Analysis of Road Traffic Congestion and Its Economic Impact on Addis Ababa City

(The case of Kolfe sub-city: Asrasement-Compressive Road)

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University College of Business and Economics in Partial Fulfillment of the Requirements for the Degree of Master of Science in Management

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Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented or submitted partially or in full by any other person for a degree in any other university, and that all sources of materials used for the purpose of this thesis have been duly acknowledged.

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Abstract

Traffic congestion is a critical problem in fast-urbanizing cities such as Addis Ababa, whose infrastructure cannot keep up with the increasing demands of traffic. This research takes into account the degree of congestion on the Asrasament-Compressive Road, which is an outlet corridor connecting city and suburban areas and experiences more stress in comparison with the central arterials. The study followed a quantitative methodology. Data collection was based primarily on an integration of field measurements and observations, manual traffic counts, and questionnaires. Subsequently, data were examined by descriptive statistics and an approach adopted from the Texas Transport Institute and World Bank 2013 which computes the economic cost in Egypt. The study measures congestion levels by travel time method and estimates economic costs. Peak hours for severe delays are in the morning (8:15–8:30 AM) and afternoon (4:15–4:30 PM) with daily total delays being 67,833 vehicle-minutes (1,130.55 hours) and 508,033 person-minutes (8,467.21 hours). Direct and indirect annual economic costs are 274.2 million Ethiopian Birr, dominated by travel time delays. The findings highlight the unique stresses on outlet corridors, and it is essential to have specific

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Lists of Acronyms

ADT	Average daily traffic
AI	Artificial intelligence
CBD	Central business district
CO2	Carbon dioxide
DVKT	Daily vehicle kilometer travelled
ESCAP	Economic and Social Commission for Asia and the Pacific.
EGP	Egyptian pound
ETB	Ethiopian Birr
GCMA	Greater Cairo Metropolitan Area
GDP	Gross domestic product
GW	weight of gasoline
HCM	Highway capacity manual
HOT	High Occupancy Toll
HOV	High Occupancy Vehicles
LOS	Level of service
NCHRP	National Cooperative Highway Research Program
NO2	Nitrogen Dioxide
PCU	Passenger car unit
PCE	Passenger car Equivalent
PM10	Particulate Mater
SCC	Social Cost of Carbon
SPSS	Statistical Package for Social Sciences
TDM	Transportation Demand Management
TTI	Texas Transport Institute
UK	United Kingdom
UN	United Nation

VMT	vehicle miles of travel
VOC	vehicle operating cost
VOT	Value of time
V/C	Volume to capacity ratio

Chapter One

Introduction

1.1. Introduction

This chapter serves as an introduction to the study, beginning with a discussion of the background and context, followed by the formulation of the research problem, objectives, and research questions, as well as an examination of the significance, limitations, and scope of the study.

1.2. Background of the Study

Transportation networks play a pivotal part in the distribution of economic activities and provide for the movement of goods and individuals. These systems are vital in transporting raw materials, labor, fuel, and finished products and in giving consumers access to goods and services. Thus, the transport sector normally takes up about 5% of the Gross Domestic Product (GDP) and is an essential investment in infrastructure (Ibarra-Rojas et al., 2015).

However, the problems of congestion, accidents, and pollution caused by transportation have grown more severe due to the surge in travel demand, encompassing vehicular traffic, public transit, freight, and pedestrian traffic (Sumalee & Ho, 2018). These afflictions have become particularly common in many cities in both the developed and the developing world (Tazzie, 2022).

The problem of traffic congestion has a profound effect on both the standard of living for locals and the overall economic output of the impacted areas (Ghazali et al., 2019). This problem disrupts everyday habits and ways of life, resulting in inadequate community life. Chronic urban congestion problems can decrease the appeal of a site for business and economic development (Falcocchio & Levinson, 2015). This makes traffic congestion a significant economic concern.

Urban road traffic congestion continues to be an annoying problem, particularly in the developed countries. Texas Transportation Researcher (2003) states that traffic is still one of the biggest problems and traffic continues to get worse in American cities. Economic growth, urbanization, population growth, growth of job opportunities, and special events such as competitions, weather, and crashes are acknowledged as important contributors to urban area traffic congestion in this country (Rahman et al., 2022). This leads well into the need to invest in Intelligent Transportation

Systems (ITS) in cities to handle congestion as best as they can. Such systems are based on technologies like traffic signal optimization and real-time monitoring. Although lockdowns have alleviated congestion during the COVID-19 pandemic, cities now have to contend with it.

Road traffic congestion remains a significant challenge in developing regions, resulting in long delays, overconsumption of fuels, and substantial economic losses. The main reason for this is poorly devised road systems that often turn into fatal bottle-neck junctions. In addition, the problem is further exacerbated due to the lack of efficient traffic management in these areas, leading to longer and longer queues of halted traffic (Jain et al., 2012).

The Numbeo Traffic Index ranked various countries based on their extent of strong congestion with Nigeria coming top as of 2024 with a time index of 63.3 minutes, Bangladesh (57.7 minutes) in second place followed by Sri Lanka (54.8 minutes), Kenya (51.2 minutes), and Egypt (48.1 minutes) (Traffic Index by Country, 2024). This data shows that traffic congestion is more prevalent in developing countries than the developed nations.

The gross differences in average commute times we see in these emerging economies as per the Numbeo Traffic Index, go on to highlight the gravity of transport issues that fast urbanizing countries have to deal with. This is in sharp contrast to the relatively low level of congestion that countries further along in the development process have experienced, highlighting the need for further investigation into the nature of the underlying gridlock problem, and targeted responses.

The problems associated with traffic congestion have received extensive attention in recent years because their impacts are far-reaching, spanning across society, economy, productivity, mobility, accessibility, and the environment (Vencataya et al., 2018).

This study aims to analyze the current situation of road traffic congestion, evaluate the monetary consequences, and suggest efficient mitigation measures in which subject knowledge is continuously evolving.

1.3. Statement of the Problem

The complex problem of traffic congestion affects not only society's quality of life but also economic productivity and environmental efficiency. Indeed, this is reflected in several congestion studies where impacts are found to extend beyond transit delays and represent societal, environmental, and economic effects.

Traffic congestion brings about great economic costs through more fuel consumption, numerous collisions, and other land travel costs, adversely affecting productivity. Moreover, funds diverted to ease congestion prevent growth and development, consequently hampering economic development (Jie, 2012).

Congestion also has an environmental impact by increasing the estimated levels of pollution and the number of greenhouse gases emitted, which brings us to a global sustainability problem (Falcocchio & Levinson, 2015). Congestion has a negative impact on the economy, as it returns less working-hours to the workforce and reduces GDP, while altering land use, and energy consumption and affecting healthcare systems (Jie, 2012). Daily liveness embraces disruption in commuting hours as workers wake up earlier to avoid the gridlock and return home even later negatively impacting work-life balance and general quality of life.

Congestion levels continue to rise around the world. According to the 2019 Urban Mobility Report, urban congestion reached new heights in the U.S., where urban Americans spent a total of 8.8 billion more hours on the road and used 3.3 billion more gallons of fuel in 2017. The economic cost of this congestion was $166 billion (Lomax & Schrank, 2019). There were several mitigation efforts, including peak-hour toll charges, expanded road capacity, improved public transit, and intelligent transportation systems, but all these did not succeed in overcoming traffic congestion at peak hours (Somuyiwa et al., 2015).

This is particularly serious in the developing cities, where vehicle ownership levels remain relatively low, yet traffic congestion occurs at lower levels of vehicle ownership (Gwilliam, 2003). Uncontrolled urban growth has outpaced infrastructure development, putting a strain on cities such as Addis Ababa, where rapid urbanization and increasing vehicle ownership have overwhelmed the road network.

Researchers have explored the economic costs associated with traffic congestion from several angles. One position even argues that travelers will adjust to the congestion, and therefore it is less damaging to the overall economy than is commonly thought (Sweet, 2011). On the other hand, in departure of work, they claim congestion reducing urban development, retards agglomeration economies and determines the economic geography by negatively affecting employment opportunities and limiting the potential for modern economic growth (Sweet, 2014; Hymel, 2009). Somuyiwa et al. (2015) showed the inverse relationship between traffic and productivity in Lagos, Nigeria, which indirectly indicates that traffic congestion negative economic impact through the productivity loss.

Road traffic congestion has been one of the major elements in the socioeconomic wellbeing of Addis Ababa, which is the capital and economic center of Ethiopia (Gunjo et al., 2024). In general, congestion in Addis Ababa has been manifested through long queues and inability to easily access destinations, mostly during peak hours, hindering daily life and business activities (Sokido, 2024).

Addis Ababa City Corridor Development Project, i.e. the 41-kilometer work of main roads that meet at the Adwa Memorial has further increased this congestion. With only a few alternative roads and poor land-use planning in Addis Ababa, problems in the flow of traffic become even more serious, especially during peak hours (The Reporter, 2024). Most noticeably, the transport policy for Addis Ababa does not take explicit action to deal with congestion, resulting in increased fuel consumption and transportation costs alongside a diminished quality of life (Gunjo et al., 2024).

Indeed, most of the research conducted in the area of transportation-related issues in Addis Ababa prior to 2020 focused on traffic accidents, road infrastructure development, public transportation, and parking problems. However, road traffic congestion and its socio-economic impacts began to attract significant attention in the recent past. For example, the way of the street corridors being used underlined by Guta Alebe et al. (2024) as one of the greatest causes, especially in the Torhayloch to Mexico corridor. Tazzie (2022) analyzed economic and environmental impacts of congestion in Addis Ababa and finally came to the conclusion that it exerts negative effects on both the economy and the environment. Gunjo et al. (2024) developed a model for estimating the congestion cost using variables such as traffic volume, modal choice, trip frequency, and socioeconomic factors, and found that these variables have significant influences on congestion costs.

Despite its numerous contributions, the research on traffic congestion in Addis Ababa has left large gaps in the study. The most critical is the outlet corridors: at the city borders, there are few roads, which cause severe congestion, especially heavy vehicles carrying agricultural products and important goods. Those areas have unique traffic patterns and socioeconomic dynamics, unlike in the city center, but remain understudied. The state of infrastructure in these corridors compounds delays and raises transportation costs due to peak periods. Furthermore, most literature has focused on recurrent congestion with regard to rush-hour traffic, at the expense of non-recurrent congestion such as accidents, roadworks, or weather disruptions. It is along these lines that this research seeks to fill the gaps by providing a more holistic analysis of both the recurrent and non-recurrent congestion of peripheral corridors, hence provided an all-inclusive estimate of the economic costs and informed targeted infrastructure improvements and policy interventions.

1.3.1. Research Questions

- What is the traffic flow characteristics in the selected corridor?
- What is the level of road traffic congestion at the selected corridor?
- What is the estimated monetary value of direct and indirect costs due to traffic congestion?

1.4. Objectives of the Study

1.4.1. General Objective

The general objective of this research is to analyze road traffic congestion and its economic impact in Addis Ababa City.

1.4.2. Specific Objective

- To examine the traffic flow characteristics
- To measure the level of road traffic congestion
- To estimate the economic impact of road traffic congestion

1.5. Hypothesis

The level of road traffic congestion in Addis Ababa's outlet corridors, such as the Asrasement-Compressive Road in Kolfe sub-city, significantly correlates with increased direct and indirect economic costs, including travel time delays, excess fuel consumption, CO_2 emissions, long waiting time, increased vehicle maintenance and traffic offense.

1.6. Scope of the Study

The study will try to estimate the economic impact of traffic congestion on roads in Addis Ababa under both recurrent and non-recurrent congestion scenarios. Its scope includes the estimation of direct and indirect economic costs relating to time delays, fuel consumption, and carbon dioxide emissions for a wide view of its economic implications. Additionally, the current level of congestion in the study corridor will be measured, together with providing mitigation measures.

Geographically, the study will cover corridors that serve as entry and exit to Addis Ababa, with a focus on those experiencing high levels of congestion. In this way, the study tries to draw a holistic picture of the problem of traffic congestion with its multi-dimensional economic impact.

1.7. Limitation of the Study

Several limitations were identified that influenced the data collection of this study: delays or failure to return questionnaires by respondents reduced the sample size; fieldwork was disrupted by security concerns, thus disturbing data collection schedules; manual traffic volume counting was tedious and not as accurate as automated systems. Also, it did not address sufficient economic cost estimations since the health, social, safety, and environmental cost estimates were excluded. Numerical estimations of traffic violations and depreciation costs were not included.

1.8. Significance of the Study

The study on road traffic congestion and its economic impact in Addis Ababa is very essential for a number of reasons. First, traffic congestion is among the major problems facing urban centers worldwide, which impacts economic productivity, environmental sustainability, and social well-being. By focusing on Addis Ababa, which is fast growing with unique socio-economic dynamics, this research contributes to the better understanding of how congestion intrudes on the local economy, environment, and daily life. Additionally, the study fills the gaps on the existing studies by considering variables and conditions specific to the local context, in order to allow for actionable insights that can provide valuable information for infrastructure investments and urban planning efforts.

1.9. Operational Definition of Terms

Congestion: Measured as the difference between actual travel time and free-flow travel time on the road segment, expressed in minutes of delay per kilometer.

Travel time: The actual time (in minutes) recorded for a vehicle or traveler to complete the road segment, measured using manual timing.

Acceptable travel time: The maximum time (in minutes) for the segment that meets local performance benchmarks for example 30km/h for arterial roads.

Average speed: The total distance (in km or miles) of the segment divided by the recorded travel time, expressed in km/h, collected from field survey data.

Acceptable travel rate: The threshold travel rate (minutes per km) determined through field studies, community standards, or transportation policy guidelines i.e., 6.64 minutes per km.

Actual travel rate: The recorded travel rate (minutes per km) for the segment, measured from real-time travel data collected via vehicle tracking or manual observations

Segment or trip length: The measured distance (in km) between the two points (inlet and outlet) along a route, obtained from odometer readings or GIS mapping

Traffic flow: The number of vehicles passing a fixed point on a road per hour, measured using manual vehicle counts.

Person volume: The number of people crossing the segment. It Can be collected by mode or estimated using occupancy rates.

Travel Delay (vehicle-hours and person-hours): is the aggregate additional total time spent by the road user when compared to the expected or acceptable travel time under free-flow conditions.

Recurrent Congestion: is the regular congestion that occurs during the morning from 7:00 AM to 11:00 AM and afternoon from 3:00 PM to 7:00.

Non-recurrent congestion: is the congestion that occurs due to special and unique events, such as traffic incidents, bad weather events, ceremonies, road maintenance, etc.

Economic Impact: The economic impact of traffic congestion includes the total financial costs associated with increased travel times, fuel consumption, vehicle maintenance, and productivity losses due to delayed transportation.

Direct Costs: are the immediate, measurable congestion-related expenses, such as fuel consumption, travel time delays, and vehicle operating costs.

Indirect Costs: refer to the less obvious, secondary economic impacts of congestion, such as lost productivity, increased healthcare costs due to pollution, and additional stress on urban infrastructure.

1.10. Organization of the Study

The whole study is, therefore, organized into a number of chapters that address a specific aspect of the research on analyzing road traffic congestion and its economic impact on Addis Ababa. The introduction covers an overview of the study, including the background, problem statement, research questions, and objectives. The literature review considers existing literature on traffic congestion, causes of traffic congestion, and economic impacts, pointing out existing gaps in the literature that this research intends to fill. The chapter on methodology brings out the research design, data collection methods, and analytical techniques followed in order to collect and analyze data on traffic volume, travel time, fuel consumption, and emissions. The results and discussion chapter will present the quantitative estimates of the economic costs of congestion and discuss the implications in the context of Addis Ababa by comparing the findings with other studies. Consequently, the last chapter summarizes the major findings and provides policymakers and urban planners with strategies to alleviate traffic congestion and enhance urban mobility through integrated transportation planning and sustainable infrastructure development.

Chapter Two

Literature Review

2.1. Introduction

Daily mobility is a necessary part of urban living. In cities, where human settlements are organized and specialized activities are concentrated in distinct regions, residents use various means of transportation to perform their daily duties and realize their interests. As opposed to a rural village, where most places are at walking distance, the physical layout of cities is divided into residential, commercial, and entertainment districts that require transportation to get from place to place. This is why accessibility, or the ease of reaching a place, is such an important factor in urban settings concerning the determination of the overall level of mobility of residents and their quality of life. (Sigurd, 2002).

The literature review in this study aims to integrate existing knowledge on traffic congestion and its economic consequences, particularly in metropolitan situations similar to Addis Ababa. By analyzing both theoretical frameworks and empirical studies, the literature gives a thorough understanding of congestion's causes, methods to measure, consequences, and strategies to alleviate. This foundational knowledge is very instrumental in identifying the gaps in the research study and refining the scope of the present study.

The literature review covers theoretical models, empirical studies, and methodological approaches related to traffic congestion. It includes studies from both developed and emerging cities, with a particular focus on urban centers that face similar socio-economic challenges to Addis Ababa.

2.1.1. History of Transportation and Its Evolution Through Time

The improvement of transportation systems has boosted the welfare of society and modernity in many ways. Since the beginning of the Bronze Age, land transportation has utilized wooden vehicles pulled by animals. The horse-drawn, two-wheeled chariot was one of the most fantastic inventions ever made. for two thousand years, this vehicle was used as the primary mode of transportation of passengers and, at the same time, as the primary weapon in conducting warfare (Rossi et al., 2016).

The history of transportation took a turn in the 18th century after the Industrial Revolution. The development of steam power altered transport when it introduced the steam-powered locomotives to construction railways. The railway network improved the transportation of goods and people in distant areas quickly and efficiently supported economic growth, industrialization, and expanding trade (Sigurd, 2002).

The invention of the automobile in the late 19th century was a groundbreaking innovation that transformed the society. In this era, there was a great technical and economic complex that came into being, one which largely helped in the mass adoption of the vehicle (Hugill, 1979). The car changed various aspects of the society, and most of these changes were massive in both towns and the countryside (Davies, 1989). Combustion engine, invented by Nicolaus August Otto in 1876, was the most decisive turning point of history, as mass production of automobiles became possible, personal mobility was transformed, and railroads became less dominant (Dietsche & Kuhlgatz, 2015).

The milestone of the 20th century was the occurrence of the first powered flight. Subsequently, airplanes were developed and improved over the century (Culick, 2003). The world has become a single organism, virtually all parts of which were interconnected, every region in the world was connected to even the most remote sections. It was the birth of global travel and international trade, alongside intercontinental tourism progress (Georgescu, 2016). Air transportation changed the geography of society as significantly as the railroad and automobile. In other words, the cost of distance has turned to almost zero for societies, considering time and costs (Bowen, 2010).

The impact of transportation on society's development has been very big, feeding into both urbanization and growth in the economy. From the chariot to modern air travel, each improvement in transportation has increased connectivity, trade, and the movement of people. This change has accelerated not only industrial expansion but also global market connections, finally impacting changes in human interaction and economic environment.

2.1.2. Importance of Transportation

Transportation is one of the key elements in the development of societies, affecting political, economic, and social aspects. Businesses need transport for their operation, the movement of goods, and the daily activities of people. In fact, efficient transportation systems are very essential to advanced societies because it makes it easy to do business, travel, and have a good quality of life. In developing countries, a lack of good transportation infrastructure holds back economic development and personal convenience from taking place (Novack et al., 2019).

This has given transportation an even greater importance in the global economy and impact on matters of economic activity, national defense, and political stability. Efficient transportation systems play a crucial role in containing the effects of disruptions that occur on a global scale by ensuring speedy movement of goods and services from substitute sources (Novack et al., 2019).

Transportation also helps the development of urban infrastructure since it meets the need of a diverse population. Moreover, it improves efficiency in logistics, making delivery faster and reducing operational costs (Lakshmi, 2017; Mantoro, 2021; Scott et al., 2020; Yagci Sokat, 2022).

More specifically, road transportation is important for economic growth and regional development. It provides support for economic activities and hence contributes to the increase in GDP while enhancing regional connectivity (Magoutas et al., 2023). This shows how transport bears multiple benefits in society and for the economy in different settings.

2.1.3. Overview of Road Traffic Congestion

Traffic congestion is not a modern phenomenon; it predates the automobile and even the Industrial Revolution (Rossi et al., 2016). Bygone days of major urban centers, such as London in the 17th and New York in the 19th centuries, knew no less traffic congestion.

Old downtowns, port districts like Tsukiji or Yokohama, and even vegetable markets were busy and cluttered a chaotic assortment of stagecoaches, wagons, and pedestrians competing for a limited resource. Street railways exacerbated the problem through competition with additional street traffic and tramway vs roadway collisions (Falcocchio & Levinson, 2015). This historical perspective reminds that vehicle congestion was not a problem unique to modernity however an age-old urban problem born hand in hand with the transportation system.

Transport congestion occurs when the demand for utilization of transportation facilities, such as walkways, stairways, roads, busways, and railways, exceeds their operational capacity (Afrin & Yodo, 2020). numerous factors, including efficiency, accessibility, and sustainability, are impacted by traffic congestion when it comes to urban transportation.

Effective governance policies can assist reduce congestion, but if they are not well-designed or coordinated, they may exacerbate the situation at times (Sun & Lu, 2022). For example, an inappropriate mix of measures may provide temporary relief in certain regions while increasing congestion in others.

2.2. Theoretical Review

2.2.1. Definition of Traffic Congestion

Many definitions have been proposed to describe traffic congestion in urban road areas, but there is no universally accepted definition of the phenomenon (Downs, 2004). In his in-depth research, (Aftabuzzaman, 2007) was able to categorize the definitions of traffic congestion into three broad categories:

1. Demand-capacity related: These definitions focus on the relationship between the demand for road usage and the available capacity of the road infrastructure.
2. Delay-travel time related: These definitions emphasize the increased travel time or delays experienced by drivers and commuters due to congestion.
3. Cost-related: These definitions consider the financial or economic costs associated with traffic congestion, such as fuel consumption, lost productivity, and environmental impacts.

The definitions related to each category are summarized in Table 2.1.

Table 2.1: Summary of the Definition of Traffic Congestion

	Definition	**Author**
Demand Capacity related	Traffic congestion results when there are too many vehicles for the available road.	(Robinson, 1984, p. 1)
	Congestion is a situation in which there are a large number of vehicles circulating, all of which are moving forward in a slow and irregular manner (Bull, 2003)	(Bull, 2003, p. 23)
Delay-travel time related	Congestion is an imbalance between traffic flow and capacity that causes increased travel time, cost and modification of behaviour.	(Pisarski, 1990, p. 1)
	Traffic congestion is a condition of traffic delay (when the flow of traffic is slowed below	(Weisbrod et al., 2001, p. 7)

	reasonable speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them.	
	In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower-sometimes much slower than normal or "free flow" speeds.	(Cambridge Systematics Inc. and Texas Transportation Institute, 2005, p. 2)
Cost related	congestion is that it occurs when the quality of service of a facility depends on the intensity of use.	(Small & Verhoef, 2007, p. 69)

It is important to note that these categories are not mutually exclusive, and definitions of traffic congestion often incorporate elements from multiple categories. The complexity of traffic congestion necessitates a comprehensive understanding that encompasses various aspects of demand, capacity, delay, travel time, and costs.

2.2.2. Theories

A) The Economic Theory of Urban Traffic Congestion

The Economic Theory of metropolitan Traffic Congestion provides a fundamental framework for understanding and dealing with the difficulties of traffic congestion in metropolitan areas. This microeconomic theory uses individual driver actions and decisions to characterize traffic patterns and congestion levels.

As cited in Arnott (2001), this theory has as its canonical macroscopic model the 1956 work of Beckmann, McGuire, and Winston to study travel on a point-input, point-output road network. The theory later evolved to distinguish between macroscopic and microscopic perspectives, with added emphasis on congestion pricing being essential in managing urban traffic effectively.

I. The Canonical Macroscopic Model

The basic economic model of urban traffic congestion developed by (Beckmann, McGuire, and Winsten 1956 as cited in Arnott, 2001) analyzes travel on a simple point-input, point-output road network. Often called the canonical macroscopic model, it embodies the essence of congestion through a cost function relating trip costs to traffic volume and road capacity. This model is very important since it forms the basis of understanding how traffic congestion evolves and hence affects urban economies.

Congestion in this model is manifested in the form of a congestion cost function, which displays how trip costs increase with traffic volume. The equilibrium point, where demand and average cost curves intersect, frequently represents the normal condition of urban traffic without any intervention. The optimal point, however, is where demand intersects with the marginal social cost, representing a scenario where congestion costs are minimized through optimal traffic management strategies such as congestion pricing. The basic model is explained as follows in Figure 2.1:

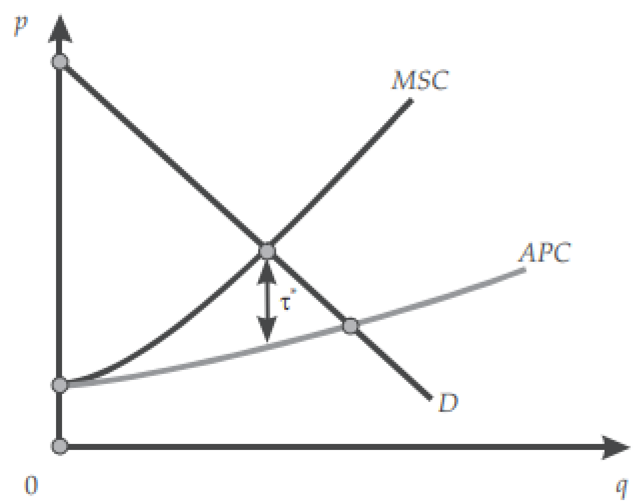

Figure 2.1:Basic Model of Urban Transport Economic Theory

(Source: Arnott, 2001, p. 19)

where the demand curve (D) relates the flow of trips demanded (q) to the trip price (p), the APC (Average Private Cost) curve reflects the increasing cost per driver due to congestion, and the MSC (Marginal Social Cost) curve represents the marginal social cost of a trip. Without government intervention, the equilibrium occurs where the demand curve intersects the APC curve, as individuals will travel up to the point where the marginal private benefit equals the marginal private cost. However, the social optimum occurs where the demand curve intersects the MSC curve, representing the traffic flow level that minimizes the total social cost. The vertical distance between the APC and MSC curves represents the marginal external congestion cost, which is the additional cost that an individual driver imposes on other drivers by taking an extra trip and slowing them down

II. The Microscopic Model

This model was developed to complement the macroscopic models and provide a more detailed analysis of urban traffic flows. These models consider the interactions between individual drivers and their immediate environments, such as decisions to accelerate, decelerate, or change lanes. Such detailed models can aid in coming up with more effective traffic management policies that target specific congestion points like intersections and highway entry or exit ramps (Arnott, 2001)

The theory also emphasizes the different margins of choice that drivers face, which include route choice, time of departure, and driving behavior. Each of these points of decision can contribute to overall levels of congestion. The theory implies that optimal congestion management needs to consider these individual choices. For example, traffic regulations that affect driver behavior, like speed limits and policies on lane usage, can have a significant effect on congestion levels and hence need to be included in an economic model of urban traffic (Arnott, 2001).

B) The Three-phase Theory

Three-phase traffic theory, which Boris Kerner developed from 1996 to 2002, is the theory devoted to explaining the physics of traffic breakdown and congested traffic on highways. The theory is an extension of the classical traffic theories that usually consider only two phases: free flow and congested traffic. Under Kerner's three-phase theory, two more phases are added: synchronized flow and wide-moving jam.

According to Kerner (2009), the three Phases of Traffic can be explained as follows:

1. Free Flow

In free traffic flow, there exists a positive relation between flow rate and vehicle density, as in this regime, the road network is functioning well and the traffic density remains low (Kerner, 2009).

2. Synchronized Flow

Synchronized flow has no significant stoppage and is commonly a continuous traffic flow at bottlenecks. During this, there is a tendency towards synchronization of vehicle speeds across different lanes on a multilane road and bunching of vehicles within each lane. Similarly, with increasing density, vehicles tend to synchronize their speeds. This regime exhibits propagating i.e., "stop-and-go" patterns backward, associated with traffic waves. These synchronizations are due to bottlenecks, lane changes, and interactions between drivers (Kerner, 2009).

3. Wide Moving Jam

At even higher densities, localized clusters of slow-moving or stopped vehicles emerge, known as "wide moving jams," which propagate upstream. Unlike synchronized flow, these jams persist even without external disturbances. The term "wide" refers to the jam's length being considerably greater than the transition zones at its front and back. The three-phase theory provides a much more detailed description of congested traffic, allowing for the distinction between different phases and challenging the alleged simplicity of vehicular traffic. This theory contrasts with the fundamental diagram of classical theory, which is inadequate for describing congested conditions (Kerner, 2009).

C) Value of time (VOT) Theory

Value of Time (VOT) Theory, originally proposed by Becker (1965) in A Theory of the Allocation of Time, provides a framework for evaluating the economic consequences that arise from delays in travel. The theory states that time is a scarce commodity with monetary value, and as such, individuals and institutions aim to use it optimally in an effort to increase productivity and well-being. In transportation economics, VOT is derived from people's willingness to pay for travel time savings or forgone wages due to delays. Higher VOT is applied for business trips and freight transport, and lower VOT for recreational trips. The inclusion of VOT in congestion analysis renders delay costs measurable in a way that time losses are in economic impact appraisals. This provides more precise cost-benefit estimates in urban traffic studies (Becker, 1965).

2.2.3. Types of Congestion

Traffic congestion can be categorized into two main types: recurrent and non-recurrent. Recurrent congestion happens when too many vehicles use the road simultaneously, typically during morning and afternoon peak hours (Chakrabartty & Gupta, 2015). In large urban areas such as Addis Ababa, these peak periods can last from 7:00 to 10:30 a.m. and 9:30 to 7:00 p.m. In smaller areas, the duration is shorter. Interestingly, recurrent congestion is also becoming more common during off-peak times. For example, in commercial areas like "Autobistera", Megenagna”, and "Merkato" congestion is always common, as the roads are often filled with people moving and crossing alongside them.

Non-recurrent congestion arises from random events such as accidents, vehicle breakdowns, adverse weather, road repair, and special events (Chakrabartty & Gupta, 2015). These unpredictable incidents make this kind of congestion harder to manage and can significantly impact travel time reliability, which is crucial for commuters and goods transporters (Chakrabartty & Gupta, 2015. The unpredictability of travel times due to non-recurrent congestion can lead to costly uncertainties, especially for those with strict schedules. fuel station queues in the case of Addis Ababa, can be regarded as non-recurrent congestion.

Some researchers also mention a pre-congestion state, where conditions are not fully congested but still impact driver behavior and the environment. This state shares some costs with full congestion, such as loss of control over the driving environment and environmental deterioration (Somuyiwa et al., 2015). This state can arise from situations like High Demand, Bottlenecks, Traffic Signal Timing, and On-Ramp and Off-Ramp Congestion.

2.2.4. Causes of Congestion

Urban traffic congestion, however, is a multi-dimensional problem with causative factors identified in various scholarly works. Following McClintock (as cited in Falcocchio & Levinson, 2015), congestion emanates from three broad causes: insufficient street capacity, factors in the traffic stream that cause obstruction to flow and insufficient traffic management. Falcocchio & Levinson (2015) continue to note that the segmentation of travel demand in areas such as central business districts and at peak times contributes greatly to congestion. The induced demand with the increase in population and employment tends to increase VMT without matching increases in road capacity. Bull (2003), notes that the urban transport systems face many challenges due to the derived demand for accessibility to different activities. Congestion is aggravated by limitations in road space, high costs of expansion of infrastructure, and the poor state of road design and maintenance effects. Additionally, driving behaviors and inadequate information about traffic conditions also further deteriorate congestion. Downs (2004) attributes the trip concentration over time due to synchrony in work and school schedules, rapid population and job growth, and the preference for private vehicle usage as the reasons for traffic congestion in American cities.

Another important factor is the affordability level and the improving quality of private cars that result in increased usage of automobiles and hence enhanced congestion.

The causes for Traffic congestion in different regions is different for example in India, congestion occurs mainly because of poor road conditions, varying roadway features, poor lane discipline, inappropriate bus-stop location and design, diversity of traffic, and unrestrained on-street parking (Mohan Rao & Ramachandra Rao, 2012). Whereas in China the cause is because of the inefficient public transport services, as well as the inverse relationship that exists between the number of vehicles and the road capacity (Zhang, 2011).

As discussed earlier, there are many causes of traffic congestion. From the literature review, the most common causes of traffic congestion are:

a) Traffic Influencing Events

These could build up to make significant causes of urban congestion in urban areas. Vehicle breakdowns and crashes block lanes, therefore reducing the available road capacity. The reduction in capacity forces vehicles to merge or slow down because of road repair work, security checks, or bad weather. Special events, such as the close of a sporting event or religious holidays, can abruptly increase the demand for transportation and overwhelm the network (Chakrabartty & Gupta, 2015; Falcocchio & Levinson, 2015). In the case of Addis Ababa, even long queues for fuel during shortages can be considered as a special event disrupting normal traffic patterns.

These types of events not only create new congestion in off-peak periods, but tend also to exacerbate the delays during normal rush hour congestion. The interaction between high traffic volumes and these disruptive events results in a breakdown in traffic flow, with speeds falling and vehicles bunching up. This temporary loss of capacity compounds the underlying congestion problems.

b) Population and Employment Increase

Population and employment growth can be a major cause of increased traffic congestion. Rapid growth in the number of households and jobs, as well as rapid percentage increases, have taken place in many large metropolitan areas throughout the world. The latter has experienced substantial gains in the number and use of vehicles, even where total population growth was slow (Downs, 2004).

According to Downs (2004) Employment growth in the 1980s and 1990s in the United States had a greater impact on causing congestion than population growth. data showed that for every 1% increase in nationwide population, there was a 1.49% increase in total jobs outside the home. This means that areas with relatively low rates of population growth still experienced more workers commuting daily, contributing to worsening traffic congestion.

The Texas Transportation Institute's 2002 Urban Mobility Report (as cited in Downs, 2004) shows that congestion is primarily increasing in areas where the populations are either very large or experiencing rapid growth in population or jobs. This emphasizes that increases in population and employment are the principal drivers of the rising traffic congestion observed in most of the metropolitan regions of the US.

The other case of Addis Ababa is that rapid urbanization and expected population growth to 7.3 million by the year 2030 are reasons for expanding job opportunities to attract more people to reside in the city. This, in turn, means more commuting and ownership of vehicles, hence increasing congestion. Similarly, if the infrastructure of the city does not keep pace with this growth, traffic issues will only get worse.

c) **Increase in Vehicle Ownership**

Increased vehicle ownership can contribute much to traffic congestion in developing countries. With increasing incomes, there exists a strong tendency for people to shift away from walking, bicycling, and public transit to the more comfortable and flexible modes of transportation like private cars and light trucks (Downs, 2004). This preference for private vehicles means that more vehicles may be on the roads during peak hours, and this can significantly increase congestion.

In fact, even those countries with relatively low levels of motorization, such as Ethiopia, which has only 65 vehicles per 1,000 persons as of 2014, according to the World Bank, can also have a high density of vehicles in a city that cause massive traffic congestion. This is because, in most of the developing countries, infrastructure and road networks cannot serve the increased number of private vehicles, hence often causing gridlock and longer travel times.

Moreover, the commuter's preference to drive alone, rather than using public transit or ride-sharing, could further intensify the problem. Driving alone gives more privacy, comfort, and flexibility, but it uses road space much less efficiently, since each car is only carrying one or a few passengers. This preference for private vehicle use has increased over time, leading to more intensive use of privately owned vehicles for all types of movement and hence contributing to increased peak-hour traffic congestion.

d) Improper Loading and Unloading of Passengers and Goods

This improper loading and unloading of passengers and goods contribute to the critical traffic jam in most of the places in Addis Ababa. Public transportation services and the logistics of freight do not possess adequate infrastructure and regulations that favor smooth boarding and disembarking processes at such places. This is because buses, taxis, and commercial vehicles normally stop in the middle of the road to pick up or drop off passengers and cargo, which blocks the flow of traffic and leads to huge delays. The situation is further deteriorated by the fact that most of the transport operations are informal, that is, vehicles stop at whatever location they please, thereby not allowing coordinated traffic management strategies to be put into practice.

e) Poor Road Condition and Maintenance Work

Poor road conditions and seasonal maintenance work have very high contribution to traffic congestion, which in turn has quite a number of negative effects on transportation systems and the users of roads. It has been established through numerous studies that deteriorated road surfaces, due to factors like overloading, inappropriate planning, and lack of maintenance cause delays, accidents, and increase in travel times (Khan et al., 2023). Common road defects, such as potholes, cracks, and depressions, are impeding traffic flow and causing discomfort to drivers; such defects are compounding the situation, considering other factors like poor drainage systems and inadequate road markings (Ali et al., 2022).

In the case of Addis Ababa, the conditions of the roads become even worse during summer thereby causing discomfort and reducing travel speed in most routes within the city which indirectly causes traffic jams to increase. Moreover, unplanned and ill-timed maintenance work on these routes especially during the daytime contributes to the disturbance in smooth flow of traffic within the city. Such a combination of deteriorating road conditions and badly scheduled maintenance activities makes the already bad congestion situation with the city's transport network even worse.

f) Inadequate Parking Spaces and Illegal Parking

Illegal parking in urban cities like Addis Ababa can have very serious negative impacts. Bad parking practices, especially on-street angle parking, may increase traffic congestion. When cars are parked on the street, they occupy lanes that should have been used by moving traffic, thereby decreasing the overall road capacity (Sisiopiku, 2001). Moreover, the maneuvers of parking and unparking further hinder the flow of traffic in adjacent lanes.

With increased parking space scarcity in Addis Ababa and with the narrow lane widths of the roads, illegal and on-street parking increases the problem of traffic congestion. Consequently, this may result in longer travel times, slower movement of goods, and possibly higher emissions from vehicles, as cars are forced to idle or move at slower speeds.

g) Poor Vehicle Maintenance and Use of Old-model Cars

Substandard vehicle maintenance, coupled with the high prevalence of using old, less-efficient car models, heightens traffic congestion in developing cities such as Addis Ababa. The study conducted by Kebede et al. (2022) has exposed that a large number of vehicles in the city are above 20 years, increasing emissions and thus air pollution. These aged vehicles, especially "Minibusses" and "Lada Taxies" contribute substantially to air pollution and traffic congestion.

Poorly maintained vehicles are more susceptible to mechanical failure, including problems with the engine, brakes, or transmission, which may cause the vehicle to break down or slow down to very low speeds, especially if driving on steep road gradients. All these cause traffic flow problems and lead to long delays because other vehicles have to find their way around the broken-down or slow-moving vehicle. Furthermore, older model vehicles usually lack the power and acceleration necessary to drive up steep inclines without causing traffic flow around them to significantly slow down. The poor performance and mechanical issues of aging vehicles also significantly contribute to the congestion challenges of hilly cities such as Addis Ababa because these cars cannot maintain the traffic flow and contribute to forming bottlenecks in traffic.

h) Illegal Trade Activities Along the Roadsides

One of the main contributors to the worsening state of traffic congestion along the roads and highways of the developing cities, especially the outlet regions, is the prevalence of illegal trade operations. These trading activities, most of which are driven by economic necessity and the lack of a means to acquire formal employment, choke the roadways, which in effect disrupts the smooth movement of both pedestrians and vehicles (Berhanu, 2021).

The roadways are often invaded by informal vendors, street hawkers, and makeshift stalls that intercept the intended use of the road infrastructure. This results in vehicles slowing or stopping to access those unauthorized trading posts, which further causes frustration in traffic patterns and forms bottlenecks. Moreover, due to the lack of space allocated for such trade operations, these are forced to occupy the main thoroughfares and thus cause major disruptions to the commuter and freight transport services that use those routes.

In Addis Ababa, the inability of local authorities to effectively regulate and manage these informal commercial activities along the roadsides exacerbated the congestion challenges.

i) Uncivil Driving Behavior

All these and more boil down to the uncivil behavior among drivers characterized by disregarding traffic laws and regulations which go a long way in aggravating the already bad traffic congestion (Arnott, 2001). Some common examples of such misbehavior include driving under the influence of alcohol, overtaking in prohibited areas, dropping off passengers on the road instead of at designated stops, neglecting road signs and markings, and making illegal U-turns.

Drivers in many developing cities often disregard the needs of other road users, catering to their convenience rather than the general efficiency of the transportation network. In cities such as Lima, for instance, some drivers will forcefully cut into intersections, blocking the passage of other vehicles, even though this exerts an enormous economic cost on others a cost many times greater than any time saved by the driver (Bull, 2003).

Similarly, the fact that buses, common in cities like Santiago, stop just before intersections makes congestion worse and increases the probability of accidents. Besides, the high number of taxis that do not work from ranks within city limits often cause traffic disturbance by slowly driving around streets in search of customers (Bull, 2003).

This uncivil behavior is particularly widespread in Addis Ababa, where the drivers of mini-bus taxis normally compete for passengers by stopping in the middle of the road, hence blocking and disrupting the flow of traffic, and thereby increasing congestion. Although there are fines on such conduct, the situation has not yet improved, hence there is a need to step up enforcement and behavioral change initiatives.

j) Poor Traffic Management

Among the major contributors to the chronic state of traffic congestion in developing countries is poor traffic management. Some factors that have been noted in different studies to exacerbate this problem include malfunctioning traffic lights, the absence of adequate road signs, and lack of effective enforcement of traffic laws (Jain et al., 2012). Furthermore, the existence of a few traffic police and a lack of facilities to tow disabled vehicles further exacerbate the challenges faced in managing traffic flow. Besides, most developing countries face economic constraints, which prevent them from acquiring modern technologies with resource requirements in managing traffics (Naz & Hoque, 2023).

With regard to Addis Ababa, some contributing factors to these problems are the lack of adequate road infrastructure and ineffective traffic light control at intersections, thereby causing substantial vehicle-minute delays (Sokido, 2024) . In proactive prevention of these problems, robot-based traffic signal management systems have been proposed to help improve the flow of traffic and alleviate the workload of traffic police (Najjar et al., 2022).

k) Insufficient Road Width

One of the major contributors to traffic congestion in a developing country, like Addis Ababa, is not having enough road capacity. Even if there is an increase in car ownership, proportionate development in the capacity of the transportation infrastructure for car accommodation doesn't take place. This is often met by financial constraints faced by the developing countries themselves (Duranton, 2023). With the increase in population and urbanization rates in Addis Ababa, there is a huge surge in travel demand; consequently, there is a discrepancy between the supply and demand of the transportation infrastructure. To be more precise, the outlets in the city have very narrow lane widths that cannot treat the increasing number of vehicles in an efficient way (Sokido, 2024).

Moreover, most of the road systems in Addis Ababa do not have adequate pedestrian facilities, which further increases the congestion problem. With such a small allocation of space to sidewalks and crossings, pedestrians are forced to share the already constrained road space with motorized vehicles, further impeding the smooth flow of traffic (Sokido, 2024). This mismatch between the growing travel demand and the inadequate road capacity is a significant contributor to the persistent traffic congestion challenges faced by Addis Ababa and other developing cities.

From observation, factors related to the poor design of roads and their maintenance can result in traffic congestion; for example, unmarked road lanes, sudden changes in the number of lanes, the stopping of random buses and other heavy vehicles at narrow streets, and inadequate alternative routes are other shortcomings that are able to obstruct the flow of traffic.

2.2.5. Measurements of road traffic Congestion

Although traffic congestion is one of the major concerns in transportation, the level of congestion on urban arterial roads is not measured and hence, addressed uniformly due to the fact that the concept of congestion does not have a standard framework, which leads to different methods of quantifying congestion either for larger areas or specific locations (Chakrabartty & Gupta, 2015). The degree of congestion varies widely among different metropolitan regions among specific locations, at different times of the week at each location, and at each time of the day in each place in response to unpredictable local circumstances. These include variations in weather, accidents, other incidents, and road construction. For example, in Addis Ababa the degree of congestion at the central city such as Mexico and Megenagna varies from the outlets Lekwanda, Ayat, and Kality. The central cities usually experience congestions due to road construction, accidents, and pedestrian movement during peak periods. Consequently, congestion in the outlets is due to heavy truck movement during early morning and late evening. So, there is no simple way to aggregate these variations into a single measure in the entire region for a given hour, day, week, month, or year. In commonsense terms, the traffic on any given artery can be considered congested when it is moving at speeds below the artery’s designed capacity because drivers are unable to go faster.

2.2.6. The Dimensions of Congestion

Travel time and delay are the foundation for congestion measurement, but many different measures are useful depending on the need. According to NCHRP (2008), four components interact in a congested roadway or system. These components are duration, extent, intensity, and reliability.

The four components and measurement concepts that can be used to quantify them are discussed below:

1. **Duration**. This is the length of time during which congestion affects the travel system.

2. **Extent.** This is described by estimating the number of people or vehicles affected by congestion and by the geographic distribution of congestion.

3. **Intensity**. The severity of congestion that affects travel measured from an individual traveler’s perspective.

4. **Variation**. This key component describes the change in the other three elements.

According to NCHRP (2008), the key takeaway from any examination of mobility and reliability metrics is that there are diverse applications and target audiences for these measures. No single metric can adequately address all the needs, and no single metric can capture all facets of mobility and reliability - there is no universal "silver bullet" measure that is suitable for every application or question.

There are many ways to quantify traffic congestion, some of which have been honed and thus become the norm for transportation agencies, while others have not because either the data costs too much to collect or the measurement hasn't gained wide acceptance (Bass, 2008). Besides, there are many other congestion metrics proposed by the research community that have not been in use or tested.

In 1992, a survey of more than 450 state, regional, and local transportation agencies was conducted to determine existing practices of defining and measuring congestion. Based on the survey results, Level of Service (LOS) is by far the most common measure of congestion. The second most used measure was Delay, which often was estimated by comparing actual travel speeds to desired free-flow speeds (Levinson et al. as cited in Lomax et al., 1997). whereas LOS (Level of Service) was widely used as a congestion measure, not many agencies considered it as the preferred method. On the other hand, there are many agencies that chose delay as a more appropriate parameter for the measurement of congestion.

Travel time measures, such as average speed and delay, are reported in the literature to be among the earliest and most commonly used methods. These travel time studies, conducted more than 60 years ago, aimed to assess system performance and identify area of delay.

According to Lomax et al. (1997) an ideal congestion measure should have the following characteristics:

1. Easy to understand
2. Provide a clear, unambiguous definition of congestion
3. Offer accurate and consistent descriptions
4. Able to assess both current and future conditions
5. Applicable across different geographic settings, time frames, and levels of detail
6. Usable for various urban travel modes, individually or simultaneously
7. Relatively inexpensive and easy to collect

When travel time-based measures are placed in the context of the evaluation criteria, they best satisfy the criteria. That is why in most situations, the use and presentation of congestion information are done in travel time-related quantities.

2.6.7. The Current Approach for Measuring Congestion

Lomax et al. (1997), summarized basic measures that can be calculated using travel time, travel volume, and roadway inventory data.

Aftabuzzaman (2007), identifies four broad classes of traffic congestion measures: basic measures, ratio measures, level of service and indices.

According to Afrin & Yodo (2020), measures of road traffic congestion can be categorized into five categories: speed, travel time, delay, level of services (LOS), and congestion indices

NCHRP (2008), categorizes the measures of road traffic congestion as time-related, volume measures, congestion indices, delay measures, and level of service (LOS) measures.

Some of the measures for measuring traffic congestion are discussed below:

a) **Time-related Measures**

Travel Time or Difference in Travel Time: the difference in travel time between modes, routes, and peak/off-peak periods are key congestion measures. They inform mode choice, travel patterns, and the integration of land uses. Travel time data can also quantify the economic costs of congestion (NCHRP, 2008).

Travel Rate: the travel rate, measured in minutes per mile, is the inverse of speed and a valuable congestion metric. Unlike speed, it is more intuitive for travelers and can be easily averaged and used in calculations. The standard deviation of travel rate can also indicate trip time reliability. Ratios of travel rate values may quantify congestion levels compared to acceptable standards (Lomax et al., 1997).

b) Delay Measures

Total Delay: The total delay in person-hours or vehicle-hours measures the sum of time lost to congestion in a transportation system or corridor. This is an all-encompassing metric showing the impacts of infrastructure improvement because it captures how the change in one segment affects the performance of the whole network. In economic and cost-benefit analysis, the major input is total delay, as this provides a measurable quantity of system-wide costs of congestion (Aftabuzzaman, 2007).

Total delay is a valuable congestion metric that can serve several purposes (Aftabuzzaman, 2007):

1. Estimating the overall duration and extent of congestion within an urban area.
2. Illustrating the systemic effects of major improvements to a specific corridor segment, as it impacts other connected elements.
3. Enabling economic and cost-benefit analyses to assess the magnitude and cost-effectiveness of mobility improvements.
4. It fulfills all the ideal congestion measure characteristics.
5. It can be used for several analysis levels such as Individual Locations, Short Roadway Sections, Long Roadway Sections or Routes, Corridors, Sub-Areas, and Regional Networks.

Note: that the Texas Transportation Institute (TTI) has been quantifying congestion levels in major U.S. urban areas by measuring total delay since 1982 (Aftabuzzaman, 2007).

Delay Rate: the delay rate, measured in minutes per mile, is the difference between actual and acceptable travel rates or times and reflects the time lost due to congestion. This measure can be used in assessing the performance of system operation with respect to expectations of standards and should lead to guidance in the prioritization of improvements to the infrastructure.

Relative Delay Rate: It is a dimensionless index of the relative delay rate that compares the level of congestion of various transportation facilities, modes, or systems with their respective mobility standards. It considers acceptable travel rates and allows more detailed assessment of congestion through a network, showing the importance of delay on different facility types.

Delay Ratio: a dimensionless measure, the delay ratio compares congestion levels between transport facilities with different operating characteristics. It quantifies the magnitude of mobility problems by relating the rate of delay to the actual travel rate rather than to some standard. In effect, this allows for more contextual examination of congestion across the network

c) Level Of Service Measures

The High way capacity manual (2010) defines level of service as a qualitative measure that describes the operational conditions within a traffic stream and how those conditions are perceived by drivers or passengers.

Level of Service (LOS) has long been a widely used measure of traffic congestion, representing a range of operational conditions. LOS is based on several traffic flow characteristics, including vehicle density, volume-to-capacity ratio, average speed, and maximum service flow rate, all of which vary depending on the facility type (Afrin & Yodo, 2020 and Aftabuzzaman, 2007). The LOS of a roadway can be evaluated precisely based on the volume-to-capacity ratio (V/C) with its scale intervals, as shown in the Table 2.2 (Afrin & Yodo, 2020, p. 7).

Table 2.2: Level of service based on the corresponding V/C ratio and operating conditions

Los Class	Traffic State and Condition	V/C Ratio
A	Free flow	0-0.60
B	Stable flow with unaffected speed	0.61-0.70
C	Stable flow with affected speed	0.71-0.80
D	High-density but stable flow	0.81-0.90
E	Traffic volume near or at capacity level with low speed	0.91-1.00
F	Breakdown flow	>1.00

The vehicle-to-capacity ratio can be calculated as;

$$V/_{C} = {}^{N_v}/_{N_{max}} \text{, where } N_{max} = \left({}^{L_s}/_{L_v}\right) * N_l$$

Where: Nv is the spatial mean volume, N_{max} denotes the maximum number of vehicles that a segment can contain as the capacity, L_s is the spatial segment length, L_v is the average vehicle length occupancy including safety distance, and N_l is the number of lanes.

Speed of Person Movement: The speed of person movement is a measure of transportation system efficiency, calculated as the product of passenger volume and average speed, usually expressed in person-miles per hour. Combining the desirable attributes of travel speed and person-moving capacity, this metric is useful in making comparisons of modal alternatives and infrastructure enhancements. However, the large numerical values make it difficult to interpret relative to a baseline or standard (Lomax et al., 1997).

Accessibility: measures the number of travel objectives, such as jobs, housing, or services, that can be reached within an acceptable time context, regardless of distance. The metric provides comprehensive assessment of the joint performance of the transportation system and land use pattern. The availability of transportation network data and relevant demographic information enables computation of accessibility—a useful tool in the evaluation of service quality and equity across modes (NCHRP, 2008).

Congested Travel: The total amount of person or vehicle travel that takes place under congested conditions is measured. It is measured by multiplying the length of each congested segment by the corresponding traffic or passenger volume and summing these for the entire transportation system. The metric gives an overall measure of the total travel affected by congestion, capturing both the spatial extent and the magnitude of the problem (Lomax et al., 1997).

Congested Roadway: the sum of the physical length of congestion on a transport network. Measured by adding up all lengths of congested segments either on roadways or transit systems (Lomax et al., 1997).

d) Volume measures

The availability of traffic volume counts and VMT data makes these measures useful for demand levels, usually measured as a V/C ratio. Although VMT is an essential input to air-quality analysis, it is not a good standalone congestion measure. Instead, congestion is more accurately measured using density, which combines both volume and speed for a specific roadway segment and is directly related to the freeway LOS.

e) Indices

Corridor Mobility Index: the corridor mobility index provides a more interpretable measure of transportation system efficiency by normalizing the speed of person travel against some standard value, say a well-performing freeway or arterial lane. This index will allow for the comparative evaluation of different transportation improvements both traditional capacity expansions and alternative treatments such as high-occupancy vehicle lanes. Such normalization is used to handle the large numerical values inherent in the raw speed of person movement metric (Lomax et al., 1997).

Researchers have developed several other types of congestion indices to measure and quantify traffic congestion. In his critical review on measuring traffic congestion, Aftabuzzaman (2007) identified various congestion indices developed by different researchers. These indices are summarized as follows in Table 2.3:

Table *2*.3: congestion indices used to measure traffic congestion

Index	Description
Congestion Index	Developed by Taylor (1992) and D'Este et al. (1999), this index is the ratio of link delay (the difference between actual and acceptable travel time) to acceptable travel time.
Travel Rate Index (TRI)	Reported in the Texas Transportation Institute's (TTI) 2005 Urban Mobility Report, the TRI compares travel conditions during the peak period to travel conditions during the free-flow period.
Congestion Burden Index	Developed by STPP (2001), this index is calculated by multiplying the TRI for each metro area by the percentage of the workforce driving to work.

Congestion Severity Index (CSI)	Originally developed by Lindley (1987) to measure freeway congestion in terms of total delay (vehicle-hours) per million vehicle miles of travel (VMT), this index was later modified by Turner (1992) to include principal arterial street delay.
Lane Mile Duration Index (LMDI)	Developed by Cottrell (1991), this index is the summation of the product of congested lane miles and congestion duration for all freeway segments, used to measure freeway congestion in urban areas.

Table 2.4: Summary of congestion measures

Travel rate	$= \frac{travel\ time (\text{min})}{segment\ length\ (mile)}$
Total delay	$=[actual\ travel\ time - acceptable\ travel\ time] * person\ volume * vehicle\ volume$
Speed of person	$=person\ volume * Avearage\ travel\ speed$
Corridor mobility index	$= \frac{speed\ of\ person\ movment}{normalizing\ value}$
Accessibility	$= \sum objective\ \ fullfilment\ opportunity\ (eg. job), where\ travel\ tin$ $acceptable\ travel\ time$
Congested travel	$=\sum[congested\ segment\ length * person\ volume]$
Congested roadway	$=\sum[congested\ segment\ length]$
Delay rate	$=[actual\ travel\ rate - acceptable\ travel\ rate]$
Relative delay rate	$=\frac{delay\ rate}{acceptable\ travel\ rate}$
Delay ratio	$=\frac{delay\ rate}{actual\ travel\ rate}$

Source; NCHRP, 2008 **and** Lomax et al., 1997

2.2.8. Economic Impact of Congestion

Business and local economies bear huge economic costs owing to traffic congestion in urban areas: fuel consumption increases, travel times get longer, and vehicle operating and maintenance costs rise (Falcocchio & Levinson, 2015; Jayasooriya & Bandara, 2017;Helmi & Wahab, 2023). It negatively impacts business productivity and market reach indirectly because of the agglomeration economies' weakening (Weisbrod et al., 2003). Such an impact of congestion varies by industry, depending on their reliance on skilled labour, access to transportation, and specialized inputs (Weisbrod et al., 2003).

A study done in 1995 by Cambridge Systematics (as cited by Bass, 2008), specified four primary costs of traffic congestion imposed on businesses: decreased accessibility by their clients, increased cost of employee's commute, higher delivery costs, and increased costs of receiving goods. The impact varies with type of business; retailers and urban-based office operations bear minimal costs while walk-in services and manufacturing experience moderate cost, and those most affected are field services, warehousing, and distribution since driving during peak hours comprise a large portion of their activities.

The global annual costs of road traffic congestion are substantial but vary significantly by region. In 2012, congestion costs reached around $121 billion in the United States. In 2015, the combined cost for Australian capital cities was $16 billion, projected to rise to $37 billion by 2030 (Hargroves et al., 2021) Estimates for the UK vary considerably from £2 billion to £20 billion a year, which reflect the differences in measurement and approach (Grant-Muller & Laird, 2007). Variations of this kind demonstrate the difficulty in measuring congestion cost, as it is a function of geography and measurement methods. In general, while congestion places high economic costs on many parts of the world, exacting precise costs remain tricky owing to the methodological hurdles outlined above and regional variations (Phillips, 2023).

Some studies have developed methodologies for measuring the costs, relating to factors such as loss of time, workforce productivity, and excess fuel consumption (Jayasooriya & Bandara, 2017). The knowledge of these impacts is instrumental in formulating effective congestion-reduction strategies and assessing urban transportation projects (Weisbrod et al., 2003). These impacts have been utilized and quantified in various regions, including Cairo, Toronto, and Mansoura, by using similar approaches; hence, it has a problem of a global scale (World Bank, 2013;World Bank, 2010;Gabr et al., 2018).

The review of the literature shows that traffic congestion might have a city's direct and indirect economic consequences. Some of the direct and indirect economic losses are discussed below:

2.2.8.1. Direct Congestion Cost

a) Travel Time Delay Costs

Travel time delay costs are one of the most prominent direct impacts of traffic congestion. These costs arise from the additional time commuters and drivers spend on the road due to slower speeds and traffic bottlenecks Weisbrod et al. (2003). According to Downs (2004), travel time delays are associated directly with economic losses since productivity will be reduced by extending the time required to commute to work or performing tasks dependent on transportation.

A comprehensive study by the World Bank (2010) on Cairo's corridors estimated that traffic congestion led to over 2.6 billion EGP in annual losses due to extended travel times. This cost was calculated by measuring the time lost during peak hours and converting this into economic terms using the Value of Time (VOT). Similar methodologies were applied in Gabr et al. (2018), which assessed the travel time delays on Mansoura City's main corridors, concluding that such delays significantly impact both personal and business productivity.

b) Vehicle Operating Cost Due to Delays

Another significant direct cost of traffic congestion is the increase in vehicle operating costs. Traffic congestion forces vehicles to operate inefficiently frequent stops, idling, and slow-moving traffic all contribute to higher fuel consumption and wear and tear on vehicles. According to Hemmerle et al. (2014) fuel consumption can more than double in congested city traffic compared to free-flow conditions.

The World Bank (2010) estimated that in Cairo, vehicle operating costs including excess fuel consumption totaled 2.85 billion EGP annually. The study emphasized that lower speeds increase fuel consumption, while frequent acceleration and deceleration during peak hours exacerbate vehicle deterioration, further increasing costs.

c) Excess Emission Cost Due to Traffic Delay

The other important direct cost is the environmental cost of traffic congestion. Increased fuel consumption due to congestion results in increased emissions of pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_2), and particulate matter (PM_{10}). These have very high social and economic costs since their effects contribute to air pollution, climate change, and public health problems.

2.2.8.2. Indirect Congestion Cost

a) Traffic Offenses Cost

Traffic Congestion can be a sure way to elevate simple traffic offenses to more serious ones, as drivers grow impatient or frustrated with delays and then speed, run red lights, or make illegal lane changes. Other indirect economic impacts associated with fines, legal fees, and insurance premiums come from accidents and injuries. In Cairo, World Bank (2010) linked traffic congestion to an increase in traffic offenses, which even increased the economic cost in terms of fines and accidents. As reported by the Ministry of Transport and Logistics (as cited by solomon, 2024), more than 2,017,930 drivers were fined in Addis Ababa in the year 2023 with the total offense cost of more than 1,129,500,000 Ethiopian birr. This shows the serious problem of traffic offenses in Addis Ababa, indicating the indirect economic effect.

b) Waiting Time Delay Cost

Waiting time delays include the time passengers and drivers spend waiting inside the vehicles while congestion occurs at the junctions or at traffic lights. This is more costly for public transport users and drivers whose livelihood is affected by the timeliness of their operations, like taxi drivers or delivery services. Weisbrod et al. (2003) estimated that waiting time delays contribute to significant productivity losses in major metropolitan areas. In the Mansoura study, Gabr et al. (2018) measured waiting for time delays based on field data and surveys, showing that congestion at bus stops and traffic signals led to annual economic losses of several million Egyptian pounds due to waiting time delays. The situation in Addis Ababa is worse where there is a lack of enough public transportation, making passengers spend much time waiting for vehicles arrival.

c) Vehicle Maintenance Cost

Traffic congestion also leads to increased costs in vehicle maintenance, since the stop-and-go nature of congestion results in greater wear on vehicles. More frequent braking, accelerating, and idling, due to congestion, put increased wear on vehicle parts such as brakes, tires, and engines. Litman (2013) revealed that during peak periods, maintenance costs were approximately 15 percent higher than under free-flow conditions. This is evidenced by the World Bank (2013) in Egypt, which shows that vehicles have considerably higher maintenance costs if they are driven in congested areas. For example, in Mansoura, the maintenance costs of Minibusses and Taxis were estimated to be 20-30% higher during peak periods compared with free-flow periods Gabr et al. (2018). The study also found that the annual vehicle maintenance cost due to congestion was in the millions of Egyptian pounds for different modes of transport.

2.2.9. Social Impact of Congestion

The social impact of congestion varies in its entities and dimensions of negativity, especially to road users, and further affects quality of life. Traffic congestion results in longer travel times, frustration, stress, loss of productivity, and a decline in income. Work commuters are found to have increased anger and frustration, resulting in high to extreme levels of stress among all segments of society. The social impacts also go further in terms of health because increased exposure to traffic congestion contributes to increased stress-related diseases (Fattah et al., 2022).

2.2.10. Environmental Impact of Congestion

As confirmed in the literature review, traffic congestion has major effect on the environment because of the increase in vehicle operation. Idling and stop-and-go driving, common in congested areas, result in higher emissions of harmful pollutants, contributing to smog, respiratory problems, and climate change. Congestion leads to increased fuel consumption, exacerbating greenhouse gas emissions, mainly carbon dioxide, which is one of the major contributors to global warming (Zhang, 2011). Congestion also brings about noise pollution, which is a danger to human health, and contributes to water pollution by increasing road runoff. In addition, congestion often brings about urban sprawl, transforming natural habitats into urban development and fragmenting wildlife corridors, which all diminish biodiversity.

2.2.11. Congestion Mitigation Strategies

According to Isa et al. (2014), “Traffic congestion relief is a process to mitigate the traffic towards less congested area with the objective to lessen the effects of traffic congestion.”

Transportation engineers and planners have developed a variety of strategies to deal with congestion. These fall into three general categories:

2.2.11.1. Adding More Capacity

Expanding highway infrastructure and enhancing transit and freight rail services can involve increasing the number and width of highways, as well as redesigning bottlenecks like interchanges and intersections to boost their capacity.

Traditionally, adding lanes to existing highways and constructing new ones has been the main strategy to address congestion. However, in many metropolitan areas, major highway expansions are becoming more challenging due to funding limitations, rising right-of-way and construction costs, and opposition from local and national organizations (Cambridge Systematics Inc. and Texas Transportation Institute, 2005).

Increasing road capacity would decrease the overall traffic congestion in the short term. However, this outcome must be taken with care since increasing all road capacities by 50% may not be economically viable (Gachanja, 2015). Some strategies related to adding capacity are discussed below:

a) Bottleneck Reduction/Removal

This strategy includes widening and reconstructing the main travel lanes and interchanges and metering, or ramp closure, ramp widening, Improvements along arterial streets include simplification of intersecting flows, new controlled-access bypass routes around congested business centers, and grade separation.(Bhargava et al., 2006)

b) Intersection Improvements

Intersection performance can also be improved by reconfiguring signal phasing, adjusting cycle lengths, and coordinating timings, among other strategies. Sometimes the geometry of an intersection can be changed by adding lanes, widening, or realigning the median. If adding lanes isn't possible, then building an underpass or an overpass can help reduce traffic at the intersection in front of the development. Moreover, there might be a need to install traffic lights at intersections formerly without them, to handle the increased flow of traffic emanating from the place (United Nations ESCAP, 1999).

Congestion can often be alleviated by minimizing conflict points through the addition of turning lanes within the current roadway width, restricting turning movements, or converting streets to one-way traffic.

c) Street Connectivity/Continuity Improvements

Straight connectivity, spacing, and continuity refer to improving how well roads are designed and linked together (Cambridge Systematics Inc. and Texas Transportation Institute, 2005).

Straight connectivity improvement refers to redesigning roads in a way that allows for direct routes between key points. This eliminates unnecessary diversions or zigszags, thus making traffic flow smoothly. The intersections, exits or entry points on the road should be in acceptable distance apart. If they are too close, then traffic tends to build up, and if the spacing is well done, vehicles get more time and space to spread out. On the other hand, Continuity is about the roads having no sudden stops or breaks. That includes ensuring roads are consistent and do not suddenly change in design or capacity, which confuses drivers and slows traffic.

d) New Roads and Roadway Widening

Traditionally, traffic congestion issues have been addressed by increasing capacity through road construction and widening. Road construction and widening for general-purpose use are commonly carried out in regions with rapid population growth. This typically involves building new freeways and arterial roads or adding lanes and shoulders to existing ones. Such strategies are often applied in areas where land for highway expansion is more accessible (Cambridge Systematics Inc. and Texas Transportation Institute, 2005). However, in densely populated metropolitan areas, physical and environmental constraints often restrict significant new road construction opportunities.

This strategy is more effective than others; however, its impact on the environment and existing facilities can be a disadvantage. For example, in Addis Ababa, the corridor development project has led to the destruction of historic commercial and recreational buildings and sites. This was due to a lack of long-term planning in the early design stage of the city. Research in the Nairobi Metropolitan Region showed that adding road capacity will reduce congestion by 50% (Gachanja, 2015).

e) New Capacity Strategies for "Priority Vehicles"

For several years, capacity expansion strategies for "priority vehicles" lanes, which include Managed Lanes (HOV, HOT, Express Toll), truck-only Lanes, and Intermodal Access Roads, have been used in response to congestion.

Managed lanes on freeways and arterial roads are most effective in areas with heavy traffic congestion, where the road design allows for necessary adjustments. Heavy occupancy vehicle lanes are reserved for the exclusive use of multi-occupancy vehicles. HOVs are usually defined as including buses, vanpools, and carpools. and Its objective is to reduce single-occupant vehicle use to improve travel time. High Occupancy Toll (HOT) lanes impose variable tolls based on traffic demand to ensure smooth traffic flow. For example, vehicles with one or two occupants pay a fee to use the lanes, whereas vehicles with many passengers use the lanes for free. Value Pricing/Express Toll Lanes exist in regions where traffic congestion is a reality. In this method, additional lanes are put into operation for vehicles that pay a fee, with the fee being varied such that a target traffic speed is maintained (Meyer, 1997).

On the other hand, truck-only lane facilities enhance safety by keeping cars separate from trucks in high-traffic truck corridors. They also offer flexibility and redundancy, allowing for traffic rerouting in case of accidents or other disruptions on a roadway.

2.2.11.2. Operating Existing Capacity More Efficiently

These strategies, also called adaptation strategies are getting more out of what we have. Here the philosophy is to mitigate the effects of a wide variety of roadway events and to manage short-term demand for existing roadway capacity.

Traffic operational improvements that increase capacity include parking restrictions, signal timing, and signal coordination improvements, turn restrictions at key intersections, one-way streets, reversible commuter lanes, movable median barriers during peak periods, better lane striping, managing road access to and from traffic generators, etc. They also include the application of advanced technologies that use real-time information on traffic conditions to implement dynamic traffic control strategies that optimize traffic flow and provide travelers with real-time information on traffic conditions.

a) Traffic signal timing and coordination

Traffic signal timing and coordination is a fundamental strategy for mitigating congestion, particularly in areas with heavy traffic. According to the Federal Highway Administration (1997) , ineffective signal timing contributes to significant delays. By optimizing traffic signal operations such as adjusting cycle lengths, minimizing phases, and coordinating signals along roadways cities can reduce stops and delays, enhancing overall traffic flow. Implementing these measures not only improves travel efficiency but also promotes safer pedestrian crossings and better transit operations, ultimately leading to a more effective transportation system.

b) Curb Parking and Loading Zone Management

Parking management involves a jurisdictional strategy for providing, controlling, regulating, or restricting parking spaces (Meyer, 1997). by implementing restrictions on curb parking during peak traffic periods, cities can quickly alleviate congestion at minimal cost. These restrictions can free up valuable roadway space for vehicle movement, enhancing overall traffic flow (United Nations ESCAP, 1999). while designating midblock locations for loading and unloading can further reduce disruptions. Effective enforcement of these measures contributes to improved travel efficiency and reduced delays, making curb parking management a crucial element in urban traffic management.

c) Intersection Turn Controls and Management

Intersection turn control and management are some of the important strategies in congestion mitigation, especially at busy intersections where left and right turns can significantly disrupt traffic flow. Reversible turn restrictions or re-routing could help cities reduce delays and gain justified improvement in overall efficiency. Prohibiting left turns simplifies traffic signal phasing for shorter cycle lengths and thus more green time for through traffic, which increases roadway capacity. Similarly, traffic control at right turns in high pedestrian areas can also decrease congestion (Cambridge Systematics Inc. and Texas Transportation Institute, 2005).

d) One-Way Streets

One-way streets are a very potent tool for congestion mitigation, increasing both traffic flow and safety in an urban setting. More than likely, the elimination of conflicts with oncoming traffic and the simplification of signal phasing will result in significant delay reductions and increased travel speeds. They allow for better signal progression, where signals can be coordinated and managed more effectively. Furthermore, the design creates more space for the placement of signals without affecting traffic flow adversely (Shi et al., 2009). The overall outcome is a reduction in crashes and emissions and safer pedestrian crossings because of less confusion in traffic movements. Though there are some disadvantages to one-way streets, like increased travel distance and possible driver confusion, one-way streets are beneficial, and their advantages make them an adequate measure to deal with urban congestion.

2.2.11.3. Demand management

This strategy is often referred to as "transportation demand management" (TDM). It promotes travel and land use patterns that put less congestion-generating pressure on the system. The typical aim of TDM is a reduction in vehicle miles of travel (VMT) in order to keep congestion at manageable levels. It promotes alternative driving and reduces driving by taking away motorists' perks. For instance, making people pay for parking instead of making it free is a disincentive to remove a subsidy that accommodates drivers. It helps to level the playing field for transportation options and lowers overall use of vehicles (Litman, 1999).

a) Direct Demand Strategies

Direct demand strategies aim to alter traveler behavior by implementing policies that use pricing or regulatory measures.

I. Pricing strategies for Roadways

Congestion pricing is a strategy to reduce traffic demand during rush hour by charging a fee (or toll) to road users, with higher rates imposed during periods of heavy congestion, typically in the morning and late afternoon. However, if road pricing is applied to only one roadway, it may cause traffic to shift to alternative routes, potentially increasing congestion on other roads. Additionally, only licensed vehicles are allowed on the roads, which helps ensure that the number of cars does not exceed road capacity, mitigating negative effects (Issa, 2014). according to Wachs (2002) Economists have long argued that the only way to completely solve the congestion problem is through congestion pricing. Despite being proposed as an economic solution to combat urban traffic congestion on numerous occasions, widespread implementation of congestion pricing has been limited due to uncertainties surrounding its potential impacts (Zheng, 2008).

II. Regulatory Restriction on Car Use

Vehicle restrictions include various regulatory strategies that limit automobile travel at a particular time and area. Issa (2014) stated that effective vehicle restrictions can reduce traffic congestion, road and parking facility costs, pollution emissions, crash risks, and local environmental impacts. They can also have a positive impact on safety.

For example, truck use restrictions, i.e., prohibiting trucks from using congested streets in city centers reduce congestion but may constrain essential commercial vehicle access. Additionally, restricting peak-period truck use of freeways could reduce freeway congestion but it could add trucks to local streets. This strategy is currently applied in Addis Ababa during peak hours.

b) Indirect Demand Strategies

I. Parking Use Regulation

Parking management is the comprehensive control of the location, quantity, price, and availability of parking. Effective parking management reduces conflict points within the site and also reduces the accumulation of vehicles at access points besides, the provision of adequate signs is valuable in managing vehicles in the parking area (United Nations ESCAP, 1999). Parking supply and demand strategies include;

limiting and controlling parking: A strict prohibition on-street parking can mitigate congestion by clearing sidewalks and roadways, making more space for pedestrians and vehicles (Hoang & Hiep, 2013). Aggressive enforcement measures, such as the revocation of parking permits and fines for violations, may immediately yield an improvement in traffic flow. However, if adequate parking facilities are not developed to correspond with demand, the use of roadways and sidewalks for parking may lead to inadequate space availability, which exacerbates congestion where there are parking restrictions.

Providing preferential parking spaces for high occupancy vehicles: Some parking spaces are reserved as incentives for carpool and vanpool riders to encourage shared rides rather than single-occupancy vehicles (SOVs) (Litman, 1999). The effectiveness of this strategy can vary. Rideshare vehicles may be charged reduced rates or no parking fees at all, while SOVs are charged regular fees. This price differential may be effective only if the price structure makes a difference in travelers' decisions and if the overall effect of carpooling is to reduce traffic congestion.

Establishing pricing incentives: This approach provides the cash equivalent to commuters of free parking if they do not drive (Litman, 1999). In the study, it is shown that this practice may decrease automobile commuting between 10-40%, while promoting equity by offering non-drivers benefits afforded to drivers. Since parking subsidies are tax deductible but cash payments are not, this approach can even increase tax revenues accruing to local governments.

II. Improving Public Transport

The promotion of modal shift aims at attracting travelers from private vehicles to public transport by upgrading the required infrastructure, such as increasing the number of public transport modes (Hoang & Hiep, 2013). This approach focuses on making public transport more attractive and hence upgrading transit stations, designing efficient routes from suburbs to the central business district and creating park facilities near transit stations to accommodate urban travelers using public transport.

III. Bicycle and Pedestrian Improvement

Improvement in bicycle and pedestrian facilities is a good strategy for congestion reduction by promoting alternative modes of transportation (Hoang & Hiep, 2013; Litman, 1999). Infrastructure developments like sidewalks, crosswalks, car-free malls make the environment for pedestrians more safe and attractive. Meanwhile, improvements in cycling facilities, such as dedicated bike lanes and secured parking, raise the number of people who cycle for short trips and reduce the rate of car dependency. Bicycle transportation effectively replaces short-distance auto trips, and this helps to alleviate traffic congestion. Designs that are pedestrian-friendly, coupled with traffic-calming measures, can further reduce vehicle speeds and volumes, enhancing safety and accessibility.

IV. Increasing Fuel Price

Increases in fuel prices could actually alleviate traffic congestion. As cited in Issa (2014) an INRIX study in 2008, which had analyzed the impact of increases in fuel prices on vehicle travel in the U.S., concluded that there had been a noticeable decline in vehicle miles traveled and highway congestion as a result of the striking increase in the price of gasoline during the first half of that year. More specifically, the national Travel Time Index dropped 3% as the average fuel prices went up by 28%, indicating better traffic flow. This would also mean that increased fuel costs can actually reduce frivolous driving as commuters seek alternative transportation modes, which would eventually ease road way congestion.

V. Distance-based Fee

Distance-based fees, also commonly known as "pay as you drive," are one of the most effective strategies used in congestion mitigation since it creates a financial incentive to reduce driving. Unlike traditional road pricing, which targets specific highways, distance-based charges apply to all travel and help to reduce congestion on surface streets without simply shifting traffic to other routes. Not only does this approach bring accuracy in the insurance prices of the vehicle, but it also makes it inexpensive while encouraging efficiency in the economy as well as a reduction in insurance claims (Issa, 2014). Through discouraging excessive travel by vehicles, distance-based charges can result in fewer crashes and emissions and substantial reductions in traffic congestion and associated road and parking facility costs. Generally speaking, this policy encourages more sustainable transportation behaviors while improving the general conditions of traffic.

Apart from the above mitigation measures, studies have recommended such demand management measures as controlling on- and off-street parking, staggered working, school, and business hours, car sharing, and discouragement or banning of the use of particular types of vehicles during peak hours, apart from the use of traffic simulation software packages (Muslih et al., 2023).

2.3. Empirical Review

This empirical review covers recent research on traffic congestion, with an emphasis on those works that have investigated the economic impacts of congestion in a variety of urban contexts. It draws together the main findings from these studies, exemplifying relevant methodologies, data sources, and key insights into the drivers, measurement, economic consequences, and mitigation of congestion.

2.3.1. Congestion as a Global Issue

Traffic congestion in roads has become a global scourge, developed countries included. Since the early 1990s, road traffic and transport demand are found increasing rapidly, resulting in serious congestion, delay, accidents, and environmental problems, especially in large metropolitan cities (Bull, 2003).

Traffic congestion varies across countries and cities around the world for many different reasons. Various studies have shown that congestion in road networks is an issue that affects most parts of the globe, and expanding road capacity does not always seem to be the right solution to traffic congestion (Anupriya et al., 2023). Various variables, including per capita income and population density, have been found to correlate with congestion levels, thus indicating the strong relationship between economic conditions and traffic patterns (Nair et al., 2019).

According to Downs (2004) congestion in large and growing metropolitan areas is a chronic problem throughout the world. The study states that, as populations and wealth levels tend to rise over the coming decades, it will probably worsen regardless of the public policies or private actions instituted around the globe to try to reduce congestion. A good example is that the world's most extended traffic jam ever happened in Beijing, China on August 14, 2010. It lasted for 12 days and extended over a length of more than 100 km. This unprecedented traffic jam is explained by a combination of factors, such as road maintenance work, a huge increase in the number of heavy trucks on the road, and accidents (Wikipedia, 2024).

In the past few years, there has been a notable increase in efforts to deal with traffic congestion by focusing on livability and sustainability (Munnich & Lee W, 2010). Various solutions have been visited to find a way out of this problem by addressing congestion pricing, traffic signals control, turning restrictions, and traffic routing (Isa et al., 2014).

Scholarly research puts an emphasis on the use of advanced modeling techniques, in-depth studies of public perception, and interdisciplinary collaboration as the proper ways to effectively address congestion (Singichetti et al., 2022; Tadić, 2022; Wachs, 2002). Moreover, the integration of artificial intelligence (AI) and machine-learning algorithms within traffic prediction models, along with the use of graph-based traffic simulations, now shows other promising ways to correctly estimate congestion levels and find congestion-free road networks (Singh et al., 2023).

From this, it can be understood that traffic congestion is a significant global challenge affecting economic productivity, environmental sustainability, and quality of life. Therefore, not only individual countries but also the global community must emphasize this issue.

2.3.2. Road Traffic Congestion in Developing Countries

This is evident with the increased frequency of road traffic congestion in developing cities, which is attributed to the steady rise in car ownership, where the number of vehicles exceeds the road capacity. Other causes of congestion in these areas include various forms of bottlenecks: merging or weaving areas, on-ramps, road traffic crashes, and construction works that disturb the smooth flow of traffic. The consequences of congestion in these areas have a much wider scope than mere delays, including environmental pollution, noise pollution, and frustration for motorists and commuters, apart from potential health implications (Ackaah, 2019).

Furthermore, the traffic systems' management in most third world countries is not effective. This is partly inherent due to the diverse mix of traffic, the lack of appropriate planning and implementation skills, as well as the low status of traffic management within city bureaucracies (Gwilliam, 2003).

2.3.3. Empirical studies

A study by Tazzie (2022) gives the most relevant insight into causes, intensity, and economic effects of traffic congestion in Addis Ababa. The study, which has been conducted recently on the Ayat-Mexico Road corridor, has found a high intensity of congestion during peak hours caused by poor traffic management, job centralization, intersection bottlenecks, inadequate public transport, and on-street parking. The study used a survey of 384 passengers and interviews with transport authorities, using descriptive statistics to analyze the data. The study established that congestion has a significant effect on economic productivity, increased fuel consumption, increased costs of vehicle operation, and delayed delivery of cargo.

The study by Gunjo et al. (2024), focusing on the drivers' and passengers' perception of the socio-economic impacts of traffic congestion in Addis Ababa, identified main socio-economic impacts perceived by respondents, such as reaching late to work, increasing travel time, and higher chances of accidents. Drawing on a survey of 3240 people, and using a generalized ordered logit model on the data, it finds perceived impacts to be related to the demographics of age, income, household size, gender, and education. While this study has not directly measured the level of congestion nor quantified its economic impacts, it points out the strong perception of such impacts among the population, bringing into focus a strong need for comprehensive mitigation strategies that will address the perceived consequences of congestion in Addiss Ababa.

In another study, Gunjo et al. (2024a) estimated the economic cost of traffic congestion in Addis Ababa through a case study of nine road segments using data from 3240 participants. The study estimated economic costs for travel time delay, vehicle operating costs, and time unreliability, and found that the total annual cost falls between 696.6 and 806.3 million Birr. This study has provided a framework through which congestion levels could be measured and economic impacts estimated using rigorous statistical modeling. This study has determined traffic volume, number of lanes, segment length, and income as significant factors that influence individual congestion costs.

The study conducted by Sokido (2024) employs a comprehensive methodology to measure congestion levels at specific intersections in Addis Ababa, utilizing a combination of quantitative and qualitative data collection methods and utilizing parameters such as travel time, traffic volume, and delay rates, which collectively indicate a substantial total vehicle-minute delay of approximately 12,708 vehicle-minutes. The research identified a significant influx of vehicles, inadequate public transportation, and subpar traffic management systems as contributing factors to congestion.

Guta Alebe et al. (2024)) try to trace the causes of traffic congestion in Addis Ababa, directly focusing on the Torhayloch–Mexico Street Corridor. This study has adopted both primary observation and secondary data analysis, where spatial data analysis through GIS technology helped in pointing out factors causing congestion. On-street parking is shown to be one of the major causes of congestion; mapping showed areas where parking hindered traffic flow. It also helped in land-use pattern analysis, shedding light on the contribution of commercial and business activities to traffic congestion within the area.

Guta Alebe et al. (2023) appraises the performance of supply-side interventions on traffic congestion in Addis Ababa with a focus on the Torhayloch – Mexico Street Corridor. The research design followed a descriptive approach while analyzing the annual average daily traffic volume using volume-to-capacity ratio as one of the parameters to measure congestion. The findings showed that even though there was spare road capacity, the corridor still experienced congestion daily. That gives evidence that part of the problem lies beyond the road capacity. That runs against the conventional wisdom that the solution to traffic problems lies in building more roads and points at other forms of intervention, such as improving public transit, traffic management strategies, and ensuring safety for pedestrians and cyclists.

Vencataya et al. (2018) investigated the causes and effects of traffic congestion in Mauritius by adopting a mixed-method approach. They designed a closed-ended questionnaire and administered it to workers in Ebene and Port Louis. Respondents strongly agreed that bad road conditions and insufficient infrastructure are the major causes of congestion. The research also indicated that congestion has spillover effects on fuel consumption, air quality, late delivery of goods, accidents, response time of emergency vehicles, and thus society and the economy.

Chakrabartty & Gupta (2015) estimated the congestion cost in Kolkata, India, by using a methodology adapted from Smeed's approach (1968). Their results state that exponential growth of vehicles as a consequence of urbanization has led to serious traffic congestion. Increased operating cost, delays, pollution, and stress to the commuters are some of the other consequences associated with traffic congestion. The researchers pointed out that there was an anomaly in road space between Kolkata and other major cities in India, showing the dire need for effective congestion management strategies; as per the study, 74,077.66 Indian rupees get lost in a mere two hours on selected roads. Although this study was conducted on Kolkata, the findings in relation to the economic impact of congestion, such as increased operating costs and reduction in productivity, are still within the parameters of the current research objectives to estimate the economic impact of congestion in Addis Ababa. The study has indicated the requirement for pro-active steps to be initiated with a view to mitigating congestion through better infrastructure, public transport initiatives, and congestion charging mechanisms.

Rajbongshi (2020) analyses the effects of traffic congestion in Shillong city, India, on private individuals, taxi drivers, and businessmen. Through an analysis employing the t-test of data derived from a structured questionnaire, the study shows that congestion has significant negative impacts on travel time, fuel expenditure, and net profit for all three groups. Congestion increased travel time and fuel costs for the private car owners, translating to more burdensome expense. For the taxi drivers, the number of trips decreased along with the net profit. This caused many businessmen not to be able to start their activities in time, which impacted the profit negatively. The study gives reason for addressing traffic congestion as the key to improving individual experiences and fostering economic growth and sustainability in Shillong.

According to Marafa et al. (2023) the economic implication of road traffic congestion in Kebbi State, Nigeria, was assessed utilizing a descriptive survey research design with a sample size of 350 respondents. According to the study, road traffic congestion had a negative impact on the state's economy by reducing economic productivity, increasing fuel consumption, transportation costs, and vehicle maintenance expenses. It also reduced the monthly incomes of laborers and businesses and caused psychological stress. The study has shown the requirement for infrastructure improvements, policy interventions, and traffic management strategies by the government to solve congestion and increase the efficiency of the economy.

Estimation of the economic impact of traffic congestion in Mansoura city was conducted by Gabr et al. (2018). The research used a mixed-method approach: a traffic questionnaire and field observations to calculate travel time delay costs, excess fuel consumption costs, and excess emissions costs. Their results showed that annually, congestion costs about 184.5 million Egyptian Pounds, where direct congestion costs constitute 59% of this amount. The largest part of these costs was the recurring and non-recurring travel time delay, vehicle maintenance, and waiting time delay. The study places particular emphasis on the fact that accurate estimation of congestion costs depends upon a variety of factors including traffic volume, speed, and road design.

According to Annan et al. (2015) the impact of traffic congestion on energy consumption and productivity in the workforce was assessed in a developing country. This study has adopted a quantitative method using a structured questionnaire and statistical analysis. From the revealed results, it was established that there was a positive relationship between private car usage and traffic congestion. It also showed that high levels of traffic congestion bore a positive relation with increased fuel consumption, which underlines the impact of congestion on energy use. This study is very important, as it provides insight into the possible limits of mass transportation in congestion mitigation and the requirement for sustainable transport policies necessary for a reduction in energy consumption.

According to the research conducted by Helmi & Wahab, (2023) concerning the impact of traffic congestion on road users in Palembang City in Indonesia, the descriptive analysis used a technique that is quantitative in nature, and a survey was conducted with 114 respondents. The study revealed that a high percentage of respondents agreed or strongly agreed that traffic congestion has negative effects on the economy, social aspects, and the environment. Specific impacts included the reduction in income from wasted fuel, decreased economic benefits because of time wastage, mental health issues, and environmental pollution. The study estimates that drivers have an average 10% increase in fuel consumption due to congestion, which means an extra Rp. 15,000 per week or Rp. 720,000 a year for an average driver. The total economic losses due to congestion in Palembang City from fuel consumption were estimated at a large amount, reaching Rp. 373,749,840,000 per year. The result of the study concerning the financial loss of extra fuel consumption and social effects of stress and frustration yields important information about the extent of congestion.

Harriet et al. 2013) noted traffic congestion in Kumasi, Ghana, and its impacts on productivity among workers using a survey approach. Findings were that congestion drastically reduced the number of trips and income earned by mini-bus and taxi drivers within the informal sector. The study also found that, in the formal sector, congestion resulted in commuters spending most of their time on the road and thereby losing an average 9% of productive hours per day.

Somuyiwa et al. (2015) conducted a study on the impact of traffic congestion on worker productivity in Lagos, Nigeria, using a multi-stage sampling technique coupled with the use of multivariate regression analysis. The study found a significant negative relationship between the distance covered, time spent in congestion, and commuting costs with workers' productivity. In particular, the longer distances beyond 20km and lateness of 90 minutes significantly reduce productivity.

One study on traffic congestion in Beijing, China, was carried out by Song et al. (2019) The research used a multi-source data fusion approach, integrating real-time traffic data, remote sensing data, and social sensing data, to map spatiotemporal patterns of congestion and associated factors. According to this study, there are six clusters of distinct traffic congestion patterns during weekdays. The most congested periods were the morning and evening peaks. Key results are the strong effects of building height and land-use interaction, public facilities, and road network density on congestion patterns. Those insights, from the complex interaction between urban form and traffic congestion, with special emphasis on mixed land use, microenvironment design, and connectivity of road networks, provide a crucial context for developing strategies related to congestion in Addis Ababa.

Bao et al. (2022) conducted a study on traffic congestion in Xining, China, by using a social-sensing hyperlocal travel data and multivariate least-square regression analysis method to research the spatial-temporal patterns of congestion and recognition of land use factors that add up to congestion. The work presented clear peaks of traffic on weekdays and pre-weekends, while education land use and residential areas contributed most to traffic congestion. Above all, such a study really drives home the importance of considering temporal factors in the development of evidence-based strategies to mitigate congestion in specific areas.

In one quantitative research by Prasad et al. (2017)), the author assessed the economic impact of congestion on an arterial route in Rajam, India. The results established that the average delay per vehicle was found to be roughly 0.83 min/trip, while the direct cost of traffic congestion was a sum equivalent to 40,586 Indian rupees per day. All these costs have been estimated in the study by considering the opportunity costs, vehicle operating costs, and wear and tear expenses. This study epitomizes the very large economic burden that traffic congestion places on local communities, hence there is an urgent need for effective traffic management strategies and infrastructure improvement.

Weisbrod et al. (2003) examined the economic impacts of urban traffic congestion on businesses in Chicago and Philadelphia with a statistical modeling approach. The study result indicated that congestion tends to impact businesses very strongly in terms of reduced market areas, lower productivity levels, and higher production costs. It also showed different industries have different elasticities with regard to congestion costs depending upon their specialization of inputs. The importance of considering impacts on business operations from congestion and potential benefits from strategies to reduce congestion is emphasized in this study.

Rahman et al. (2022) used a structural equation modeling framework to study urban traffic congestion in the United States and found some important factors causing congestion, including urban population size, income, and employment agglomeration. It also, however, found tempering effects of congestion due to the self-regulation impact of congestion, non-car mode choice behaviors, adequate highway infrastructure, focused community structures, urban density, and socioeconomic factors like car ownership. The emphasis of the study is on considering a comprehensive set of urban factors and implementing integrated policies for effective treatment of congestion.

Sweet (2014) investigated the economic impacts of traffic congestion on regional employment growth and productivity per worker in 88 U.S. metropolitan statistical areas (MSAs). This article pursued a quantitative research design and a panel data approach, in which econometric modeling was employed to establish correlations and causal relationships between congestion and economic indicators. The results indicated that traffic congestion has a negative impact on regional employment growth and productivity per worker, which means that increased congestion implies higher transaction costs and reduced economic efficiency. The results show a non-linear relationship between congestion and employment growth. For levels of delay above about 35-37 hours per auto commuter and 11,300-11,400 average daily traffic (ADT) per freeway lane, greater congestion is related to slower growth in employment. On the other hand, the impact of congestion on productivity growth per worker seems to be linear: an increase in ADT per freeway lane slows productivity growth. The research also underlines the importance of integrating transportation planning with economic development strategies for sustainable growth.

Struyf et al. (2022) tried to quantify the different congestion cost components within Flanders, Belgium, using a modular model approach for each of the transport scenarios covering freight, commuting, and leisure. The model has taken into consideration not only the direct costs such as time delays and fuel consumption but also indirect costs associated with congestion, including environmental externalities related to emissions and noise pollution. The study indicated excess demand for road space, insufficient infrastructure, and a rising number of vehicles as the major cause of congestion in Flanders, which caused costs to rise abruptly, especially during peak hours. The biggest contributors to this were time delays and fuel consumption. This single congestion event was estimated to cost €216,563.67 in total. The study also found evidence of a decrease in average travel speeds during peak hours and forecast a 29% decrease across Europe by the year 2030. More often than not, the external costs of congestion notably time delays and operational expenses are not accounted for in transport pricing, and as such, congestion has an even greater economic burden.

A World Bank (2013) study on the economic cost of road traffic congestion provides an in depth empirical review of traffic congestion in GCMA, noting peak traffic volumes during morning and evening rush hours with significant congestion on major corridors such as the 6th October Bridge and the Ring Road. The study has estimated the direct economic cost of travel time delays, unreliability, excess fuel consumption, and CO2 emissions using both quantitative and qualitative methods. The study indicates that economic congestion costs an estimated $2,442.6 million annually attributed to travel time delays, $1,525.8 million attributed to travel time unreliability, $1,093.6 million attributed to excess fuel consumption, and $63.3 million attributed to CO2 emissions, adding up to the total of $2,846.5 million indirect costs. It is also replete with information on what causes congestion: vehicle breakdowns, random stops, and poor traffic management. These results provide an essential baseline that helps develop targeted policies and interventions aimed at mitigating traffic congestion in Cairo. This study, therefore, in estimating the economic burden of congestion, will help frame a methodology for estimating the economic impact of congestion in Addis Ababa.

In an effort to mitigate traffic congestion El-Kadi (2013) brings a host of strategic recommendations applicable to Addis Ababa. The study suggests developing a better level of public transport systems as the principal solution to congestion, whereby expanding and modernizing the bus system and introducing park-and-ride facilities would allow the use of public transport over private vehicles. Furthermore, stricter traffic management policies, especially enforcement of traffic rules and regulations by setting up dedicated lanes for public transports, will go a long way in easing congestion and improving the flow of traffic. The study provides momentum to develop infrastructure for pedestrians safe crossing points, walkways to make non-motorized transportation modes more popular and reduce dependence on personal vehicles. Taken together, these measures are not only expected to reduce congestion but also the attendant economic effects since in Cairo, the costs of traffic inefficiencies are estimated to account for about 4% of the GDP. Putting in place parallel measures in Addis Ababa could provide a model for dealing efficiently with the city's traffic burden.

Gachanja (2015), calls for an integrated approach that brings together both the demand and supply side measures as a mitigation measure in the Nairobi metropolitan region. Effectiveness varies to great extents according to various evidence. on the other hand, increasing the road capacity is reported to lower overall traffic congestion by 50% during the short term. Also, promoting the modal shift from private car use to public transport, combined with increasing the carrying capacity of vehicles, is estimated to reduce congestion by 41%. Bypass road construction would result in a reduction in congestion of around 11%, while a policy of decentralizing the CBD into multiple centers of attraction would reduce congestion by about 10.7%. Furthermore, flexible work timings should also be introduced so that traffic congestion can be avoided during peak hours by staggering the timings of arrival and departure of the employees. The paper also proposes dedicated public transport lanes for guaranteed and predictable times of travel to have better efficiency of public transport services.

2.4. Summary and Gap in the Literature

A glimpse through the literature review renders it a very complex issue attributed to several contributing factors. Globally, it results in huge economic, social, and environmental costs. Several studies have noted some of the major causes of traffic congestion: high vehicle ownership, inadequate road infrastructure, poor traffic management, and socio-economic elements like population increase and urbanization. Traffic congestion causes direct economic costs to the increase of travel time and fuel consumption for vehicles, besides the additional maintenance costs. Other studies in the line of Weisbrod et al. (2003) and the World Bank (2013) demonstrate these direct costs are compounded by indirect costs: productivity loss due to congestion, increased pollution, increased costs related to vehicle maintenance, and public health impacts. Moreover, there is also a loss in business productivity, as it limits the access to the market, increasing the cost of operation. Methodologies to estimate these impacts ranged from surveys, analyses of travel time, and fuel consumption to statistical modeling across different urban settings in Cairo, Mansoura, and Addis Ababa.

A range of measures has been developed in the literature to quantify congestion's intensity, extent, duration, and impact. The former includes indices of travel time comparing actual to free-flow travel times; the latter, delay-based metrics quantify the amount of time lost due to congestion. Other common metrics in assessing the financial impact of congestion on drivers and businesses include vehicle operating costs (VOC) and fuel consumption. Also, traffic volume-to-capacity ratios and average speed analyses are standard methods to capture congestion intensity, especially during peak periods.

Theoretical approaches such as the Economic Theory of Urban Traffic Congestion and the macroscopic models of congestion have been applied in an attempt to understand the complex dynamics driving congestion. These models will normally account for demand-capacity relationships and travel time delays as important measures to be utilized in congestion cost evaluation.

Empirical evidence has shown that there are significant economic impacts due to congestion. For example, the World Bank estimated that Cairo's congestion costs about US$2.44 billion per year, mainly due to time lost and extra fuel used. Another example is the study about Flanders that calculated the cost of a single congestion event, estimating it at €216,563, where delays in time and fuel expenses are not the smallest contributors. Other studies, such as that carried out in Mansoura, underlined the very important role played by traffic volume and mix of vehicles say, heavy vehicles to increase congestion, thus increasing further both fuel consumption and emissions. However, the lack of a standard set of definitions and measurement techniques contributes to inconsistencies in the reported figures, hence the need for a robust analytical framework that should guide policy formulation.

In conclusion, the literature review provides a strong foundation for measuring and analyzing economic impacts of congestion in Addis Ababa.

2.4.1. Gaps in the literature

While the existing literature provides comprehensive insights into the causes and consequences of traffic congestion, several gaps remain. First, much of the research conducted in Addis Ababa focuses on the central city area, particularly the Ayat to Mexico corridor. However, these studies may not adequately represent the traffic conditions at the outskirts of Addis Ababa, as these areas exhibit different traffic flows and socio-demographic characteristics. This research aims to address this gap by focusing on these outer areas. Additionally, most existing studies only examine recurrent congestion when measuring the current level of congestion and analyzing its costs. In contrast, this research will consider both recurrent and non-recurrent congestion to provide a more comprehensive analysis.

Furthermore, while much research has been conducted on evaluating the congestion situation and its impact on the city, more work is needed on estimating the economic impact of congestion in monetary terms. Finally, in all previous studies conducted in Addis Ababa, the indirect costs of congestion have yet to be fully determined.

By addressing these gaps, this research can contribute to a deeper understanding of the economic impact of traffic congestion in Addis Ababa, offering more tailored recommendations for policy interventions and congestion mitigation strategies.

2.5. Conceptual Framework

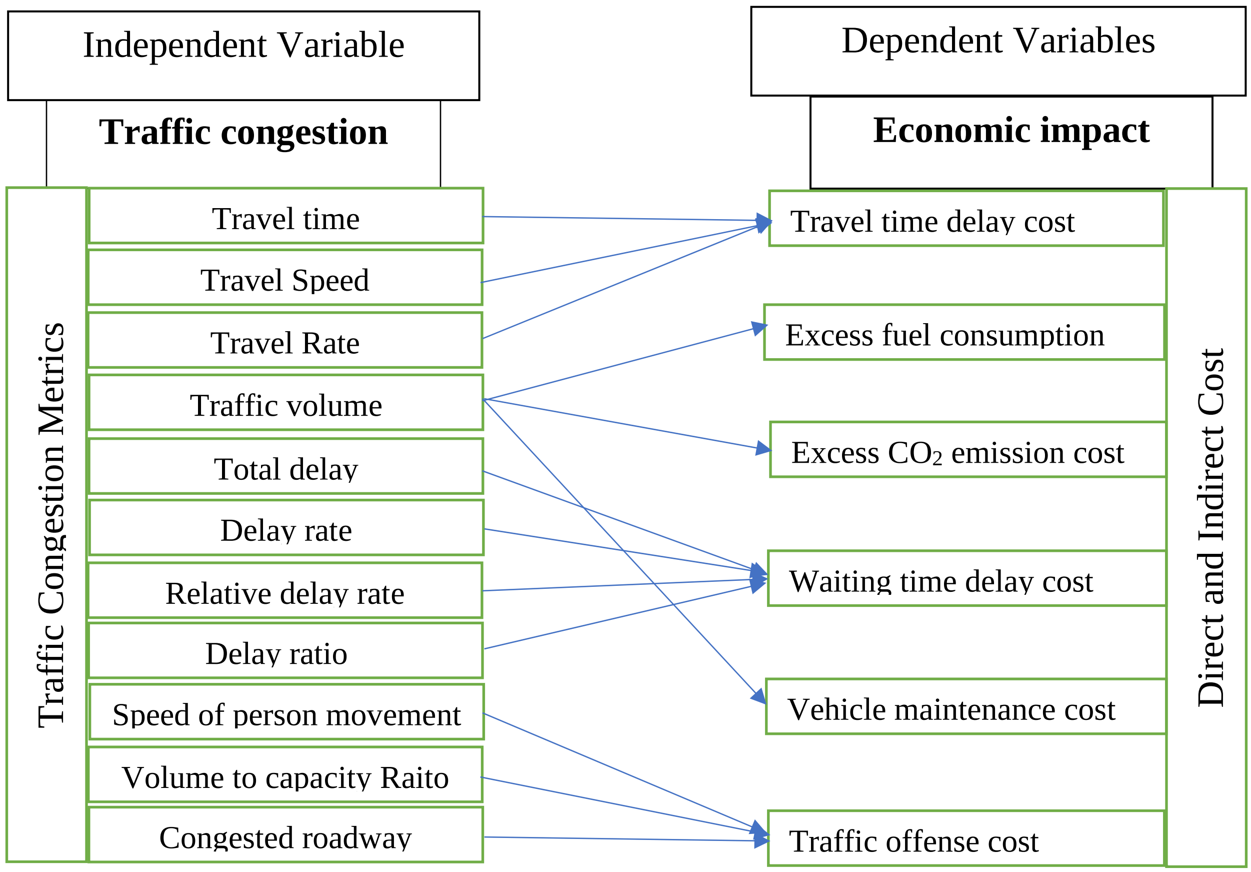

Figure 2.2: Conceptual Framework

Source: (Author, 2024)

Chapter Three

Research Methodology

3.1. Introduction

The research analyzed traffic congestion and its economic impact on the study area. This chapter states in detail the methods and procedures employed, which are in conformity with the objective of the research, the description of the study area, types, and ways of data collection, and the methods used for data analysis. In this thesis, the methodology followed was designed in such a manner that it answers the research questions properly. With the rapid urbanization of the city and growing number of vehicles, especially in peripheral corridors, there is felt a need to adopt a multi-disciplinary approach that incorporates both the field measurement and survey streams of research. The study estimated not only the direct costs of traffic congestion these would include time delays and operating costs of vehicles, but also the indirect costs.

3.2. Research Design

Descriptive research integrated with an experimental design was used in this study. This research provided an accurate description and a better understanding of the traffic flow characteristics in the study area. Additionally, the study involved on-site observations to record actual data in real time and assess the impact of certain variables on others. These methods enhance the research by grounding it in actual conditions, thereby improving the overall quality of the findings.

3.3. Research Approach

A quantitative approach was followed in this research, covering both field measurement and survey methods of data collection and analysis. This paper quantitatively describes the current traffic flow attributes, including travel time, traffic volume, and congestion levels, with regard to delays and travel duration, while also exploring its economic implications as derived from field data and survey findings. Quantitative data and analysis were used in determining the total cost of congestion and in estimating congestion levels in terms of total segment delay. The study sought to understand the current state of congestion in specific peripheral corridors in the city where high traffic volumes significantly affect economic activities. In a nutshell, the study used an explanatory design to clearly state and understand the economic implications of road traffic congestion in the region, as stated in the objectives of the study. Using this approach equips readers with clear, objective, and reliable information, enhancing their ability to understand complex issues.

3.3. Study Area

Addis Ababa, in the geographical heart of Ethiopia, is the nation's biggest city and also its political, economic, and symbolic hub (Weldeghebrael, 2021). Standing at 2,400 meters above sea level, the city covers over an area more than 540 square kilometers of undulating landscape of mountains including the 3,200-meter Entoto Hill (Gezahegn et al., 2017). The city is divided into 11 sub-cities and 118 woredas, with a population of approximately 5.7 million, equating to 19.5% of the overall Ethiopian urban population. Addis Ababa is anticipated to reach 7.3 million inhabitants by 2030, driven by urbanization at a rate of 4.45% yearly (World Population Review, 2024). The city hosts the African Union and the United Nations Economic Commission for Africa and is Ethiopia's commercial and political capital. With double-digit economic growth, Addis Ababa produces 29% of the nation's urban GDP and 20% of national urban employment, and as such, it is a major driver of Ethiopia's economic growth (UN-Habitat, 2017).

The study was conducted in Addis Ababa, the capital and largest city of Ethiopia. The study area generally focused on the peripheral corridors with a heavy vehicle flow. More precisely, the "Asrasement Mazorya" to "Comprhessive" peripheral corridor, which is located in the westward direction of the city, was selected.

These corridors, which include roadways connecting agricultural and industrial hubs, are critical for transporting essential goods and services. Additionally, this corridor serves as a passageway for many commuters living in the surrounding countryside, such as Ashewameda and Anfo. It is also a passageway for neighboring towns like Ambo. They are distinct from the city center due to their unique traffic dynamics and socioeconomic characteristics, which contribute to significant congestion issues (See Figure 3).

Figure 3.1: Study Area

3.4. Population and Sampling

3.4.1. Sampling Technique

The population source were the drivers, commuters, and the traffic authorities. A combination of the methods of convenience and purposive sampling was oriented toward this research for its comprehensiveness. The value of the convenience sampling lied in the fact that through this method, the collection of data occurred at peak periods hence allowed us to collect information from people who were currently experiencing congestion at the specified location and time. It enables one to collect data just in time showing the real state of traffic conditions at that moment. We were also be able to effectively capture experiences and views of a wide range of drivers and passengers by concentrating on available respondent groups. We also used purposive sampling in our research by directly selecting key individuals based on expertise and specific roles in traffic management, which involves the traffic authorities themselves, passengers, public bus drivers, minibus operators, truck drivers, and private vehicle owners who live within the area. Such targeting of these key groups provide the ability to tap into experiences from regular commuters who use the road segment under consideration daily.

3.4.2. Sample Size

No sample will be perfect, so we need to decide how much error to allow. The confidence interval determines how much higher or lower than the population means you are willing to let the sample mean fall. Confidence Level means how confident we want to be that the actual mean falls within our confidence interval. The most common confidence intervals are 90% confident, 95% confident and 99% confident. For this thesis, 95% confident level were taken. To determine the sample size we use an equation developed by Cochran (1963) which is applicable when the population is large.

$$n = \frac{z^2 * p\ (1-p)}{e^2} = \frac{1.96^2 * 0.5\ (1-0.5)}{0.05^2} \approx 385$$

Where: n= Sample size required for the study Z= Critical value (=1.96) for the 95 percent confidence level, the amount of uncertainty that one can tolerate. Most researchers recommend 95 per cent confidence level. P= Proportion of people expected to have the basic knowledge about the problem. (i.e., 0.5). e = Margin of error that can be tolerated: it is the discrepancy between the sample size and the population. The recommended value is 5 percent (=0.05)

3.5. Data Collection Methods

Gathering of primary data involved both field measurements and questionnaire surveys with a view to collect quantitative information regarding the study corridor. The quantitative data were utilized to estimate the economic cost and level of traffic congestion, in addition to that these data were collected to capture people's perceptions of economic impacts and levels of congestion. Organized questionnaires were administered to regular users of roads in the form of drivers, passengers, and traffic authorities with a view to gather further information. Video camera equipment mounted on top of buildings combined with manual traffic volume counts were deployed to collect volume and flow data at 15-minute intervals. This provides opportunity for examining the vehicular composition, vehicle occupancy rates, travel times, and average speeds for both free-flowing and congested conditions on the study route.

3.6. Data Analysis

In this study, the respondents' perceptions of traffic congestion level and economic impacts were analyzed descriptively. On the other hand, the quantitative data collected through field measurements were be analyzed through methods which were used by World Bank (2010 & 2013) on traffic congestion studies, and travel time approach to measure the level of congestion and to estimate the economic impact as described below. In recording and analyzing the data, Statistical Package for Social Sciences 25 (SPSS) and excel 2021 were used. The method used to estimate cost of time delay and the cost of excess fuel consumption is primarily based on the methodology developed by the Texas Transportation Institute.

3.6.1. Economic Impact Analysis

3.6.1.1.The Direct Cost of Congestion

a. Travel Time Delay Costs

The most widely used factor to assess the economic impacts of traffic congestion is the cost of delayed travel time. The typical approach for estimating this cost is to apply the Value of Time (VOT) metric to calculate the delay-related expenses.

$$\begin{aligned}&Recurring\ travel\ time\ delay\ cost\\&\quad = vehicle\ occupancy_{(passenger/vhicle)} * value\ of\ time * 250\ working\ days\\&\quad * length\ of\ the\ corridor(km)\\&\quad * volume\ of\ vehicle\ at\ congested\ period\ (pcu)\\&\quad * [1/(average\ congested\ speed(km/hr)) - 1/(free\ flow\ speed(km/hr))]\end{aligned}$$

$$\begin{aligned}&non - Recurring\ travel\ time\ delay\ cost\\&\quad = incident\ delay\ ratio * vehicle\ occupancy_{(passenger/vhicle)}\\&\quad * value\ of\ time * 250\ working\ days * length\ of\ the\ corridor(km)\\&\quad * volume\ of\ vehicle\ at\ congested\ period\ (pcu)\\&\quad * [1/(average\ congested\ speed(km/hr)) - 1/(free\ flow\ speed(km/hr))]\end{aligned}$$

b. Excess Fuel Consumption Cost

As calculated by Texas Transport Institute, the fuel that is wasted due to congestion is the difference between the fuel consumed at peak and free-flow speeds.

$$\begin{aligned}&daily\ fuel\ wasted\ (L)\\&\quad = DVKT/(free\ flow\ travel\ speed)\\&\quad * (free\ flow\ speed)/(average\ fuel\ economy)\\&\quad - (peak\ period\ system\ congested\ speed)/(average\ fuel\ economy)\end{aligned}$$

Where DVKT: daily vehicle kilometer travelled at peak periods, which equals traffic volume at peak period multiplied by road length in kilometers, the average fuel economy is calculated to estimate the fuel consumption of the vehicles in congested and uncongested conditions.

Average fuel economy = 3.71+0.066*average congested hour speed(km\L)

$$cost\ of\ Annual\ fuel\ wasted(\$) = Daily\ fuel\ wasted_{(L)} * 250 * total\ volume\ of\ vehicles\ during\ congested\ period * \%of\ vehicles\ using\ this\ fuel\ type * cost\ of\ fuel\ type_{(\frac{\$}{L})} + subsidy\ cost\ of\ fuel\ type$$

c. Excess Emission Costs

The annual excess weight of carbon dioxide, CO_2, can be calculated as stated by (World Bank, 2010). Thus, the total annual excess emission cost can be determined from the following equation.

$$W_{CO2} = GW * 2.40 + DW * 2.41$$

$$C_{CO2} = W_{CO2} * U_{CO2}$$

Where; GW is the annual weight of wasted gasoline (Lit), DW is the annual weight of wasted Diesel (Lit), and Uco2 is the unit cost of CO_2.

3.6.1.2.Indirect Congestion Costs

a. Waiting Time Delay Cost

Delays due to waiting at stations during peak periods will be computed using the following formula:

$$Wc = MDPHV * \%Tc * Avg.Wt * Vo * Vot * No.Wd$$

Where; Wc: Annual waiting time delay cost; MDPHV: Maximum daily peak hour volume, representing the highest vehicle volume during peak traffic periods; %TC: Percentage of each transport mode in the overall traffic composition; Avg. Wt: Average waiting time delay for each transport mode (in minutes); Vo: Vehicle occupancy of each transport mode; VOT: Value of time of passengers for each mode; No.Wd: Number of working days per year (250 days).

3.7. Validity and Reliability

This research gains validity and reliability through its thorough design and implementation. In this study, congestion levels were quantified using standard measures such as delay ratio, travel time, and average speed. Content validity is achieved in the research by using techniques to measure congestion costs from existing literature, hence it is based on established frameworks. The empirical data, being a result of systematic observation and survey, reflects real conditions and, therefore, enhances construct validity. It encompasses the comparison of the current findings with the literature-based ones and using questioners from published sources to ensure external validity. Standardized data collection tools coupled with the systemic observation of flow and delay do reduce the tendency towards bias, thus adding to reliability. Cronbach's Alpha was calculated for the survey responses, yielding a value of 0.76, which falls within the acceptable range **(**$\alpha \geq 0.70$**).** This indicates that the questionnaire demonstrates a sufficient level of reliability, meaning the items are consistently measuring the intended concepts.

3.8. Ethical Considerations

The integrity of the study needed to be safeguarded, together with the protection of the participants. Participants were informed not to participate unless on their free will. Information that related to participants was made confidential and anonymous by safely storing data and erasing personal details. There was an assurance that no unnecessary harm would be occasioned on participants and their integrity maintained through honest data collection and analysis. We adhered to all institutional and national ethical standards and conducted our fieldwork in a manner that minimized disruption to both the environment and the community.

Chapter Four

Results and Discussions

4.1. Introduction

This chapter presents the findings and analyses based on the research undertaken. To achieve the stated objectives, there was a need to use a holistic approach in data collection that would include both field measurement and respondents experience. Empirical data that consisted of traffic volume, average speed of travel, vehicle occupancy, among other traffic flow parameters, was diligently collected. Additionally, a structured questionnaire was administered to passengers and drivers in order to obtain information about their experiences, behaviors, perceptions, and quantitative aspects of traffic congestion.

The congestion analysis focused on those segments for which travel time data were collected, with the results being interpreted and discussed accordingly. In this analysis, congestion measurement metrics were established through a travel time methodology.

Following this, the economic implications of congestion were examined, taking into account variables such as prolonged travel duration, heightened fuel usage, and the related indirect expenses borne by individuals and the environment.

4.2. Demographic Profile of Respondent

A total of 385 questionnaires were distributed to respondents, and 273 (70.9%) were collected. On the other hand, 112 (29.1%) of the total is uncollected.

Table 4.1: Demographic Profile of Respondents

No	Item	Category	Frequency	Percentage
1	**Sex**	Male	208	76.2%
		Female	65	23.8%
2	**Age**	18 - 25 years	61	22.3%
		26 – 35 years	143	52.4%
		36 – 45 years	66	24.2%
		46– 55 years	2	0.7%
		Above 55 years	1	0.4%

3	**Level of Education**	Primary level	30	11.0%
		Secondary level	106	38.8%
		Diploma	82	30.0%
		Degree	50	18.3%
		Masters and above	5	1.8%
4	**Occupation**	public employed	50	18.3%
		private-employed	93	34.1%
		self-employed	96	35.2%
		Student	34	12.5%
5	**Income**	Below 5,000	59	21.6%
		5,001-10,000	130	47.6%
		10,001-15,000	65	23.8%
		15,001-20,000	15	5.5%
		20,001-25,000	3	1.1%
		Above 25,000	1	0.4%

Source: survey data, 2024

4.2.1. Sex Profile Respondent

The sex profile of the respondents was 23.8% for females and 76.2% for males, reflecting the traditional nature of gender roles in the area. Men are often responsible for driving and working outside, while cultural norms may limit females' mobility and decision making in terms of travel.

4.2.2. Age Profile of the Respondents

The age distribution of respondents shows that 52.4% are within the 26-35 years age group, implying this is the age group mainly engaged in commuting and economic activities in area. The 18-25 years age group also constitutes a large percentage of 22.3%, which implies many young people, likely students or in the early stage of their career, live in the city. Contrastingly, the demographics represented for the older age ranges are fairly minimal, those above 46-55 years, possibly indicative of fewer workforce entries or commuting habits common to elderly people.

4.2.3. Educational Background of the Respondents

The educational level of respondents shows that the highest percentage, 38.8%, has completed secondary education, while 30% hold diplomas. It means that the majority have basic and vocational training. A smaller percentage, 18.3%, hold a degree, and only 1.8% have a master's degree or above. this reflects the restricted access to higher education for commuters in the area. This distribution may have implications for their ability to get jobs and influence their commuting patterns.

4.2.4. Occupation Profile of the Respondent

Analysis of the occupational categories of respondents outlines that the local working population is quite diverse: 35.2% are self-employed, while 34.1% work in the private sector. Public sector employment is at 18.3%, and the rest are students at 12.5%. A high percentage of self-employed could mean a very strong entrepreneurial environment, which may affect commuting habits and traffic congestion.

4.2.5. Income Profile of the Respondent

The distribution of respondents by income level demonstrates that 47.6% receive income between 5,001 and 10,000 Birr, revealing a large proportion of this population within a middle-income category. 21.6% earn less than 5,000 Birr and an additional 23.8% reported earning between 10,001 and 15,000 Birr. Very few have earnings of between 15,001 and above with only 7%. That may influence travel patterns, the availability of transportation alternatives, and the necessity for affordable and efficient transit creation to address the requirements that exist with the predominant commuter population in Addis Ababa.

4.3. Traffic Flow Characteristics in the Corridor

Among the respondents, 156 (57.1%) classified as Drivers, while 117 respondents (42.9%) identified as Passengers. Travel frequency reported by these people was an indication of dependence on roads in their daily routines. A large majority, 67.0%, reported traveling along this route 5-6 days a week, indicative of regular use most likely linked with work or other necessary activities. Specifically, 14.3% of the respondents admitted that they use the road daily, hence showing the importance of the road in their daily activities. On the other side, only 16.1% of the respondents claimed that they travel 3-4 times a week, while only 1.1% said that they travel 1-2 days a week, and 1.5% claimed not to travel at all. This trend shows how important this corridor is for daily transportation, which is only going to get worse due to congestion. The findings have implications for the creation of tailored traffic control measures that address the needs of frequent users.

The main reason for travel reported by respondents is very important, as the road provides access to job opportunities, as demonstrated by 87.9% of respondents for whom the main purpose of using the road is to travel to their workplace. This figure shows the important role played by the road in facilitating access to employment opportunities throughout the corridor. On the other hand, the percentage of respondents who claimed educational travel as the primary purpose was 11.0%, while a much smaller 1.1% sited shopping as the major reason. The big gap between the two percentages tells that the highway is predominantly used as a major trunk road for economic activities and work and not for any other purpose of travel.

The travel behaviors of respondents show widespread activity during peak traffic times. many respondents, 41.1% travel in the morning from 8:00 AM to 11:00 AM, while 40.8% travel in the afternoon, between 3:00 PM and 7:00 PM. These hours align with typical operating work hours and illustrate how the road functions as an access route for commuting to work. This type of trend in the concentration of usage during peak demand times likely leads to traffic congestion. On the other hand, the percentage of those who mentioned traveling during off-peak daytime hours was only at 12.3% indicative that it is work-related constraints which mainly determine travel patterns. Moreover, a relatively small percentage of night-time travelers (5.8%) can be attributed to the cultural reason or safety-related problems, added to a lesser number of public transport options available in those times.

A look at the transport modes used by respondents shows varied commuting patterns. Taxis come out as the leading means of transportation, used by 38.1% of participants, which signals a dependence on this flexible and highly available option in daily commute. Private cars come in second place with 28.9% of the respondents using them indicative of a strong penchant for personal vehicles, most probably due to their ease and efficiency. Public buses made up 25.3% of the respondents, showing a very important role in fulfilling the community's commuting needs. On the other hand, only 1.1% of respondents used motorcycles, indicating that there is a very limited preference for this mode of transportation due to possible safety or infrastructural reasons. Walking made up 6.6% of the respondents' modes of travel, indicating that while some people do live in walkable distances, current pedestrian infrastructure is still likely inadequate for general use. As shown in Figure 4.1, the modal share in the corridor is composed significant amount of private cars followed by public bus transportation such as Minibuses and Buses. The rest are occupied by small Truck and Heavy Truck.

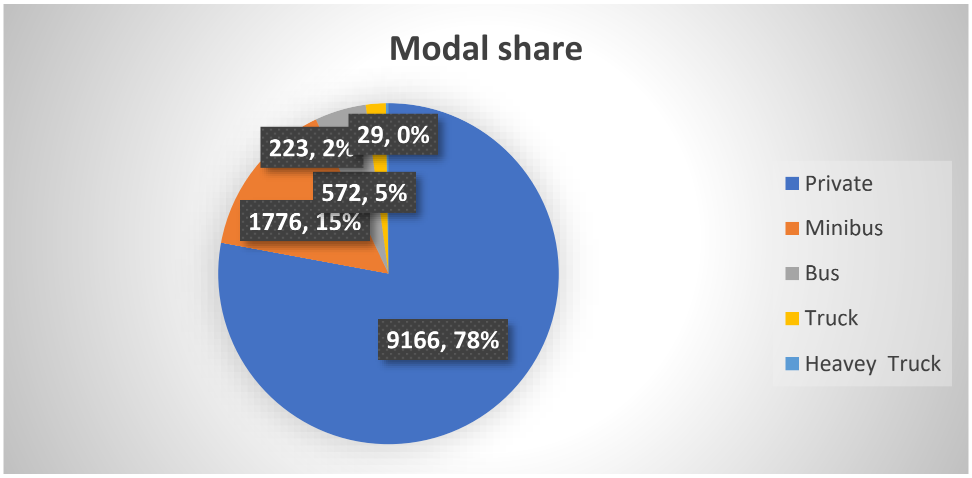

Figure 4.1: Modal Share of the Road segment

4.4. Congestion Analysis

The congestion analysis utilized a travel time approach, focusing on several key congestion measures, including average travel speed, travel rate, delay rate, delay ratio, and total segment delay. The subsequent sections will present the analysis of each measure, with the detailed results provided in the appendix B.

The responses to the common causes of traffic congestion reveal numerous crucial issues related to the efficiency of the road network. For example, 22.5% of the subjects have identified insufficient parking spaces and the prevalence of illegal practices of parking as one of the main causes for this problem. This suggests that insufficient parking space greatly contributes to congestion, where traffic may block lanes due to searching for a parking spot, or may engage in illegal ways of parking. Consequently, 22.1% and 19.5% are recorded for insufficient width of the road and poor management of passengers and freight loading and unloading, respectively. The findings recommend the need for infrastructural improvement and strengthening the laws on loading areas and bays to achieve efficiency in the flow of traffic. In addition, poor traffic management, as mentioned by 19.1% of respondents, requires better traffic flow control, which includes managing traffic lights, deploying traffic officers at the right time, and strictly enforcing traffic laws. A small percentage, 3.1%, of respondents reported other causes, such as accidents, unprofessional attitudes of some traffic officers, lack of alternative routes, and inadequate pedestrian crossing points.

In addition, the unexpected congestion caused by erratic variables gives further insight into the challenges faced by those traveling through this corridor. A booming 74.7% of respondents said they encounter traffic "sometimes," and 20.5% said it occurs "often." This demonstrates that unforeseen circumstances, including bad weather, collisions, and car breakdowns, are frequent sources of traffic jams that impact most commuters. However, only 3.3% of respondents said they had encountered traffic "rarely," and 1.5% said they had "never" encountered such circumstances. The small percentage of respondents who said there was little to no congestion illustrates how susceptible the transportation system is to interruptions. Non-recurring congestion, which is defined as congestion resulting from unforeseen events other than regular peak-hour traffic, is closely related to the results obtained. It follows that a higher share of non-recurring congestion means that more commuters face unexpected congestion, making it more difficult to implement effective traffic management strategies and increasing overall congestion.

The responses to the question about the frequency of congestion in traveling to work reveal an important fact for the travelers of this highway. Fully 85.7% of the respondents stated that they experience congestion "always," indicating that the delay in traffic is a constant problem for the majority. By contrast, only 9.5% said they are congested "often," while an even smaller number, 4.0%, reported that congestion happened "sometimes," and a minimal 0.7% claimed it happens "rarely." These relatively small figures reveal that to most respondents, congestion is not some infrequent nuisance but rather one that happens frequently enough to probably impact their punctuality and general productivity.

The perceived traffic conditions of the street act as a critical indicator of congestion levels, and therefore show a disturbing trend among commuters. A remarkable 70.3% described the traffic as "highly congested," implying regular experiences of considerable delays. Another 19.4% felt the traffic flow was "congested," hence underlining the prevalent perception of challenging conditions. In contrast, only 6.2% of those questioned considered the congestion to be "moderately congested" and only 1.5% considered it "lightly congested." Only 2.6% of all surveyed claimed that the street is "not congested at all.". The low percentages observed in categories characterized by less congestion indicate that a high proportion of commuters face considerable traffic challenges, hence the critical need for effective measures to improve.

4.4.1. Traffic Volume

Traffic volume data is needed for the understanding of patterns of traffic flow and the identification of peak flow rates and periods. It allows the analysis of the relation between traffic volume and congestion levels. Conducting traffic volume counts makes it possible for researchers to study the number, movements, and types of vehicles at specific points. This data helps in the identification of critical time windows of high traffic, analyzes the impact of heavy lorries and pedestrians on the traffic flow, and are instrumental in the analysis of level of service at the facilities and quantifying congestion intensity. The data were collected, compiled, and recorded through a video recording device at 15-minute intervals during two different time periods: the morning peak period (7:00 AM – 11:00 AM) and the evening peak period (3:00 PM – 7:00 PM). Traffic volumes were recorded for two days, Monday and Wednesday. The daily traffic volume was converted to Passenger Car Units (PCU). Vehicles were categorized into "Private Cars," "Minibuses," "Big Buses," "Small Trucks," and "Heavy Trucks." The Transportation research board (2000), states that the PCE values are as follows: Private Cars have a PCE of 1, Minibuses also have a PCE of 1, Small Trucks have a PCE of 1.5, while both Big Buses and Heavy Trucks have a PCE of 3. These PCE values are important measures used to determine the effect of different vehicle types on traffic flow and congestion. The traffic volume data for the corridor are shown in appendix A.

The analysis of traffic flow on the specified road segment reveals noteworthy trends that typify rush-hour commuting habits in the area. During the morning peak duration, the traffic volume relentlessly increases, attaining the maximum of 546 vehicles between 8:15 and 8:30 AM. This is essentially the characteristic of rush-hour traffic when people are travelling to work or school where the levels of congestion are recorded high. After that, it has a slowly declining trend from 10:00 AM onwards, and the count comes down to 220 vehicles in the time slot between 10:45-11:00 AM as there is a shift into decreased morning activity. During the afternoon peak hours, there is a considerable number of traffic activities; on that account, traffic flow is notably high for two slots, with 489 vehicles between 3:30 and 3:45 PM, and 443 vehicles between 5:00 and 5:15 PM. This phenomenon highlights the importance of the afternoon peak hours, driven by people commuting back home from work, which in turn worsens road traffic congestion (See Figure 4.3).

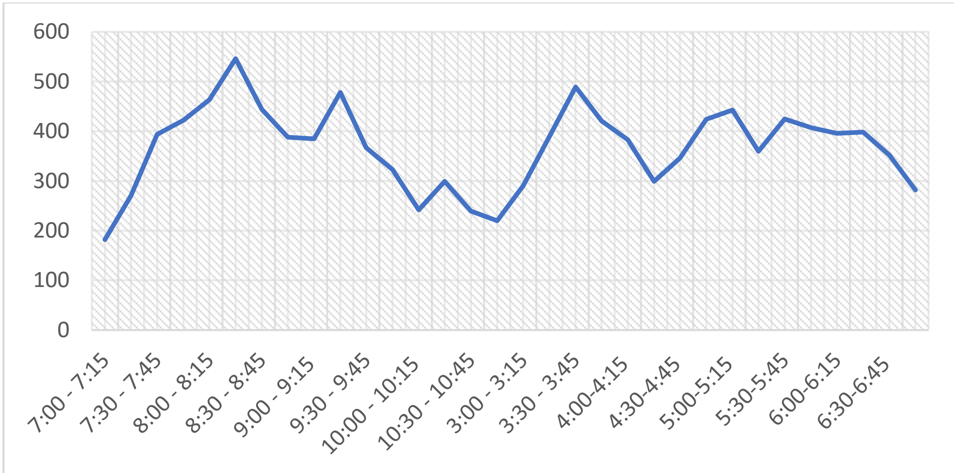

Figure 4.2: Traffic Volume pattern from Asrarsement to Compressive Road

4.4.2. Travel Time

Data of actual travel time required for vehicles to pass the section of the roads was collected using video camera and recorded data is shown in appendix A. data is taken two periods of the day: the morning peak hours (7:00 AM – 11:00 AM) and the afternoon peak hours (3:00 PM – 7:00 PM) was measured using stop watch. The travel time data were recorded two days (Monday and Wednesday) within 15 minutes and minimum of 3 samples were recorded for each 15 minutes.

The data for the Morning Peak Hour, between 7:00 AM and 11:00 AM, shows a fluctuating trend in travel time during this time, with the longest travel time recorded between 8:15 to 8:30 AM at 738 seconds. This is consistent with the general pattern of commuting since traffic congestion tends to peak during the hours when workers and students are on their way to their respective workplaces and schools. A consistent rise in travel duration is observed between 7:00 and 8:15 AM, reaching its peak from 8:15 to 8:30 AM with a duration of 738 seconds, and maintaining elevated levels until the period from 9:00 to 9:15 AM. After this period of time, travel time falls gradually to its lowest point between 10:45 and 11:00 AM at 264 seconds. This might suggest that the intensity of traffic congestion decreases as the peak time of the morning has gone. This trend is in line with previous research findings, which note that morning peak hours usually face increased congestion due to the increased demand for vehicles relative to the fixed road capacity (Tazzie, 2022). The strong peak followed by a decline shows the impact of commuting behaviors on traffic conditions.

Travel time increases linearly in the afternoon period from 3:00 PM to 7:00 PM, peaking at 4:15-4:30 PM with a value of 774 seconds as shown in figure 4.4. This is greater than any other values for the day, so it probably represents the most congested time of the day. The peak travel time corresponds with the end of school and work hours when road demand peaks. Following the peak period, travel time tapers off gradually, with slight fluctuations between 4:45 PM and 5:45 PM. More importantly, after 6:00 PM, congestion drops off noticeably, and there is a steady decrease in travel times, with the lowest travel time of the afternoon taking place between 6:45 and 7:00 PM at 258 seconds. This downtrend coincides with the post-rush hour period in which traffic begins to dwindle. Prior studies by Bao et al., (2022) similarly identifies the afternoon peak as highly congested due to overlapping commuter and school traffic.

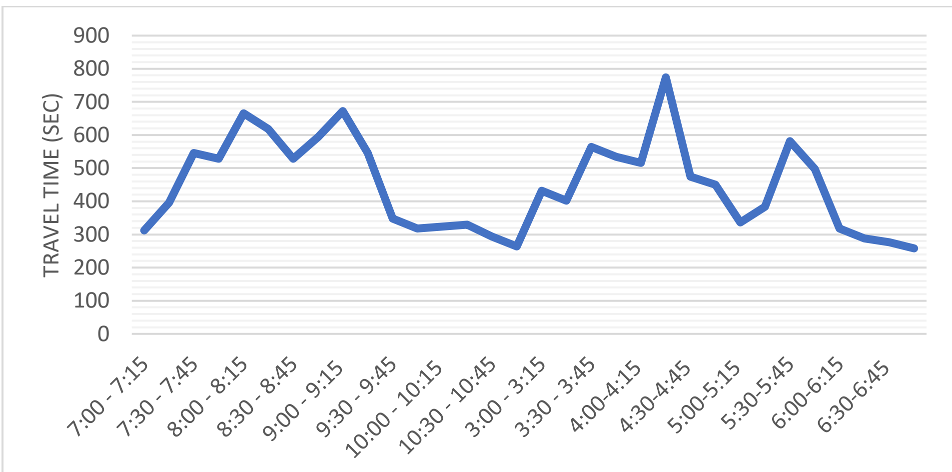

Figure 4.3: Average Travel time from Asrarsement to Compressive Road

4.4.3. Travel Speed

During the morning peak hours, there is a significant decline in travel speeds, especially between 7:00 AM and 8:30 AM, with the speed being as low as 5.61 km/h from 8:15 to 8:30 AM. This means that during this period, there is a great deal of congestion, where vehicles are delayed due to increased volumes of traffic; the lowest speed recorded is 5.85 km/h from 7:45 to 8:00 AM. As the morning wears on, speeds gradually get somewhat better, rising to 15.68 km/h by 10:45-11:00 AM, reflecting a gradual reduction in congestion as the peak period comes to an end. Afternoon peak hours, this travel speed data in turns first, of a very low speed: from 5:35 between 4:15–4:30 pm a trend that clearly goes uphill. The tendency would only suggest that it perpetuates well into the late afternoon due to reverse commuting trips. At odds to the morning hours, a distinct increase in speeds marks the closure of the period with peak speeds of 16.05 km/h between 6:45 and 7:00 PM. This is indicative that there is a certain relation between traffic volume and travel speed, where it causes huge delays during either peak (See Figure 4.5).

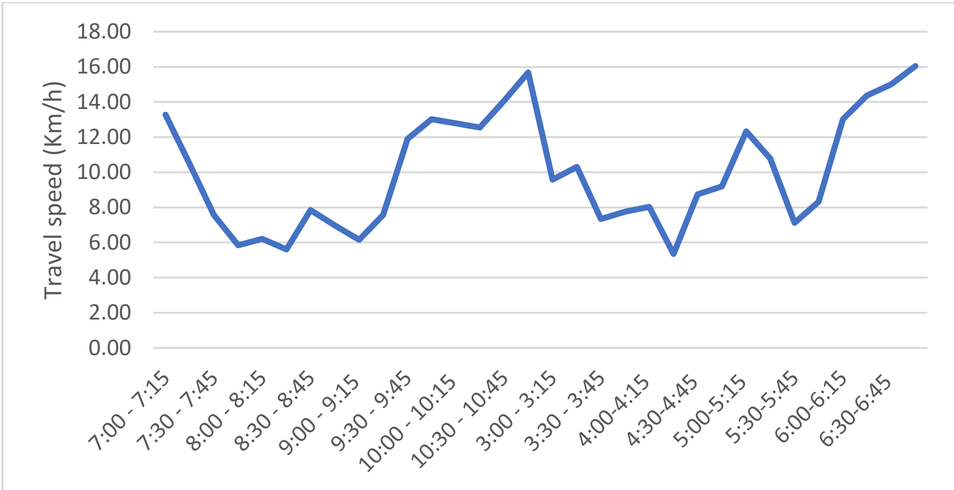

Figure 4.4: Average Travel speed from Asrarsement to Compressive Road

4.4.4. Travel Rate

The travel rate which is the inverse of travel speed is a very important parameter in congestion analysis. Based on the data collected, during the morning peak, the travel rate shows a clear upward trend in congestion, especially between 7:30 AM and 8:30 AM, where rates peak at 10.70 minutes/km between 8:15 and 8:30 AM. the lowest recorded rate of 4.52 minutes/km happens between 7:00 and 7:15 AM, indicating relatively lighter traffic at this time as shown in figure 4.6. Moving up the morning, the travel rate increases steadily, indicating increasing congestion as more and more vehicles get into the road network. The rates begin to decline after 10:45 AM to 3.83 minutes/km by 10:45-11:00 AM, possibly due to reduced traffic volume as the peak period ends.

During the afternoon peak hours, travel rates are very volatile. The highest rate of 11.22 minutes/km was recorded between 4:15 and 4:30 PM—the travel rate during this time is symptomatic of heavy congestion. Travel rates to follow the same trend in which smaller values like 4.00 minutes/km were recorded between 6:30 to 6:45 PM. The data points out that there are indeed some time periods marked with huge delays, but at the same time, there are periods showing improvements in traffic flow, especially late in the evening. Thus, the travel rate data emphasizes the great delays faced by commuters during peak hours.

The average travel time on the highway is 6.64 minutes per km, which is roughly equivalent to 4.13 minutes per mile. The rate is higher than the acceptable travel time of 2 minutes per mile which is used for fringe major streets according to Lomax et al. (1997).

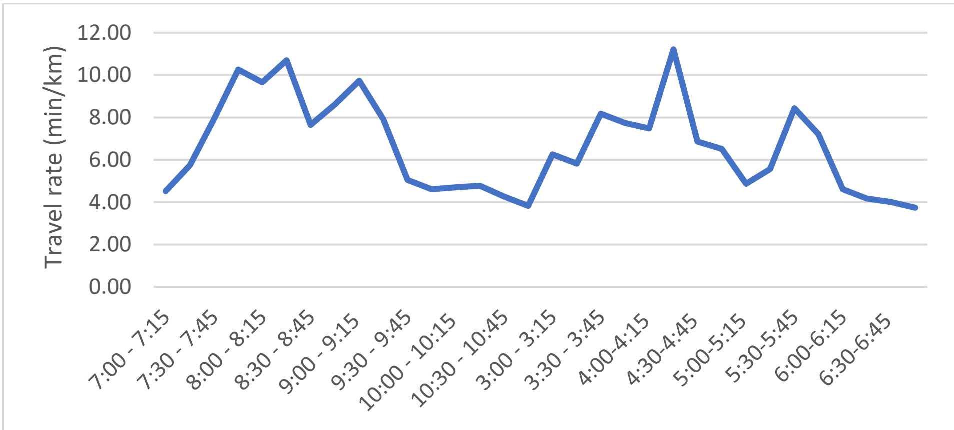

Figure 4.5: Average Travel Rate from Asrarsement to Compressive Road

4.4.5. Delay Rate, Delay Ratio, and Delay per Traveler

These calculations were performed by determining the travel times recorded at times when there was little traffic. That is, under conditions when there was no congestion, the travel time for each section was systematically recorded to establish a norm or unconstrained travel time. Under these ideal conditions of travel time, this study is able to accurately measure delays due to congestion during periods of heavy traffic.

There are big delays in these rates across the day and, obviously, through rush-hour traffic, where data reaches its most extreme changes throughout the time of the day. Congestion apparently peaks very early: the time bin 8:15 to 8:30 marks a record delay of about 8.78 min/km and is definitely pointing to real congestion for traffic, maybe because that hour marks travel to work rush. As the morning progresses, the delay rate decreases to 1.91 minutes/km during the period of 10:45-11:00 AM, showing a reduction in traffic congestion as the peak commuting hours come to an end. In the afternoon, the delay rate shows similar variability, with a peak of 9.30 minutes/km between 4:15 and 4:30 PM, illustrating the plight of the commuters on their return trip home. The findings emphasize the need for effective traffic management strategies that could reduce delays during peak periods.

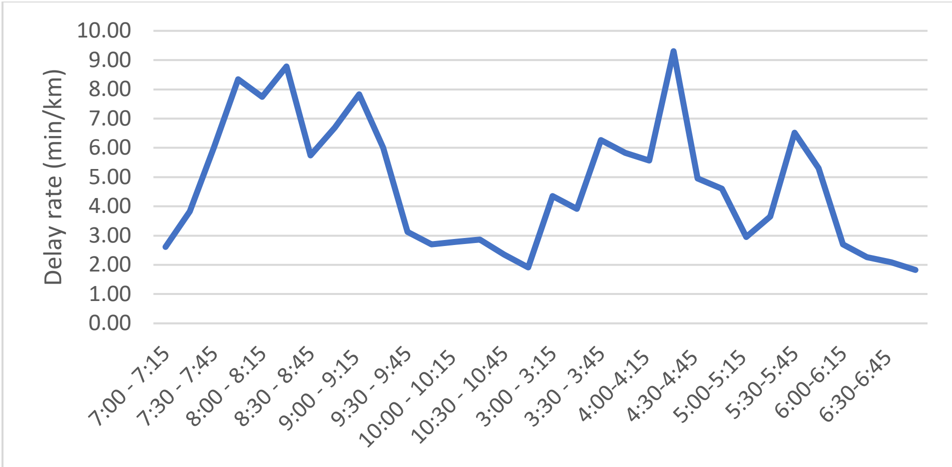

Figure 4.6: Delay Rate from Asrarsement to Compressive Road

The delay ratio, representing the fraction of time spent in delay relative to total travel time, exhibits a progressive pattern of increasing congestion both during the morning and afternoon peaks. This ratio increases to 0.82 during the period between 8:15-8:30 AM, revealing that over 80% of the total travel time is spent on delays at this peak. A similar pattern is observed in the late afternoon hours where a very high ratio of 0.83 was recorded between 4:15 and 4:30 PM as shown in figure 4.8. This indicates that delays play a significant impact on the overall commuting experience. A gradual decrease in the delay ratio during the non-peak periods leads to better traffic conditions and shows there is an earnest need for focused interventions during peak periods to reduce not only the delays but also their ratios.

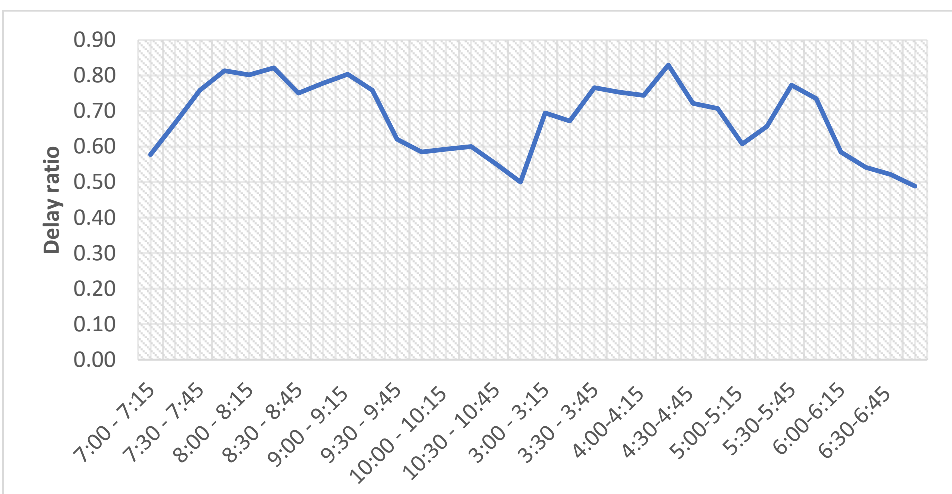

Figure 4.7: Delay Raito from Asrarsement to Compressive Road

Delay per traveller is defined as the average time spent during a given annual period due to traffic congestion. Most notably, during the peak morning hours, delay per traveller reaches its maximum of 42.08 hours between 8:15 and 8:30 AM as a clear example of the multiplier effect of delay on individual travellers. This pattern continues through the peak afternoon hours, with a maximum delay of 44.58 hours between 4:15 and 4:30 PM. Those are fairly large delays per commuter and suggest broader implications in productivity and general commuter satisfaction. A decrease in delay per commuter during the off-peak hours may be an indication that such traffic management strategies are effective and may alleviate problems experienced during peak hours (see figure 4.9).

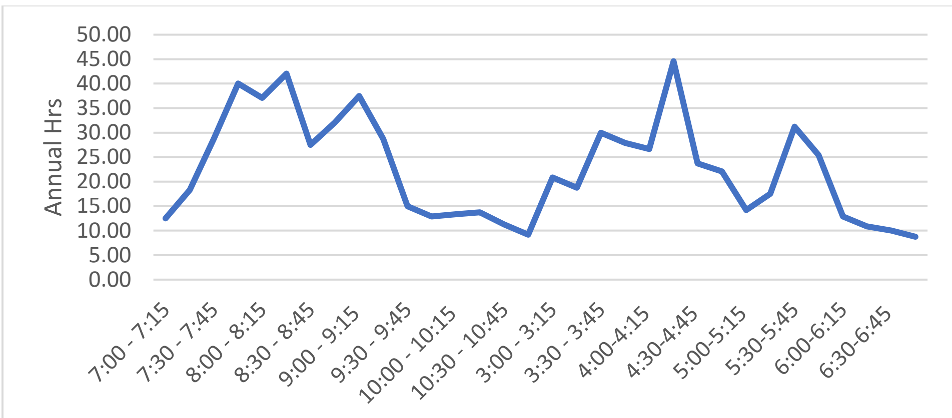

Figure 4.8: Delay per Traveler (annual-hours) from Asrarsement to Compressive Road

4.4.6. Total Segment Delay (vehicle-min and person-min)

Total segment delay, measured in vehicle minutes or person hours, is used as a surrogate measure for the magnitude of traffic congestion. It is, therefore, a measure of not just how much backing up occurred, but it is reflective of its person-hours impact on people. In the morning, total segment delay peaked at 5,514.6 minutes or (91.91 hours) from 8:15–8:30 AM consequently proving that heavy traffic congestion impacts the persons working. This sharp increase from 546 vehicle minutes at 7:00-7:15 AM to over 4,051 vehicle minutes by 8:00-8:15 AM shows the effect of growing traffic volumes. While the delays drop off somewhat as the morning wears on, they remain high, meaning there is an ongoing traffic control problem. In the afternoon, the same congestion pattern re-emerges, with delays peaking at 3,520.8 vehicle minutes. that is, 58.68 hours between 3:30 and 3:45 PM, further underlining the continuing difficulties of returning commuters as shown in the figure 4.10.

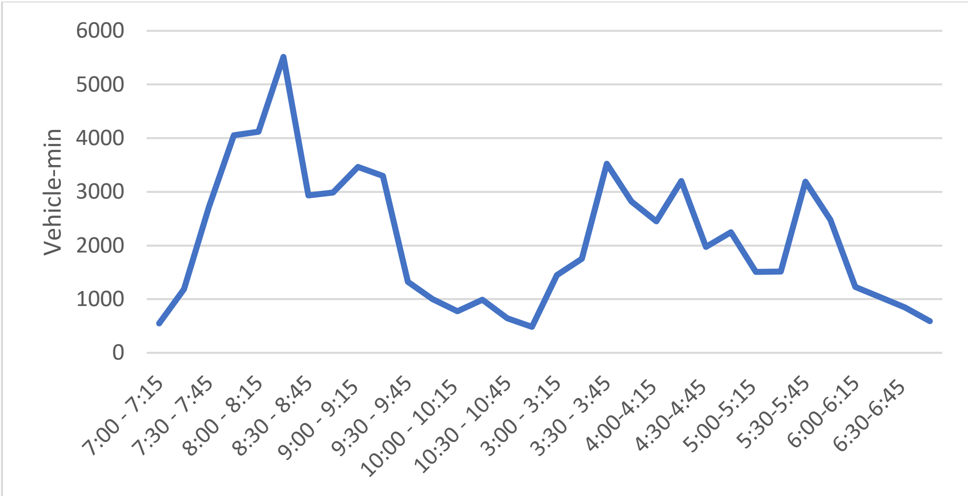

Figure 4.9: Total segment delay (vehicle-minutes) from Asrarsement to Compressive Road

When total segment delay is measured in terms of person minutes, the impacts of congestion on each traveler are made far more transparent. In the peak period between 8:15 and 8:30 AM, delays rise to 55,961.575 person minutes, showing that vehicle delays mean many minutes lost by commuters. The increase in traffic congestion is well brought out by the rise in person minutes, from 5,034.75 at 7:00-7:15 AM to over 34,000 person minutes by 8:00-8:15 AM, in a real sense showing that traffic congestion tends to worsen the commute experience, since more people are driving. Total delays reached 26,854.2 person minutes between 3:30 and 3:45 PM in the afternoon, more evidence of heavy congestion during the back-commute (see figure 4.11).

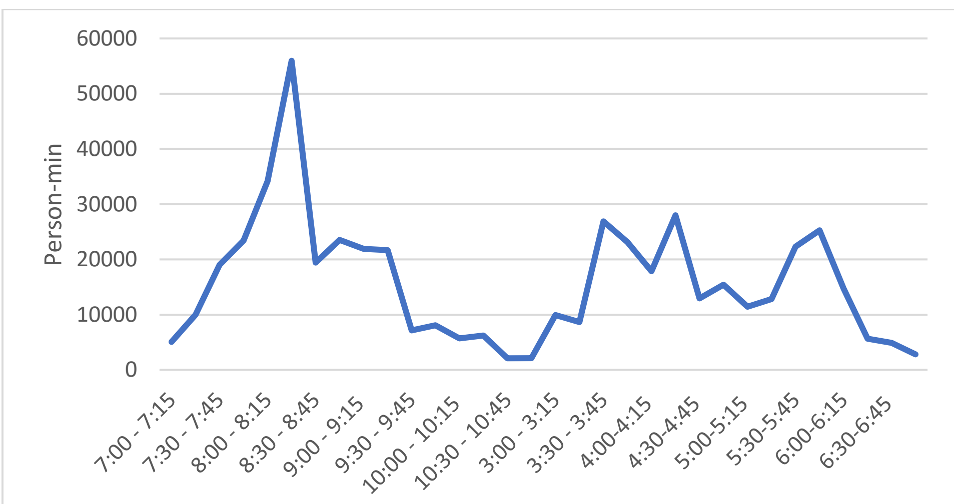

Figure 4.10:Total segment delay (Person-minutes) from Asrarsement to Compressive Road

The total segment delay recorded in vehicle minutes and person minutes per day was 67,833 and 508,033, respectively. This implies that all vehicles traveling on this road collectively experienced a total delay of 67,833 minutes, while all passengers experienced a total delay of 508,033 minutes per day, compared to if they had traveled at free-flow speeds.

4.5. The Economic Cost of Congestion

This section looks at the total cost of traffic congestion by evaluating the different causes that lead to such costs. The economic effect of traffic congestion is a subject of much debate in economic forums. Nevertheless, traffic congestion greatly impacts productivity and the working life of many individuals.

4.5.1. Travel Time Delay Cost

Delay costs are the largest component of direct and indirect costs of congestion in most cases. To estimate the travel time delay costs, speeds during uncongested flow must be compared to those during free-flow conditions.

The costs are segregated into recurring and nonrecurring delays. In order to estimate these costs correctly, it is necessary to calculate the value of time (VOT), vehicle occupancy, and the incident delay ratio beforehand.

In the context of travel for work, VOT represents an economic gain from the saving of travel time since it enables more productivity when less time is spent traveling. Using data from the traffic questionnaire, which provided information on monthly income and hours of work, VOT can be calculated. An average of 26 days and 8 hours a day is assumed. Respondents reported an average income of 40 Birr per hour. A study by Gunjo et al. (2024a) indicated that in Kolfe Keranyo sub-city, on average, drivers made 35 Birr while passengers made 32 Birr. Based on this, a VOT of 40 Birr per hour is applied in this study.

Texas Transportation Institute indicates that the incident delay ratio for arterial roads is 1.1. Considering these factors, the recurring travel time delay cost for the specified road segment is estimated at 87,240,542.98 Birr annually, while the nonrecurring travel time delay cost is approximately 95,964,597.28 Birr annually. This leads to a total travel time delay cost of 183,205,140.26 Birr, as detailed in Appendix C.

4.5.2. Excess Fuel Consumption Cost

The (World Bank, 2013) reports that the average fuel economy formula was developed for vehicles up to 20 years old. Hence, it makes sense to apply it to our scenario. Based on this calculation, the study segments indicate an excess daily fuel consumption of 1,278 liters for gasoline and 1,062.8 liters for diesel vehicles, amounting to a cumulative daily fuel wastage of 2,840.84 liters. Taking into consideration the current fuel prices of both diesel and gasoline, there is an estimated 212,430 birr a day as cumulative cost spent due to excessive fuel consumption. This gives a striking annual financial loss of 53,107,505.48 birr owing to congestion as shown in appendix C. The sums of excess fuel used present huge inefficiencies in the flow of traffic, initiated mainly by congestion.

The financial strain stemming from the annual loss of over 53 million birr attributed to fuel wastage is more than just a number; it represents a considerable opportunity cost to the city. This foregone revenue can be reinvested in basic services such as education, health, and infrastructure development basic prerequisites for urban growth and the improvement of quality of life. Moreover, overconsumption of fuel results in increased emissions of greenhouse gases and air pollution, hence deteriorating environmental conditions and affecting public health adversely. This combined effect of financial detriment and ecological harm puts a strong emphasis on the great need for efficient traffic management strategies.

4.5.3. Excess Emission Cost

The increase in the use of fuel on roads has high implications for ecological sustainability and public health. While vehicle fuel consumption increases, the amount of greenhouse gases emitted into the atmosphere also increases, thus contributing to poor air quality. This increase in emissions is quite a significant problem since it helps advance climate change and poses health risks to local populations.

The volume of fuel consumed is a direct measure of the level of emission a vehicle produces. According to Prest et al. (2022), a typical car emits 2.347 kilograms of CO_2 for every liter of petrol burned. This gives an excellent insight into how much potential carbon emissions society has to put up with just from gasoline-powered vehicles. Besides that, it also holds significantly higher potential consequences brought about by diesel-powered vehicles, which emit roughly 2.689 kgs of CO_2 for each liter spent. This difference in emission shows the ecological impact involved between diesel and gasoline, where diesel engines are often viewed to be more economical but at the same time are responsible for high levels of CO_2 emissions in every liter used.

The economic ramifications of these emissions extend beyond environmental concerns. According to estimates from Prest et al. (2022), the Social Cost of Carbon (SCC) i.e., a measure used to estimate the economic harm from carbon dioxide emissions is valued at $185 per ton of CO_2. When converted, this translates to approximately 19.42 Birr per kg of CO_2.

Accordingly, this study estimates that the overall additional fuel consumption in this section of the road has caused an extra cost of 28,437,858 Birr annually, which accounts for the cost of CO_2 emissions. This is the cost of congestion that society must pay for because of the increased emission thereafter. These financial outlays may include medical costs due to air pollution, deterioration of the environment, and even long-lasting climate change.

4.5.4. Waiting Time Delay Cost

Delays arising while waiting to board at transfer stations during peak hours were quantified with the use of questionnaires. The average measured waiting time was 5.24 minutes. It is a representation of general time wasted by commuters while waiting for public transport at peak hours. These are the most critical delays, since this directly affects the effectiveness and reliability of the whole system and infrastructural investment made.

To estimate the economic loss of such delays, the total annual cost due to waiting time delay was calculated using the above formula and was found to be approximately 9,460,132 birr for the road section affected by traffic congestion. The annual costs of delays caused by waiting time are an enormous economic loss for commuters, showing not only the wastage of time inefficiently used but also the lost productivity that could have been otherwise used for work or recreational activities. This economic impact trickles down to businesses dependent on the timely delivery of goods and services. Although 5.24 minutes might seem like a negligible amount of time to wait, cumulatively added to the daily commuters, it amounts to great frustration and dissatisfaction. This kind of delay could potentially discourage people from using public transport and increase the dependence on private vehicles, which may further increase traffic congestion with its attendant problems.

4.5.5. Vehicle Maintenance Cost

Based on traffic surveys conducted for various transport modes, the average monthly vehicle maintenance costs including tire replacement, lubricants (oil and grease), maintenance parts, service costs, and overhead were calculated as follows: 2,500 birr for private cars, 4,767 birr for minibuses, 37,250 birr for buses, 25,341 birr for trucks, and 69,909 birr for heavy trucks. These figures represent total maintenance costs during both peak and off-peak periods. According to, Litman (2013) as cited by Gabr et al. (2018) vehicle maintenance costs during peak periods are 15% higher than during free-flowing conditions, a finding supported by the World Bank (2013), which noted the relationship between Vehicle Operating Cost (VOC) and average speed. This would suggest that the particular road stretch notably raises the average monthly maintenance cost of vehicles that run in peak hours. However, due to lack of information of total daily distance travelled by vehicles, any estimation of the annual additional maintenance cost through congestion on this highway can't be made.

4.5.6. Traffic Offenses Cost

Traffic congestion has a very important effect on the behavior of drivers, where traffic rules are often disobeyed. A survey of 156 drivers showed that 96.2% of them confessed to having broken traffic laws due to congestion, thus showing a general trend of disregard for rules in an attempt to navigate through heavy traffic. Frequent violations included illegal parking, improper changing of lanes, and driving in the wrong direction. Illegal parking was most prevalent, which suggests that drivers park illegally out of frustration and because there are not enough parking spaces. In addition, aggressive lane changing not only is dangerous but also worsens current traffic congestion.

The relationship between traffic congestion and driver offenses has a lot of economic implications. Whenever drivers break traffic rules, they are usually fined by traffic authorities, which may lead to increased financial burdens. This is evidenced by previous information indicating that 2,017,930 drivers were fined in Addis Ababa, which summed up to a financial loss of 1,129,500,000 Ethiopian birr (Ministry of Transport and Logistics as cited by Solomon, 2024).

The frequency of violations revealed that 43.6% of drivers reported breaking rules at least once a month, with 21.8% doing so three times a month, indicating a normalization of risky behaviors.

This pattern of behavior can lead to a cycle of increased enforcement and penalties, further straining drivers financially and contributing to a negative economic impact on the community. While a small percentage claimed to never violate traffic rules, the high rate of infractions raises concerns about road safety and the potential for habitual offenders, which can exacerbate congestion and its associated costs.

4.5.7. Other Indirect Costs

The survey results show that a large majority of respondents (74%) often miss work or appointments due to traffic congestion, while only a small number say they rarely experience such disruptions. This pervasive problem brings to light the indirect costs of congestion with regard to the loss of productivity. Regular delays may lead to absences from work, which will cut down salaries and reduce the performance of the job, affecting not only the income of a person but also the overall productivity of the economy. Moreover, anxiety and uncertainty associated with traffic congestion amplify these indirect costs, showing the huge burden that congestion is on people's ability to fulfill their professional and personal commitments. The high frequency of missed work and appointments may lead to decreased productivity and increased stress, which may have potential economic consequences for both individuals and employers.

4.6. Discussion

In summary, the road segment analyzed presents the biggest delays during morning and afternoon peak times, with a maximum traffic volume of 546 and 489 vehicles in 15-minute time frames, respectively. Besides, travel speeds can decrease to as low as 5.35 km/h. Congestion metrics show large delays, with total segment delays of 5,514.6 vehicle-minutes in the morning and 3,520.8 in the afternoon, resulting in daily losses of 67,833 vehicle-minutes (1,130.55 hours) and 508,033 person-minutes (8,467.21 hours). Travel time reaches a maximum of 738 seconds during the morning and 774 during the afternoon, which flags severe congestion during the peak hours. Annual hours of delay per traveler in the morning, 42.08 hours, in the afternoon, 44.58 hours come as yet another reminder to improve the management and infrastructure of traffic

Economic losses due to traffic congestion along the roadways have quite a few faces. First, the direct costs relate to travel time delay costs per annum of 183.2 million Birr, one may safely say that due to longer travel times, productivity losses are rather huge there. Second, as a consequence of inefficient flow, the traffic causes overconsumption of fuel at an annual additional cost of 53.1 million Birr; the estimated amount of daily fuel wastage is 2,840 liters. This inefficiency also results in excess CO2 emissions amounting to 28.4 million Birr per annum; hence, the environmental and health implication associated with increased greenhouse gas emissions.

This financial burden is even more acute with indirect costs. The average waiting time during peak demand is 5.24 minutes, which results in an annual loss valued at 9.46 million Birr. Moreover, maintenance cost due to vehicle wear and tear is also higher in the presence of severe congestion compared to the state of free-flowing traffic, which is an added element in increasing operation cost for all types of vehicles. Moreover, infractions like illegal parking and weaving in traffic congestion have brought about mass fining, where many drivers incur huge monthly costs while paying no attention to traffic rules.

Table 4.2: Summary of Congestion analysis

Congestion measures	Morning Peak (7:00-11:00 AM)	Afternoon Peak (3:00-7:00 PM)
Travel Time (Seconds)	738 (8:15-8:30 AM)	774 (4:15-4:30 PM)
Travel Speed (km/h)	5.61 (8:15-8:30 AM)	5.35 (4:15-4:30 PM)
Delay Rate (Minutes/km)	8.78 (8:15-8:30 AM)	9.30 (4:15-4:30 PM)
Delay Ratio	0.82 (8:15-8:30 AM)	0.83 (4:15-4:30 PM)
Delay Per Traveler (Annual Hours)	42.08 (8:15-8:30 AM)	44.58 (4:15-4:30 PM)
Total Segment Delay (Vehicle-Min)	**67,833**	
Total Segment Delay (Person-Min)	**508,033**	

Table 4.3: Summary of Economic Costs

Type of cost	Category	Annual cost in (birr)
Direct Costs	**Travel Time Delay Costs**	
	- Recurring Delays	87,240,543
	- Nonrecurring Delays	95,964,597
	Excess Fuel Costs	
	- Annual Cost of Excess Fuel	53,107,505
	Excess Emissions Costs	
	- CO2 Emissions Cost	28,437,858
Indirect Costs	**Waiting Time Delays**	9,460,132
Total Annual cost		**274,210, 635**

The current study, therefore, supplements previous studies by showing that the peak volumes rise during early morning and afternoon. This corroborates the assertion made by Tazzie (2022) of the high levels of congestion at the peak times of Addis Ababa. Importantly, all studies show that the congestion patterns exhibit their peak every morning from 7:00 am and 10:00 am, and also within the afternoon block between 2:00 pm and 6:00 pm, which compares to the current findings. At the same time, during the peak periods, travel speed can drop to the minimum value of 5.35 km/h, indicating the high level of congestion. These findings are supported by the study of Struyf et al. (2022), who noticed, for Flanders, a decrease in average travel speeds at peak hours, suggesting similar congestion patterns in different urban settings.

The study conducted in Addis Ababa by Gunjo et al. (2024) reported that the total economic cost of congestion in Kolfe Keranyo subcity, covering a road length of approximately 15.98 km and assuming reference speeds of 30 km/hr, amounted to 43,534,449.19 Birr per km/year. The study took into account economic variables such as travel time delay cost, unreliability cost, and vehicle operating cost. It was noted that during peak hours, the average speed was 10.5 km/hr. The average incomes of the respondents in this study were 35 and 33 Birr for passengers and drivers, respectively. The study revealed that travel, vehicle operation, and unreliability costs comprised 74%, 6%, and 20%, respectively, of the total congestion costs.

In contrast, Sitotaw (2019) estimated the total costs of congestion by focusing solely on delay costs. Measuring the average peak hour speed of 10.6 km/hr along three road stretches that together covered 1.45 km in the city's eastern corridor, the study found a total economic burden of 42,897.752 Birr an hour, that is equivalent to 4,947,8376 Birr per kilometer per annum, a considerable decline as compared to previous assessments. This variance may stem from the study's exclusive consideration of the travel time delay cost component. Andargie (2017) also found that estimated the total congestion costs, including delay costs and wasted fuel costs of passenger and truck vehicles. By using four road segments with a total segment length of 1.18 km, they estimated 180,000,000 Birr per km/year.

Another study conducted by Gabr et al. (2018), in Egypt during the year, evaluated total congestion costs, considering components such as travel time delay cost, reliability cost, excess fuel cost, excess emission cost, vehicle maintenance cost, waiting time delay cost, traffic offenses cost, and lost productivity of injured persons because of traffic congestion accidents. The analysis determined a total economic cost of 184.5 million EGP, which translates to 93,860,181.18 Birr per km/year, attributable to congestion, based on the prevailing exchange rate at the time. This calculation was derived from an average peak hour speed of 14.56 km/hr, along with the utilization of five road segments, cumulatively measuring 5.5 km in length. The largest components of the most expensive traffic congestion in the study area were recurring, non-recurring, and waiting time delays, which totaled to 55% of the total annual cost. Those costs were greatly increased by maintenance costs and illegal stops. The expenses associated with reliability were affected by variables including travel duration and the length of roads, while traffic violations constituted a minor segment of the overall annual expenditures, which also encompassed fuel usage, emissions, and productivity losses resulting from injuries.

The findings of this study showed an average financial loss of 238,444,030.4 Birr per kilometer per year, with an average speed of 10.02 kilometers per hour. The levels of income that were reported by respondents in this study were quite high, at 40 Birr, which could have contributed to the higher results when compared with previous studies. This variation is likely due to the addition of other economic costs, such as the costs of waiting time delays and additional emissions. The economic impacts of congestion turned out to be a function of several variables, such as the number of lanes, the length of the road section, traffic density, and also the income level of respondents. The study further showed that 66.81% of the costs associated with the road section had to do with costs emanating from travel time delays, 19.36% with excess fuel usage, 10.37% with extra emissions, and the rest 3.46% with waiting time delays.

The estimated direct costs resulting from travel time were very close to those reported by the World Bank (2013), which estimated substantial economic costs due to travel time delays occurring in the Greater Cairo Metropolitan Area (GCMA), amounting to 110.2 million Birr per kilometer annually. In addition, the added cost due to extra fuel consumption is in conformity with the results of Helmi & Wahab (2023), who found a 10% rise in fuel consumption caused by congestion, which is tantamount to enormous annual financial costs of 373,749,840,000 Indian Rupees to the city of Palembang. This study, on the other hand, further calculates extra CO2 emissions, underlining the environmental impact of congestion. This assertion is supported by Struyf et al. (2022), who note the environmental externalities associated with congestion, including emissions and noise pollution.

Regarding the level of congestion, the current study's findings show a higher total segment delay of 67,833 vehicle-minutes compared to the previous one. For instance, a study by Sokido (2024) found a total segment delay of 12,708 vehicle-minutes while considering a 0.375km long road segment

In general, existing studies, reinforce the idea that traffic congestion adversely affects the economy through diminished productivity, heightened fuel consumption, and escalated vehicle maintenance costs. Furthermore, augmented operating expenses, delays, and environmental pollution. Furthermore, most previous studies report that the travel time delay cost is the biggest share of congestion cost, which is in line with the current findings. However, some studies, such as the World Bank (2013), give a smaller emission cost than the present study. The reason for this discrepancy is that the current study assumes a current cost of CO2 much larger than the previous values. In addition, the present findings on the cost of waiting time delays were higher than those reported by Gabr, which supports the fact that our city has insufficient transportation infrastructure. Overall, this research tries to make comprehensive analysis by evaluating economic costs from different perspectives, an aspect which was not well covered in previous studies, especially in the context of Addis Ababa.

Chapter Five

Summary of Major Findings, Conclusion, and Recommendation

5.1. Summary of Major Findings

In this study it was able to examine the traffic flow characteristics, the congestion level in the study area and its economic impact in terms of monetary value. Thus, it was analyzed the costs of travel time, excess fuel, emission, waiting time and vehicle maintenance cost resulted from congestion. Based on the analysis of data collected, A significant portion of respondents (67.0%) travel along the route 5-6 days a week. 87.9% of respondents indicate that work is their main reason for travel. Peak travel times occur in the morning (41.1%) and afternoon (40.8%), contributing to congestion. Taxis are the most utilized mode of transport (38.1%), followed by private cars (28.9%) and public buses (25.3%), indicating diverse commuting preferences and reliance on flexible transport options.

During Peak congestion periods mainly in the morning 8:00-9:00 AM and afternoon 3:00-4:00 PM, travel speed falls to as low as 5.35 km/h and delays of 9.30 minutes per kilometer, which flags congestion as a major concern in the area.

The level of congestion quantified into 67,833 vehicle-minutes lost and 508,033 person-minutes of losses annually that equate to 1,130.55 and 8,467.21 hours, respectively. This accounts for the extra time spent by vehicles queuing up or traveling at very slow speeds due to the congestion and would be additional time wasted by the people aboard these vehicles, thus creating much personal and economic distress.

The financial impact of congestion is striking and directly consists of travel time delay costs amounting to 183.2 million Birr per year, whereas excess fuel consumption and emission-related costs amount to 53.1 million Birr and 28.4 million Birr, respectively. Indirect costs entailed delays attributed to the waiting times, amounting to 9,460,132 Birr, adding it to a comprehensive economic deficit amounting to 274,210,635 Birr. Not only that, but the maintenance of vehicles and traffic-related fines also add to the enhanced economic burden.

5.2. Conclusion

Based on the study, the outlet corridor exhibits congestion levels similar to those experienced in central urban arterials; indeed, it is even higher in some respects. The concentrated travel behavior of road users during early morning and afternoon hours results in peak congestion which leads to significantly reduced travel speeds and extended travel times. Consequently, the cumulative impacts of congestion translate into huge losses in vehicle and person-minutes Daily, which is a pointer to the individual and significant economic problems brought about by increased travel times.

5.3. Recommendation

Traffic congestion cannot be completely eliminated due to the growing population and increasing number of vehicles, particularly passenger cars. But through cooperative work of stakeholders, the effects can be minimized specially for the recurrent congestion. On this study the following recommendations are suggested to solve the issues in outlet corridors of Addis Ababa.

- ❖ Stakeholders should give special attention to outlet corridors, as they experience higher congestion levels compared to central city routes. This emphasis is critical to improving traffic flow and supporting the connectivity of urban and suburban areas.
- ❖ construct alternate routes in outlet corridors, like the ones being constructed in central city corridors in the city government's corridor development program. Given that outlet corridors are just as important as central city corridors, budgetary allocations for infrastructure upgrading in central areas should also cover these peripheral routes.
- ❖ Develop off-street parking facilities and multi-story parking structures in outlet corridors by encouraging businessmen to invest in these as parallel businesses. This approach can create a mutual benefit, providing income opportunities for investors while freeing up road space and reducing congestion caused by on-street parking.
- ❖ Establish High-Occupancy Vehicle (HOV) lanes in outlet corridors, similar to the projects already underway in central city corridors. The special lanes will provide priority to public transportation and carpool vehicles, thus increasing the attractiveness and efficiency of shared transportation modes.

5.4. Future Research

The present research considered some of the factors that can be used in estimating traffic congestion and its economic impacts, such as vehicle speed, travel time, and traffic volume. Future research is encouraged to broaden the analysis to include the effects of poorly designed roads on traffic congestion. The costs related to noise pollution, and associated health and social costs should also be considered. The total cost incurred on vehicle maintenance and services combined with the above variables has to be figured out so that the public may get the full extent of the scenario. Secondly, analysis on other outlet corridors would give answers to several questions like reliability, consistency, findings in the given study.

5.5. Theoretical Contributions and Policy Implications

The study offers a fresh perspective on traffic congestion through the analysis of peripheral corridors, which contrasts with the previous focus on central business districts. This new perspective furthers the understanding of congestion dynamics. The paper, with a broad review of the economic impacts supported by in-depth data and insights, creates a strong base for future studies to further explore the different dimensions of the issue, hence letting later research build on the findings and explore additional dimensions of traffic congestion. All these data can be used by the different organizations, government agencies, and academic institutions for the development of effective measures for the solution and mitigation of traffic congestion.

This study provides insights that are very important to policymakers and other stakeholders, urging them to examine traffic congestion from many angles in view of the fluctuations in traffic patterns and their intensity. It highlights the need to enhance the very poor traffic management system and recommends that advanced technologies, including surveillance cameras and automated systems, can be very instrumental in easing congestion. By adopting a comprehensive approach, the authorities can actually improve urban mobility and increase economic productivity in Addis Ababa.

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APPENDICES

APPENDIX A: Travel Time, Traffic Volume, and Vehicle Occupancy Data

AVERAGE TRAVEL TIME AT CONGESTED SEGEMENTS (in sec)	
Segment	Asrasement mazorya-Compressive segment
Time: from-to	1.15km
7:00 - 7:15	312
7:15 - 7:30	396
7:30 - 7:45	546
7:45 - 8:00	528
8:00 - 8:15	666
8:15 - 8:30	618
8:30 - 8:45	528
8:45 - 9:00	594
9:00 - 9:15	672
9:15 - 9:30	546
9:30 - 9:45	348
9:45 - 10:00	318
10:00 - 10:15	324
10:15 - 10:30	330
10:30 - 10:45	294
10:45 - 11:00	264
3:00 - 3:15	432
3:15 - 3:30	402
3:30 - 3:45	564
3:45 - 4:00	534
4:00-4:15	516
4:15-4:30	774
4:30-4:45	474
4:45-5:00	450
5:00-5:15	336
5:15-5:30	384
5:30-5:45	582
5:45-6:00	498
6:00-6:15	318
6:15-6:30	288
6:30-6:45	276
6:45-7:00	258

Survey Summary Sheet for Classified Vehicle Counts						
Date	**Monday 23 sep 2024**					
Road Name	Asrasement mazorya - compressive					
Time from-to	Private Car	Minibus	Bus	small truck	Heavy Truck	Total
7:00 - 7:15	136	26	16	3	1	182
7:15 - 7:30	220	31	17	1	1	270
7:30 - 7:45	314	64	16	0	0	394
7:45 - 8:00	344	59	15	4	0	422
7:00 - 8:00	1014	180	64	8	2	1268
8:00 - 8:15	375	67	21	0	0	463
8:15 - 8:30	421	92	32	1	0	546
8:30 - 8:45	354	69	19	2	0	444
8:45 - 9:00	309	53	26	0	0	388
8:00 - 9:00	1459	281	98	3	0	1841
9:00 - 9:15	301	49	17	16	2	385
9:15 - 9:30	367	71	18	21	1	478
9:30 - 9:45	298	37	14	17	1	367
9:45 - 10:00	243	41	27	9	3	323
9:00 - 10:00	1209	198	76	63	7	1553
10:00 - 10:15	169	36	23	11	3	242
10:15 - 10:30	215	42	15	22	5	299
10:30 - 10:45	191	27	0	19	2	239
10:45 - 11:00	167	31	3	15	4	220
10:00 - 11:00	742	136	41	67	14	1000
3:00 - 3:15	220	44	13	12	1	290
3:15 - 3:30	301	54	10	23	1	389
3:30 - 3:45	381	73	17	18	0	489
3:45 - 4:00	324	61	21	15	0	421
3:00 - 4:00	1226	232	61	68	2	1589
4:00-4:15	306	57	17	3	0	383
4:15-4:30	215	53	29	2	0	299
4:30-4:45	262	69	15	0	0	346
4:45-5:00	328	71	23	1	1	424
4:00 - 5:00	1111	250	84	6	1	1452
5:00-5:15	361	65	15	0	2	443
5:15-5:30	291	49	19	1	0	360
5:30-5:45	317	90	16	2	0	425
5:45-6:00	321	61	25	0	0	407
5:00 - 6:00	1290	265	75	3	2	1635
6:00-6:15	296	66	33	0	1	396
6:15-6:30	310	73	13	2	0	398
6:30-6:45	276	57	18	1	0	352
6:45-7:00	233	38	9	2	0	282
6:00 - 7:00	1115	234	73	5	1	1428
Total	9166	1776	572	223	29	11766
PCE	1	1	3	1.5	3	
Total PCU	9166	1776	1716	334.5	87	13079.5

AVERAGE VEHICLE OCCUPANCY (PERSON/VEH)						
Time from-to	Private Car	Minibus	Bus	Small truck	Heavy Truck	Total
7:00 - 7:15	2.00	11.25	69.25	1.50	1.25	9.22
7:15 - 7:30	2.50	11.25	80.75	1.50	1.25	8.42
7:30 - 7:45	1.75	11.25	93.00		0.00	7.00
7:45 - 8:00	2.50	11.25	60.50	1.50	0.00	5.78
7:00 - 8:00						30.42
8:00 - 8:15	2.25	11.25	106.75	0.00	0.00	8.29
8:15 - 8:30	2.25	12.00	109.00	1.50	0.00	10.15
8:30 - 8:45	2.25	11.25	72.00	1.50	0.00	6.63
8:45 - 9:00	2.25	11.25	67.75	0.00	0.00	7.87
8:00 - 9:00						32.94
9:00 - 9:15	2.50	10.75	67.75		1.25	6.32
9:15 - 9:30	2.25	11.25	82.50	1.50		6.57
9:30 - 9:45	2.50	11.25	56.50	1.50		5.39
9:45 - 10:00	2.50	11.25	56.50	1.50		8.07
9:00 - 10:00	9.75	11.13	12.79	1.50	1.25	26.35
10:00 - 10:15	2.25	11.50	42.25	1.50	1.25	7.38
10:15 - 10:30	2.00	11.25	62.75	1.50		6.28
10:30 - 10:45	2.25	11.75		1.50		3.24
10:45 - 11:00	2.50	11.25	56.50	1.50		4.36
10:00 - 11:00						21.26
3:00 - 3:15	2.00	11.25	79.50	1.50	1.25	6.85
3:15 - 3:30	2.25	11.25	60.75	1.50		4.95
3:30 - 3:45	2.75	12.50	102.50	1.50		7.63
3:45 - 4:00	2.25	11.50	95.00	1.50		8.19
3:00 - 4:00						27.62
4:00-4:15	2.25	12.00	83.00	1.50		7.28
4:15-4:30	1.75	11.25	56.50	1.50		8.74
4:30-4:45	1.75	12.00	65.50			6.56
4:45-5:00	2.00	12.00	60.75	1.50	1.25	6.86
4:00 - 5:00						29.44
5:00-5:15	2.25	12.50	115.50		1.25	7.58
5:15-5:30	2.75	12.50	86.25	1.50		8.48
5:45-6:00	2.25	12.50	106.25			10.17
5:00 - 6:00						33.25
6:00-6:15	2.00	11.75	102.50		1.25	12.00
6:15-6:30	1.75	12.25	56.50	1.50		5.46
6:30-6:45	1.50	12.00	51.75	1.50		5.77
6:45-7:00	1.75	12.00	51.25	1.50		4.71

APPENDIX B: Congestion Analysis

CONGESTION ANALYSIS SHEET

Corridor Name	**Asrasement mazorya -compressive**
Corridor Length	**1.15km**

Duration	Average travel Time (S)	Delay (s)	Average Travel Speed (km/h)	Travel Rate (min/Km)	Delay Rate (min/Km)	Travel Time Index	Traffic Volume (Vec)	Average Vehicle Occupancy (persons/veh)	Travel Time (Person - Min)	Total Segment Delay (Vehicle Min)	Total Segment Delay (Person Min)	Delay Per Traveler (Annual Hours)	Delay Ratio
7:00 - 7:15	312	180	13.27	4.52	2.61	2.00	182	9.22	8,726.90	546	5034.75	12.50	0.58
7:15 - 7:30	396	264	10.45	5.74	3.83	2.54	270	8.42	15,010.05	1188	10006.7	18.33	0.67
7:30 - 7:45	546	414	7.58	7.91	6.00	3.50	394	7.00	25,093.25	2718.6	19026.75	28.75	0.76
7:45 - 8:00	708	576	5.85	10.26	8.35	4.54	422	5.78	28,759.55	4051.2	23397.6	40.00	0.81
8:00 - 8:15	666	534	6.22	9.65	7.74	4.27	463	8.29	42,615.68	4120.7	34169.325	37.08	0.80
8:15 - 8:30	738	606	5.61	10.70	8.78	4.73	546	10.15	68,151.23	5514.6	55961.575	42.08	0.82
8:30 - 8:45	528	396	7.84	7.65	5.74	3.38	444	6.63	25,905.00	2930.4	19428.75	27.50	0.75
8:45 - 9:00	594	462	6.97	8.61	6.70	3.81	388	7.87	30,224.70	2987.6	23508.1	32.08	0.78
9:00 - 9:15	672	540	6.16	9.74	7.83	4.31	385	6.32	27,255.20	3465	21901.5	37.50	0.80
9:15 - 9:30	546	414	7.58	7.91	6.00	3.50	478	6.57	28,583.10	3298.2	21672.9	28.75	0.76
9:30 - 9:45	348	216	11.90	5.04	3.13	2.23	367	5.39	11,470.95	1321.2	7119.9	15.00	0.62
9:45 - 10:00	318	186	13.02	4.61	2.70	2.04	323	8.07	13,821.08	1001.3	8084.025	12.92	0.58
10:00 - 10:15	324	192	12.78	4.70	2.78	2.08	242	7.38	9,645.75	774.4	5716	13.33	0.59
10:15 - 10:30	330	198	12.55	4.78	2.87	2.12	299	6.28	10,322.13	986.7	6193.275	13.75	0.60
10:30 - 10:45	294	162	14.08	4.26	2.35	1.88	239	3.24	3,799.95	645.3	2093.85	11.25	0.55
10:45 - 11:00	264	132	15.68	3.83	1.91	1.69	220	4.36	4,216.30	484	2108.15	9.17	0.50
3:00 - 3:15	432	300	9.58	6.26	4.35	2.77	290	6.85	14,311.80	1450	9938.75	20.83	0.69
3:15 - 3:30	402	270	10.30	5.83	3.91	2.58	389	4.95	12,909.23	1750.5	8670.375	18.75	0.67
3:30 - 3:45	564	432	7.34	8.17	6.26	3.62	489	7.63	35,059.65	3520.8	26854.2	30.00	0.77
3:45 - 4:00	534	402	7.75	7.74	5.83	3.42	421	8.19	30,687.20	2820.7	23101.6	27.92	0.75
4:00-4:15	516	384	8.02	7.48	5.57	3.31	383	7.28	23,976.80	2451.2	17843.2	26.67	0.74
4:15-4:30	774	642	5.35	11.22	9.30	4.96	299	8.74	33,720.60	3199.3	27969.8	44.58	0.83
4:30-4:45	474	342	8.73	6.87	4.96	3.04	346	6.56	17,925.10	1972.2	12933.3	23.75	0.72
4:45-5:00	450	318	9.20	6.52	4.61	2.88	424	6.86	21,810.00	2247.2	15412.4	22.08	0.71
5:00-5:15	336	204	12.32	4.87	2.96	2.15	443	7.58	18,814.60	1506.2	11423.15	14.17	0.61
5:15-5:30	384	252	10.78	5.57	3.65	2.46	360	8.48	19,539.20	1512	12822.6	17.50	0.66
5:30-5:45	582	450	7.11	8.43	6.52	3.73	425	7.01	28,886.60	3187.5	22335	31.25	0.77
5:45-6:00	498	366	8.31	7.22	5.30	3.19	407	10.17	34,370.30	2482.7	25260.1	25.42	0.73
6:00-6:15	318	186	13.02	4.61	2.70	2.04	396	12.00	25,181.63	1227.6	14728.875	12.92	0.58
6:15-6:30	288	156	14.38	4.17	2.26	1.85	398	5.46	10,436.40	1034.8	5653.05	10.83	0.54
6:30-6:45	276	144	15.00	4.00	2.09	1.77	352	5.77	9,342.60	844.8	4874.4	10.00	0.52
6:45-7:00	258	126	16.05	3.74	1.83	1.65	282	4.71	5,710.40	592.2	2788.8	8.75	0.49
Avg	**458.44**	**326.44**	**10.02**	**6.64**	**4.73**	**2.94**	**367.69**	**7.16**	**21758.84**	**2,119.78**	**15,876.02**	**22.67**	**0.68**
Total										**67,832.90**	**508,032.75**		

APPENDIX C: Economic Impact Analysis

Travel time delay cost					
Time	VOC	volume of vhehicle(pcu)	average congeted speed	free flow speed	Total Cost
7:00 - 7:15	9.22	217.5	13.27	31.36	927,511.57
7:15 - 7:30	8.42	306.5	10.45	31.36	1,751,148.18
7:30 - 7:45	7.00	426	7.58	31.36	3,171,410.17
7:45 - 8:00	5.78	454	5.85	31.36	3,880,553.32
8:00 - 8:15	8.29	505	6.22	31.36	5,745,460.20
8:15 - 8:30	10.15	610.5	5.61	31.36	9,646,337.83
8:30 - 8:45	6.63	483	7.84	31.36	3,258,237.34
8:45 - 9:00	7.87	440	6.97	31.36	4,109,742.15
9:00 - 9:15	6.32	431	6.16	31.36	3,779,797.84
9:15 - 9:30	6.57	526.5	7.58	31.36	3,680,119.59
9:30 - 9:45	5.39	405.5	11.90	31.36	1,212,714.01
9:45 - 10:00	8.07	387.5	13.02	31.36	1,495,035.74
10:00 - 10:15	7.38	299.5	12.78	31.36	1,090,509.72
10:15 - 10:30	6.28	350	12.55	31.36	1,117,568.44
10:30 - 10:45	3.24	252.5	14.08	31.36	341,003.23
10:45 - 11:00	4.36	241.5	15.68	31.36	356,727.08
3:00 - 3:15	6.85	324	9.58	31.36	1,711,776.67
3:15 - 3:30	4.95	422.5	10.30	31.36	1,451,713.30
3:30 - 3:45	7.63	532	7.34	31.36	4,503,913.98
3:45 - 4:00	8.19	470.5	7.75	31.36	3,980,095.91
4:00-4:15	7.28	418.5	8.02	31.36	3,005,679.04
4:15-4:30	8.74	358	5.35	31.36	5,162,752.76
4:30-4:45	6.56	376	8.73	31.36	2,166,666.87
4:45-5:00	6.86	472.5	9.20	31.36	2,647,742.86
5:00-5:15	7.58	477	12.32	31.36	1,896,087.73
5:15-5:30	8.48	398.5	10.78	31.36	2,188,094.24
5:30-5:45	7.01	458	7.11	31.36	3,710,549.37
5:45-6:00	10.17	457	8.31	31.36	4,372,493.54
6:00-6:15	12.00	464	13.02	31.36	2,660,401.07
6:15-6:30	5.46	425	14.38	31.36	930,543.23
6:30-6:45	5.77	388.5	15.00	31.36	829,304.16
6:45-7:00	4.71	301	16.05	31.36	458,851.84
Total (recuring)					**87,240,542.98**
Total (non-recuring)					**95,964,597.28**
Total					**183,205,140.26**

Ecxess Fuel wasted															
Vehicle types	volume (PCU)	Brnzene type	Diesel type	DVKT (benzine	DVKT (Diesel	free flow speed	Avg congested speed	Avg. fuel economy	daily fuel wasted (benzine)	daily fuel wasted (Diesel	unit cost of benzine (birr)	unit cost of Diesel (birr)	cost of annual benzine fuel wasted (birr)	cost of annual benzine fuel wasted (birr)	Total cost of exess fuel wasted
private	9166	6874.5	2291.5	7905.675	2635.225	31.36	10.02	4.37	1230.32968	410.109892	91.14	90.28	28,033,061.67	9,256,180.26	53,107,505.48
minibus	1776	266.4	1509.6	306.36	1736.04	31.36	10.02	4.37	47.6776239	270.173202	91.14	90.28	1,086,334.66	6,097,809.18	
bus	1716	0	1716	0	1973.4	31.36	10.02	4.37	0	307.112623	91.14	90.28	0.00	6,931,531.89	
truck	334.5	0	334.5	0	384.675	31.36	10.02	4.37	0	59.865485	91.14	90.28	0.00	1,351,164.00	
H truck	87	0	87	0	100.05	31.36	10.02	4.37	0	15.5703952	91.14	90.28	0.00	351,423.82	
Total	13080	7141	5939						1,278.01	1,062.83			**29,119,396.33**	**23,988,109.15**	

Exess Emission cost				
ecxess benzine wested per year	ecxess disel wested per year	emission per liter of fuel (benzine)	emission per liter of fuel(diesel	cost of anuual ecxess C02 emission
319501.825	265707.8993	2.347	2.689	**28,437,858.08**

waiting time delay cost				
MDPHV	Percentage of each	avg waiting time delay	VOC for bus and minibus	total waiting time delay
1,841.00	0.21	0.09	30.90	9,460,132.25

APPENDIX D: Questionnaire

Questionnaire on Analyzing Road Traffic Congestion and its Economic Impact in Addis Ababa

Dear Respondent; Thank you for taking part in this study.

I am Abdulfeta Bahiru from Addis Ababa University, College of Business and Economics. May I wish to notify you that this questionnaire aims to gather information about the study titled "Analyzing Road Traffic Congestion and its Economic Impact in Addis Ababa." This is purely an academic study, which is being conducted as a partial fulfillment for the award of degree on Masters of Science in Management at Addis Ababa University. Through this information, the researcher will be able to analyze and document the economic impact of road traffic congestion in Addis Ababa region. It should be noted that all information obtained will be treated very confidentially and used for the intended purpose only. Please feel free to answer the questions according to your experience and understanding.

Instructions:

1. Kindly answer all questions correctly as instructed.

2. Do not write your name on this questionnaire as it might not be associated with your answers.

Section 1: Demographic Information

1) Sex

A). Male ☐ B). Female ☐

2) Age

A) 18 - 25 years ☐ C) 36 – 45 years ☐ E) Above 55 years ☐

B) 26 – 35 years ☐ D) 46– 55 years ☐

3) Education level

A) Primary level ☐ C) Diploma ☐ E) Masters and above ☐

B) Secondary level ☐ D) Degree ☐

4) Occupation

A) public employed ☐ C) self-employed ☐

B) private-employed ☐ D) Student ☐

5) Salary Scale in Birr

A) Below 5,000 ☐ C) 10,001-15,000 ☐ E) 20,001-25000 ☐

B) 5,001-10,000 ☐ D) 15,001-20,000 ☐ F) Above 25,000 ☐

Section 2: Travel Behavior

1. Please Specify your category.

   A) Driver ☐ B) Passenger ☐

2. How many days per week do you travel on this road?

   A) 1-2 days ☐ C) 5-6 days ☐ E) Only this day ☐

   B) 3-4 days ☐ D) 7 days ☐

3. What is the primary purpose of your travel?

   A) work ☐ C) shopping ☐

   B) school ☐ D) Social/Recreational ☐

4. What time of day do you usually travel? (select all that apply)

   A) Morning peak period (7:00 AM - 11:00 AM) ☐

   B) off-peak daytime (11:00 AM - 3:00 PM) ☐

   C) Afternoon peak period (3:00 PM - 7:00 PM) ☐

   D) off-peak Night time (7:00 PM – 7:00 AM) ☐

5. What mode of transport do you primarily use?

   A) private car ☐ C) Motorcycle ☐ E) Walking ☐

   B) Taxi ☐ D) Public bus ☐

Section 3: Experience with Traffic Congestion

1. What are the most common causes of traffic delays you experience? (Select all that apply)

   A) Uncivil Driving Behavior ☐

   B) Inadequate Parking Spaces and Illegal Parking ☐

   C) Improper loading and unloading of passengers and goods on the road ☐

   D) Insufficient road width ☐

E) Poor traffic management ☐

F) Other (please specify): ☐

2. How often do you experience traffic congestion due to unexpected events such as bad weather, accidents, and vehicle breakdowns?

A) Always ☐ C) sometimes ☐ E) never ☐

B) often ☐ D) rarely ☐

3. How often do you experience traffic congestion during your commute?

A) Always ☐ C) sometimes ☐ E) never ☐

B) often ☐ D) rarely ☐

4. How do you see the level of traffic congestion along the street?

A) Highly Congested ☐ C) Moderately Congested ☐ E) Not Congested ☐

B) Congested ☐ D) Slightly Congested ☐

Section 4: Economic Impact of Congestion

1. What type of fuel does your vehicle consume?

A) Gasoline ☐ B) Benzene ☐

2. How often do you miss work or appointments due to traffic delays?

A) Always ☐ C) sometimes ☐ E) never ☐

B) often ☐ D) rarely ☐

3. On average, how much extra time do you spend waiting for transport in stations when there is traffic congestion?

A) Less than 2 minutes ☐ C) 6-8 minutes ☐ E) more than 11 minutes ☐

B) 3-5 minutes ☐ D) 9-11 minutes ☐

4. What is your average yearly expenditure on vehicle service and maintenance including tire replacement?

A) Less than 20,000 birr ☐ C) 31,000-40,000 birr ☐ E) More than 50,000 birr ☐

B) 21,000-30,000 birr ☐ D) 40,000-50,000 birr ☐

5. Have you violated traffic rules due to congestion and were penalized for that on this road?

A) Yes ☐ B) No ☐

6. If yes, which traffic rule did you violate? (Select all that apply)

A) Driving in the opposite direction ☐

B) Illegal parking ☐

C) Improper lane usage (weaving between lanes) ☐

D) Other (please specify)……………☐

7. How many times do you violate traffic rules due to congestion in a month?

A) one time in a month ☐ C) three times in a month ☐ E) Never ☐

B) two times in a month ☐ D) more than three times ☐