅) through the routes R_{2E} and R₃.

Average length of the Route=20.7 Km						
Average of morning and afternoon results						
A	No. of stop idling	13		F	Measured time at idling (Min)	26.5
B	No. of cruise idling	8		G	Idling due to traffic light or traffic police	11.0
C	Total number of stops (no of idling times)(A+B)	21		H	Ideal total travel time	36.0
D	Percentage of stop idling from total Idling ,%	62%		I	Actual total travel time(Min)	72
E	Percentage of cruise Idling from total Idling (A/C), %	38%		J	Unmeasured time at Idling (Min) (I-H-F-G)	0
-	-	-		K	Total time at idling(F+G+J)	38
-	-	-		L	Percentage of idling from actual travel time (J/H),%	52%
				M	Idling per hour(min/hr)	20

From the total idling times measured along the route to Merkato, the test-vehicle stopped twenty one times which is a very great number of stops to make in one travel. From the total number of stops, 62 % (average number of stops=13) of the idling occurred as stop idling and 38% (average number of cruising =8) of the idling occurred as cruise idling. On average, on this route the test-vehicle made one stop per kilometer.

The test vehicle cruised and stopped almost for equal number of times from the total idle times which shows that vehicles experienced a long line of congestion along the route in which they face both types of idling.

Figure 29 shows the estimated percentage shares of cruise Idling and stop Idling from the total idling time for reaching the freight destination at Kera.

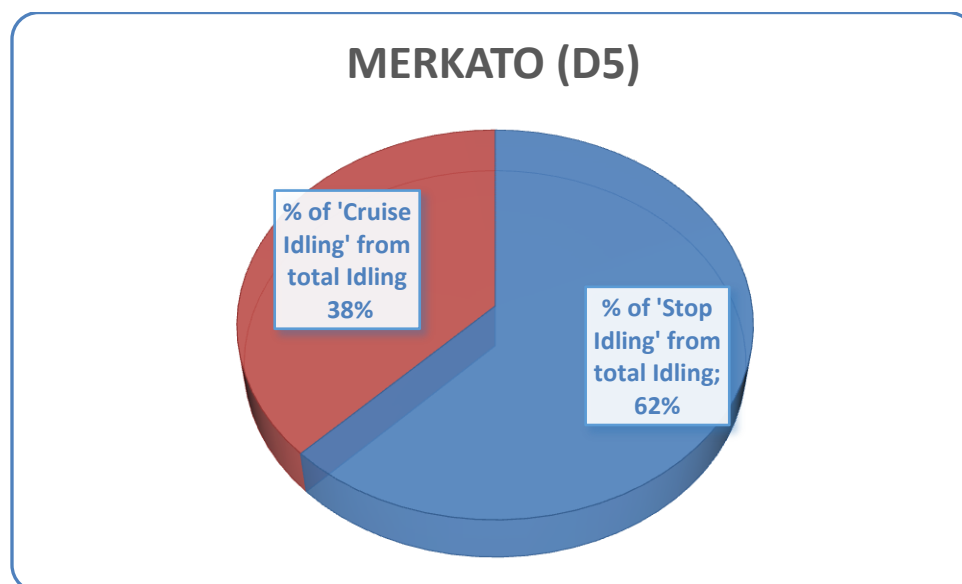


Figure 29: Estimated percentage shares of cruise idling and stop idling from the total idling time for reaching the freight destination at Kera

The routes to Merkato are observed to be the most congested roads as Merkato is the major market center in the city, there are different and numerous commuting freight vehicles towards and from it. The results from the comparison of the ideal and the actual travel times also confirms that the idling situation on the routes. From the results it was found that the actual travel time it took for the test vehicle to reach to Merkato was double the time it must have taken in a no idling (except due to traffic light) situation.

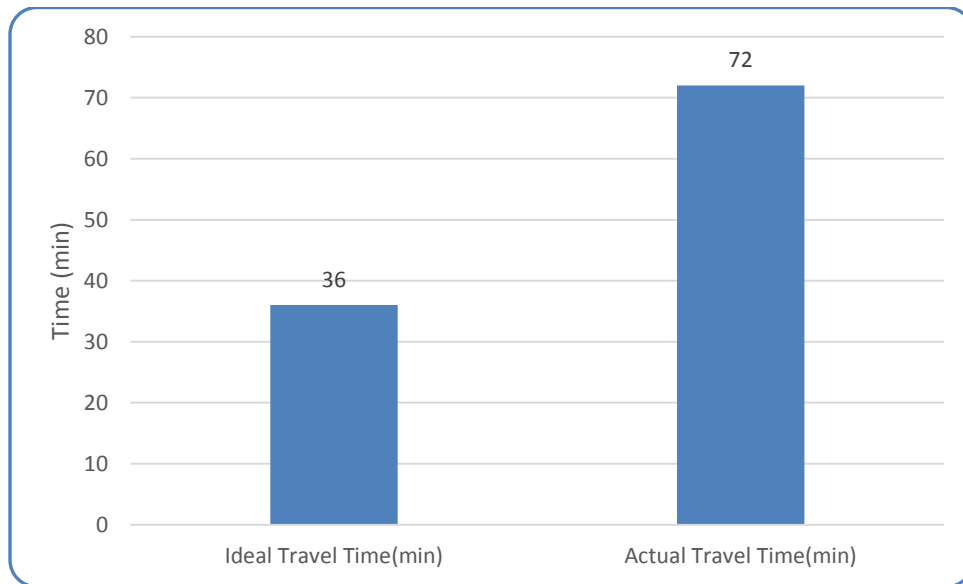


Figure 30: Ideal time versus average actual travel time (Akaki -Merkato)

From the total travel time to reach this destination the test vehicle idled 52% of the time which is more than half of the time it actually traveled which indicates that there is a very high level of idling on this route also.

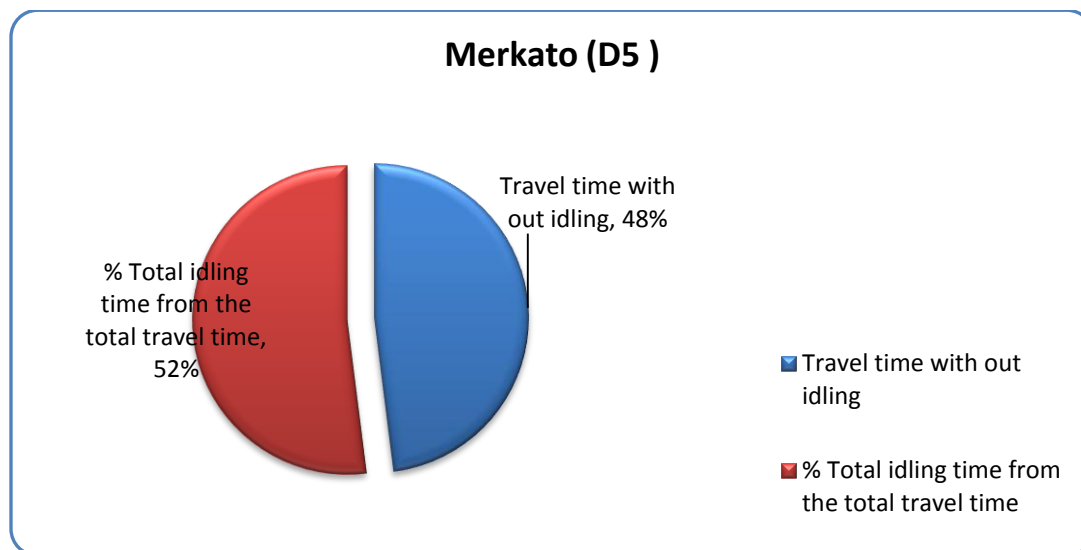


Figure 31: Estimated percentage shares of idling time and travel time without idling from the total travel time (Akaki -Merkato)

In all of the freight routes congestion is found highly severe. The average travel time it took the test vehicle to reach the destinations is approximately double (or more than double) the time it must have taken in an ideal situation where the traffic does not idle at all except at traffic lights during red light stopping. The difference between the two times is exaggeratedly seen on the routes to CMC to Merkato.

Figure 32 shows the comparison between the ideal and average actual travel times for all of the routes.

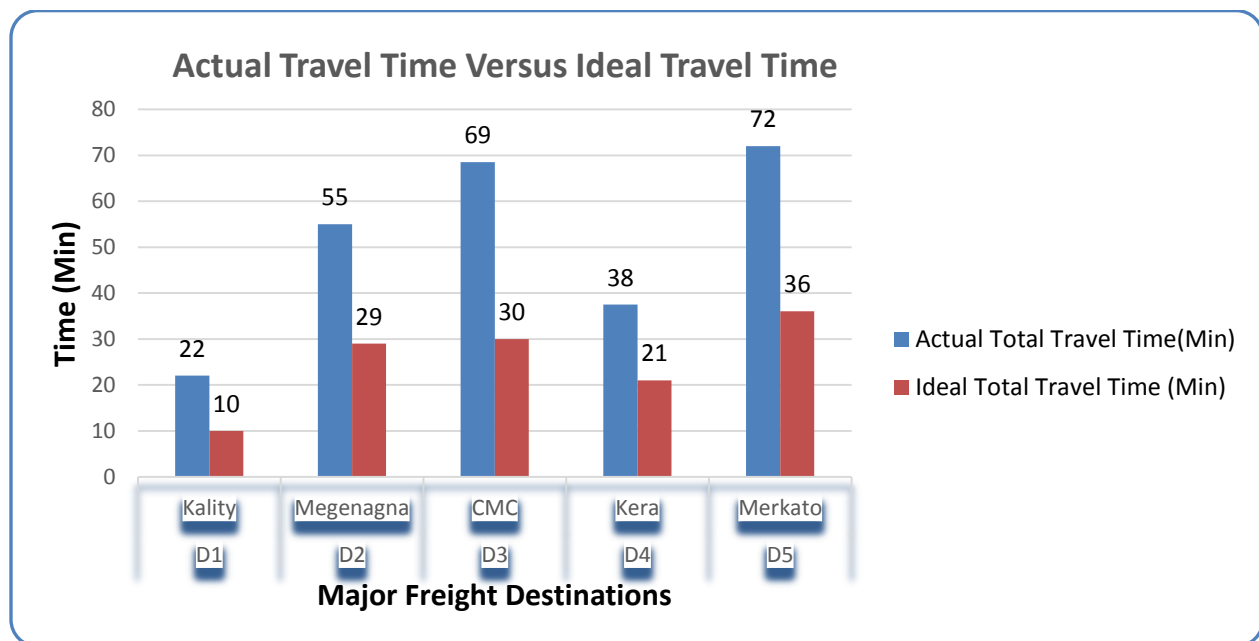


Figure 32: Comparison between actual travel time and ideal travel time on each of the freight destinations

4.3.6. Idling time per hour spent on the routes to the freight destinations

The results of the average lost times (idle times) in an hour due to red light stop idling and congestion idling for each of the routes are depicted on Table 14.

Table 14: Measured idle time per hour towards each destination

Destination		Idling per hour (min/hr)
D ₁	Kality	11
D ₂	Megenagna	28
D ₃	CMC	23
D ₄	Kera	19
D ₅	Merkato	20

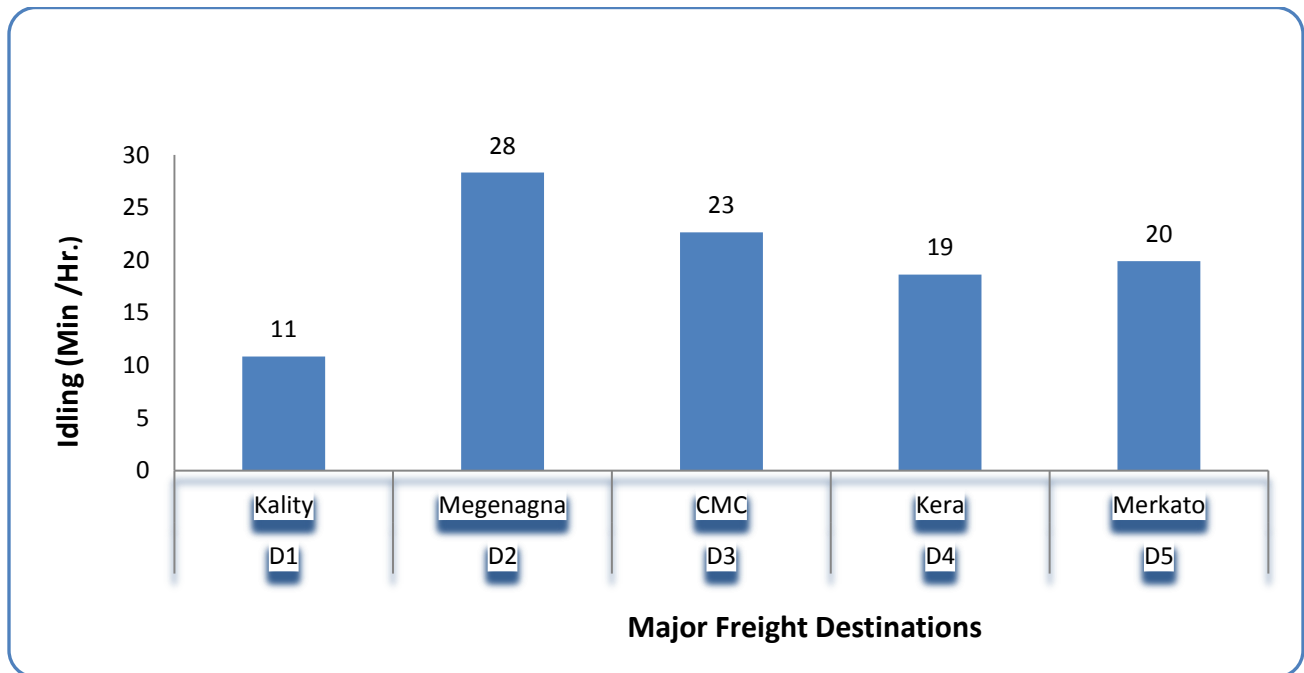


Figure 33: Idling time per hour on each of the routes to the different destinations of the city

From the results it can be seen that, in an hour a significant amount of time is lost in all of the routes. It is estimated that on the route to Megenagna and then to CMC the highest idling time in an hour occurs. The results also signify the severity of congestion in the city routes to the main freight destinations which supports the hypothesis that idling is significantly high on the roads of Addis Ababa.

4.4. Inputs for the empirical model

4.4.1. Annual Average Daily Traffic of freight vehicles entering the city of Addis Ababa through the corridor (I)

Based on the analysis made on Section 3.1.1., a yearly total of 50,786, 45,917 and 47,300 freight vehicles entered the city in the years 2013, 2014 and 2015 respectively through the Mojo corridor. Average Annual Daily Traffics were calculated to be

139,126,130 freight vehicles respectively on the years mentioned. These total and average numbers of vehicles are presented on Figure 34.

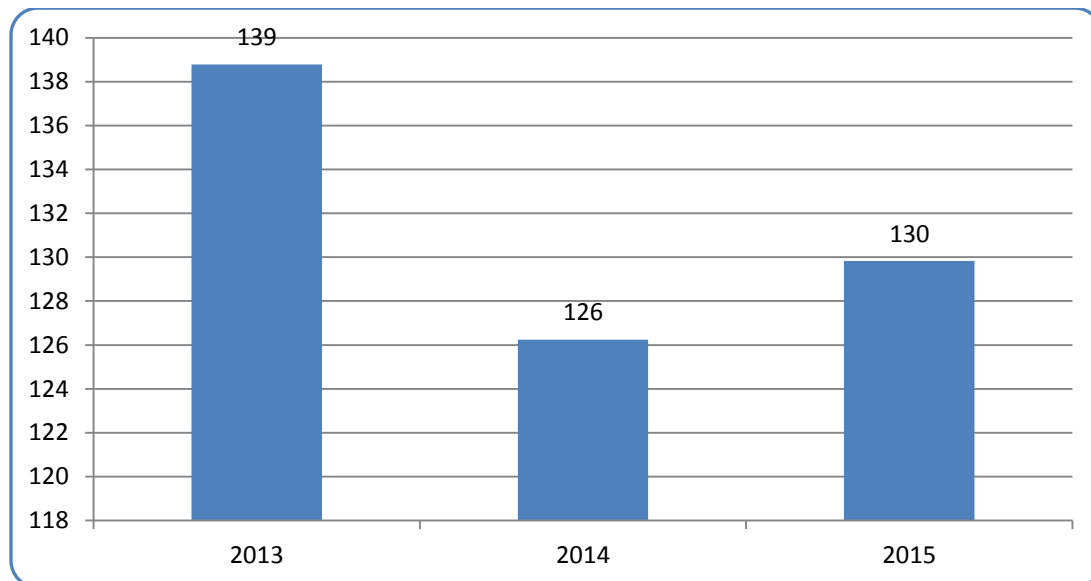


Figure 34: Annual Average Daily Traffic Increase of freight vehicles that have entered Addis Ababa from Mojo from year 2013 up to 2015.

It can be observed from Figure 34 that the AADT decreased from the year 2013 to 2014 and again increased in the year 2015 which shows that the numbers of freight vehicles that enter the city through the corridor fluctuates.

For this research paper, since the analysis is made on the year 2015 and all input data measured through primary data collection were on 2015, the AADT of this year is taken for the overall empirical analysis made on the section 3.1.4. whose results are presented on section 4.4.4.

4.4.2. Percentage shares of the different freight destinations in the city of Addis Ababa from the gate of Kality, and Idle time quantification

A. Percentage shares of different destinations in the city of Addis Ababa from the corridor. (II)

According to the research of Kebede (2013), from the 200 vehicles, during the study period, the larger share of freight vehicles from the gate of Kality i.e. 38 % went to Merkato which is in Addis Ketema sub city; 25% them went to the Akaki-Kality sub city, 15.5% went to Kirkos, 10% went to Megenagna in Bole sub city, 7% of them went to CMC and the remaining went to other parts of the city. These results are summarized on Figure 35.

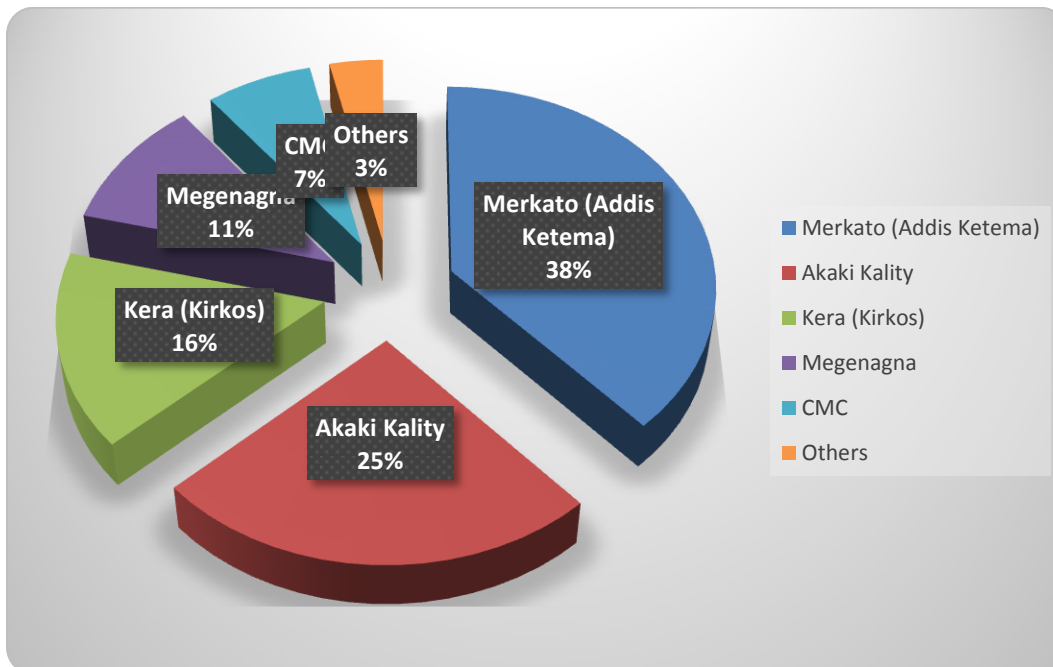


Figure 35: Percentage shares of destinations from secondary data, %

On the other hand from the primary data analysis, 20 vehicle drivers were interviewed, the destinations of 20% of them were going to Merkato in the Addis Ketema Sub city, another 20% to Kera in Kirkos sub city, another 20% to Kality in Akaki Kality Sub city,

15% to CMC which is not officially considered as part of the city and is located in the Oromia Region, and another 15 % at Lideta in the Lideta Sub city and the remaining 5% at Keranyo in Kolfe Keranyo Sub city.

The result of the primary data collection is presented on Figure 36

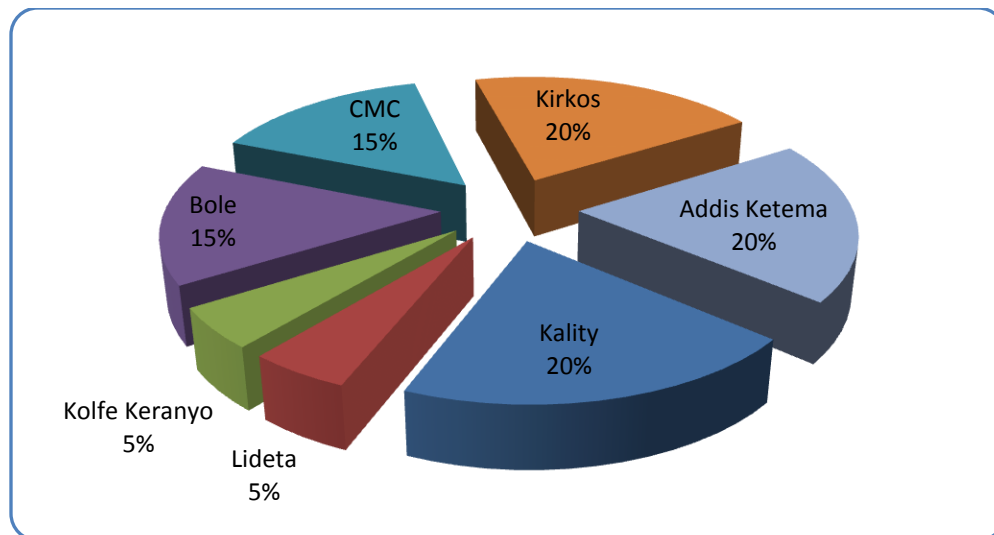


Figure 36: Freight Destination of Vehicles from Akaki to the City Addis Ababa (from primary data)

The primary data collection executed was in line with the rough observations and literatures reviewed on freight movement patterns in the city, and support the results from the research of Kebede (2013) which is used for the empirical analysis due to its robustness and representativeness.

B. Determining average number of stops to the different destinations (idle-time quantification) (III)

Data collected from the field on idling and data retrieved from the collected data are presented on sections 4.3.1.-4.3.5. from which the summarized values of the number of stops made on traveling from the origin, Akaki to each of the freight destinations are summarized on Table 15.

For the empirical analysis made on section 3.2., the following summary was used.

Table 15: Counted average number of stops on each route.

Destination		Route	Average No. of Stops on the Route (III)
D ₁	Kality	R ₁ ,R ₂ ,R ₃	4
D ₂	Megenagna	R ₁	11
D ₃	CMC	R _{1E}	18
D ₄	Kera	R ₂	10
D ₅	Merkato	R _{2E} ,R ₃	21

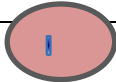
4.4.3. Field data collection - smoke emissions (IV)

The opacity measurements converted to transmittance values by Eq. 2 and the determined smoke density values from transmittance by Eq.3 are presented on Appendix C.

4.4.4. The overall empirical analysis

From the results obtained from sections 4.4.1- 4.4.3 the inputs to the empirical model are obtained. On the year 2015 and Annual Average Daily Traffic of 130 was obtained. This input is presented on Table 16.

Table 16: Average number of vehicles that has entered Addis Ababa through the gate of Kality on the year 2015

	
*AADT on the year 2015	130

The major share of the freight vehicles from the gate of Kality i.e. 38 % go to the freight destination at Merkato. This is because Merkato is the largest open-air marketplace in Addis Ababa. It is also is the largest open air market in Africa, covering several square miles and employing an estimated 13,000 people in 7,100 business entities. It is the

center of both import and export and local commodities. The second largest shares of vehicles go to Kality. Kality is an area of industries. Many of the manufacturing industries in the city are located from Akaki to Kality. The least shares of the freight vehicles go to Bole and CMC this is because the two areas are mostly residential areas and the probabilities of freight vehicles are less.

Table 17: Percent shares of freight destinations


Destination		Sub city of the destination	% Share
D1	Kality	Akaki-Kality	25
D2	Megenagna	Bole	11
D3	CMC	CMC	7
D4	Kera	Kirkos	16
D5	Merkato	Addis	38

The number of stops estimated for reaching Merkato indicates that the route to Merkato is highly congested and that vehicles stop approximately one time in one kilometer which indicates that there is a great number of a stop and go situation in the route which makes vehicles idle for some time and accelerate abruptly. Due to this idling the diesel freight vehicles on the route are forced to use unnecessary fuel consumption which in turn forces them to emit smoke on every stop and go scenario. The second greatest number of stops was estimated from the measurement towards CMC. As discussed earlier in section 4.3.3, since the route taken to CMC was the route extended from Megenagna it was found strange to have found a big difference of number of stops between Megenagna and CMC.

The number of stops estimated on the routes towards the destinations at Megenagna, Kality and Kera are also significant. On both of the routes, on average, one stop is made per two kilometers which indicates that for every two Kilometers the freight vehicles face one stop and go scenario which is led to un-necessary fuel consumption which in turn leads to smoke emission.

Table 18 shows the average number of stops made on each of the routes to each of the freight destinations.

Table 18: Average number of stops made on each of the freight destinations

				
Destination		Route-Used	Average length of the Route (Km)	Average number of stops made on the route
D ₁	Kality	R ₁ , R ₂ , R ₃	7.7	4
D ₂	Megenagna	R ₁	20.2	11
D ₃	CMC	R _{1E}	15.3	18
D ₄	Kera	R ₂	25.3	10
D ₅	Merkato	R _{2E} , R ₃	20.7	21

As discussed in section 4.2 emission of smoke is correlated with vehicles age therefore, a weighted average value of smoke density estimated based on vehicles' age group is used.

Table 19: Weighted average of measured smoke density values

IV			
Engine model year group	Number of vehicles tested in the	Average measured smoke	Weighted** average value of smoke density (meter⁻¹)
1959-1989	13	22.5	8
1990-2000	19	14	
2000-2010	27	2.4	
2010-2014	26	0.8	
**Weighted Average is calculated for smoke density values based on their model year group because the number of vehicles tested from each group			

The threshold for smoke density values of the European Standards is only 0.5 meter⁻¹ but from the measurements a weighted average value of 7.6 meter⁻¹ which has a huge gap from the standard

The average result of smoke density was taken to the empirical model. (Eq.1).

As discussed in section 3.1. all the input parameters discussed are taken to the Empirical model (Eq. 1)

$$\text{ASD per day} = \frac{\text{AADT}}{\text{(I)}} \times \frac{\text{D (\%)}}{\text{(II)}} \times \frac{\text{S(No.)}}{\text{(III)}} \times \frac{\text{SD(meter}^{-1}\text{)}}{\text{(IV)}} \quad \text{Eq. 1}$$

Where:

ASD per day - Average Smoke Density (Per meter), per day on Idling

AADT- Average Annual Daily Traffic of the year 2015

D (%)-Percent Share of the Destination (%)

S (No.) - Average Number of Stops on the Route

SD (meter⁻¹) -Weighted average value of smoke density per stop (meter⁻¹)

Table 20: Results on the overall empirical analysis

Destinations		AADT	SD(meter ⁻¹)	D (%)	S (No.)	ASD (meter ⁻¹)	Standard of EU VI	***	Percentage increase from the threshold
D ₁	Akaki	130	8	25	4	988	0.5	65	93%
D ₂	Megenagna			11	11	1141		75	
D ₃	CMC			7	18	1245		82	
D ₄	Kera			16	10	1531		101	
D ₅	Merkato			38	21	7884		519	

*** Expected threshold ASD (per day) with the standard of EU VI These values are values that are expected Average Smoke Density (Per meter) per route, per day on Idling by using the empirical Model of this research paper according to the standard of smoke density (meter⁻¹), of the EU i.e. 0.5 (meter⁻¹) in Eq. 1

The smoke densities estimated and placed on the last column of Table 20 are values that are calculated based on the idea that, “What amount of smoke density would result from the empirical model (developed on this research paper), had all the diesel vehicles emitted just only the maximum standard value of smoke density set by the European Standard (EU VI).” From the results it can clearly be seen that the average smoke density (meter⁻¹), per day on idling estimated from this analysis is very much lower

than the estimated value of average smoke density (meter⁻¹) per day per route on Idling, obtained from the results of measurements made for this research paper.

The estimated results of smoke emitted through the tailpipes of the diesel freight vehicles to the atmosphere of the city of Addis Ababa, being in a very large gap with the standards of the European Union (EU VI) indicates the environmental and health impacts from these vehicles in the city is also very high.

As idling of vehicles is not an intended part of travel, any problem associated with it to be considered as a noteworthy problem.

The estimated smoke from the diesel freight vehicles that entered the city of Addis Ababa from the Djibouti through the gate of Kality is one of the most important sources of atmospheric soot and fine particles, which is a type of air pollution implicated in human heart and lung damage. Even though much attention is not given to vehicular emissions and particularly in the city, from the results it can be shown that the health of inhabitants of Addis Ababa are affected and exposed by the emission of smoke from diesel freight vehicles in the city. Even though, not quantified, it can be vividly concluded that health impacts of the smoke produced from the diesel freight vehicles is high from the fact that the smoke densities estimated from the measured values in this research paper highly exceed the standard of the EU (VI). The high smoke produced from the diesel freight vehicles in the city not only implicates health impacts but also environmental impacts. Particulates that are released into the air via car exhaust can have an impact upon the precipitation that an area gets. It has also been found that diesel exhaust can cause an area to get less rain, which can have a significant impact upon the water sources of an area.

4.5. Research Constraints

- The non-availability of GPS tracking system for freight trucks in the country made the collection and data analysis for idling difficult and tedious.
- The non-availability of chassis dynamometer in the country also limited the simulation of actual road travel conditions which made the research to be focused only on road side tests. A chassis dynamometer is a device that accurately simulates road driving conditions in controlled laboratory conditions. It tests the entire vehicle instead of just the engine by driving the vehicle on rolls, assess real world emissions and the benefits of fuels and vehicle technologies. It also measures the performance of heavy hybrid trucks and buses.
- The non-availability diesel gas analyzers limited the research from the measurement of other pollutant gases from freight diesel vehicles other than smoke. Especially for NO_x as Nitrogen Oxides are also as pollutant as the black carbon from diesel powered vehicles.
- The fact that the concept of vehicular emission is not an emphasized issue in the country made a shortage of references.
- The non-existence of developed emission factors in the city limited the usage of international emission models.

4.6. Further Researches

- The total smoke emission in the city can be estimated using a more robust data including both entering and existing freight vehicles in and from the city of Addis Ababa through all of the five gates of the city.
- The actual health impacts of smoke can be estimated so that the seriousness of the problem is more emphasized in the country.
- Horse Power of vehicles can be used to calculate fuel consumptions and hence emissions of different gases.

- Studies on emissions should be done on the impacts posed by vehicular emission on inhabitants due to their proximity to roads.
- As the emission of Nitrogen Oxides (NO_x) from diesel engines is as important as the emission of Particulate Matter (Soot, Smoke etc...) studies should also be made on vehicular emissions of NO_x so that the health and environmental impacts of emissions from diesel freight vehicles in Addis Ababa can be generalized.
- Epidemiological studies detecting and differentiating the health effects of emissions should be made for the city of Addis Ababa.

5. Conclusions

Freight vehicles in the city of Addis Ababa are producing higher level of smoke due to their old age and their rate of emission is aggravated by the excessive idling which is caused due to the high level of congestion and the lack optimized traffic management systems in the city.

The high levels of congestions and the overall un integrated traffic management system combined with the chaotic driving behavior in the city of Addis Ababa highly affects the mobility of traffic movement which in turn is the reason for the increased idling times in which vehicles consume fuel which results in un burnt hydrocarbons of fuel and are exhausted as black carbon (smoke) and also other pollutant gases of environment.

On all of the routes to the major freight destinations in the city of Addis Ababa studied on this paper, idling time is significantly high taking an average share of 55% from the total travel time and an average idling time of 11 min /hr. on the route to Kality, 50% from total travel time and 28 min/hr. on the route to Megenagna, 50% from total travel time and 28 min/hr. on the route to Megenagna, 60% from total travel time and 23 min/hr. on the route to CMC, 46% from total travel time and 19 min/hr. on the route to Kera and 64% from total travel time and 20 min/hr. on the route to Merkato. These high indications of idling times implicates the excess fuel consumption of engines with no load and hence emission of pollutant gases and specifically black carbon (smoke). When the amount of fuel wasted is estimated according to the emission research and measurement division Environment Canada (2000) approximately 0.28-1.15 liters of fuel is wasted on the route to Kality ,0.69-2.92 liters of fuel on the route to Megenagna, 0.57-2.4 liters on the route to CMC, 0.47-1.98 on the route to Kera and 0.5-2 liters of fuel is wasted on the route to Megenagna. In terms of number of stops, along the routes to the freight destinations, a minimum of one stop and go scenario occurs on the routes to Kality, Megenagna and Kera and a minimum of one stop and go scenario per Kilometer on the routes to CMC and Merkato which are significant number of stop and go scenarios to cause high levels of smoke emission at idling. The lack of stringent traffic

laws and precisely lack of laws on idling in the city is what encourages drivers to drive randomly and hence cause congestions. The low level of awareness on individual contribution for the reduction of congestion is also one of the law implementation problems.

Vehicles of model year 1959-1991 and 1991-2000 are found to emit very high smoke density with average smoke opacities of 80% and 73 % respectively which are well above the standards of US EPA which is 40 % for pre 1991 diesel freight vehicles and 50% for post 1991 diesel freight vehicles. The smoke densities of these same model year groups i.e. 22.4 meter⁻¹ for the 1959-1991 and 14 meter⁻¹ were found very high when compared with the standards of the European Union (EU VI). Even though the average smoke opacities and smoke densities obtained for the tested diesel freight vehicles of newer model year groups i.e. 2000-2010 and 2010-2014 are found lower than the older model year groups, the values of smoke densities i.e. 2.4 meter⁻¹ for the vehicles of model year group 2000-2010 and 0.8 meter⁻¹ for the model year group were still found to be higher than the standards of the European Union (EU VI).

From the overall results it can be concluded that older freight vehicles are responsible for the observable smoke emissions from freight vehicles in the city of Addis Ababa which is supported by correlation constant obtained by the correlation made between vehicles age and smoke densities & vehicles age & smoke opacities. These emissions are significantly high to cause health and environmental impacts in the city.

The major reasons for the existence of old freight vehicles in the city is the inexistence of banning laws for old aged vehicles in Ethiopia, in general.

Finally it can be concluded that the empirical model can be used to determine smoke densities from all diesel powered heavy duty vehicles entering, leaving and circulating with in the city by considering all the freight movement patterns of the city provided that some modifications are made to the input parameters; such as, idle time quantification could, instead of in terms of numbers of stops, be made with actual idle times. The model can also be used to estimate other emission gases from idling at freight vehicles as well as idling of passenger vehicles provided that the necessary modifications are

made to fit the movement patterns to quantify the actual idle times spent on the routes of Addis Ababa.

From the over analysis and results of the empirical model, it can be concluded that the freight vehicles entering the city through the gate of Kality indisputably emit high level of smoke per day at idling which are well above the standards of the European Union (EU VI) indicating their great potential of health impacts particularly of the cardiovascular and the respiratory systems of children and the elderly in the city of Addis Ababa.

6. Recommendations

From the research, it is concluded that idling shares the great portion of the travel time ;and traffic congestion and red light stop idling have greatest shares from idling on the freight routes towards the major freight destinations in the city of Addis Ababa. To alleviate the problems of idling, the Transport Authority of Addis Ababa should develop strategies with enforcement procedures which must include outreaching individual drivers and also integrating them with business and truck fleet strategies. In the strategies, it is highly recommended to work on researches on the overall transportation problems to study the very route problems of congestion and hence to introduce systems which can minimize the problem in the city; such as the introduction and implementation of Intelligent Transport Systems (ITS) which give drivers real time traffic information on choosing the best route, information on traffic incidents and hence rerouting drivers from roadways with incidents which will lessen the potential of congestion.

Construction of flyovers and interchanges, turning movement restrictions, optimization of cycle timings, widening of roads, and synchronized traffic signals can in general address the various traffic engineering and management measures to reduce delays at the intersections.

Awareness creation can play a critical role in idling reduction strategies. Banners, signs and posters could be used to remind drivers to shut off their engines instead of idling them during congestion times. Information and signage could be posted in public areas such as schools, hospitals, hotels, gasoline stations and truck delivery zones.

Although it requires a huge investment and execution plan, the shift of road freight transportation to electric rail transportation, as stated on other researches on different countries, is another measure which plays a great role in reducing gaseous emissions from fuel consumptive vehicles. Post-occurrence measures such as the assignment of exclusive routes for heavy duty vehicles especially around schools as children are the most vulnerable groups, can reduce impacts of vehicular emissions.

Stringent traffic congestion laws should be formulated and implemented by the integration of the Transport Authority of Addis Ababa and the Environmental Protection Authority of Addis Ababa. One of the traffic laws can be congestion pricing which is a system of surcharging users of public goods that are subject to congestion through excess demand such as higher peak charges for use of bus services and road pricing to reduce traffic congestion. This pricing strategy regulates demand, making it possible to manage congestion without increasing supply. More stringent environmental laws should also be formulated and implemented in the country which must include banning of importing old aged vehicles in Ethiopia based on researches made on the effect of old aged vehicles on the environment.

All the proposed recommendations should be primarily supported by exhaustive researches which must be made on each issues of congestion and idling.

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2016

Appendix A: Sample of the data collected from the weight and size station of Modjo

AX-003

ETHIOPIAN ROADS AUTHORITY
SIZE & WEIGHT CONTROL STATION
COMMODITY MOVEMENT REPORT- SUMMARY

Station:- MODJO
period From: Jan 1st - 2015 TO Jan 31st - 2015 Date: 01/02/2015

It.	Origin	Destination	Total .NO. Of vehicles	Total Tonnage In ton
1	A/A	mekele	9	310.0
2	"	Djibuti	59	2351.5
3	"	Arazrete	72	2118.4
4	"	Shashemene	95	2235.0
5	"	Awassa	113	2509.1
5	"	Harer	29	1160.1
7	"	D/Dawa	15	552.0
8	"	Awash	9	285.0
9	"	modjo	46	815.3
10	"	wolayta	39	1525.0
11	modjo	A/A	373	9169.8
12	meki	"	822	13201.2
13	Alomtienia	"	1073	16237.7
14	Zeway	"	195	3160.5
15	Shashemene	"	45	1255.0
16	Langano	"	56	840.0
17	Sodere	"	14	210.0
18	Nazrete	"	372	6621.3
19	mekele	"	61	2263.6
20	Djibuti	"	771	30308.5
21	D/Dawa	"	61	2264.9
22	Djibuti	Abay	29	1160.0
23	Wanji	A/A	14	410.0
24	"	Awassa	23	595.4
25	Djibuti	wolayta	298	11919.6
26	"	wolega	39	1560.0
27	Nazrete	Shashemene	92	3309.7
28	Awassa	A/A	33	1021.1
29	Shashemene	Nazrete	45	1248.4
30	mekele	G/Gibie	71	1237.3
TOTAL			4937	123155.4

Prepared by: Daniel nepete
Title: Inspector/Axle Lead
Sign: [Signature]

Approved by: [Signature]
Title: [Signature]
Sign: [Signature]

Figure A .A-1: Origin and destination of freight vehicles passing through the size and weight control station at Mojo

Appendix B: Idle Time Quantification along the routes to the freight destinations

Denotation	Destination	Route		
From (Time)				
Till (Time)				
Data collected				
	Name of the	Arrival	Departure Time	Reason for
Origin	Akaki			
Stop number 1				
Stop number 2				
Stop number 3				
Stop number 4				
Stop number 5				
Stop number 6				
Stop number 7				
Stop number 8				
Stop number 9				
Stop number 10				
Stop number 11				
Stop number 12				
Stop number 13				
Stop number 14				
.				
.				
.				
Destination				
Total Time of Idling (min)				

Keys for reasons of the Stop	
Reasons For Stop	Letter Code
Idling due - Traffic	A
Congestion	B
Cruise Idling (Idling	C

Appendix C: Measurements of smoke opacity values (%) and calculated smoke density values (meter⁻¹)

Recorded Data						Measure d Data	Calculated	
No.	Vehicle's Model Year Group	Vehicle's Make	Vehicle's Carrying Capacity	Vehicle's Engine	Odometer's Reading group	Opacity (%)	Transmi ttance (%)	Smoke (/m) For
1	1959 - 1989	Fiat	>30	10.1L	-	99	1	36.26
2	1959 - 1989	Fiat	>30	10.7L	-	99	1	36.26
3	1990 - 2000	IVECO	20-30	6.0L	350000-500000	87	13	16.06
4	2000 - 2010	Sinotruck	20-30	9.7L	350000-500000	1	99	0.08
5	2010- 2014	Isuzu	3.6-7	8.3L	0-30000	7	93	0.57
6	2000 - 2010	Isuzu	3.6-7	8.3L	500000-750000	8	93	0.61
7	2000 - 2010	Sinotruck	20-30	9.7L	30000-60000	55	45	6.29
8	2000 - 2010	Isuzu	3.6-7	8.3L	110000-140000	1	99	0.08
9	1959 - 1989	IVECO	20-30	9.5L	750000-900000	99	1	36.26
10	2010- 2014	Isuzu	3.6-7	8.3L	0-30000	1	99	0.08
11	1990 - 2000	Isuzu	3.6-7	8.3L	750000-900000	73	27	10.25
12	2000 - 2010	Isuzu	3.6-7	8.3L	500000-750000	26	74	2.33
13	2000 - 2010	Sinotruk	20-30	9.7L	0-30000	23	77	2.05
14	1990 - 2000	IVECO	20-30	9.5L	110000-140000	81	19	13.08
15	2010- 2014	Sinotruk	20-30	9.7L	30000-60000	1	99	0.08
16	1990 - 2000	DAF	>30	9.7L	200000-350000	91	9	18.96
17	1990 - 2000	Iveco	20-30	8.7L	-	78	22	11.92
18	1959 - 1989	Mercedes	1.5-3.5	8.5L	-	92	8	19.89
19	2010- 2014	Sinotruk	20-30	9.7L	110000-140000	1	99	0.08
20	2000 - 2010	IVECO	20-30	6.0L	500000-750000	1	99	0.08
21	2000 - 2010	Mitsubishi	1.5-3.5	7.5L	140000-170000	29	71	2.74
22	1959 - 1989	Mercedes	1.5-3.5	8.6L	-	81	20	12.87
23	1990 - 2000	IVECO	20-30	9.5L	-	88	12	16.69
24	2000 - 2010	IVECO	20-30	8.7L	-	67	33	8.73
25	2000 - 2010	IVECO	20-30	9.7L	-	1	99	0.08

Assessment of Smoke Emissions Generated From Freight Vehicles At Idling Conditions In The City Of Addis Ababa 2016

Recorded Data						Measured Data	Calculated	
No.	Vehicle's Model Year Group	Vehicle's Make	Vehicle's Carrying Capacity	Vehicle's Engine Size	Odometer's Reading group	Opacity (%)	Transmittance (%)	Smoke (/m) For EOPL=
26	2010- 2014	Sinotruck	20-30	9.7L	30000-60000	1	99	0.08
27	2010- 2014	IVECO	20-30	8.7L	60000-90000	35	65	3.39
28	2000 - 2010	VOLVO	7--12	9.6L	500000-750000	24	76	2.14
29	2000 - 2010	Isuzu	3.6-7	8.3L	350000-500000	3	97	0.27
30	1959 - 1989	Mercedes	1.5-3.5	8.3L	750000-900000	87	13	16.06
31	2000 - 2010	Isuzu	3.6-7	8.4L	350000-500000	14	86	1.15
32	2000 - 2010	Isuzu	3.6-7	8.3L	500000-750000	1	99	0.08
33	1990 - 2000	IVECO	20-30	6.0L	-	72	28	9.97
34	2010- 2014	IVECO	20-30	8.7L	60000-90000	2	99	0.12
35	1959 - 1989	Mercedes	1.5-3.5	8.6L	-	98	2	30.80
36	1990 - 2000	IVECO	20-30	9.5L	350000-500000	89	11	17.38
37	2010- 2014	Sinotruk	20-30	9.7L	60000-90000	1	99	0.08
38	1959 - 1989	Fiat	>30	10.7L	-	99	1	36.26
39	1990 - 2000	IVECO	20-30	9.5L	-	89	11	17.38
40	2010- 2014	Isuzu	3.6-7	8.4L	0-30000	1	99	0.08
41	1990 - 2000	Isuzu	3.6-7	8.4L	140000-170000	98	2	30.80
42	2000 - 2010	Isuzu	3.6-7	8.4L	30000-60000	31	69	2.94
43	2000 - 2010	Sinotruck	20-30	9.7L	350000-500000	1	99	0.08
44	2010- 2014	Sinotruck	20-30	8.7L	60000-90000	5	95	0.39
45	2000 - 2010	Isuzu	3.6-7	8.4L	140000-170000	0	100	0.03
46	2010- 2014	Isuzu	3.6-7	8.4L	30000-60000	1	99	0.08
47	1990 - 2000	IVECO	20-30	9.5L	-	99	1	36.26
48	1990 - 2000	IVECO	20-30	9.5L	-	91	9	18.96
49	2010- 2014	IVECO	20-30	8.7L	30000-60000	2	98	0.19
50	1990 - 2000	IVECO	20-30	9.5L	-	78	22	11.92
51	2010- 2014	IVECO	20-30	8.7L	60000-90000	8	92	0.66
52	1990 - 2000	IVECO	20-30	9.5L	30000-60000	78	22	11.92

Assessment of Smoke Emissions Generated From Freight 2016 Vehicles At Idling Conditions In The City Of Addis Ababa

Recorded Data						Measured Data	Calculated	
No.	Vehicle's Model Year Group	Vehicle's Make	Vehicle's Carrying Capacity	Vehicle's Engine Size	Odometer's Reading group	Opacity (%)	Transmittance (%)	Smoke (m) For EOPL=
53	2010- 2014	IVECO	20-30	8.7L	30000-60000	13	87	1.12
54	1990 - 2000	IVECO	20-30	9.5L	-	71	29	9.75
55	2010- 2014	IVECO	20-30	8.7L	30000-60000	1	99	0.08
56	2010- 2014	IVECO	20-30	8.7L	30000-60000	1	99	0.08
57	1959 - 1989	IVECO	20-30	9.5L	-	98	2	30.80
58	2010- 2014	Nissan	12--20	8.2L	30000-60000	39	61	3.92
59	2010- 2014	Sinotruck	20-30	9.7L	30000-60000	1	99	0.08
60	2010- 2014	Scania	12--20	-	350000-500000	11	89	0.88
61	1990 - 2000	Iveco	20-30	-	-	73	27	10.43
62	1990 - 2000	Nissan	12--20	-	200000-350000	15	85	1.25
63	2010- 2014	Daf	>30	-	60000-90000	32	68	3.00
64	2000 - 2010	Nissan	12--20	-	200000-350000	3	98	0.20
65	1959 - 1989	-	>30	-	750000-900000	12	88	1.02
66	2000 - 2010	Isuzu	3.6-7	-	170000-200000	1	99	0.08
67	1959 - 1989	TURBO	12--20	-	200000-350000	45	56	4.64
68	2000 - 2010	Isuzu	3.6-7	-	200000-350000	19	81	1.64
69	1990 - 2000	EURO	12--20	-	60000-90000	14	86	1,19
70	2010- 2014	Sinotruck	20-30	-	0-30000	1	99	0.08
71	2010- 2014	Isuzu	3.6-7	-	90000-110000	3	97	0.26
72	1959 - 1989	-	>30	-	90000-110000	97	3	27.61
73	2000 - 2010	Isuzu	3.6-7	-	140000-170000	61	39	7.50
74	2000 - 2010	Isuzu	3.6-7	-	200000-350000	21	79	1.89
75	1959 - 1989	Volvo	7--12	-	350000-500000	36	64	3.56
76	2010- 2014	Iveco	20-30	-	750000-900000	2	98	0.16
77	2000 - 2010	Isuzu	3.6-7	-	30000-60000	47	53	5.01
78	2010- 2014	Iveco	20-30	-	30000-60000	1	99	0.08
79	1990 - 2000	Mitsubishi	1.5-3.5	-	140000-170000	18	82	1.56
80	2000 - 2010	Isuzu	3.6-7	-	110000-140000	29	71	2.67
81	2010- 2014	Isuzu	3.6-7	-	110000-140000	39	61	3.89
82	2010- 2014	Isuzu	3.6-7	-	0-30000	1	99	0.08
83	2000 - 2010	Isuzu	3.6-7	-	90000-110000	81	19	13.20
84	2000 - 2010	Iveco	20-30	-	200000-350000	10	90	0.80
85	2000-2014	Mercedes	1.5-3.5	-	-	33	67	3.11

Assessment of Smoke Emissions Generated From Freight Vehicles At Idling Conditions In The City Of Addis Ababa

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Table A. D- 1 Opacity (%) and smoke density values (meter⁻¹) of the model year 1959-1991(left) measures of central tendency(middle), moments of statistical distribution measures of dispersion (right)

Measured Data on Vehicles Model yr 1959-1991			Opacity (1959-1991)		Smoke Density (1959-1991)	
No.	Opacity (%)	Smoke(/m) For EOPL=0.128				
1	99	36.26	Mean	0.80	Mean	22.48
2	99	36.26	Standard Error	0.08	Standard Error	3.76
3	99	36.26	Median	0.97	Median	27.61
4	92	19.89	Mode	0.99	Mode	36.26
5	81	12.87	Standard Deviation	0.29	Standard Deviation	13.55
6	87	16.06	Sample Variance	0.09	Sample Variance	183.47
7	98	30.80	Confidence Level	0.18	Confidence Level (95%)	8.18
8	99	36.26	Lower Bound (CI 95	62	Lower Bound (CI 95 %)	14.29
9	98	30.80	Upper Bound (CI 95	98	Upper Bound (CI 95 %)	30.67
10	12	1.02				
11	45	4.64				
12	97	27.61				
13	36	3.56				
Average Opacity			80%			
95% confidence			62%-98%			
Average Smoke			22.48			
95% confidence			14.3-30.1			

Assessment of Smoke Emissions Generated From Freight Vehicles At Idling Conditions In The City Of Addis Ababa

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Table A. D- 2 Opacity (%) and smoke density values (meter⁻¹) of the model year 1991-2000(left) measures of central tendency(middle), moments of statistical distribution measures of dispersion (right)

Measured Data on vehicles of Model yr 1991-2000			Opacity (1991-2000)		Smoke Density (1991-2000)	
No.	Opacity (%)	Smoke (/m) For EOPL=0.128	Mean	0.72	Mean	13.98
1	87	16.06	Standard Error	0.061	Standard Error	2.03
2	73	10.25	Median	0.78	Median	11.92
3	81	13.08	Mode	0.78	Mode	11.92
4	91	18.96	Standard Deviation	0.26	Standard Deviation	8.87
5	78	11.92	Sample Variance	0.07	Sample Variance	78.76
6	88	16.69	Confidence Level (95%)	0.12	Confidence Level	4.27
7	72	9.97	Lower Bound (CI 95	60	Lower Bound (CI 95	9.70
8	89	17.38	Upper Bound (CI 95 %)	86	Upper Bound (CI 95	18.26
9	89	17.38				
10	98	30.80	Average Opacity Value	73%		
11	99	36.26	95% confidence Interval	60%-86%		
12	91	18.96	Average Smoke Density	13.99		
13	78	11.92	95% confidence Interval	9.7-18.26		
14	78	11.92				
15	71	9.75				
16	73	10.43				
17	15	1.25				
18	14	1.19				
19	18	1.56				

Assessment of Smoke Emissions Generated From Freight Vehicles At Idling Conditions In The City Of Addis Ababa

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Table A. D- 3 Opacity (%) and smoke density values (meter⁻¹) of the model year 2000-2010 (left) measures of central tendency(middle), moments of statistical distribution measures of dispersion (right)

Measured Data on Vehicles of Model yr 2000-2010		
No.	Opacity	Smoke (/m) For
1	1	0.08
2	8	0.61
3	55	6.29
4	1	0.08
5	26	2.33
6	23	2.05
7	1	0.08
8	29	2.74
9	67	8.73
10	1	0.08
11	24	2.14
12	3	0.27
13	14	1.15
14	1	0.08
15	31	2.94
16	1	0.08
17	0	0.03
18	3	0.20
19	1	0.08
20	19	1.64
21	61	7.50
22	21	1.89
23	47	5.01
24	29	2.67
25	81	13.20
26	10	0.80

Opacity (2000-2010)	
Mean	0.21
Standard Error	0.04
Median	0.16
Mode	0.01
Standard Deviation	0.23
Sample Variance	0.05
Confidence Level (95%)	0.09
Lower Bound (CI 95 %)	12
Upper Bound (CI 95 %)	31

Average Opacity Value	21%
95% confidence Interval for	12%-31%
Average Smoke Density	2.41
95% confidence Interval for	1.09-3.73

Smoke Density (2010-2014)	
Mean	2.41
Standard Error	0.63
Median	1.39
Mode	0.07
Standard Deviation	3.26
Sample Variance	10.64
Confidence Level	1.31
Lower Bound (CI)	1.09
Upper Bound (CI)	3.73

Assessment of Smoke Emissions Generated From Freight Vehicles At Idling Conditions In The City Of Addis Ababa

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Table A. D- 4 Opacity (%) and smoke density values (meter⁻¹) of the model year 2010-2014 (left) measures of central tendency(middle), moments of statistical distribution measures of dispersion (right).

Measured Data on Vehicles of Model yr 2010-2014			Opacity (2010-2014)		Smoke Density (2010-2014)	
No.	Opacity	Smoke				
1	7	0.57	Mean	0.09	Mean	0.84
2	1	0.08	Standard	0.02	Standard	0.25
3	1	0.08	Median	0.02	Median	0.12
4	1	0.08	Mode	0.01	Mode	0.08
5	1	0.08	Standard	0.13	Standard	1.31
6	35	3.39	Sample	0.02	Sample	1.72
7	2	0.12	Confidence	0.05	Confidence	0.52
8	1	0.08	Lower	4	Lower	0.32
9	1	0.08	Upper	14	Upper	1.36
10	5	0.39				
11	1	0.08	Average	8%		
12	2	0.19	95%	4%-		
13	8	0.66	Average	0.78		
14	13	1.12	95%	0,46-		
15	1	0.08				
16	1	0.08				
17	39	3.92				
18	1	0.08				
19	11	0.88				
20	32	3.00				
21	1	0.08				
22	3	0.26				
23	2	0.16				
24	1	0.08				
25	39	3.89				
26	1	0.08				

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