ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

ASSESSMENT OF TRAFFIC CONGESTION ANALYSIS MEASURES IN ADDIS ABABA CITY (A CASE STUDY OF MEXICO SQUARE TO GERMAN ROUNDABOUT ROAD SEGMENT)

BY:

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ADVISOR:

Dr. BIKILA TEKLU

A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering

(Road and Transport Engineering)

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DECLARATION

I certify that this research work titled "**Assessment of Traffic Congestion Analysis Measures in Addis Ababa City (A Case Study of Mexico Square to German Roundabout Road Segment)**" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged/ referred.

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ABSTRACT

One of the most prevalent issues with urban transportation systems is traffic congestion. When there is a disruption in the regular flow of traffic, it leads to a decrease in speed, a delay in travel, and a substandard quality of service, this is known as traffic congestion.

Depending on the causes, traffic congestion can either be recurrent or non-recurrent. Recurrent congestion is brought on by transient signal changes, capacity violations, and excessive traffic demand. On the other side, unusual events like work zones, severe weather, and other occurrences could cause non-recurring congestion. Numerous methods for evaluating traffic congestion have been devised, taking into account various factors such as speed, travel duration, frequency of delays, quality of service, and other congestion indicators. The level of service method and travel time-based measurements, which are the two categories into which the already existing congestion measures were divided, then examined within this research.

The road segment Mexico square – German roundabout was chosen from the city's core area and three road sections were selected from this segment to achieve the stated objective. The relevant data was manually collected by the researcher from selected segments, utilizing equipment appropriate for the study's objectives. The results showed the travel time based measures showed variations in the congestion state while indicating a similar congestion trend during peak and Off-peak hour for the Africa union – Pushkin square and Mekanisa Abo – Mekanisa road sections while showing a uniform congestion state for the Mekanisa – German Roundabout Road section. The capacity for the level of service was modeled using three traffic flow models, the Greenshields, Greenberg and Underwood model. The result indicates the underwood model better explained the data compared to the other two models. And, the advantages and disadvantages of the measures used have been discussed from the results.

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List of Acronyms

HCM: Highway Capacity Manual

TTI: Travel Time Index

TRI: Travel Rate Index

BTI: Buffer Time Index

PTI: Planning Time Index

CI: Congestion Index

SPI: Speed Performance Index

SRI: Speed Reduction Index

VLSI: Very Low Speed Index

CMI: Corridor Mobility Index

RSCI: Road Segment Congestion Index

CSI: Congestion Severity Index

LOS: Level of Service

V/C: Volume to Capacity

ERA: Ethiopian Roads Authority

PCU: Passenger Car Units

PDF: Probability Density Function

CDF: Cumulative Distribution Function

CHAPTER ONE: INTRODUCTION

1.1. Introduction

Whether it's for employment, school, or business, everyone travels. Transport is the medium through which such activities take place; it serves as the adhesive that holds the communities and their activities together. The challenge of transportation has been and is to be meeting these demands. Because of advancements in transportation technology and lifestyle, people's ways of living and working have altered. This has caused a gradual transition in mobility from walking to using animals to using cars, and even from first-generation, slower vehicles to the quickest vehicles of the twenty-first century.

While the movement of people, goods, and information has improved over time due to advancements in transportation capabilities, concurrent economic development and a high rate of urbanization have created many challenges for the transportation system (Aftabuzzaman M., 2007). As the population grows and living standards rise, a better road infrastructure, particularly transportation systems, has become essential for everyone. Numerous problems, such as traffic congestion, Nosie pollution, high accident rates, life losses, etc. are developing as a result of the inability to satisfy this demand.

Worldwide, traffic congestion is by far the biggest issue that both industrialized and developing nations must deal with. All facets of society, including academia, the media, decision-makers, and the general public, commonly use the word "congestion." There is still no agreed-upon definition of traffic congestion, though (Palash C.D., 2018). The fact that congestion is both a subjective experience that varies from person to person, time to time, and location to place, as well as an actual physical reality of the transportation network, is one of the main causes of this lack of agreement. According to the majority of academics, congestion is a situation on road networks that develops as traffic volume rises and is characterized by slower speeds, longer travel times, and more vehicle waiting. Congestion starts to happen when there is a high enough demand for transportation that interactions between cars cause the flow of traffic to slow down. Congestion increases as demand approaches a road's (or a road's junctions') capacity. (Feb 2019 Work Stream 1, Defining Congestion).

Delay, or the time wasted when the flow of traffic is hampered, is the outcome of traffic congestion. failure to effectively predict journey times, which causes drivers to spend more time traveling and less time engaging in productive activities. Fuel wastage and rising air pollution are major issues, since clogged cars release CO (carbon monoxide) and other pollutants that can cause everything from runny noses to global warming. wear and tears on cars brought on by continuous acceleration and braking as well as idling in traffic, which results in more frequent repairs and replacements, as a result of the stop-and-go nature of the traffic congestion, passengers and drivers experience stress and irritation, which weakens them. Congestion further increases the risk of accident, which may result in numerous injuries and fatalities. Some agricultural produce also perishes. Many agricultural items, including tomatoes, mangoes, and other fruits and vegetables (Albert Bull, LC/G.2199-P January 2004)

Background of the study

Addis Ababa, which is the capital city of Ethiopia and the seat for many international organizations with more than 100 embassies, has now become one of the fastest growing relatively modern cities in the sub-Saharan Africa. Following the current economic development in the country, Addis Ababa has become the economic hub of the nation due its geographical as well as political significance.

Congestion is occasionally becoming a more severe issue in Addis Ababa due to a number of causes, including population increase, natural growth, and a pull effect that draws individuals from around the nation to the city in search of work. It is obvious that these additional societal groups also require transportation services to do their daily tasks in order to maintain the city. The city, however, is unable to meet the current high demand for transportation services. Additionally, bad infrastructure, ineffective land use planning, and a lack of effective traffic management are the main causes of the issue of traffic congestion. Therefore, substantial study must be done in order to identify solutions to alleviate congestion. This study proposes to quantify the degree of traffic congestion at significant road segments using various congestion analysis measures and evaluate their effectiveness. The study's findings can be used to assess the recommended measures for assessing congestion and looking for solutions.

1.2. Statement of the problem

Addis Ababa, the capital city of Ethiopia, is characterized by the largest share of road traffic flow comparative to other cities in the nation as a result of continuing modernization and industrialization. the majority of road accidents, congestion and related traffic problems are highly concentrated in the city. Now days it seems that traffic congestion is becoming forcefully acceptable excuses for workers being late to work in the city. The poor road infrastructure of the city, coupled with inadequate and inefficient transport activities, sudden surge in the car ownership have combined to complicate Addis Ababa traffic problems.

The city currently uses various measures to analyze and manage traffic congestion, such as traffic surveys, travel time studies, capacity analysis etc. but the efficiency and limitation of this measures are not well represented. So, in order to effectively curb traffic congestion in the city, we need to adopt a traffic congestion measurement approach that will not only represent the current conditions on the ground but enable us to closely track the rapidly changing traffic situation.

Thus, in this thesis a comprehensive assessment was conducted on the travel time-based measures and Level of service method used for analyzing the performance of the selected road segment.

1.3. Research Questions

- What are the features of current traffic flow?
- What are the available congestion measures that can be applied for the selected road segment?
- Does the current traffic congestion lead to delay and increase travel time?

1.4. Objective of the study

1.4.1. General objective

The main objective of this study is, to analyze the performance of selected road segment in Addis Ababa city. in this case study, the Mexico Square – German Roundabout Road segment is selected and analyzed with various congestion measures.

1.4.2. Specific objective

- To assess travel-time based (Travel rate, Travel Time Index, delay rate, delay ratio, speed performance index, speed reduction index and road segment congestion index) and Level of service method (volume to capacity ratio) for analyzing the selected segment.
- Compare the travel time-based measure and the level of service method.
- Make a recommendation on best practice to be followed when conducting congestion analysis.

1.5. Significance of the study

The findings from this study can provide independent information to guide the Federal and State governments, including concerned private companies and international agencies in identifying the appropriate and effective congestion analysis measure while responding to the challenges of traffic congestion in Addis Ababa and other Ethiopian cities. Besides, it will also trigger further studies in attempt to find a suitable congestion measure.

1.6. Scope of the Study

In this study, performance evaluation on a selected road segment, Mexico Square – German Roundabout, will be assessed by analyzing the selected road sections and quantifying overall congestion on the sections.

This research is focused on assessing travel - time based congestion analysis methods and level of service method in quantifying congestion and showing the degree of the specified problem.

The analysis measure that will be forwarded will be pointed out as recommendations and made open for further studies.

1.7. Limitation of the study

There are two types of traffic congestion, recurrent traffic congestion and non- recurrent traffic congestion. However, the first type of congestion was considered since it is easier to track and analyze because it is observed many times of the day in Addis Ababa. Due to time and budget constraints, selected road sections along the study segment were considered.

1.8. Structural Framework of the Study

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

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

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

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

Chapter four: Presents the collected data from different sources and by different methods. This data is analyzed mathematically and statistically to come up with a vital discussion.

Chapter five: Contains the final conclusions and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

Throughout the world Traffic saturation causes chronic congestion, which has many negative effects in terms of irritation, stress, wasted time, and environmental annoyance. The quality of urban life is significantly impacted by the ongoing rise of vehicle traffic, and billions of dollars are spent annually to address this issue. Additionally, every day, billions of hours are lost in traffic. Despite advancements in vehicle technology, cities are becoming a significant and rising source of air pollution, greenhouse gas emissions, traffic noise, and the more efficient use of non-renewable resources due to the development of traffic and the irregular nature of driving in urban areas. traffic congestion is also an ongoing challenge for the development of a region and can result in terms of both direct and indirect costs linked to productivity losses, business activities and the free displacement of goods and people.

Traffic congestion is an ever-growing global phenomenon resulting from high population growth, increasing motor vehicles and their infrastructure, and spread of rideshare and delivery services (Reed, T et.al., 2019). The social, economic, and environmental impacts of traffic congestion in recent years are quite significant. Particularly in the densely populated areas, the urban transport system is affected by the extensive amount of delay and cost due to congestion. (Laval, J.A. et.al., 2006; Wang, Y et.al., 2013; Falcocchio, J.C et.al., 2015). In the year 2020 only, traffic congestion cost people at Megenagna Diaspora intersections (roundabout) about 1,033,292.87 ETB and Lamberat Semen Bus Terminal intersection about 899,757.40 ETB, (Habtamu G.T., 2020). One reason for this is, the capacity of existing roadways cannot accommodate the increasing number of automobiles. Aging transportation infrastructure—such as the conditions of roads, highways, or bridges—are often seen as one of the intrinsic causes of traffic congestion. However, congestion is also somewhat the reason for the physical degradation of transportation infrastructure, which is in turn reducing the transportation network performance.

Even though numerous recovery strategies have been established to improve the damaged network performance, most of these approaches are not adequate or even might not be appropriate for congested road traffic conditions. multi-disciplinary mitigation actions are needed in order to guarantee a sustainable and resilient transportation system for combating road traffic congestions (Aftabuzzaman M., 2007). For several years, diverse attempts have been applied from the government, public and private sector policy-makers, researchers, and experts to lessen the impact due to congestion. It is observed that the first step to structure an effective traffic control management system is appropriate monitoring of the traffic condition. doing this will allow as to start preventive actions before the peak of the congestion hours and the congestion levels can be quantified promptly. Measuring possible congestion can also be valuable while preparing for traffic management during special events (Transportation Research Board, Highway Capacity Manual, 5th Edition, 2011).

Various measurement approaches have been developed throughout the years by researchers, transportation experts and Policy-makers to estimate traffic congestion accurately. Presently, a variety of traffic congestion measures are available depending on various performance criteria, such as speed, travel time, delay, level of services, congestion indices. However, different countries adopted different measures, even some countries have states that use different congestion measures and there is no fixed universal method of measuring traffic conditions at present-day. The Highway Capacity Manual (HCM) is one of the few first manuals to propose using the level of service as an evaluation index of road performance in 1985.

Traffic congestion is a global issue that creates a difficulty for a robust and sustainable transportation system. This paper's long-term objective is to aid in the creation of a resilient and sustainable transportation management system that attempts to reduce the adverse socio-economic and environmental effects of congestion. One of the first stages in assessing congestion is to monitor the traffic flow in the region. Since there are numerous congestion measures existing, it might be a complex task for a researcher to consider all those congestion measures. So, this paper compares selected measures in a case study by reviewing various traffic congestion measures.

It is essential to assess the available options in order to select the best congestion control strategies for use in road traffic analysis. This paper seeks to provide decision-makers with a preliminary review of comparing each strategy through data analysis in addition to only listing the various congestion control measures that are currently available.

2.2. What is traffic congestion

Engineers and the general public regularly use the word "congestion" in the context of road traffic. According to Webster's Dictionary, congested is "to overcrowd, overload, or fill to excess so as to block or hamper" anything. It is typically understood as meaning a condition in which there are a huge number of vehicles circulating, all of them are moving forward in a sluggish and irregular manner. These definitions are not sufficiently precise and are of a subjective nature.

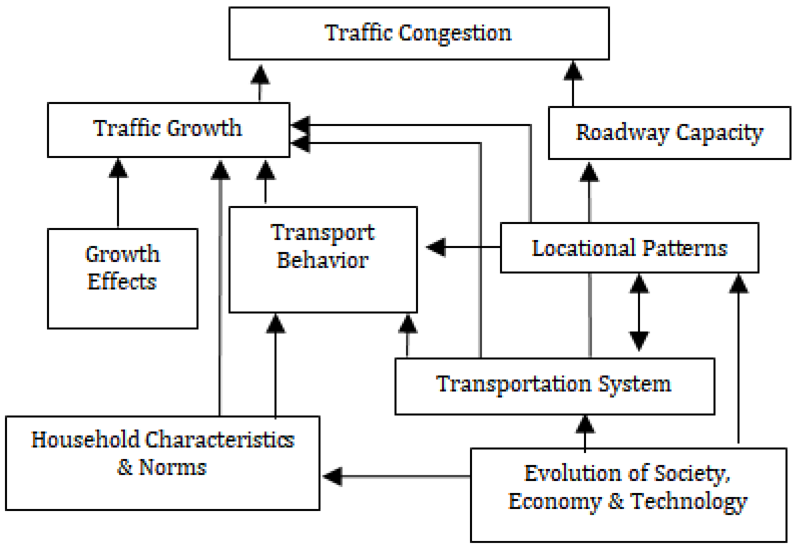
Even the most specialized studies do not give a forward definition of congestion. So, two well-known experts in transport modeling reflect that Congestion occurs when demand exceeds the capacity of the transportation system and transportation times increase significantly compared to when demand is low (Ortúzar and Willumsen, 1994). Their definition does not propose accurate limits for the point at which the phenomenon starts but it reflects the perceptions of the average citizen.

Mutual interference among vehicles in the traffic flow can be considered as the central cause of traffic congestion. to a certain degree of traffic flow depending on legal speed limit, frequency of intersection and other factors vehicles can circulate at a relatively freely determined speed. But each additional vehicle becomes an issue to others circulating when there are higher levels of traffic. in short, the phenomenon of congestion appears. A likely objective definition would be: “congestion is the state where the traffic flow increases the trip time of others by the introduction of an additional vehicle.’’ (Thomson and Bull, 2001).

As a result of the existing relationship between the volume of flows and the speed of moving vehicles in the situation of the exhaustion of infrastructure capacity, traffic congestion may be described as the mutual hindrance of traffic by the cars. It can also be defined as a reduction in moving vehicle speed or full impediment of free movement caused by the volume of vehicle traffic exceeding the capacity of the road. (Ko´zlak and Wach, 2018).

2.3. Causes of Traffic Congestion

Various reasons can create Congestion in urban areas such as excess demand, signal, incidents, work zones, weather-related, or special events.



Source (Palash C.D. et.al.,2018)

Fig 2-1: Causes of congestion

Congestion can be of two main types- Recurrent (too many vehicles using the same road at the same time), non-recurrent (disabled vehicles, accidents, work zones such as street cleaning) congestion (Palash C.D., 2018).

In almost all medium to large cities, traffic is congested every day during peak hours. FHWA estimates that almost half of the congestion that traffic users encounter is recurrent (Yodo, N., 2018).

Recurrent congestion

- **Bottlenecks and capacity:** Blockages are the main source of congestion. When more lanes are meeting on a road, tunnel and bridge than the capacity these facilities have, bottlenecks normally happen during peak traffic hours (M. Rahman et.al., 2005; Chandra, S et.al., 2000; Hamad, K 2002). It may also happen if a road's capacity is surpassed by demand. The quantity and breadth of lanes, the distance required to merge at interchanges, and the orientation of the road may all affect capacity.

- **Insufficient infrastructure**: One of the main causes of congestion, especially in densely populated places, is inadequate infrastructure. The number of automobiles likewise rises along with the population growth rate. Congestion arises when the available infrastructure cannot accommodate the growing number of automobiles (Boarnet, M.G., 1998).

- **Variation in traffic flow:** as a result of the fluctuation in daily traffic needs, some days have larger volumes than others. When these demands surpass the set capacity a delay may happen (West J.E. and Glens T., 2007).

- **Inadequate traffic controllers:** Poorly programmed signals or the layout of traffic controllers, such as stop signs, speed bumps, or railroad crossings, can obstruct a regular flow of traffic, causing congestion and changes in travel times (West, J.E. and Glens T 2007).

Nonrecurring Congestions

Nonrecurring traffic jams typically resulted from unpredicted conditions, such traffic accidents, construction zones, bad weather, or other unique situations (Feng, X., 2016; West, J.E., 2007). Nonrecurring congestion can cause fresh congestion to start up during off-peak hours and can lengthen the delay caused by recurring congestion. Common instances of intermittent congestion include:

- **Traffic incidents/accidents:** Vehicle collisions, breakdowns, and debris in the lanes of traffic are the most frequent types of occurrences. These incidents interfere with the regular flow of traffic, typically by obstructing the lanes, which further reduces capacity (Lomax, T., 1997; He F. et.al., 2016).

- **Work zones**: Work zones are defined as areas where construction is taking place that physically alters the highway environment. These modifications result in changes to the number or width of travel lanes, lane "shifts," lane diversions, the deletion or decrease of shoulders, and momentary closures of the road.

- **Weather:** Weather or environmental changes can have an impact on how people drive and how traffic moves. These might alter the way roads are built, as well as traffic control devices like signals and railroad crossings. Around 28 percent of all highway collisions and 19 percent of all fatalities are caused by weather-related road conditions (Transportation Research Board, "Highway Capacity Manual, 2016).

- **Other special events:** Demand fluctuations in traffic patterns related to a specific event that often deviate from the regular flow pattern. These occasions might include concerts, sporting games (game days), or other social gatherings. During special events, a sudden increase in traffic demand might overload the infrastructure and cause congestion.

2.4. Other causes of congestion

- **caused by private car users**

Whether a country is developed or not, traffic congestion has been on the rise and will only worsen, endangering the quality of urban life (Jain, V., 2012). Between 2005 and 2050, 2.3 billion new cars are anticipated globally at the current rate of motorization, with more than 80% of those cars likely to wind up on the roads of emerging nations (Chamon, M., 2008). Rising economic levels have led to a rise in the ownership of automobiles. Major city blocks are getting increasingly congested as a result of the middle class's desire to convert from non-motorized or public transportation to private cars (Suzuki, H. et.al., 2013).

- **The state of the roads**

Issues with maintenance and design Congestion are unnecessarily increased by poor road system design or maintenance. Traffic lanes are sometimes not marked, and other issues that impede smooth traffic flow are frequently present in many areas. Similar to this, roads with poor conditions, particularly those with potholes, lead to increased restrictions on road capacity and worsen traffic.

- **Some driving habits cause more congestion than others**

There are some motorists that do not respect other users of the road. Many drivers in places like Addis Ababa strive to shave off a few seconds from their travel schedules by ramming through crossings and obstructing the path of other automobiles. Additionally, a large number of taxis that do not regularly operate from designated taxi ranks creep along in search of passengers, adding to the congestion.

- **Insufficient information is available on traffic conditions**

Lack of current traffic situation is another element that worsens congestion. If a driver had two options for getting to his destination, A and B, and he/she had information about the traffic on road A was heavy, he might use route B instead, where his personal contribution to congestion would be lower. According to Dillip K.D. et.al. (2016) being aware of traffic conditions in various areas of the road network helps alleviate congestion considerably by traffic diversion from different congested roads during peak hours and assigning them to connected underutilized roads could ease traffic congestion more effectively than taking harsh steps like charging people to use crowded roadways (IMT, 2000).

- **There is also an institutional problem**

It is evident that the issue has outgrown how well-equipped the institutions are able to handle it. traffic management in the city is very minimum and infant in its establishment and organization in the city. However, the office has not yet operated autonomously; rather the majority of the office activities are undertaken by the unit at the road authority with minimum involvement of the process. As a result, many of the activities in traffic management aspect of the city are not been accomplished (Hagere, Y., 2016).

Hagere Y. Found that there are internal and external factors that hamper the traffic management practice. undefined organization structure, lack of sufficient and competent manpower, weak human resource management, lack of training and development program. Moreover, she found that higher government officials were not giving recognition for strong professional traffic management, the institution had poor enforcement capability, poor integration between transport and land use plan, poor data base system.

2.5. Measuring congestion

How to assess congestion has been a topic of debate among several scholars from various disciplines. Lomax et al. (1997) indicate that a clear and simple congestion control measure would be optimal (understandable, unambiguous and credible). That involves the capacity for statistical analysis as well as the ability to characterize current conditions and forecast changes (ability to apply statistical techniques to provide a reasonable portrayal of congestion and replicability of result with a minimum of data collection requirements). It also has broad relevance to several modalities, facilities, and time frames. The methods to quantify congestion can be generally grouped into Highway Capacity Manual (HCM) measures and travel time-based measures. These methods are briefly explained below.

2.5.1. Travel Time based Methods

The travel time-based measures to quantify congestion are primarily based on travel time, travel speed, and delay. Given that traffic congestion is a dynamic phenomenon that incorporates factors of space and time, travel time-based measures are more appropriate as they are flexible enough to describe traffic conditions at various levels of resolution in both space and time. This makes travel time-based measures appropriate for handling specific locations as well as entire corridors (Grant, M. et.al, 2005).

2.5.1.1. Travel time

Travel time is the time taken to cross a section of a road by a vehicle, this time used as a parameter in traffic congestion studies. Urban Link's performance evaluation was conducted based on travel time. Some measures related to travel time are listed below.

2.5.1.1.1. Travel Time Index (TTI)

It is a dimensionless quantity that compares travel conditions in the peak period to travel conditions during free-flow or posted speed limit conditions. TTI is proposed in the 2005 Urban Mobility Report (Tang, J. et.al, 2018; He, F. et.al, 2016). This index compares peak period travel and free flow travel by contrasting travel times during free flow conditions and those during peak hours, this indicator is expressed. Index provides the benefit of indicating traffic congestion both spatially and temporally (Schrank, D. et.al 2001).

$$TTI = T_{pp}/T_{ff} = V_{ff}/V_{pp} \quad \text{……………………………(2.1)}$$

where Tpp=is the peak period travel time,

Tff=is the free-flow travel time,

Vff=is the free-flow travel speed, and

Vpp=is the peak period travel speed.

The travel time index measure provides information about user experience as well as system operating condition i.e., it reflects the average level of congestion and mobility (Unit et al, 2001).

2.5.1.1.2. Travel Rate Index (TRI)

The TRI shares similarities with the TTI as they are both dimensionless measures that compare travel conditions during peak periods to those during free-flow or posted speed limit conditions. This index computes the “amount of additional time that is required to make a trip because of congested conditions on the roadway (Schrank, D. et.al 2001). By concentrating on time rather than speed, it assesses how quickly a trip may happen during the peak period. (Levinson and Lomax, 1996).

$$\text{Travel rate index} = \frac{\left(\dfrac{\text{Freeway travel rate}}{\text{Freeway freeflow rate}} \times \text{Freeway peak-period VMT}\right) + \left(\dfrac{\text{Principal arterial street travel rate}}{\text{Principal arterial street freeflow rate}} \times \text{Principal arterial street peak-period VMT}\right)}{\left(\text{Freeway peak-period VMT} + \text{Principal arterial street peak-period VMT}\right)} \quad \text{……………………………(2.2)}$$

2.5.1.1.3. Buffer Index

The buffer index calculates the extra percentage of travel time a traveler should allow when making a trip in order to be on time 95 percent of the time (Lomax, T. et.al., 2001). It shows the additional buffer time (or time cushion) that the majority of passengers include in their travel plans in order to guarantee on-time arrival. This additional time is included to allow for unforeseen delays. As dependability declines, the buffer index's value rises and is reported as a percentage. Instead of using average travel time to handle trip problems, this strategy employs the 95th percentile travel rate and the average travel rate. The additional percentage of a passenger's time that must be on time for the buffer time index to be 95 percent accurate (Nakat et al., 2014).

$$BTI = \frac{95\%TT - ATT}{ATT} \times 100\% \qquad (2.3)$$

2.5.1.1.4. Planning Time Index

PTI is the ratio between the 95th percentile travel time (95 percent TT) and the free-flow travel time. (Karuppanagounder and Muneera, 2017). PTI grows along with trip duration. Therefore, PTI should act as minimally as possible for improved traffic operation. A PTI of 1.60 indicates that, in order to guarantee on-time arrival 95% of the time, passengers should plan on spending an additional 60% of travel time above the free-flow travel time (or most of the time) (A.K. Ekman, 2013; Praveen. Et.al., 2013).

$$PTI = \frac{95\%TT}{FFTT} \qquad (2.4)$$

2.5.1.2. Delay

Many signal optimization methods employ delay as their major performance metric. It serves as the main performance indicator in several intersection analysis methods, including the HCM. The average delay experienced by all cars as they traverse throughout a section during the analysis period is typically how delay is described in this context. Delay in oversaturation also refers to delays that continue past the conclusion of the analytical period. It is necessary to compare the complexity of physical design and signal timing to the anticipated operational results determined by the calculation of delay.

2.5.1.2.1. Delay Rate

The delay rate is “the rate of time loss for vehicles operating in congested conditions on a roadway segment or during a trip (Lomax, T. et.al., 1997). The difference in travel speed between a congested and uncongested environment is the delay rate. The amount of time needed to travel a specific segment length may be used to calculate the pace of travel. It is the reciprocal of velocity, expressed as Sec/meter at any segment. The difference between the permissible travel rate and the actual travel rate may be used to compute it as

$$Dr = Tr_{ac} - Tr_{ap} \quad \text{(2.5)}$$

where, Dr is the delay rate,

Trac is the actual travel rate, and Trap is the acceptable travel rate.

2.5.1.2.2. Delay Ratio

The delay ratio can be used to compare mobility levels on roadways or among different modes of transportation (Lomax, T. et.al., 1997). It highlights the importance of the mobility issue in light of the current circumstances. Equation (2.6) may be used to get the delay ratio by dividing the delay rate by the actual travel rate. It is used to compare the relative levels of traffic congestion on various roads (Wang, J. et.al., 2014; X. Yu. Et.al., 2012).

$$D = \frac{Dr}{Tr\,a_C} \quad \text{(2.6)}$$

where D denotes the delay ratio,

Dr is the delay rate, and Trac is the actual travel rate.

2.5.1.2.3. Congestion index

The ratio between the delay and FFTT is the CI metric. The distinction between ATT and FFTT in this case is delay. ATT for commuters should be as low as possible for improved traffic management (Karuppanagounder and Muneera, 2017). The equation for finding the CI is given by (Richardson and Taylor, 1978).

$$Congestion\ Index(CI) = \frac{Actual\ travel\ time - free\ flow\ travel\ time}{Free\ flow\ travel\ time} \quad \text{(2.7)}$$

A CI value of zero means that the actual travel time and free flow travel time are equal. A value of one means that the actual travel time is twice the free flow travel time. An index greater than 2 indicates congested condition (Taylor et al., 2000; D’Esteet al., 1999).

2.5.1.3. Speed

The most popular performance indicator for congested roads and traffic is speed. There are numerous approaches to determine speed, starting with using the average trip time and the length of the corridor under consideration. You may determine the average trip speed using

$$Average\ Travel\ Speed = \frac{Length\ of\ the\ Section}{Average\ Travel\ Time} \text{.........................} (2.8)$$

2.5.1.3.1. Speed Performance Index (SPI)

Vehicle speed is a crucial metric for assessing the condition of the road traffic. To assess the situation of urban road traffic, Traffic SPI was developed (He, F. et.al., 2016). The index value, which ranges from 0 to 100, represents the speed of the vehicle in relation to the maximum speed allowed. Equation (2.9) defines the ratio of vehicle speed to the maximum allowed speed as the SPI value (which ranges from 0 to 100). The traffic state level may be categorized using four threshold values in order to measure the traffic status on the route using this index (25, 50,75 and 100). Table 2.1 displays the categorization criterion for the urban road traffic situation.

$$\text{SPI} = \left(\frac{v_{avg}}{v_{max}}\right) \times 100 \text{..} (2.9)$$

Where:

SPI: denotes the speed performance index;

Vavg: denotes the average travel speed, km/h;

Vmax: denotes the maximum permissible road speed, km/h.

Table 2.1. Speed Performance Index with Traffic State

No	Speed Performance Index	Traffic State Level	Description of Traffic State
1	(0,25)	Heavy Congestion	Low average speed, poor road traffic state
2	(25,50)	Mild Congestion	Lower average speed, road traffic state bit weak
3	(50,75)	Smooth	Higher the average speed, road traffic state better
4	(75,100)	Very Smooth	High average speed, road traffic state good

2.5.1.3.2. Speed Reduction Index (SRI)

This measure "represents the ratio of the decline in speeds from free flow conditions." (Lomax, T. et.al., 1997). By employing a constant as a scale to differentiate between several classes of traffic congestion at various degrees, this rate enables comparing the degree of traffic congestion for various types of transportation services. As a result, it may be used for certain metropolitan road routes or specific road segments during peak or off-peak hours (Kukadapwar and Parbat, 2015). It provides a way to compare the amount of congestion on different transportation facilities by using a continuous scale to differentiate between different levels of congestion (Lomax, T. et.al., 1997). To keep the SRI value between 0 and 10, the SRI ratio is multiplied by 10. When the index value inches to 10, congestion ensues. Values under 4 suggest an uncongested situation.

$$\text{SRI} = \left(1 - \frac{v_{ac}}{v_{ff}}\right) \times 10 \qquad (2.10)$$

where SRI denotes the speed reduction index,

vac indicates the actual travel speed, and

vff means the free-flow speed.

When deciding on the free flow for different facilities, vehicle speed is thought to be a crucial component. Since motorized traffic speed directly impacts traffic flow at a given road, it is a crucial macroscopic traffic characteristic in traffic flow theory. Speed is a random variable that varies continually. A normal distribution has been suggested by numerous researches to describe the traffic speed distribution (Debashis R.S. & Parveern K., 2024).

However, due of the variation in traffic flow under mixed-traffic conditions, the speed distribution differs from the normal distribution. According to Haight and Mosher, a gamma or lognormal distribution might be more appropriate for displaying speed distributions than a normal distribution. The advantages offered by these non-normal distributions continue to have the same functional structure even after the time-speed distribution changed to a space-speed distribution (Debashis R.S. & Parveern K., 2024). Similar to this, Rupali, Pritam, and Ashoke (Rupali et al., 2017) found that speed data with coefficients of variation between 0.11 and 0.18 and for various vehicle types follow a normal distribution.

To characterize an integrated random phenomenon of traffic flow, a statistical speed model incorporating both theoretical and simulation-based traffic modeling is necessary for both theoretical and simulation-based traffic modeling, if an adequate speed distribution model is intended. Numerous traffic flow variables can be evaluated analytically and theoretically with the aid of statistics. Additionally, a precise speed distribution hypothesis is essential for calibrating models intended to forecast operating speeds (85th percentile) throughout urban and rural road segments (Debashis R.S. & Parveern K., 2024). So, it is important to identify the appropriate speed distribution in a mixed traffic situation with a reasonable degree of precision for various vehicle kinds and traffic compositions.

Understanding the distribution characteristics of vehicular speed is extremely valuable and should not be overlooked. This includes understanding the features, patterns, and regularities in how speed is distributed. Fitted distributions can be classified as single-mode distributions and other distributions (multi-mode distribution and truncated distribution) (Chen, Zhen & Fan, Wei. (2019). Vehicular speed is traditionally modeled with unimodal distributions, such as normal, lognormal, Gamma, Weibull, Burr, Logistics and Loglogistics distributions to fit the speed data (Ji, Yuxiong et al., 2015). Since the mean is a commonly used summary statistic for variables that are unimodally distributed, some studies specifically focused on the mean travel time (or speed) estimation (Ji, Yuxiong, et al., 2015). Candidate distribution models with their Probability Density Functions (PDFs) and parameters are given in Table 2.2.

Table 2.2. PDFs and CDFs of candidate distribution models

Model	PDF	CDF	Parameter
Normal	$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$	$F(x) = \frac{\bar{\phi}}{}\left(\frac{x-\mu}{\sigma}\right) = \frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right]$	μ ϵ R σ ϵ R >0
Lognormal	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(lnx-\mu)^2}{2\sigma^2}}$	$F(x) = \frac{1}{2}\left[1 + erf\left(\frac{lnx-\mu}{\sigma\sqrt{2}}\right)\right] = \frac{\bar{\phi}}{}\left(\frac{x-\mu}{\sigma}\right)$	μ ϵ (-∞, +∞) Location σ ϵ >0 Scale
Gamma	$f(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} x^{\alpha-1} e^{-\beta x}$	$F(x) = \frac{1}{\Gamma(\alpha)} \Upsilon(\alpha, \beta x)$	α >0, Shape β >0, rate
Weibull	$f(x) = \begin{cases} \frac{k}{\lambda}\left(\frac{k}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k}, & x \geq 0 \\ 0, & x < 0 \end{cases}$	$F(x) = \begin{cases} 1 - e^{-\left(\frac{x}{\lambda}\right)^k}, & x \geq 0 \\ 0, & x < 0 \end{cases}$	λ ϵ (0, +∞) Scale k ϵ (0, +∞) Shape
Logistics	$f(x) = \frac{e^{-\left(\frac{x-\mu}{s}\right)}}{s\left(1 + e^{-\left(\frac{x-\mu}{5}\right)}\right)}$	$F(x) = \frac{1}{1 + e^{-\frac{(x-\mu)}{s}}} = \frac{1 + tan\frac{x-\mu}{2s}}{2}$	μ, location(real) s > 0, Scale(real)

Loglogistics	$f(x) = \frac{\left(\frac{\beta}{\alpha}\right)\left(\frac{x}{x}\right)^{\beta-1}}{\left(1+\left(\frac{x}{\alpha}\right)^{\beta}\right)^{2}}$	$F(x) = \frac{1}{1+\left(\frac{x}{\alpha}\right)^{-\beta}}$	α >0, Scale β >0, Shape

However, recent studies have revealed that speed distribution tends to be bimodal and even multimodal on urban areas than freeways (Ji, Yuxiong, et al., 2015). vehicles navigating urban environments are strongly influenced by elements not present on freeways, such as traffic signal controls, pedestrian crossings, and conflicting traffic from intersecting roads. This disrupted nature of urban traffic flows would probably result in substantial variations in speed.

2.5.1.3.3. Very-low-speed Index (VLSI)

The very-low-speed rate is computed as the ratio between time spent driving at a much slower pace and the overall amount of time traveled is known as the very low-speed index (Kukadapwar & Parbat., 2015). It's been applied in traffic congestion evaluation on the urban roadway. Thus, a very low-speed index can be calculated by using the following equation

$$\text{VLSI} = \frac{\text{Time Spent in Delay}}{\text{Total Travel Time}} \quad \text{...(2.11)}$$

This value is between 0 and 1, 0 being the best condition (least congestion), with no delay, and 1 being the worst condition, with most of the travel time spent in delayed conditions.

2.5.1.3.4. Corridor Mobility Index (CMI)

CMI is a measure of the mobility level provided by transportation facilities in a corridor in relation to a recognized operating standard (Timothy J. et.al. 2002). The measure is calculated as the product of passenger volume and average speed (in miles per hour) for a particular route, divided by the standard value.

$$\text{Corridor mobility index} = \frac{\text{Person volume (persons)} \times \text{Average travel speed (mph)}}{\text{Normalizing value (e.g., 25,000 for streets or 125,000 for freeways)}} \quad \text{.. (2.12)}$$

$$\text{Person volume} = \frac{\text{Person-miles of travel}}{\text{Lane-miles of facility}}$$

It does not, however, directly address the reduction in travel time that might result from land use changes and should be used only as a transport system measure (Timothy J. et.al. 2002).

2.5.1.3.5. Road Segment Congestion Index (Ri)

Schrank and Lomax (1997) developed a Road segment Congestion Index (RSCI) as a measure of area wide severity of congestion. The RSCI is used to describe the degree of traffic congestion on any traffic node. The RSCI value ranges between 0 and 1 and the smaller the RSCI value, the more the road segment is congested (Li et al., 2016; He et al., 2016).

The normal road segment state and the length of the non-congestion state throughout the observation time may be used to calculate the degree of road segment congestion, represented by Ri. (He, F. et.al., 2016). The traffic state when the speed performance index (SPI) is more than 50 is included in the non-congestion state.

$$R_i = \left(\frac{SPI_{avg}}{100}\right) \times R_{Nc} \quad \text{......(2.13)}$$

$$R_{Nc} = \frac{t_{NC}}{t_t}$$

Where:

Ri is the road segment congestion index,

SPIavg is the average of the speed performance index.

RNC denotes the proportion of non-congested state

tNC denotes the duration of the non-congested

tt is the length of the observation period.

2.5.1.3.6. Congestion Severity Index (CSI)

CSI was used as a measure of urban area freeway delay, which calculates delays travel per million vehicle kilometers**.** The CSI employs an incidence database to estimate each hour of a typical day using the 1985 HCM computation and local freeway traffic volume distribution to predict recurrent delays, Lindley (1987) conducted a study detailing this. using this index presented a threshold for congestion (v/c ratio of 0.77 or greater) on a different section of a freeway.

Because the majority of trip time-based metrics lack dimensions, it is useful to evaluate the degree of mobility between various roads or forms of transportation. It also allows analysts to perform comparisons over long periods of time, e.g., years or decades. The measures associated with the time or speeds are easy to understand and interpret by both the transportation professionals and the traveling public. Travel time-based measures translate easily into other measures like user costs, and can be used directly to validate planning models such as travel demand forecasting models. Another advantage is that the travel time-based measures are applicable across modes (Laird, D., 1996) and reflect the combined effects of geometric and operational features of the road. Travel time measures can do a better job at pinpointing locations of congestion and can help in identifying congestion causes (Beverly, N, 2004).

2.5.2. Highway Capacity Manual (HCM) based Method

The Highway Capacity Manual (HCM) contains concepts, guidelines, and computational procedures for computing the capacity and quality of service of various highway facilities, including freeways, highways, arterial roads, roundabouts, signalized and unsignalized intersections, etc. The HCM based method mainly uses the volume to capacity (V/C) ratio and delay (LOS) as performance measures to measure/quantify congestion.

2.5.2.1. Level of Services (LOS)

The overall functioning of a highway can be greatly influenced by the quality of service provided at any intersection. Consequently, enhancing the level of service at each intersection typically leads to an enhancement of the highway's overall operational performance. An analysis procedure that provides for the determination of capacity or level of service at intersections is therefore an important tool for designers, operation personnel, and policy makers. Factors that affect the level of service at intersections include the flow and distribution of traffic, the geometric characteristics, and the signalization system. A major difference between considerations of level of service on highway segments and level of service at intersections is that only through flows are used in computing the levels of service at highway segments, whereas turning flows are significant when computing the levels of service at signalized intersections. (Nicholy J. & Laster A. 2009)

The concept of quality of service involves quantitative measures that assess operational conditions in a traffic stream. Level of service denotes the range of operating conditions on a transportation facility accommodating various traffic volumes. It helps gauge performance and user satisfaction. These concepts aid in improving transportation efficiency and the overall user experience. Highway capacity manual (HCM) developed by the transportation research board of USA provides some procedure to determine level of service. It divides the quality of traffic into six levels ranging from level A to level F. Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed and level F represents the worst quality of traffic.

HCM has defined six levels of service, level A to level F based on the mentioned measure of effectiveness. Level of service A represents the zone of free flow. Here the traffic volume will be less; traffic will be experiencing free flow. Level of service B represents zone of reasonably free flow; free flow speeds are still maintained at this level of service. The driver's freedom to choose their desired speed is only slightly restricted. At level of service C, the presence of other vehicles begins to restrict the maneuverability within the traffic stream. At level of service D, the average speeds begin to decline with increasing flows. Freedom to maneuver within the traffic stream is noticeably restricted. Level of service E defines operation at capacity. At this level, the stream reaches its maximum density limit. Finally, Level of service F describes conditions in a queue that has formed behind a point of breakdown or disruption. Level of service is defined based on the measure of effectiveness (MOE). Typically, three parameters are used under this and they are speed and travel time, density, and delay. One of the important measures of service quality is the amount of time spent in travel. Therefore, speed and travel time are considered to be more effective in defining LOS of a facility. Density gives the proximity of other vehicles in the stream. Since it affects the ability of the driver to maneuver in the traffic stream, it is also used to describe LOS. Delay is a term that describes excess or unexpected time spent in travel.

Table 2.3. Level of service (LoS) based on the corresponding V/C ratio and operating conditions

No	LoS Class	Traffic State and Condition	V/C Ratio
1	A	Free flow	0–0.60
2	B	Stable flow with unaffected speed	0.61–0.70

3	C	Stable flow but speed is affected	0.71–0.80
4	D	High-density but the stable flow	0.81–0.90
5	E	Traffic volume near or at capacity level with low speed	0.91–1.00
6	F	Breakdown flow	>1.00

While conceptually simple and easy to understand by the professional transportation community, HCM based measures tend to be abstract for the traveling public. They usually require detailed, location-specific input data, which makes them more appropriate for localized analyses and design than for area-wide planning (Quiroga, C.A., 2000). Thus, they tend to be most appropriate for individual highway segments or intersections, rather than for corridors or region-wide analysis, although composite or index measures can be calculated based on these measures, such as percent of the roadway network operating at LOS F (Grant, M., 2005). Also, HCM measures are difficult to use for long-range comparisons because concepts such as capacity and speed-flow relationships tend to change over time. Sometimes, estimating capacity even within 10 percent of its actual value can be a difficult task because of many variables which can influence capacity (Beverly, N., 2004).

2.6. Literature on various congestion measures

Levinson and Lomax (1996) defined congestion and described various methods for congestion measurement. A congestion index was developed by the concept of the position of the vehicle to describes the time and speed, they established an analytical computation tool that is easily understandable by the general public and can be used to judge issues and policies. For determining the level of congestion on arterial roadways, a fuzzy inference-based measure was proposed by Hamad and Kikuchi (2002). It is a combination of two measures such as a very low-speed rate and travel speed rate. It might be used to depict the flow of traffic on certain geographical areas, road network streets, or roadway segments. The obtained congestion index value can be used for temporal and spatial comparison of traffic conditions. Dias et al. (2009) stated the occurrence of traffic accidents by using the Bayesian Belief theory on traffic information such as traffic density, volume, and congestion index. It was found that when a road section is getting congested, i.e., when the CI and density increase, chances for an accident also increase. Lee and Hong (2014) proposed the Traffic Congestion Score (TCS) based concept on the spatiotemporal aggregation method. TCS measures the capacity of the existing road which found a range from 0 to 100 percent by using an approximation ratio of the speed limit. Ye, Hui, et al. (2013) suggested a way for assisting policy decision-makers and transportation planners in understanding traffic conditions in order to measure the effects of traffic congestion on travelers. It defines the three new indicators of congestion to estimate urban road congestion based on travelers' feelings such as travel time satisfaction (TTS), transportation environment satisfaction (TES), and traffic congestion frequency and feeling (TCFF).

A resilience-oriented approach for quantitatively assessing recurrent spatiotemporal congestion on urban roads was proposed by Tang and Heinimann (2018) The signs of the congestion index not only provide information about the level of congestion but also indicate how traffic is being released after congestion occurs. This metric has been proven effective in both arterial roads and freeways. Additionally, in signal-controlled traffic, the congestion index performs satisfactorily. Stipancic et al. (2016) proposed measures to represent the level of congestion for spatiotemporal in an urban (Quebec City, Canada) using data collected from GPS-enabled smartphones of regular drivers. The congestion measured using the CI during PM-peak periods was found to be positively correlated with an accident frequency Stipancic et al. (2016).

Patel and Gundaliya (2016) used operational and volume characteristics of traffic movement to quantify congestion on the urban mid-block sections, it was shown through this study that defining LOS quantitatively could be a better option. The effect of the width of a carriageway on the level of congestion was also determined. It was concluded that by increasing one lane or widening the carriageway, congestion can be reduced up to 30–50%.

Maitra et al. (1999) proposed a methodology for finding out the congestion which includes the volume and the operational characteristics of the traffic. The researchers took three urban roads for their study. By gathering relevant data, they made a comparison between the estimated level of congestion and the service volumes. The aim was to assess the impact of the number of traffic lanes on these factors. The authors noted that the level of congestion at various traffic volumes is significantly influenced by the number of traffic lanes and the width of the carriageway.

Marwah and Singh (2000) attempted to estimate the level of service for urban heterogeneous traffic conditions. To determine the Level of Service (LOS), the authors considered several parameters, including the journey speed of cars, concentration of motorized two-wheelers, and road occupancy. They utilized those factors to develop a traffic simulation model based on the collected data. By incorporating these parameters into the model, a comprehensive analysis of the road segment's performance could be conducted. Based on the simulation results of the benchmark road and the traffic composition, the LOS were classified into four groups (LOS I, II, III, and IV). The simulation study results clearly demonstrate the capability of the model to simulate the heterogeneous traffic flow conditions of the Urban streets.

A comparative study of the performance evaluation on the urban link under heterogeneous traffic conditions using the travel time-based indices such as delay, travel time index, congestion index, and planning time index was reported by Karuppanagounder and Muneera, (2017). It was estimated that the performance indicators have higher values when the value of travel time was high on that link.

Matewos G.A, et al. (2023) investigated whether the recurrent congestion in Addis Ababa along the Torhayloch – Mexico Street corridor is caused by traffic volume exceeding road capacity using volume to capacity ratio. He’s Findings revealed that the volume-to-capacity ratio of the Torhayloch – Mexico Street corridor was between $0.5 \leq v/c \leq 0.8$, It suggests that even though the street corridor is generally congested every day, it is not operating at full capacity. This is suggestive of the other causes of congestion along the Torhayloch – Mexico Street corridor and corresponding measures of intervention to reduce congestion other than building more roads.

Bedada B.D. and Kula K.T. (2020) used one-stage object detectors to detect traffic congestion from recorded video. they collected data from different video footage and frames extracted from videos to prepare a dataset. They showed that it is possible to detect traffic congestion from a surveillance camera in Ethiopia using one-stage object detectors.

2.7. Negative Impacts of traffic congestion

Traffic congestion has a number of negative effects:

- Wasting drivers' and passengers' time ("opportunity cost"). Congestion is a non-productive activity for the majority of people, which harms the area economy.
- Delays, which might lead to being late for work, meetings, or school and result in lost revenue, disciplinary action, or other losses for the individual.
- Inability to precisely predict journey times, which causes drivers to budget more time for travel "just in case" and less time for useful activities.
- Fuel wastage from greater idling, acceleration, and braking increases air pollution and carbon dioxide emissions.
- The wear and strain on cars brought on by repeated acceleration and braking as well as idling in traffic, which results in more frequent repairs and replacements.
- Stressed-out and irritated drivers who are more likely to lash out on the road and have poorer health.
- Traffic congestion may prevent emergency vehicles from reaching locations where they are urgently required.
- Rat running, or the spillover effect from crowded main thoroughfares to subsidiary roads and side streets, which may have an impact on local amenities and real estate values.
- Greater likelihood of crashes as a result of close spacing and frequent stopping and starting

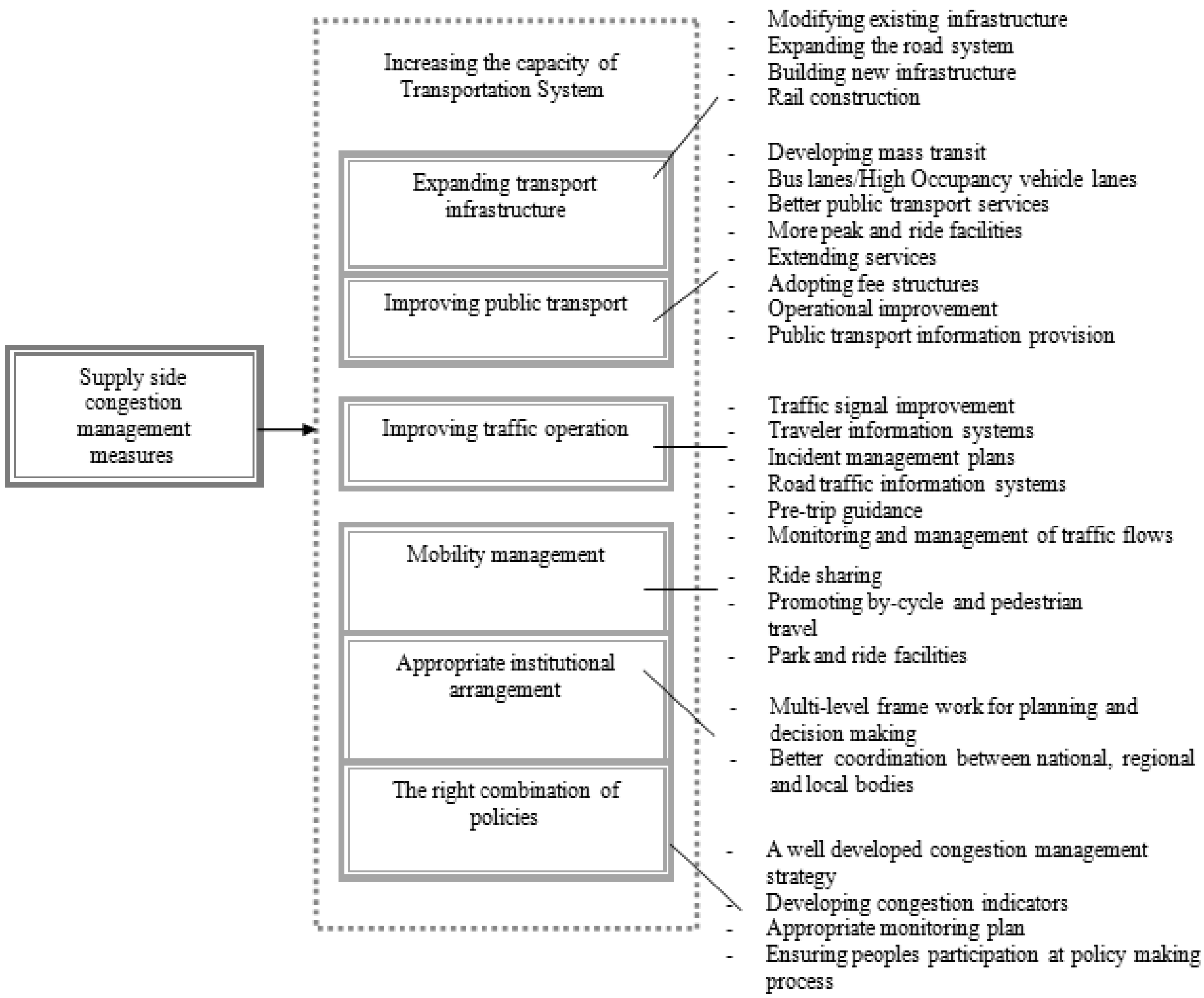
2.8. Mitigation measure for traffic congestion

There is no absolute solution to fully eradicate traffic congestion problem from the society as it is fully related with individual land use pattern and existing transport policies to each urban region. Both developed and developing nations suffer greatly from traffic congestion in their cities. Longer travel times, more accidents, environmental issues, and a decline in quality of life are all results of the rising demand for urban transportation and transit, all of which are unacceptable to the general public.

literatures (Talukdar, 2013; Strickland et al., 1995; & Ramón, 2000). have systematically classified congestion management measures into two groups, namely supply-side measures and demand-side measures.

2.8.1. Supply side Measures

The supply-side strategies consist of the Developing new highways or roads, expanding existing streets to enhance their capacity, improving the efficiency of mass transportation and non-motorized transport systems, and implementing innovative traffic management techniques and traffic control methods. (Matewos G.A et.al.; Talukdar, 2013).

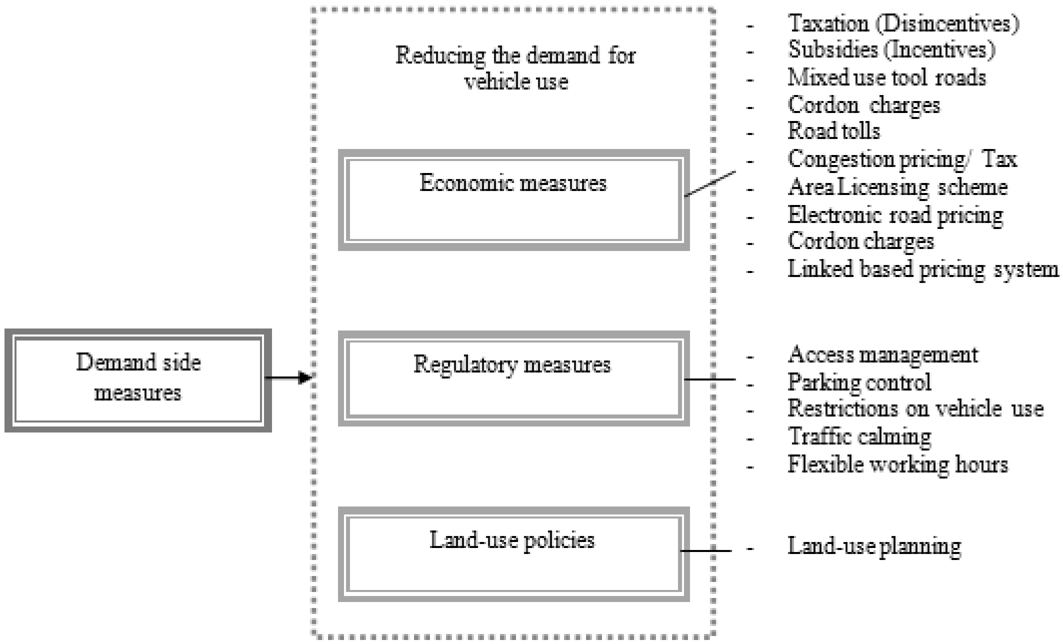


Source: Talukdar, 2013

Fig 2-2: Supply side mitigation measures

2.8.2. Demand side Measures

The demand-side schemes basically regulate travel demand using procedures, for example, instruments of planning, monetary actions, and regulation. Examples of economic means comprise high oil tax imposition, increasing automobile or car registration charges, or congestion pricing. (Matewos G.A et.al.; Talukdar, 2013).



Source: Talukdar, 2013

Fig 2-3: Demand side mitigation measures

CHAPTER THREE: METHODOLOGY

3.1. Introduction

This chapter provides a detailed presentation of the Materials, Procedures, and Methods used in this investigation. All of the original data were gathered from different areas including direct field measurements, the method utilized to accomplish the study purpose, the sort of data tested, and the research design. The techniques of data collection and measurement, the sorts of instruments utilized, and the sample approach used are all highlighted.

3.2. Description of the study area

The chosen road stretch in Addis Ababa was the subject of the investigation. The road section is located in the city's core, Addis Ababa. The capital and largest city of Ethiopia's Federal Democratic Republic is Addis Ababa, sometimes written Addis Ababa. It is situated in the geographic middle of the nation on a plateau that receives plenty of water, surrounded by hills and mountains. It is a grassland habitat and is situated at a height of 2,300 meters at 9°1′48′′N 38°44′24′′E. According to coordinates, the settlement is located at the base of Mount Entoto and is a part of the Awash watershed. The city climbs to almost 3,000 meters in the Entoto Mountains to the north from its lowest point, around Bole International Airport, at 2,326 meters above sea level on the southern perimeter. The city, which was founded in the late 1800s, has grown both socially and physically throughout the years as a result of ongoing development changes.

Due to its historical, diplomatic, and political significance for the continent, Addis Ababa—home to the African Union and its predecessor, the OAU—is sometimes referred to as the political capital of Africa. More than 81 distinct countries, each with their own culture, language, and affiliation with a different religious group, are represented in the city. The population of Addis Ababa makes up 25% of all the country's urban population, with a growth rate of 4.44 percent (CSA, 2013). Addis Ababa had a total population of 5.23 million in 2022 GC and was projected to grow to 7.3 million and 8.9 million in 2030 and 2035, respectively.

The study is solely concentrated on the road stretch from Mexico square to German roundabout since performing congestion analysis on the full city would demand enormous resources and a lot of time. the road segment is characterized as being through routes to residential settlement and the road segment is home to many commercial operations, it is quite busy, especially during peak hours compared to midday. The road portion under study has a length of 5.7 kilometers, as seen in the image below.

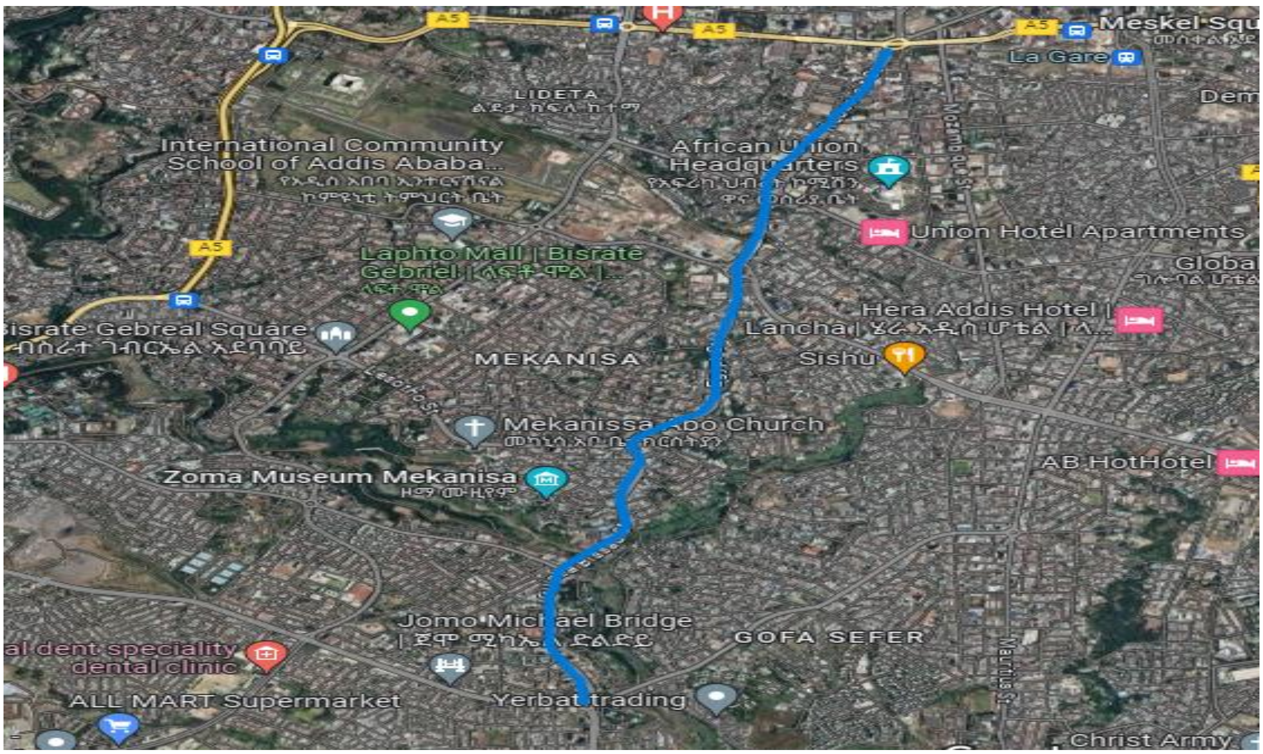


Figure 3-1 Study Section

3.3. Description of the Selected Road segment

The study road segment is a congested route and it is very vital because it connects residential areas of southern Addis Ababa to the center of the city and has a total length of about 5.7 km starting from German Roundabout to Mexico square which is the city core area. different trip attraction spots and governmental and nongovernmental institutions are found along this route. in addition, the road segment is selected for the following reasons:

- Severe peak hour congestion on most intersections
- Severe peak hour congestion on the roadways

– Severe pedestrian movement on intersections
– Different types of intersections
    - unsignalized intersection around Metec Mexico
    - signalized intersection around National Tobacco Enterprise
    - signalized intersection around African Union
    - Pushkin Square roundabout with an underpass
    - Mekanisa Abo roundabout
    - Mekanisa Signalized Intersection

Table 3.1. Road Segments in the study area

No	Road Segments in the study area	Length (M)
1	Mexico Roundabout - Metec Mexico	550 m
2	Metec Mexico - Africa union old gate	250 m
3	Africa union old gate – Africa union Intersection	300 m
4	Africa union Intersection - Pushkin Square	545 m
5	Pushkin Square - Mekanisa Abo	1,470 m
6	Mekanisa Abo Roundabout – Mekanisa Intersection	1,080 m
7	Mekanisa Intersection – German Square	1,070 m

Due to time and budget constraint, the researcher decided to take only three sections for further analysis. Based on site observation.

Table 3.2. Selected Section in the study road segment

No	Location	Length
1	African Union Intersection - Pushkin Square (Section 1)	100 M
2	Mekanisa Abo – Mekanisa Intersection (Section 2)	110 M
3	Mekanisa Intersection – German Square (Section 3)	100 M

Figures 3-2,3-3 and 3-4 show the afore mentioned road segments stated in the table 3-2 above

Figure 3-2 African Union - Pushkin Square road section

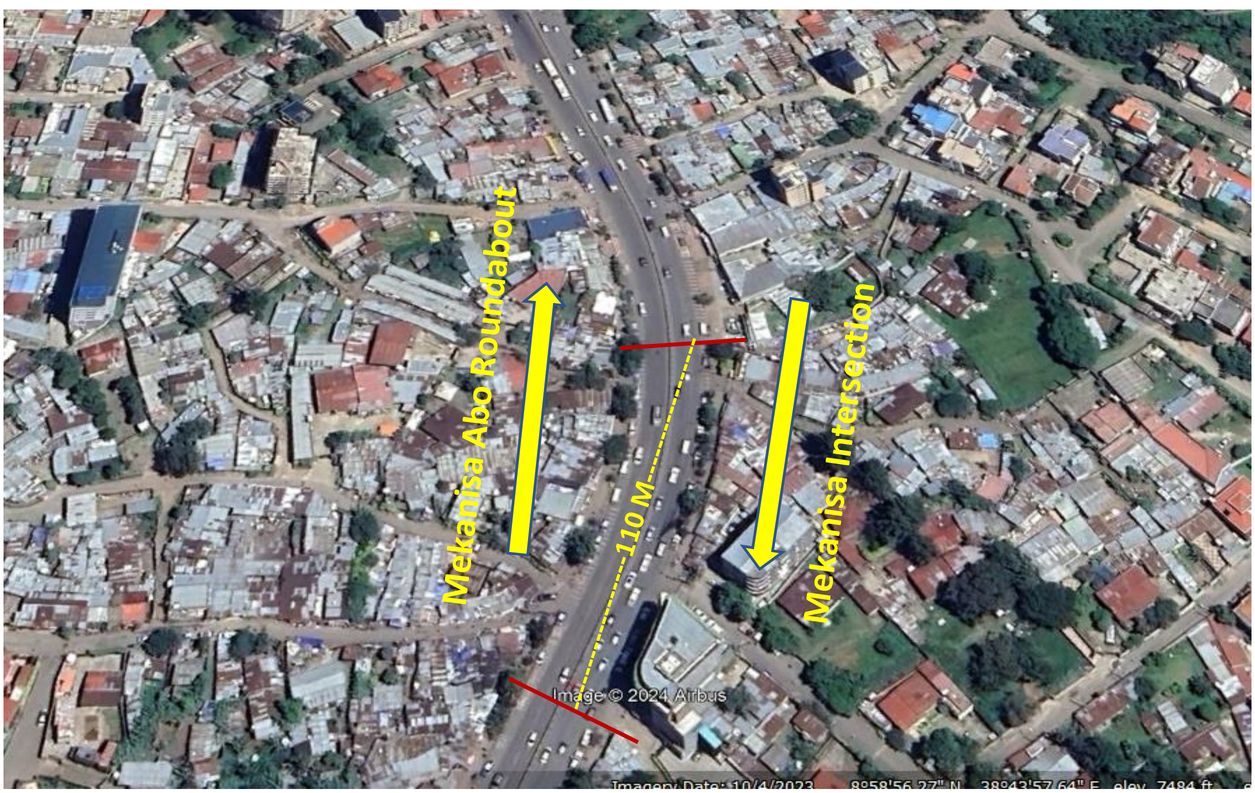


Figure 3-3 Mekanisa Abo – Mekanisa Intersection road section

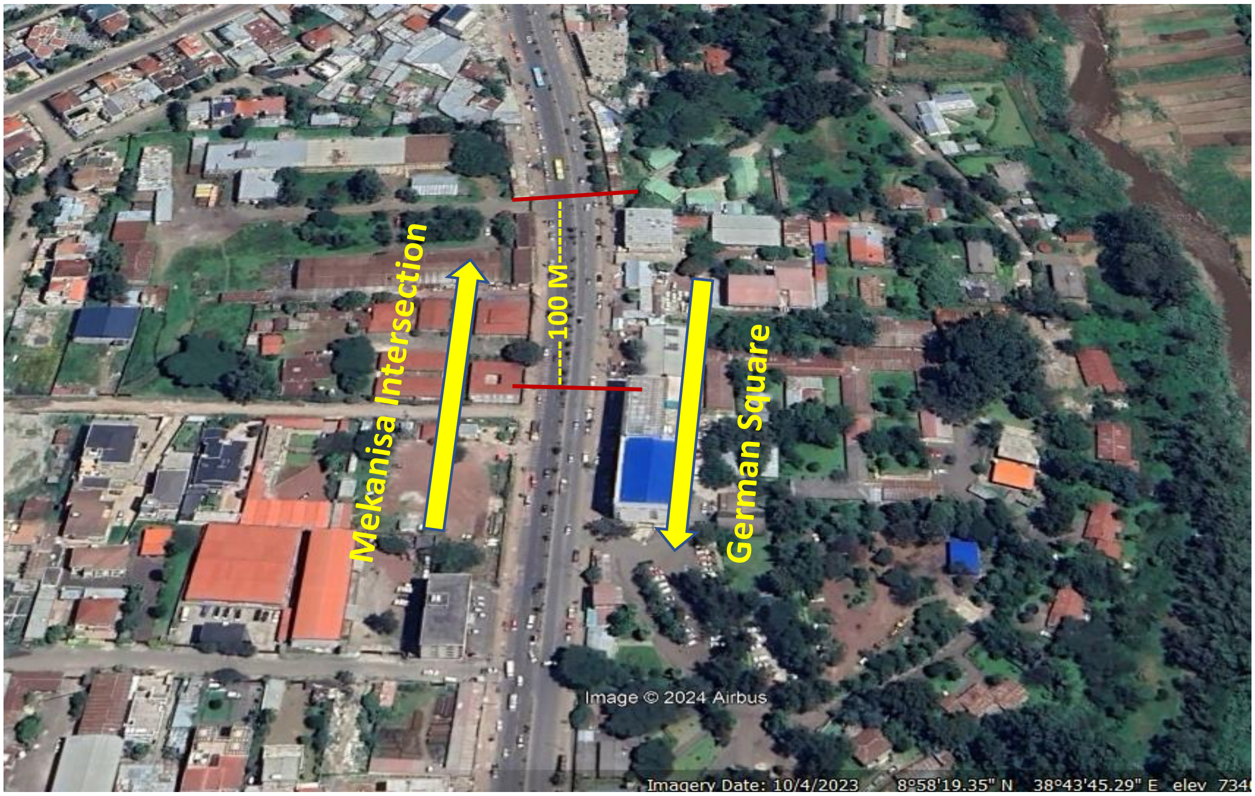


Figure 3-4 Mekanisa Intersection – German Square road section

sample pictures from the study site are shown below:

Figures: 3-5,3-6 and 3-7 sample Images for Section one, Section Two and Section Three respectively.

3.4. Research methodology

literature review was conducted to determine the research topic after the research problem was identified through investigation of the real-world problem. To find solution for this problem, research questions and objectives were clearly stated. Next, necessary data was gathered from primary and secondary sources which are vital to analysis.

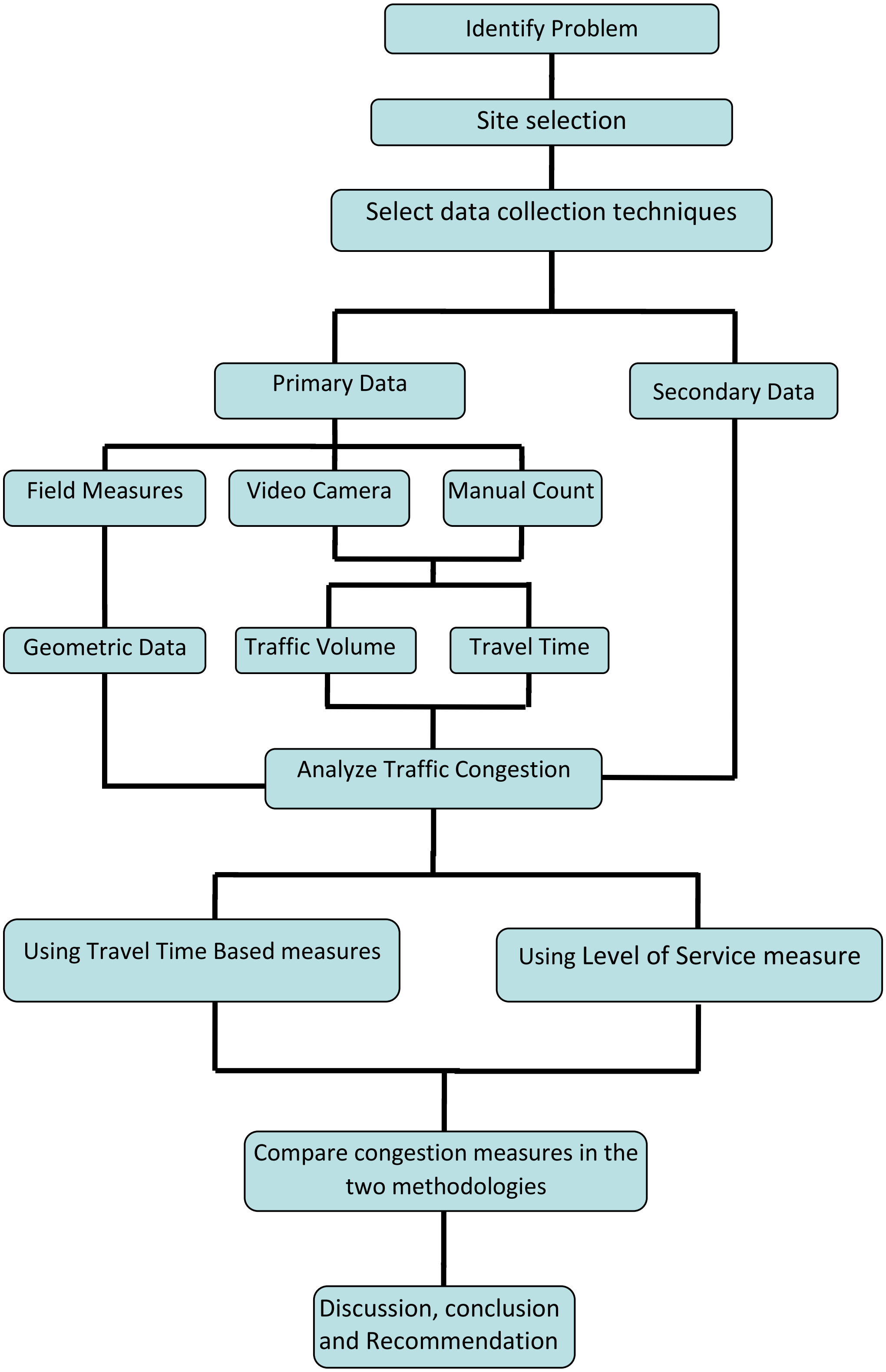


Figure 3-8: Outline of the Study

3.5. Data collection

Both qualitative and quantitative data were collected for the purpose of this study to enable the researcher to fully analyze the situation on the ground and to interpret the findings sufficiently. the quantitative data described are the traffic flow, road characteristics, travel speed and travel time. The qualitative data was done through observation on the selected hours of the day.

Both primary and secondary data was collected to gather both qualitative and quantitative data for the study Segment. Quantitative data was used to determine the level of service, Time based measures, delay-based measures, speed-based measures and travel time reliability measures. while qualitative data were used to gather information about the overall segment.

The primary data is collected using the following techniques:

- Traffic volume counts
- Travel Time measure
- Travel speed measure

3.5.1. Traffic volume

To ascertain the quantity, movements, and types of road vehicles at a certain site, traffic volume studies are carried out. For purposes of research, planning, design, and setting priorities and strategies for traffic improvements, traffic statistics are necessary. The quantity, composition, and time & route distribution of volume for each region under investigation may be determined and understood using these data. The type of count being taken and the purpose for which the data will be used will determine how long the sample period is.

The traffic volume count was made for 8 hours a day for 2 days of the week, the two days was chosen from weekday for the three road sections selected. The days selected were Tuesday and Thursday, because Mondays and Fridays are often considered peak travel days, and they may not be fully representative of typical traffic patterns throughout the week. The volume count was made on-peak and off-peak hours. starting from 7:00 AM to 4:00 AM in the morning, from 1:00 PM - 3:00 PM in the afternoon and from 4:00 PM to 7:00 PM in the evening using a video camera mounted on building tops. Once the video recording was done, the count was made on 15 minutes interval and the vehicles were counted in their respective categories as per ERA vehicle classification.

3.5.2. Travel time

Travel time, or the amount of time required to complete a route between any two points of interest, is a crucial measure in the transportation industry. The floating car approach, the license matching technique, driver interviews, the spot speeds of all traffic at a given place as compared to overall speeds, and ground or aerial images are some of the more prominent methods for calculating travel time.

To obtain a complete dataset covering all vehicular traffic during periods of high traffic volume and low traffic volumes within the study area, data was gathered on all the vehicles that traveled through the chosen road sections for the analysis. The data was collected for both the peak hour time period as well as the off-peak hour time period once the length of the road had been decided for the selected road sections. for this study the method used to collect the travel time data was the license plate matching technique, by extracting data from a video recording and using pen and paper to record the data.

3.5.3. Travel Speed

Travel speed is defined as the distance that is covered by a vehicle in specific period of time. The travel speed was measured by dividing the distance traveled with the average time taken to traverse the section. The speed was calculated from the travel time data collected by dividing the distance of the section selected to time required to traverse that section.

The speed data was calculated by taking the travel time data and dividing it by the length of the respective road segments to determine the speed. The speed data that was collected was then organized and grouped based on the category or type of vehicle. So, the speeds were compiled separately for different classes of vehicles, such as passenger cars, 4wd and Minibus, etc. Additionally, the speed data was aggregated and summarized in one-minute intervals, which was used to analyze the speed patterns and trends over time.

3.6. Methods of analysis

3.6.1. Volume to Capacity Ratio

In order to determine the level of service for the selected sections, the volume to capacity ratio metric was selected. In order to calculate the V/C, capacity of the road was needed. To calculate the capacity, the following procedure was used.

3.6.1.1. Flow Rate Calculation

Traffic volume was measured by counting the number of vehicles that pass a predetermined line in the study section during the selected time. For this study, time interval was taken as one minute. The hourly flow rate was calculated by using the following equation:

$q = \Sigma V_i * 60$.. (3.1)

Where:

q= the hourly traffic flow rate, in (vehicle /hr)

Vi=the number of vehicle type i which pass the study section in the time interval.

3.6.1.2. Density Calculation

The observed traffic flow rate and weighted average stream speed are used to find the traffic density for every One-minute interval using fundamental traffic flow equation.

Density was calculated using the following equation:

$k = \frac{q}{u_s}$.. (3.2)

Where:

q= the hourly traffic flow rate, in (vehicle /hr)

us= space mean speed(Km/hr)

3.6.1.3. Speed, Density Flow Relationship

To develop the Speed flow Density relationship, space mean speed was determined by one minute interval and density was calculated using fundamental traffic flow equation. The speed – flow relationship was determined, after which the capacity was calculated.

There are various models available to calculate flow density curve. However, the three most widely used models are the Greenshields model, Greenberg model and Underwood Model.

Table 3.3. Traffic flow Models and their parameters

No	Traffic Flow Model	Function	Parameters	Model Type
1	Greenshields Model	$u = uf\ (1 - k/kj)$	uf and kj	Linear
2	Greenberg Model	$u = u_o \ln(\frac{kj}{k})$	u_o and kj	Logarithm
3	Underwood Model	$u = u_f\, e^{\left(\frac{-k}{k_0}\right)}$	uf and k_0	Exponential

Calibration process

The most common method of approach is regression analysis.

$$Y = a + b * X$$

Greenshields Model: Y= u, X=k, a= u_f, b=$\left(\frac{-U_f}{k_j}\right)$, $q_{max} = \frac{u_f x k_j}{4}$

Greenberg Model: Y= u, X=lnk, **b= (-** u_o), $q_{max} = \frac{U_0 \times k_j}{e}$

Underwood Model: Y=lnu, X=k, **a=** lnu_f, $b = \left(\frac{-1}{k_0}\right)$, $q_{max} = \frac{u_f \times k_0}{e}$

Where:

Uf = free flow speed (Km/hr)

u_o= speed at capacity

Kj=Jam Density (Veh/Km)

K_0=density at capacity.

K=Density (Veh/Km)

q_{max}=Capacity (Veh/hr)

3.6.2. Road Segment congestion index

3.6.2.1. Compute the average speed

$$V_i = \frac{d}{t_i} \text{ X } (3{,}600\ sec/hour) \quad \text{.. (3.3)}$$

$$V_{avg} = \frac{\sum v_i}{n} \quad \text{.. (3.4)}$$

Where:

Vi= speed of the ith vehicle (km/h)

Vavg= Average speed

d= Distance of road segment (Km)

ti= time take to traverse the segment (sec)

n= number of vehicles

3.6.2.2. Compute the Speed Performance Index

The SPI is developed to assess the condition of urban road traffic congestion. SPI is the ratio of the vehicle's average speed and maximum permissible speed.

$$SPI = \frac{Vavg.}{Vmax} \times 100 \qquad \text{.. (3.5)}$$

Vavg. = the average vehicle speeds, Km/h.

Vmax= the maximum permissible speed, Km/h. which is the speed limit.

3.6.2.3. Determine the Traffic state level

Table 3.4. Speed performance index with traffic state

Speed Performance Index	Traffic State Level	Description of Traffic State
(0,25)	Heavy congestion	Low average speed, poor road traffic state
(25,50)	Mild congestion	Lower average speed, road traffic state bit weak
(50,75)	Smooth	Higher the average speed, road traffic state better
(75,100)	Very smooth	High average speed, road traffic state good

3.6.2.4. Compute the average SPI and Proportion of Non-Congested State

$$\overline{R_v} = \frac{SPI}{n} \qquad \text{.. (3.6)}$$

$$R_{NC} = \frac{t_{NC}}{T_t} \qquad \text{.. (3.7)}$$

Where:

Rv= denotes the average of speed performance index

SPI= speed performance Index

RNC=denotes the proportion of non-congestion state tNC= denotes the duration of non-congestion state, minute. (The time the speed performance index is greater than 50)

Tt= denotes the length of the observation period, minute. (60 minutes)

3.6.2.5. Compute the road segment congestion index

$$R_i = \frac{\overline{R_v}}{100} \times R_{NC}$$ ……………………………………… (3.8)

Ri= denotes the road segment congestion index;

Rv= denotes the average of speed performance index;

RNC=denotes the proportion of non-congestion state;

3.6.3. Speed Reduction index (SRI)

The SRI was calculated using the formula show below:

$$\text{SRI} = (1 - v_{ac}/v_{ff}) \times 10,$$ ……………………………………… (3.9)

Vac= average Speed (Km/hr)
Vff= Free flow Speed (Km/hr). (The 85th percentile free flow speed was taken for this study)

3.6.4. Travel time reliability

3.6.4.1. Planning Time Index(PTI)

PTI=$\frac{95\%TT}{FFTT}$ ……………………………………… (3.10)

Where:

95*%TT:* Determined form the Cummulative frequency distribution of the travel time collected

FFTT: Travel time during free flow conditions

3.6.4.2. Buffer Time Index(BTI)

BTI=$\frac{95\%TT-ATT}{ATT} \times 100\%$ ……………………………………… (3.11)

Where:

95*%TT:* Determined form the Cummulative frequency distribution of the travel time collected

ATT: Average Travel time

3.7. Passeneger car Unit estimation

It is vital to transform heterogeneous traffic into homogeneous traffic using a common unit in order to determine the capacity and traffic facility of heterogeneous traffic. Chandra's model was employed in this study to determine the PCU of various car classes. Chandra(2004) which proposed the concept of dynamic PCU which vary dynamically with various traffic flow parameters such as speed, vehicle composition and volume capacity ratio. According to Chandra, the PCU of a conventional vehicle is inversely proportional to the space occupancy ratio and directly related to the clearing speed ratio. The physical dimensions of a vehicle serve as a key indicator of pavement occupancy, which is important for understanding the oppressive features of the traffic flow. Because many Ethiopian drivers lack lane discipline, vehicles rarely move in their designated lanes. In these situations, area best reflects vehicle occupancy.

Ethiopian Road Authority vehicle classification was used for the study and PCU for bicycle, motor cycle and Bajaj were taken from ERA. in order to calculate the PCU the average rectangular area was calculated then the average speed of vehicles by their respective categories were worked out. Table below shows the rectangular area.

Table 3.5. Rectangular Plan Area of Vehicles

Vehicle	Average Dimension		Rectangular Area
	Length	Width	
Passenger car and Taxi	4.233	1.747	7.42
4WD	4.495	1.748	7.89
Mini Bus	5.06	1.815	9.38
Medium Bus	8.19	2.32	19.37
Bus	11.56	2.5	29.07
Small Truck	5.7	1.93	11.00
Truck	8.41	2.42	20.39
Truck & Trailor	15.9	2.43	39.6

CHAPTER FOUR: RESULTS AND DISCUSSION

The research was done to study traffic congestion with various analysis methods. In This chapter the findings from the collected data are presented, analyzed and discussed empirically, graphically and in tabular form.

4.1. Traffic Volume

To find out the peak hour in the selected segments for both direction of roads, traffic count was made on the selected segments. And as described in chapter three the traffic volume was conducted for eight hours for two days of the week starting from 7:00 Am – 10:00 Am in the morning, 1:00 Pm – 3:00 Pm in the afternoon and 4:00 Pm – 7:00 Pm in the evening. the traffic volume of the road sections was collected for both sides of the road.

- Section one: Africa Union – Pushkin Square Road segment
- Section Two: Mekanisa Abo – Mekanisa road segment
- Section Three: Mekanisa – German roundabout road segment

4.1.1. Traffic Volume for Section One

The section is a two-way road divided by a solid median and has three lanes on both sides of the road. The traffic count was conducted for three hours of each peak time and two hours of off-peak time. As shown in Figure, distribution of total average traffic volume at the section for north bound and south bound directions.

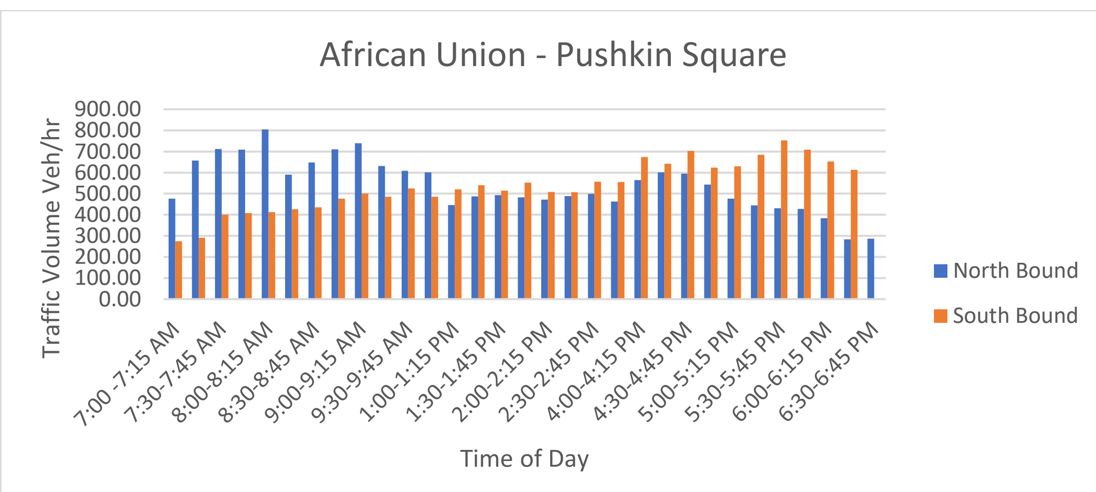


Figure 4-1. Traffic Volume for Section one

As can be seen from the graph both directions have different peak hours, the north bound direction has its peak in the morning because people are using this road to travel to work, school or to other destinations from their place of origin. While the south bound direction has its peak in the evening as a result of people returning to their place of origin.

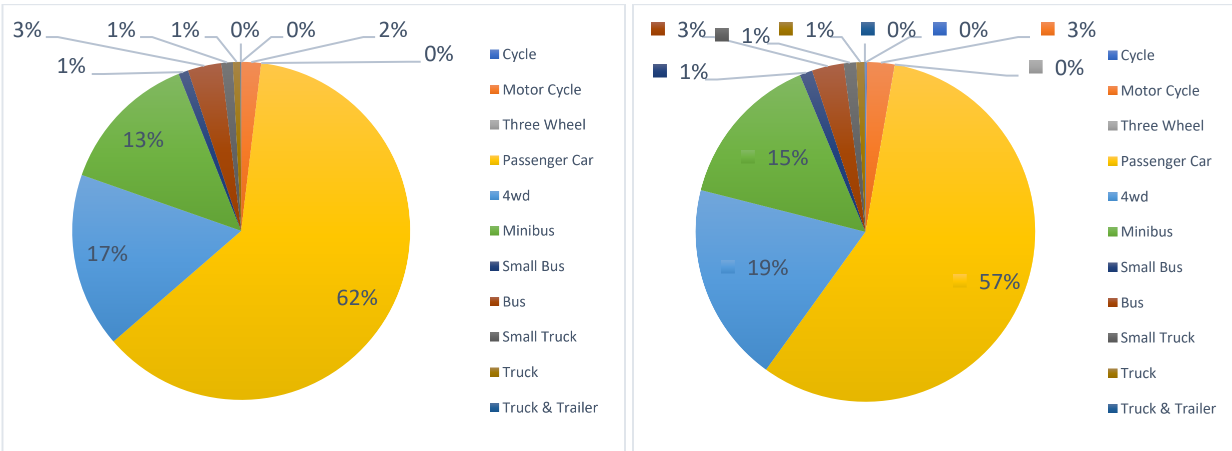


Figure 4.2. Percentage of vehicle composition on section one, north bound and south bound direction

Regarding the traffic composition, passenger cars (62% & 57%) was the highest followed by 4WD (17% & 19%) and minibus with (13% & 15%) of the share. Contribution of standard car, 4WD and Minibus together was (92% & 91%) on this Section. The result also showed that the proportion of three wheelers was zero and the proportion of cycle and truck & trailer was nearly zero while the rest had a percentage of 1% to 4% for both directions.

4.1.2. Traffic Volume for Section Two

This section is also two-way road divided by a solid median and has three lanes on both sides of the road. The traffic count was conducted for three hours of each peak time and two hours of off-peak time. As shown in Figure 4-3, distribution of total average traffic volume at the section for northbound and south bound directions.

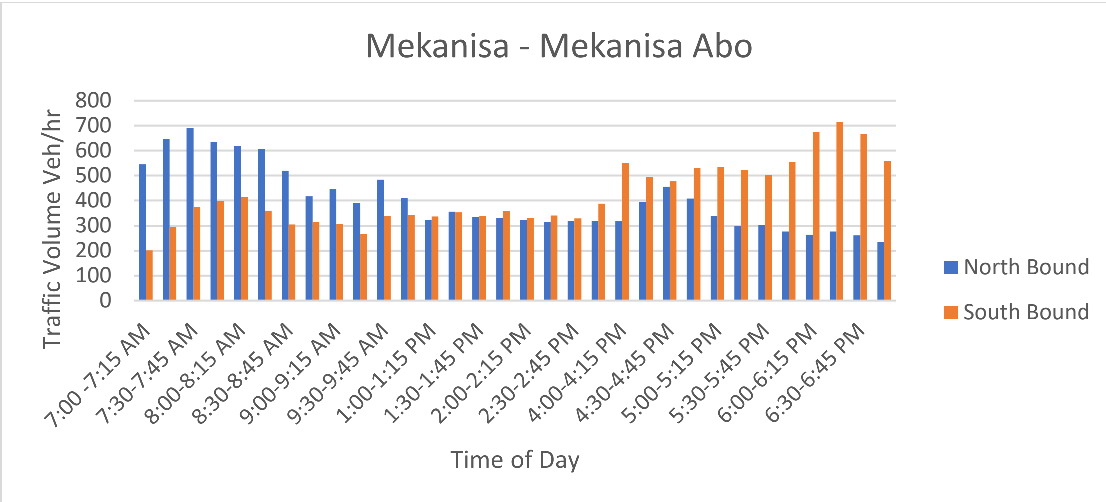


Figure 4-3. Traffic Volume for Section Two

As can be seen from the graph both directions have different peak hours, like that of section one peoples movement differs for both directions.

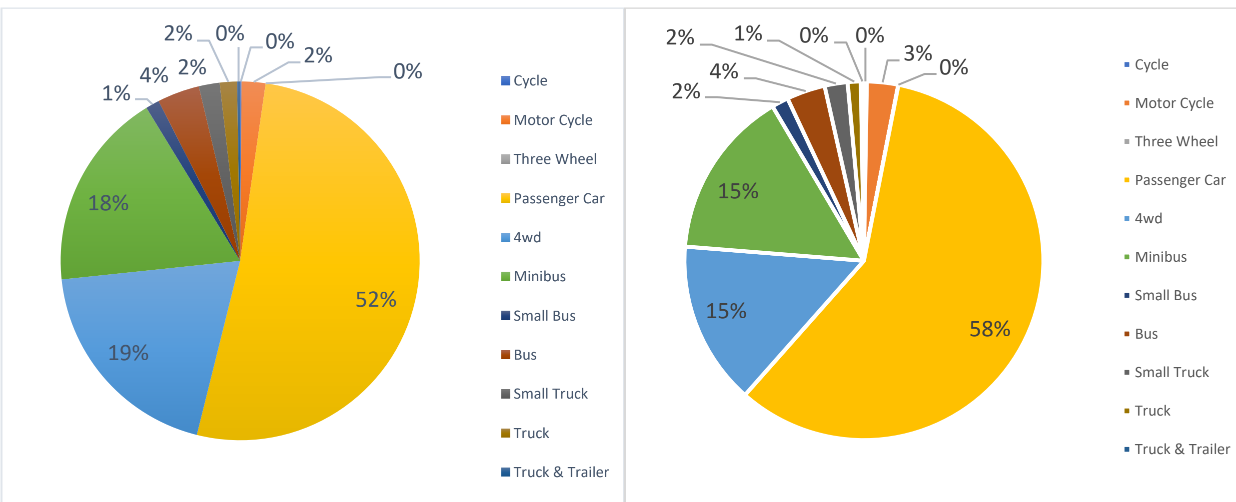


Figure 4.4. Percentage of vehicle composition on section two, north bound and south bound direction

When we see the traffic composition, passenger cars (52% & 58%) were the highest followed by 4WD (19% & 15%) and minibus (18% & 15%). Contribution of standard car, 4WD and Minibus together was (89% & 88%) on this Section. The result also shows that the proportion of three wheelers was zero and the proportion of cycle and truck & trailer was nearly zero while the rest had a percentage of 1% to 4% for both directions.

4.1.3. Traffic Volume for Section Three

This section is also a two-way road divided by a solid median and has three lanes on both sides of the road. The traffic count was conducted for three hours of each peak time and two hours of off-peak time. As shown in Figure 4-5, distribution of total average traffic volume at the section for north bound and south bound directions.

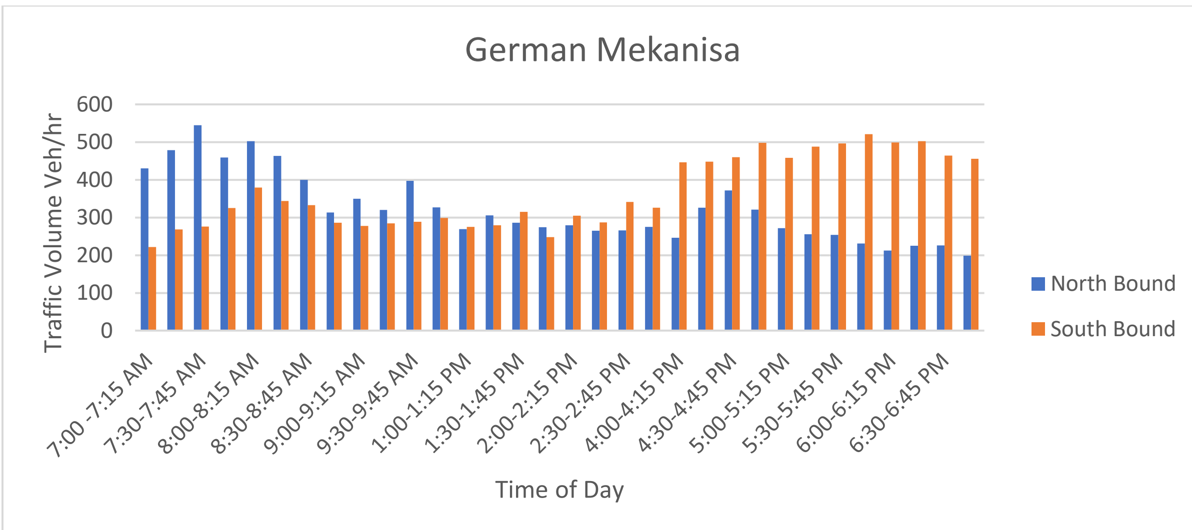


Figure 4-5. Traffic Volume for Section Three

Like the previous two sections, both directions have different peak hours and people's movement differs for both directions.

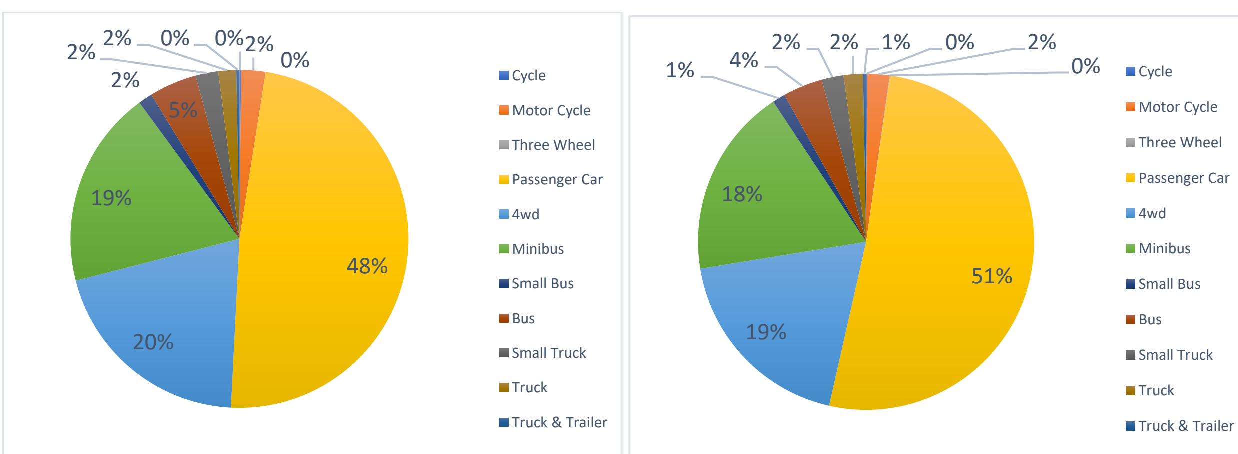


Figure 4-6. Percentage of vehicle composition on section Three, north bound and south bound direction

The traffic composition shows that passenger cars (48% & 51%) were the highest followed by 4WD (20% & 19%) and minibus (19% & 18%). Contribution of standard car, 4WD and Minibus together was (87% & 88%) on this Section. The result also shows that the proportion of three wheelers was zero and the proportion of cycle and truck & trailer was nearly zero while the rest had a percentage of 1% to 5% for both directions.

Since only one direction was going to be taken for performance evaluation of the road segment, the direction with the highest traffic volume was taken for further study. After looking at the traffic volume data for both directions, the north bound direction was chosen for analysis.

4.2. Performance Evaluation

Based on the travel time based and level of service method, a congestion study was conducted to determine the necessary congestion measures. These congestion measures are grouped as time-based measures, delay-based measures, speed-based measures and volume to capacity ratio.

4.2.1. Travel Time

Travel time of the vehicles traveling along the selected road was determined for the selected sections. According to the result shown in the Figure 4-7, 4-8 and 4-9 below, it shows the morning peak periods recorded the highest travel times and the lowest travel times were recorded during the afternoon off peak period for Section one and section two. While section three exhibited a uniform value for both peak and off-peak hours.

For section one and section two, the wide spread of the travel time in the peak period indicates that travel times during peak hours can vary significantly. Which suggests the sections experience high levels of unpredictability and unreliability during congested periods. Which leads to Commuters facing different travel times even on the same route depending on the specific conditions of that peak hour. On the other hand, during off-peak hour travel times are generally much lower and less variable compared to peak hours. which means that travelers can reliably plan their journeys during these less busy times, as the travel times are relatively stable and predictable.

For section Three, the peak period shows a slightly spread travel times when compared to the afternoon off-peak period. While the off-peak period shows a relatively free-flowing situation when compared to peak period. But it shows a uniform value for both periods.

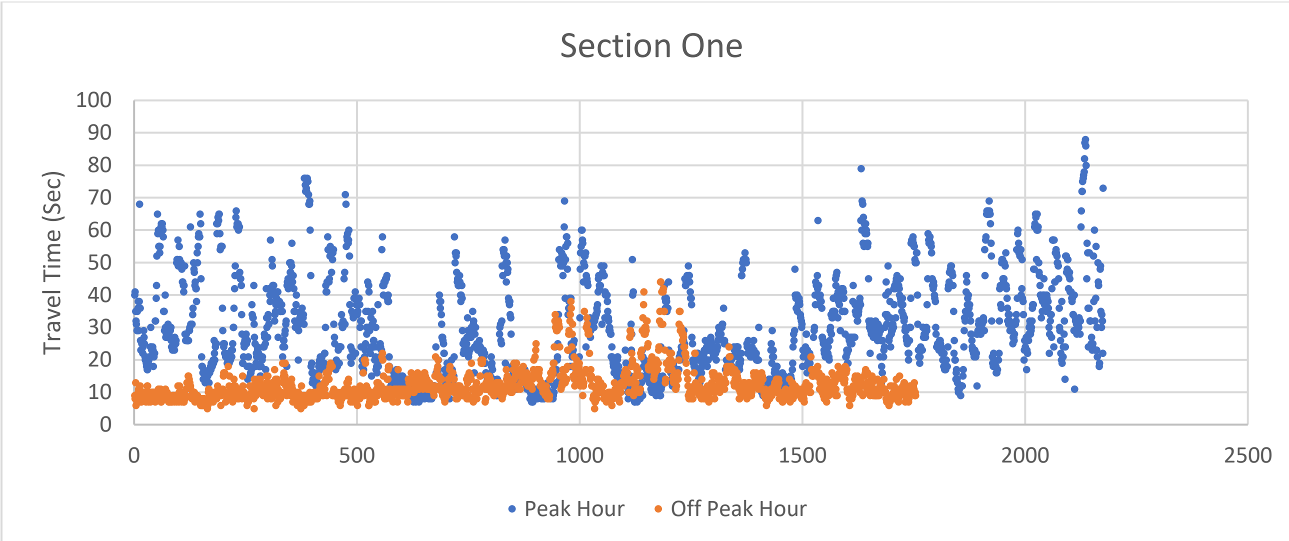


Figure 4-7. Travel Time for Section One

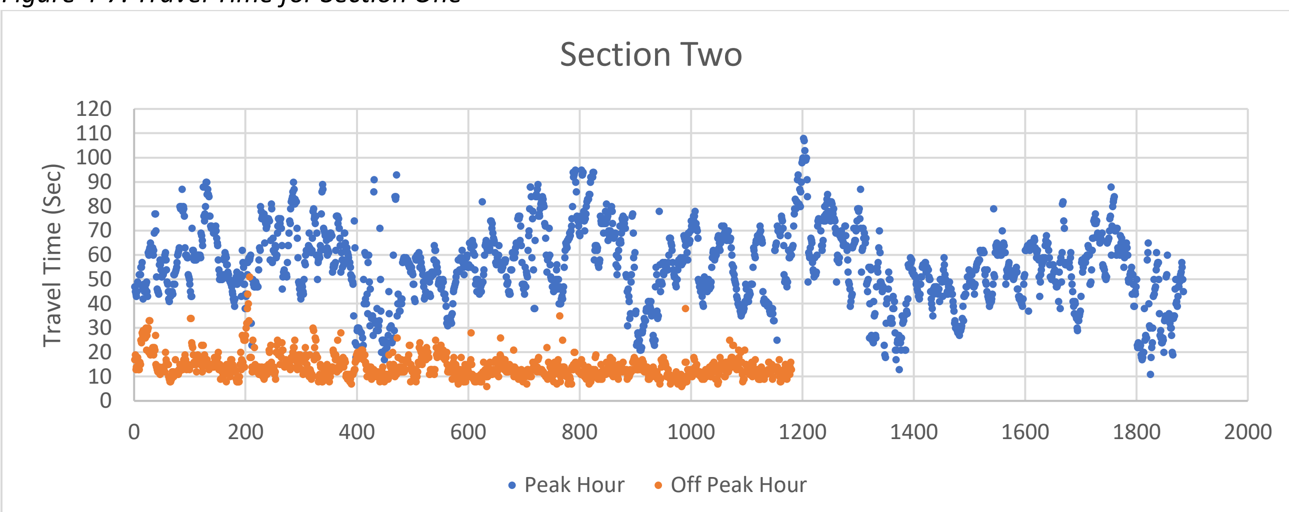


Figure 4-8. Travel Time for Section Two

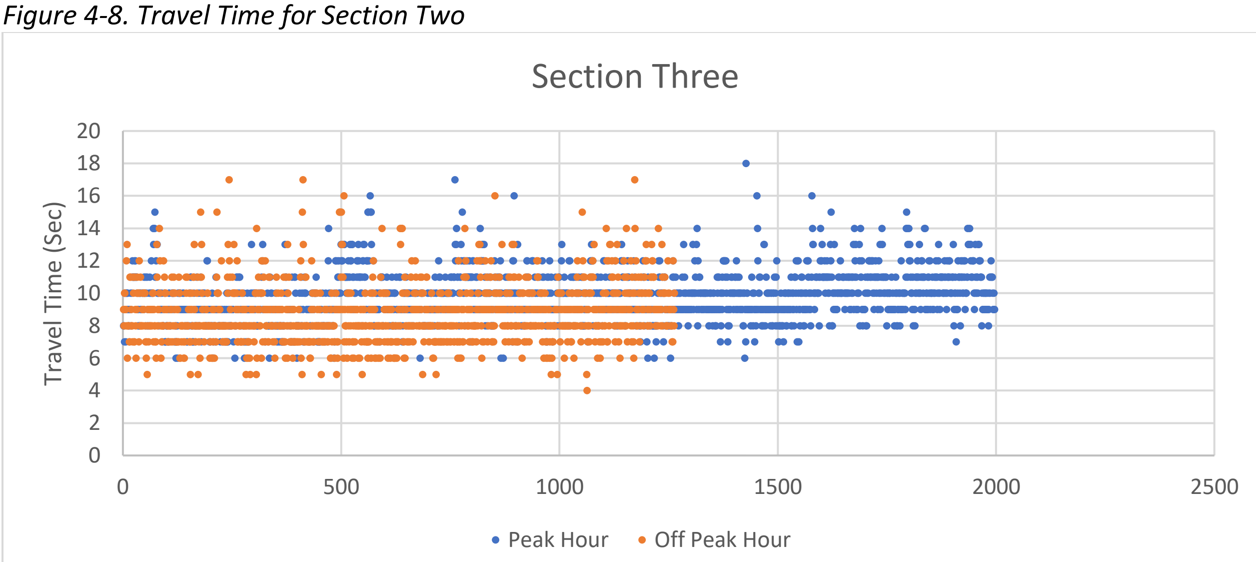


Figure 4-9. Travel Time for Section Three

4.2.2. Travel Speed

The speed on the selected road sections was determined by averaging the travel time by one minute interval and calculating the speed. This was done for the sections previously selected. Figure 4-10 below shows average speed distribution for the peak and off-peak hours of the day for the road sections. As per the result, during morning period, the travel speed is low. Section Two recorded the lowest speed in the morning period compared to the other two road sections while section three recorded the highest speed. Section one and two had a similar trend but section three had relatively uniform speed throughout the day.

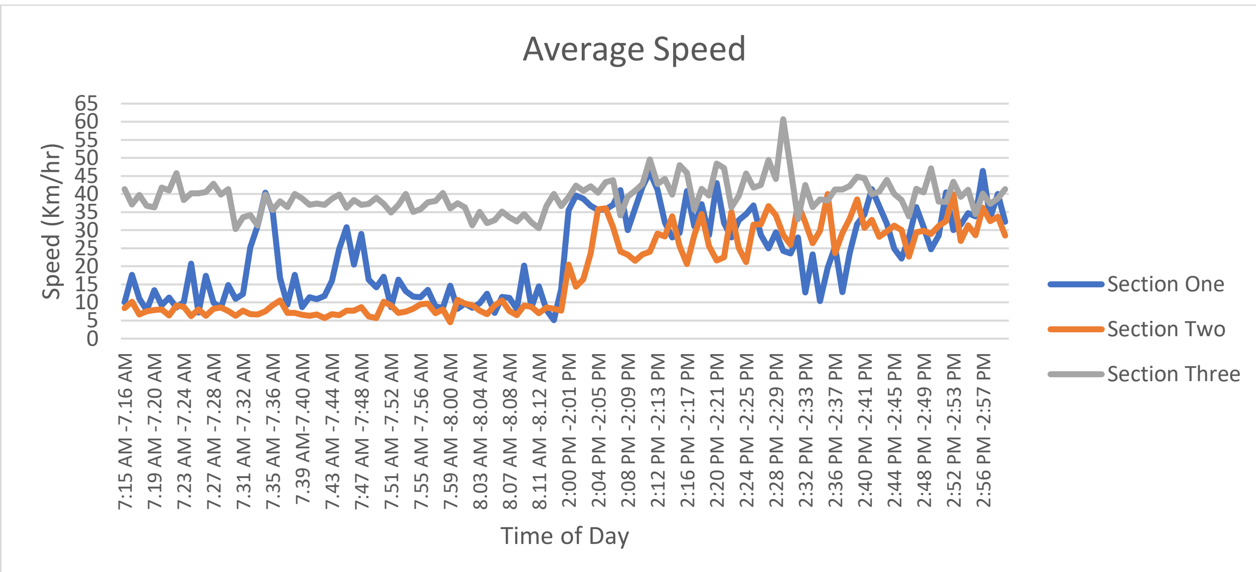


Figure 4-10. Average Travel Speed for the selected road sections

4.2.3. Travel Rate

Travel rate is the inverse of travel speed. Since travel rate reflects trip time for a unit segment length, it is quite practical to determine the level of congestion on the chosen corridor. The data shows sections one and two have higher travel rates in the peak periods when compared to the Afternoon off-peak periods, Section two recorded the highest travel rate compared to the other two sections which means it experiences the highest levels of congestion during rush hours. Section one also has higher travel rate in the morning peak period but the magnitude is generally lower compared to Section two. Section three has a relatively steady travel rate for both periods of the day, with fewer significant fluctuations.

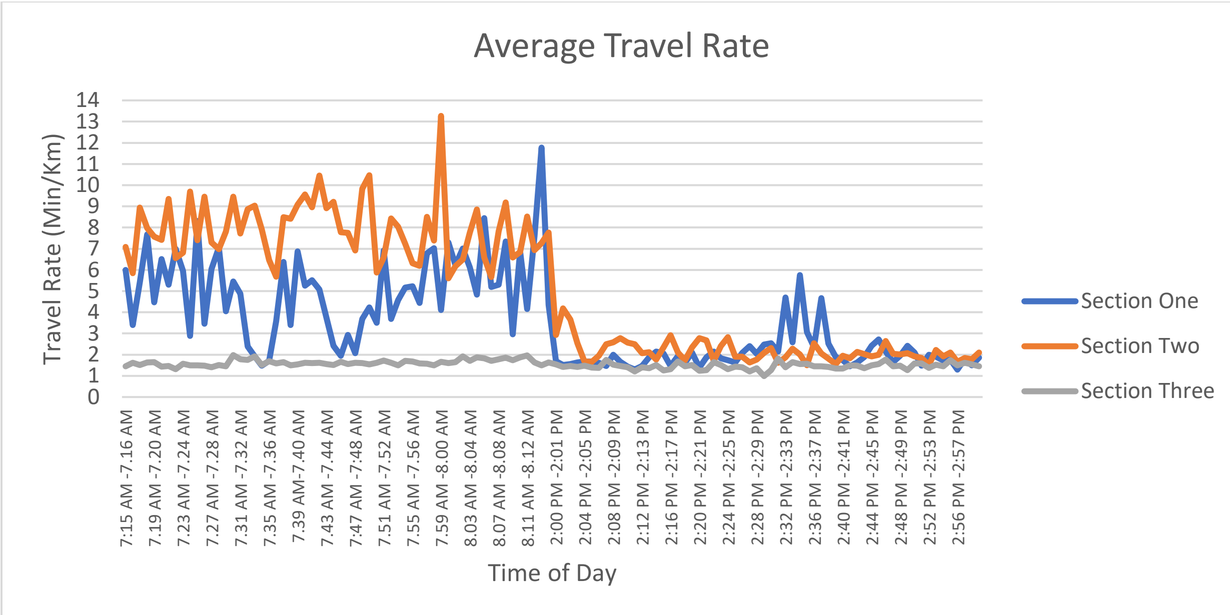


Figure 4-11. Average Travel Rate for the selected road sections.

4.2.4. Travel Time Index

The travel time index is the ratio of the actual travel time to the travel time under free-flow conditions. Section one and section two show the highest travel rate in the morning peak period, while section one shows the most pronounced variations in the travel time index than section two which shows less variation. Section three exhibits a low and consistent travel time index overall.

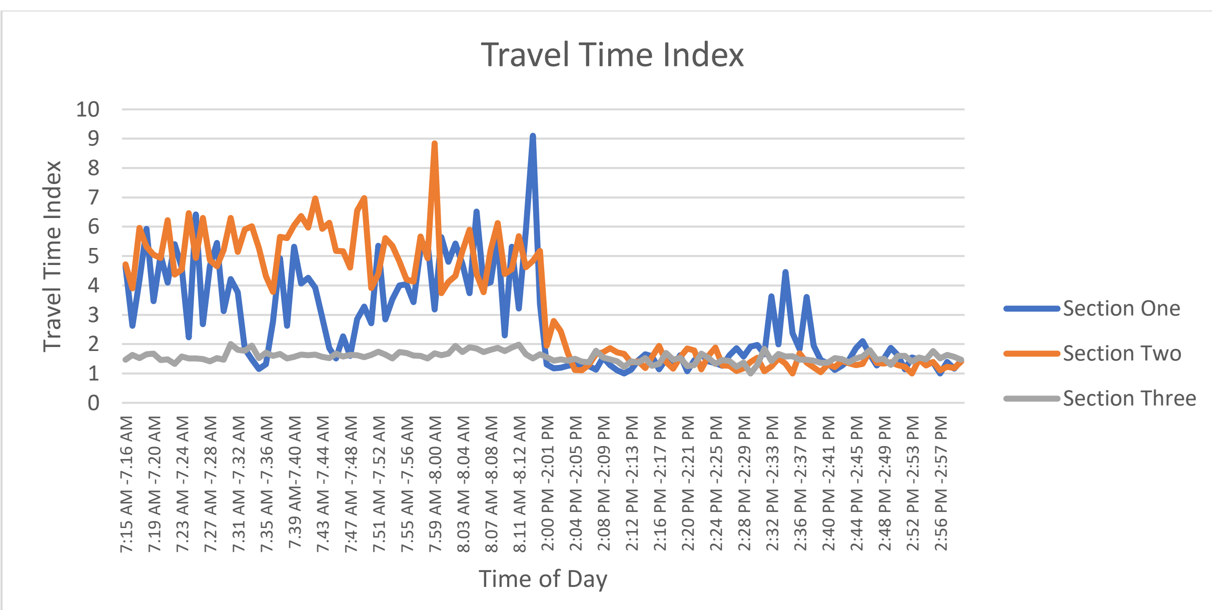


Figure 4-12. Average Travel Time Index for the selected road sections.

4.2.5. Delay

Congestion on the roadways results in additional time required to complete a journey, which is commonly referred to as delay. The calculation of this delay is based on a baseline speed, which represents the lowest travel time recorded over the course of the study period. This baseline speed serves as a reference point, allowing the delay to be quantified as the difference between the actual travel time and the travel time that would be experienced under minimal traffic conditions.

Figure 4-13 below shows maximum delay occurred in the morning peak period; section one and section two exhibited the highest delay in the peak period and lowest delay in the off-peak period. While Both Sections experienced substantial variations in delay during the study period. Section three demonstrated the most stable and consistent delay levels overall. While there are some smaller peaks, the delay experienced in this section is significantly lower compared to the other two sections.

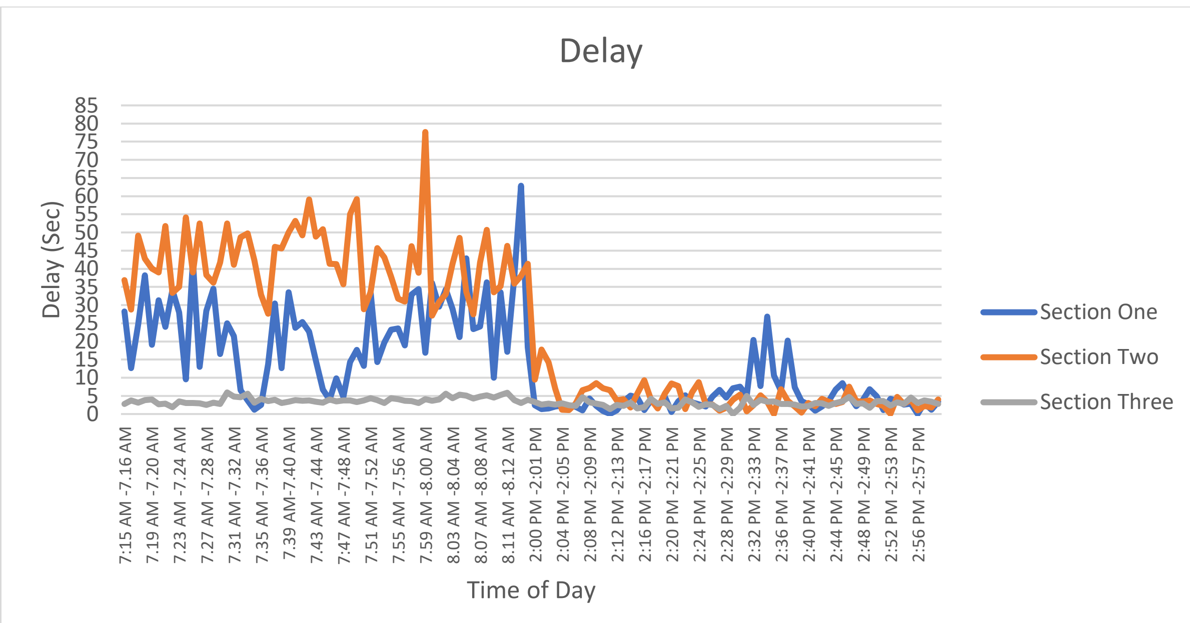


Figure 4-13. Delay for selected Road Sections

4.2.6. Delay Rate

The delay rate is a measure that quantifies the amount of delay experienced per unit of distance along a road segment. Rather than simply expressing the total delay in minutes, the delay rate shows the delay in terms of minutes per kilometer. This formulation provides a more meaningful and standardized way to measure and compare the level of congestion across different road segments.

From Figure 4-14 section one and section two experienced the highest delay rate fluctuations for the study period. Both showed their highest delay rate in the morning peak hour and low in the afternoon off-peak period. while section three exhibited the most stable and consistent delay rate.

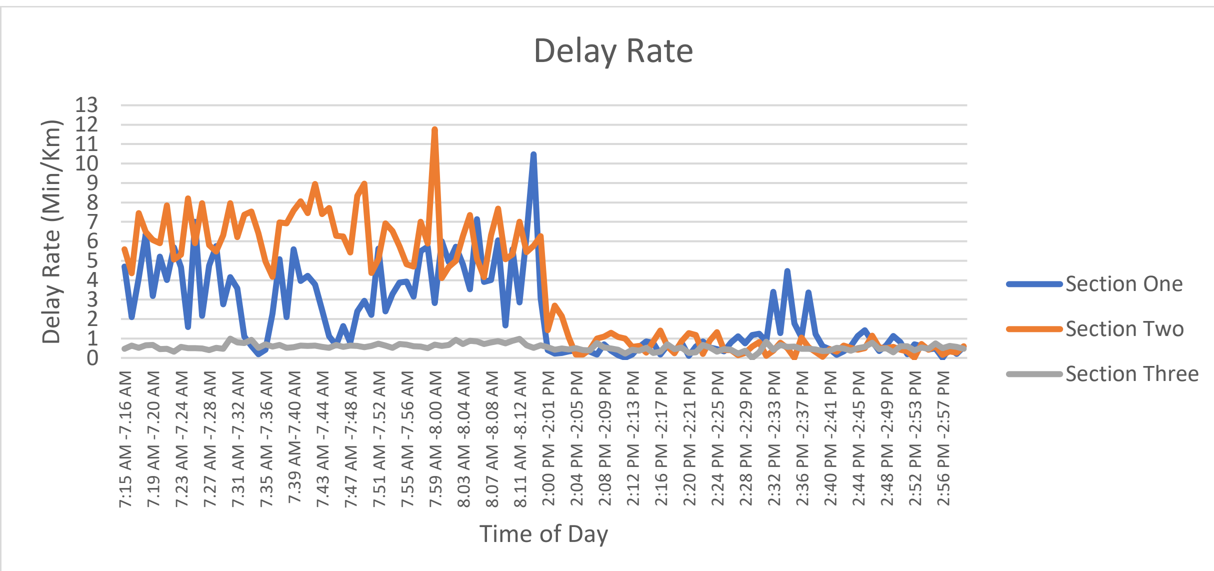


Figure 4-14. Delay Rate for selected Road Sections

4.2.7. Delay Ratio

The delay ratio is calculated by dividing the delay rate by the actual travel rate. This ratio provides a dimensionless value that indicates the relative magnitude of the delay experienced compared to the normal travel time.

Section one exhibits the most significant variations in delay ratio during both periods. There are several pronounced peaks, indicating periods of substantially higher delays compared to the baseline rate. Section Two also shows notable delay ratio spikes, but they are generally smoother compared to Section One. While section three demonstrated the most stable and consistent delay ratio overall.

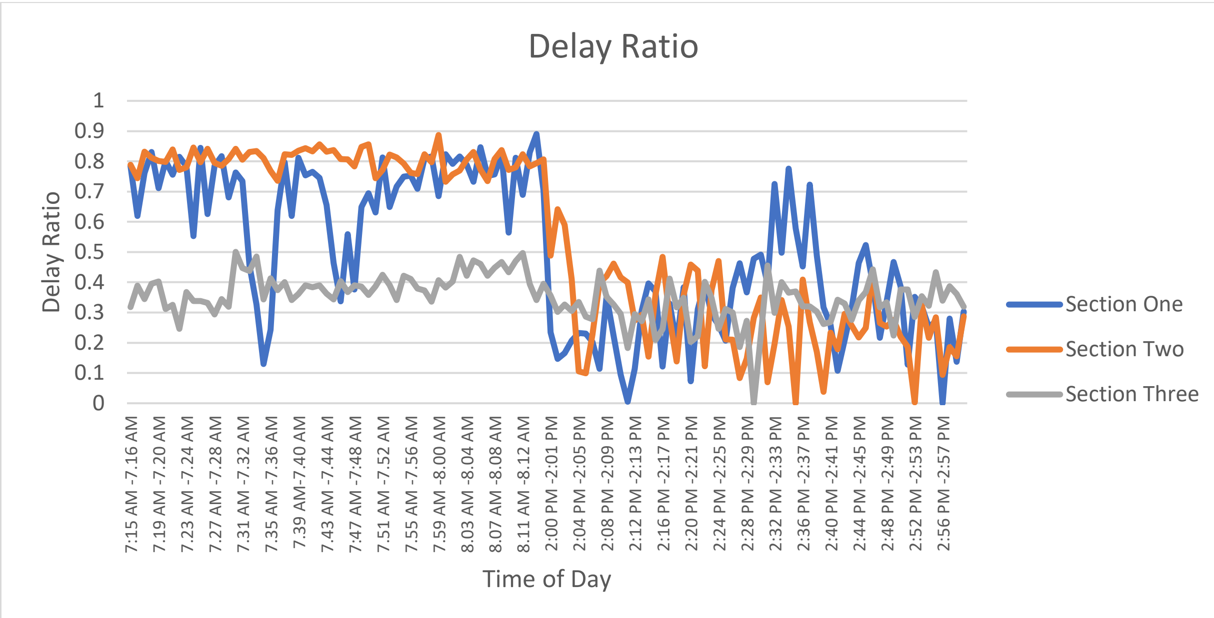


Figure 4-15. Delay Ratio for Road Sections

4.2.8. Total Segment Delay

Total segment delay is another useful metric in the analysis of traffic congestion. This measure provides an estimate of the overall delay experienced by vehicles traveling along a specific road segment, rather than just the delay rate or delay ratio.

The calculation of total segment delay takes into account factors such as the traffic volume, and the difference between the actual travel time and the baseline, uncongested travel time. This provides a more complete picture of the cumulative impact of congestion.

As shown in Figure below, the highest segment delays occur during morning peak hour periods, when the section experiences the highest traffic volumes. Section two exhibited the highest segment delay having recording the highest value of more than 3,000 Veh-Min. section one also has a high segment delay. Section three had a uniform segment delay for the study period and the delay experienced in this section is significantly lower compared to the other two sections.

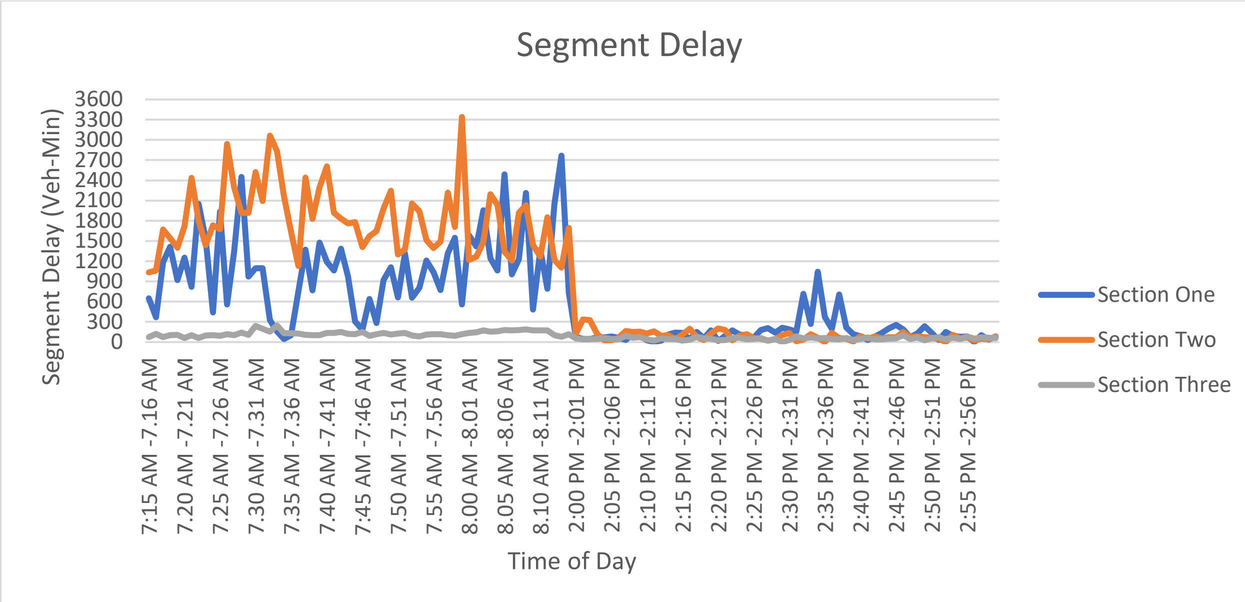


Figure 4-16. Total Segment Delay for Road Sections

4.2.9. Speed Performance Index Analysis

Speed performance index (SPI) is a measurement of traffic congestion, and it can be defined by the ratio between vehicle speed and the maximum permissible speed (He F., et.al., 2016).

Once the peak hour was determined for all sections, Average speed at 1 min interval was determined for all sections for their entire Peak and Off-Peak hour.

Section one

The area is characterized as having a medium-sized or moderate commercial markets, indicating a reasonable level of business and economic activity in the area. Similarly, the area experiences medium or moderate levels of pedestrian movement, suggesting it is not an extremely busy commercial district, but also not a particularly quiet or inactive one.

The graph you see below shows the speed performance index for Section one, as can be seen, the graph shows fluctuations for both peak and off-peak hours. The morning peak period has the lowest SPI. The morning peak period recorded the lowest SPI of 10.39, while the highest SPI was recorded in the afternoon off-peak period with an SPI of 94.48.

We can understand from the data the average SPI for the morning peak period was found to be 31.12, which was categorized under the 25-50 range, which is a mild congestion traffic state level. The SPI for the afternoon off-peak period was found to be 66.20 which is under the 50-75 range, which is a smooth traffic state level.

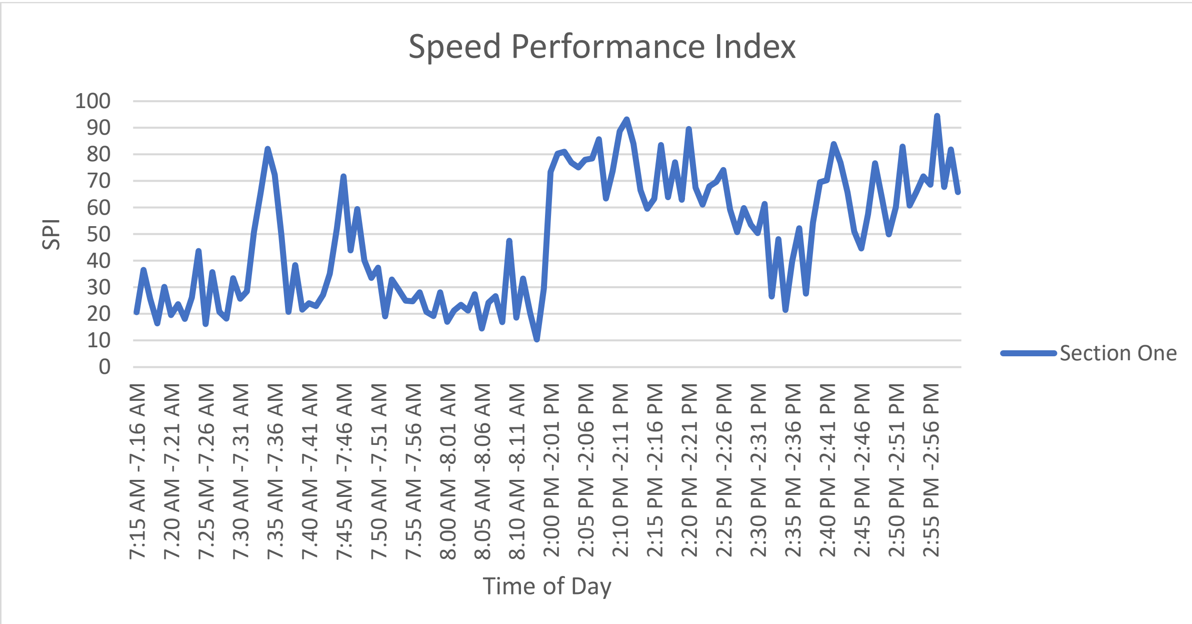


Figure 4-17. Speed Performance Index for Section one

Section Two

The area is described as having a large and high commercial market, indicating a substantial level of business and economic activity in the area. Similarly, the area experiences a significant amount of pedestrian movement, suggesting it is a busy commercial district.

The graph below shows the speed performance index for section two, as can be seen, the graph exhibits a uniform value for the morning peak period and a slight fluctuation on the afternoon off-peak period. The morning peak period has the lowest SPI with great margin than the afternoon period. The morning peak period recorded the lowest SPI of 11.65 while the highest SPI was recorded in the afternoon off-peak period with an SPI of 86.38.

We can understand from the data the average SPI for the morning peak period was found to be 17.88, which was categorized under the 0-25 range, which is a heavy congestion traffic state level.

The SPI for the afternoon off peak period was found to be 61.36 which is under the 50-75 range, which is a smooth traffic state level.

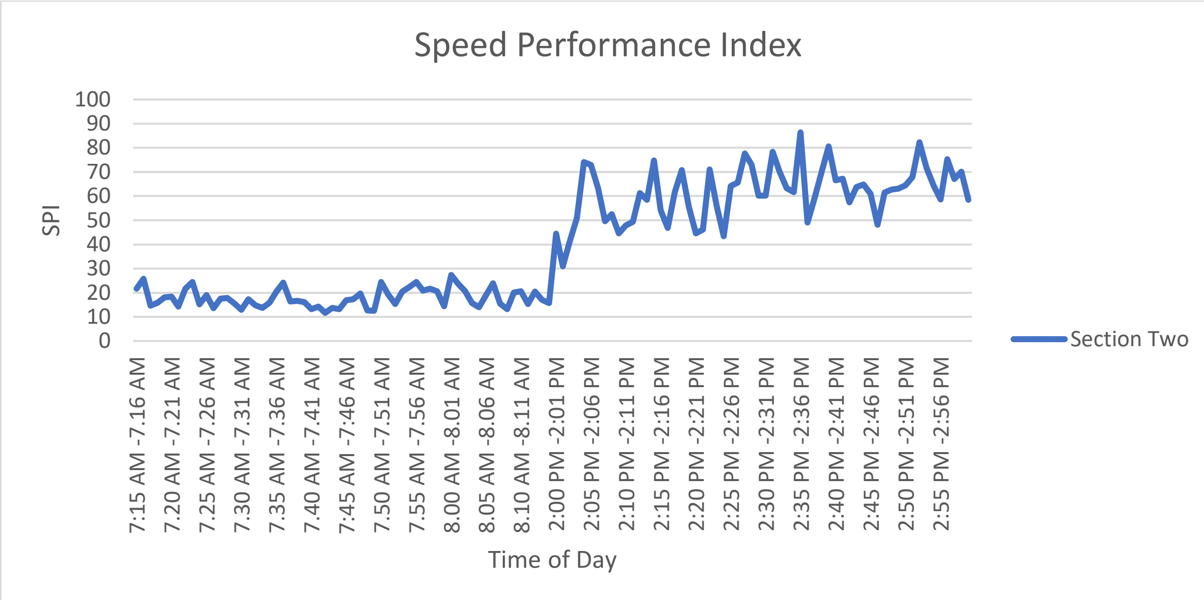


Figure 4-18. Speed Performance Index for Section Two

Section Three

The area is characterized as having a minimal commercial presence, with few active markets or retail establishments. Also, there is low levels of pedestrian activity and movement throughout the area.

The graph below shows the speed performance index for section three, as can be seen, the graph shows a uniform value for both periods with slight fluctuations. The morning peak period has the lowest SPI than the afternoon period. The morning peak period recorded the lowest SPI of 61.66 while the highest SPI was recorded in the Afternoon off-peak period with an SPI of 99.17.

We can understand from the data the average SPI for the morning peak period was found to be 75.66, which was categorized under the 75-100 range, which is a very smooth traffic state level. The SPI for the afternoon off peak period was found to be 86.35 which is under the 75-100 range, which is a very smooth traffic state level.

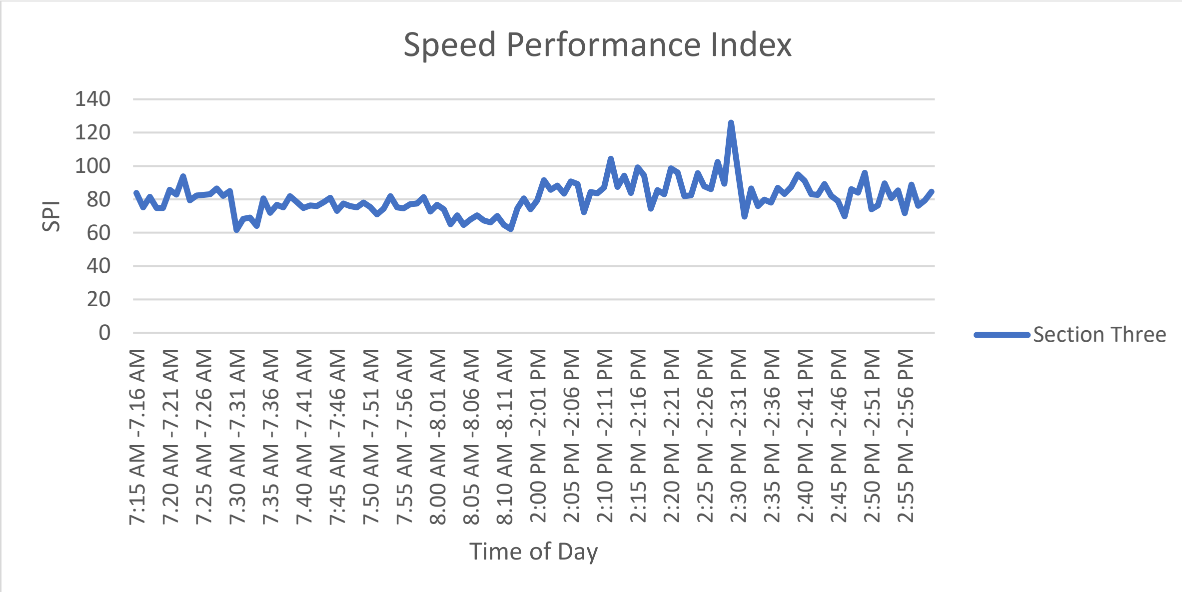


Figure 4-19. Speed Performance Index for section Three

4.2.10. Congestion Index

The length of time that a typical road segment was in a non-congestion condition during the observation period was used to calculate the state of road segment congestion (He et al., 2016). Any traffic node's level of traffic congestion may be expressed using the Road Segment Congestion Index (RSCI). The road segment is more crowded when the RSCI number, which ranges from 0 to 1, is smaller (Li et al., 2016; He et al., 2016). The RSCI equation has been discussed in chapter two and we will adopt those equations to determine the degree of congestion for the selected road segments.

To determine the non-congested state, we need to look at the speed performance index calculated in the previous section. And it is determined by checking how many of the minutes in the observation period, which is 60 minutes the speed performance index is 50 or above (Li et al., 2016; He et al., 2016). The table 4.1. below shows the non-congestion state of the selected road sections for both north bound and south bound approaches.

Table 4.1. Calculation of Non-congested State of Road Segments

No	Section Name	Direction of Travel	Observation Period, 60 Minutes	
			Morning Peak	Afternoon off peak

			Non-Congested State (Min)	Proportion of non-congested state	Non-Congested State (Min)	Proportion of non-congested state
1	Section 1	North Bound	7	0.117	53	0.883
2	Section 2	North Bound	0	0	47	0.783
3	Section 3	North Bound	60	1	60	1

As it can be seen from the table there are periods where the section is heavily congested and there are times where the section is in smooth state. The table 4.2. below shows the road congestion index.

Table 4.2. Road Segment Congested Index for the selected sections

No	Section Name	Time of Day	proportion of non-congested state	Average speed performance index	Road Segment Congestion Index
1	Section 1	Peak Hour	0.117	31.12	0.036
		Off-Peak Hour	0.883	66.20	0.584
2	Section 2	Peak Hour	0	17.88	0
		Off-Peak Hour	0.783	61.36	0.480
3	Section 3	Peak Hour	1	75.66	0.757
		Off-Peak Hour	1	86.35	0.864

We can deduce from the table:

- Section One experiences high congestion during peak hour, since its value is closer to 0, which signifies a congestion state. While showing a significantly lower congestion during off-peak hours with a value closer to 1, which signifies a free flow traffic state level.
- Section Two exhibited a very severe congestion state level during peak hour, with a value of 0, While showing moderate level of congestion during off-peak hours.
- Section Three experienced moderate congestion during peak hour, while having a good traffic state level in the off-peak period.

4.2.11. Speed Reduction Index Analysis

Speed reduction index (SRI) measure represents the ratio of the decline in speeds from free flow conditions. The SRI has value between 0 and 10. When the index value inches to 10, congestion ensues. Values under 4 suggest an uncongested situation ((Lomax, T. et.al., 1997). In order to calculate the SRI, the free flow speed must be determined, so the 85th percentile free flow speed was calculated from the collected speed data considering the Off-peak hour for all the selected sections. In order to calculate a representative 85th percentile speed, we needed to find the distribution model that will best fit the speed data.

several studies have recommended normal distribution to characterize the distribution of traffic speed, However, the speed distribution deviates from the normal distribution because of the diversity in the traffic flow in mixed-traffic conditions (Debashis R.S. & Parveern K., 2024). So, the normality of the data must be tested first.

Table 4.3: Test for Normality

Location	Time of Day	Kolmogorov - Smirnov test			Shapiro Wilk test		
		Statistics	Df	P-Value	Statistics	df	P-Value
Section One	Off-Peak Hour	0.076	1,754	0.000	0.984	1,754	0.000
Section Two	Off-Peak Hour	0.104	1,180	0.000	0.980	1,180	0.000
Section Three	Off-Peak Hour	0.172	1,263	0.000	0.946	1,263	0.000

The test for normality is summarized in table above. We can see from the two tests conducted using SPSS that the p-value is lower than 0.05 significance level, which indicates the speed data collected in all the selected sections does not follow the normal distribution. And the normal distribution is not the best way to describe vehicular speed characteristics and finding a suitable distribution is necessary.

Five commonly used distributions were considered for fitting the speed data, the normal, Lognormal, Gamma, Weibull and Logistics distributions. Before fitting the data to the distributions, the data must be preprocessed to remove any outlier values. The reason lies on data collected in urban settings, i.e., difficulty in determining whether vehicle has traveled exactly along the route between two locations without making unexpected stops and whether or not it is representative of the average traffic conditions on the link considered at that time. And if there are Such travel speeds, they must be removed from the dataset to avoid bias in the analysis results. So, the Quartile screening method using quartile interval was applied in this study to reflect the variation scale.

Specifically, the data interval is the difference between the upper and lower quartiles. If the data lies outside the interval, then it will be identified as abnormal data and deleted. Figure below shows a Box Plot showing the data selected and the data that were removed for all three sections.

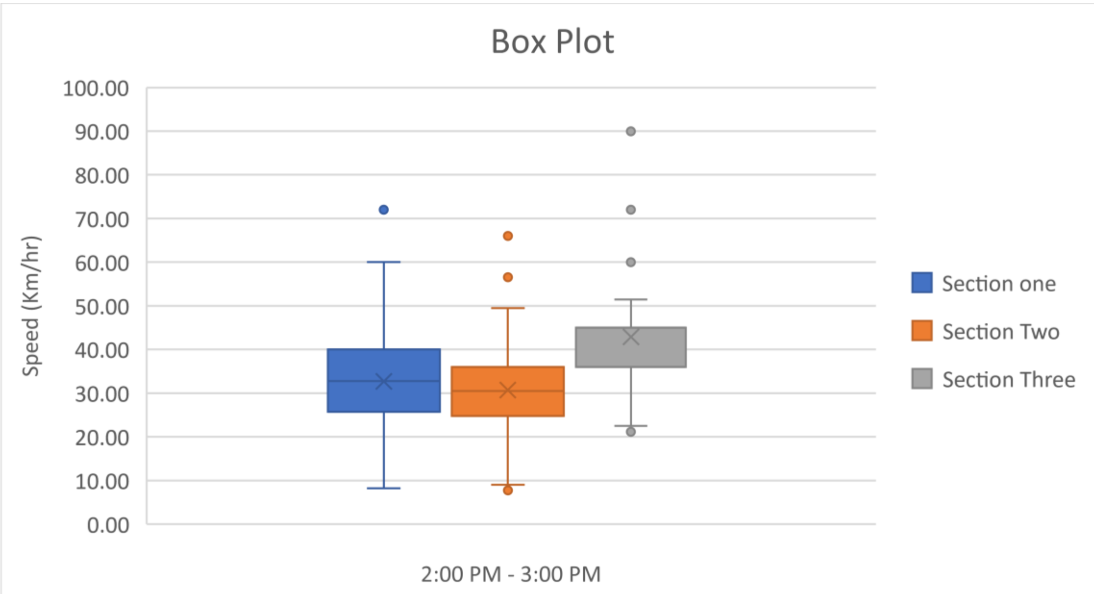


Figure 4-20. Box Plot for all the selected sections

The graph has a lower limit of 4.29, 7.88 and 22.5 for section one, two and three respectively while having an upper limit of 61.43, 52.88 and 58.5 for section one, two and three respectively. so, values above and below this limit were removed from the data set. And after the adjustment was done, a total of 1,750, 1,164 and 1,177 samples of data for section one, two and three respectively was used for the analysis.

Once the data have been processed, the parameters of each distribution were estimated by using the distribution fitter in MATLAB based on the speed data. The goodness-of-fit results of each distribution were then determined by the Kolmogorov–Smirnov test.

Section One

In the first step, visualization of the data was important. This was done by drawing histograms of observed link speeds and by superimposing a theoretical p.d.f. on the graph. So, figure 4-21 below shows a probability density plot that visualizes the speed data by superimposing five distributions (Normal, Lognormal, Gamma, Weibull and Logistic) and the cumulative probability of the fitted distributions for the afternoon Off-peak period.

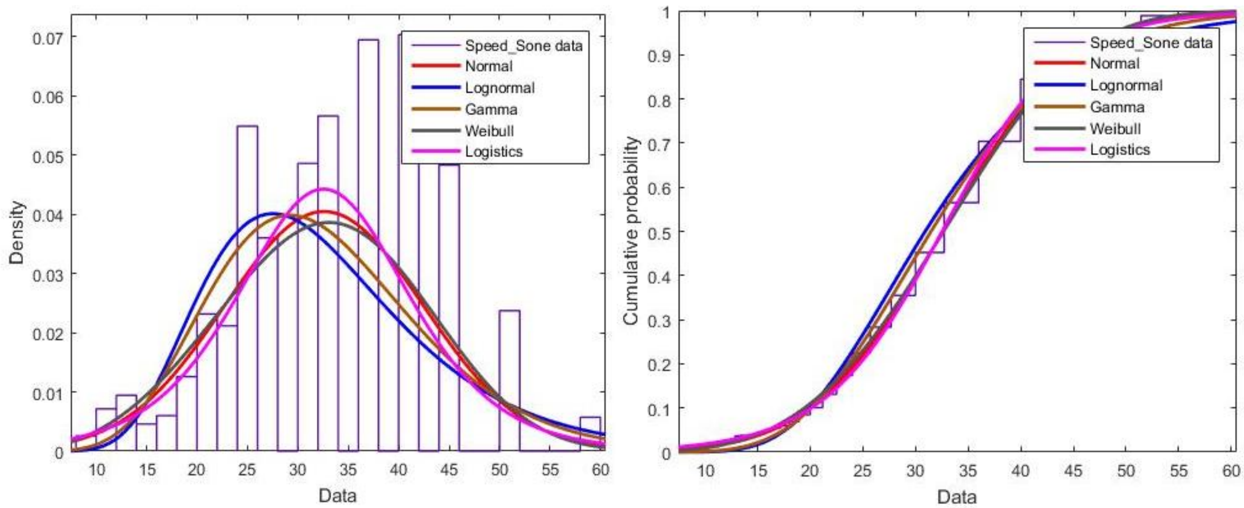


Figure 4-21: PDF and CDF curves of each distribution type for section one

Table 4.4 summarizes the goodness-of-fit test results for the speed data. The test was considered for determination of potential best fit statistical distributions. We can see from the table below the fitted distributions with their test statistics and P-value.

Table 4.4. Goodness of fit test for the selected distributions for Section One.

	Name of distribution	Time of Day	Kolmogorov–Smirnov	
			Test Statistics	P-Value
1	Normal	Off-Peak	0.071	4.42155E-8
2	Lognormal	Off-Peak	0.114	0.000
3	Gamma	Off-Peak	0.098	0.000
4	Weibull	Off-Peak	0.080	0.000
5	Logistics	Off-Peak	0.085	0.000

We can see from the test the normal distribution gave a better p-value than other distributions. In addition to this, we can also look at test statistics against the critical value at 0.05 significance level for the K-s test. We can get the critical value from the one sample k-s test table. For sample size greater than 50, the table gives a formula for calculating the critical value. So, for a significance value of 0.05, $Dn, \alpha = \frac{1.35810}{\sqrt{n}}$.

For n=1,750: $Dn, 0.05 = \frac{1.35810}{\sqrt{1,750}} = 0.0329$,

When we compare the test statistics value of the distributions with the critical value we can see for this section, normal distribution gave a better result than the others.

Section Two

Figure 4-22 below shows a probability density plot and the cumulative probability of the fitted distributions for section two.

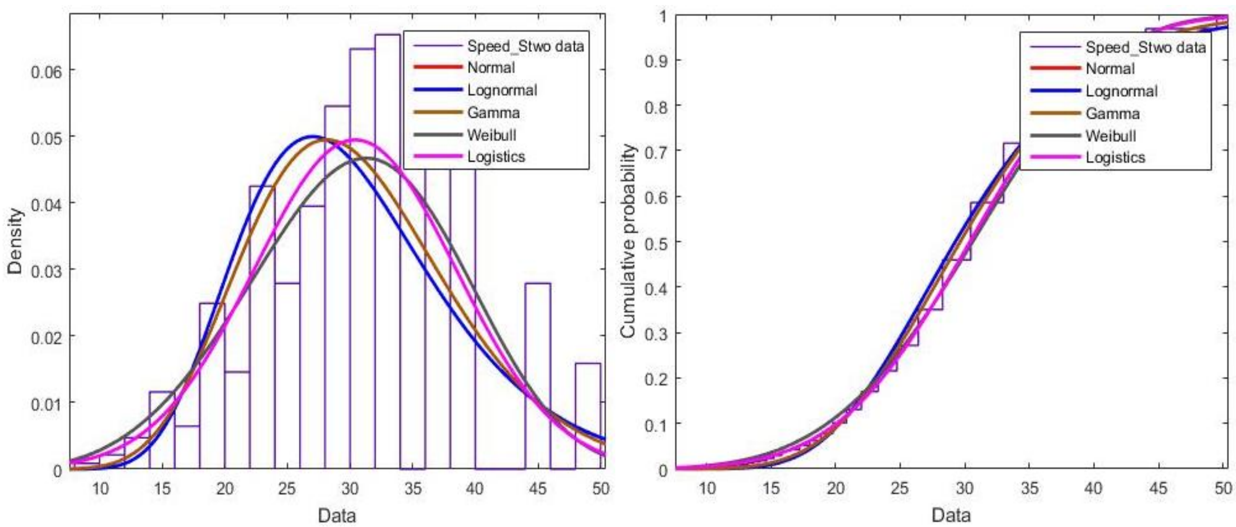


Figure 4-22: PDF and CDF curves of each distribution type for section Two

Table 4.5 summarizes the goodness-of-fit test results for the speed data for section two. We can see from the table that, from the fitted distributions Normal, Gamma and Logistics distributions had a slightly higher values than the other distributions which is indicative of the distributions fitting the data a slightly better.

Table 4.5. Goodness of fit test for the selected distributions for Section Two.

	Name of distribution	Time of Day	Kolmogorov–Smirnov	
			Test Statistics	P-Value
1	Normal	Off-Peak	0.090	1.09577E-8
2	Lognormal	Off-Peak	0.101	0.000
3	Gamma	Off-Peak	0.082	2.68178E-7
4	Weibull	Off-Peak	0.106	0.000
5	Logistics	Off-Peak	0.074	0.0000063

We can see from the test the logistic distribution gave a better p-value than other distributions. Again, we can calculate the critical value for this section. By using the previous formula for 0.05 significance level, $Dn, \alpha = \frac{1.35810}{\sqrt{n}}$.

For n=1,180: $Dn, 0.05 = \frac{1.35810}{\sqrt{1,180}} = 0.0395$, When we compare the test statistics value of the distributions with the critical value we can see for this section, logistics distribution gave a better result than the others.

Section Three

Figure 4-23 shows a probability density plot and the cumulative probability of the fitted distributions for section three.

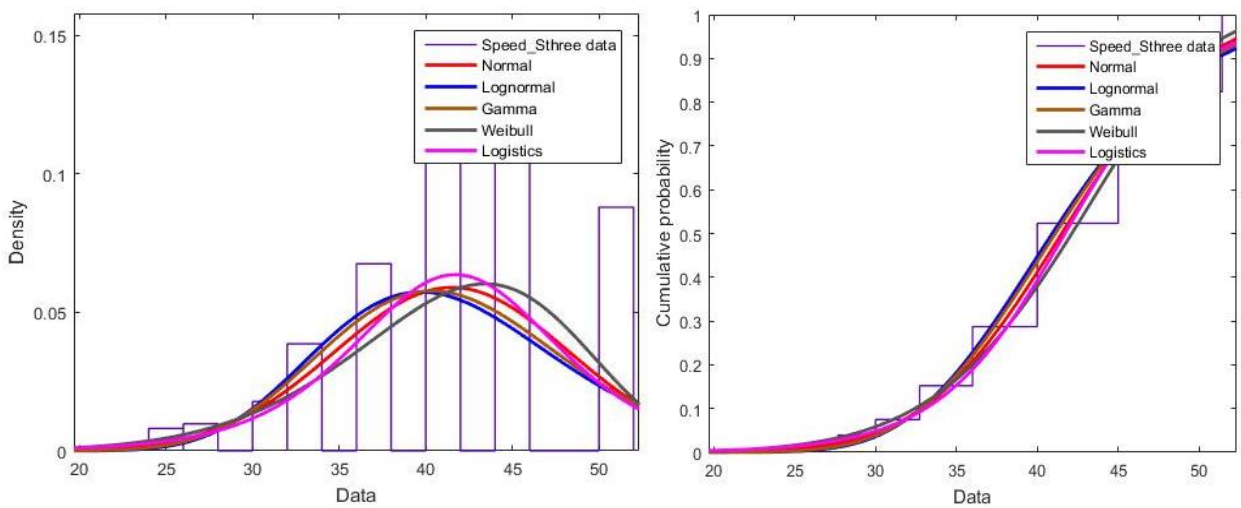


Figure 4-23: PDF and CDF curves of each distribution type for section Three

Table 4.6 summarizes the goodness-of-fit test results for the speed data for section three.

Table 4.6. Goodness of fit test for the selected distributions for Section Three.

	Name of distribution	Time of Day	Kolmogorov–Smirnov	
			Test Statistics	P-Value
1	Normal	Off-Peak	0.174	0.000
2	Lognormal	Off-Peak	0.186	0.000
3	Gamma	Off-Peak	0.182	0.000
4	Weibull	Off-Peak	0.153	0.000
5	Logistics	Off-Peak	0.174	0.000

We can see from the test that it is hard to differentiate by their p-values like the other sections. So, we will use the critical value for determining which distribution fitted the data better, by using the previous formula for 0.05 significance level, $Dn, \alpha = \frac{1.35810}{\sqrt{n}}$.

For n=1,263: $Dn, 0.05 = \frac{1.35810}{\sqrt{1,263}} = 0.0382$, When we compare the test statistics value of the distributions with the critical value we can see for this section, Weibull distribution gave a better result than the others.

Once the better fit distribution has been decided for the three sections, we can calculate the 85th percentile free flow seed. By using MATLAB, the calculated values are summarized in the table below.

Table 4.7: Calculated 85th percentile free flow speed values

No	Section	Selected Distribution	85th percentile free flow speed
1	Section One	Normal	42.82
2	Section Two	Logistics	38.76
3	Section Three	Weibull	48.53

By Using the above reference speeds the SRI was calculated below.

Section One

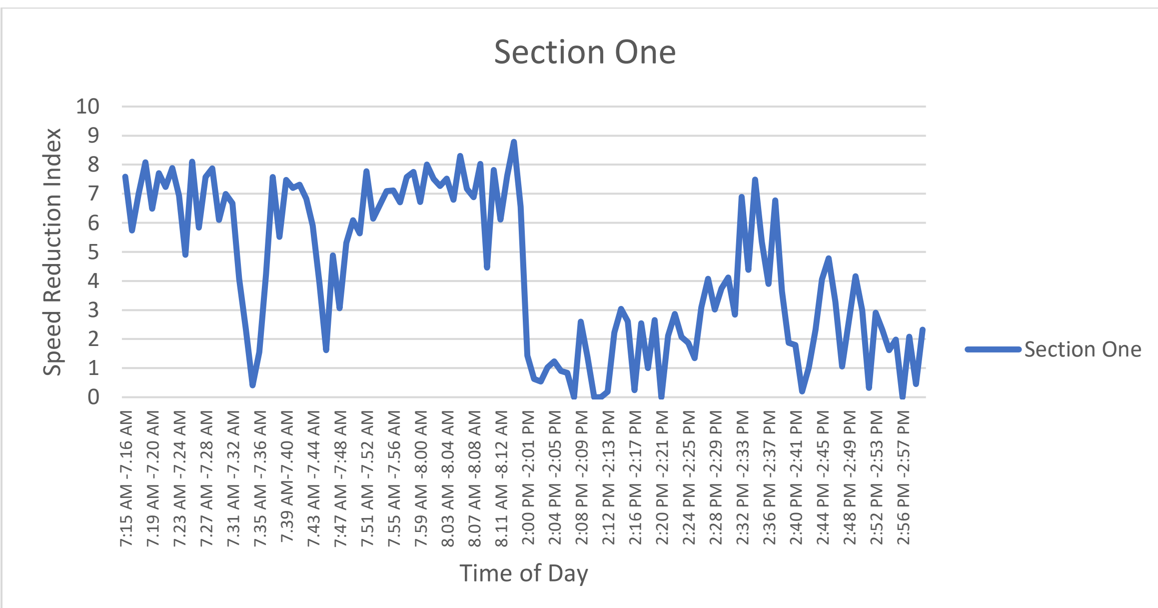


Figure 4-24. Speed Reduction Index for section one

Figure 4-21 shows the substantial speed reductions that occur in the morning peak period for Section One. During this time, the SRI reached its highest value of around 8.8, indicating a significant slowdown in traffic speeds. In contrast, the afternoon off-peak period does not display the same dramatic decline in speed, in fact an SRI value of 0 was recorded multiple times during this period. The SRI appears to remain relatively lower compared to the peak period.

Section Two

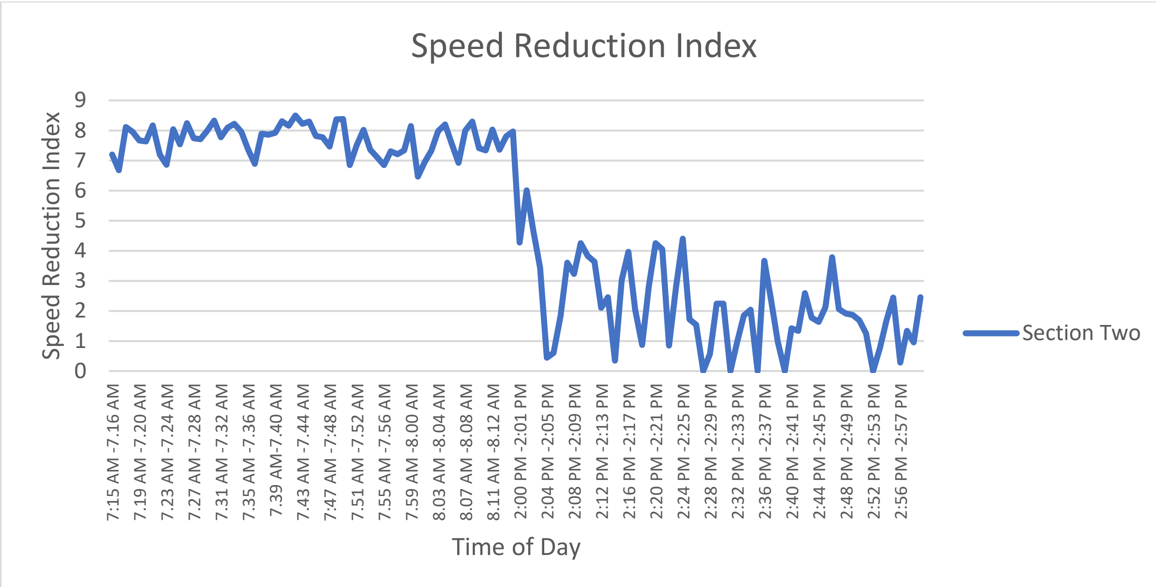


Figure 4-25. Speed Reduction Index for section Two

Like section one, the morning peak period has the highest SRI, reaching a value of around 8.5. which indicates significantly reduced speeds or higher congestion levels during the morning hours. But unlike the previous section it doesn't displays significant fluctuations in the SRI values, it has uniform values. In contrast, the afternoon off-peak period recorded the lowest SRI, with a value close to 0. This suggests traffic flows much more freely and at higher speeds during this time of day.

Section Three

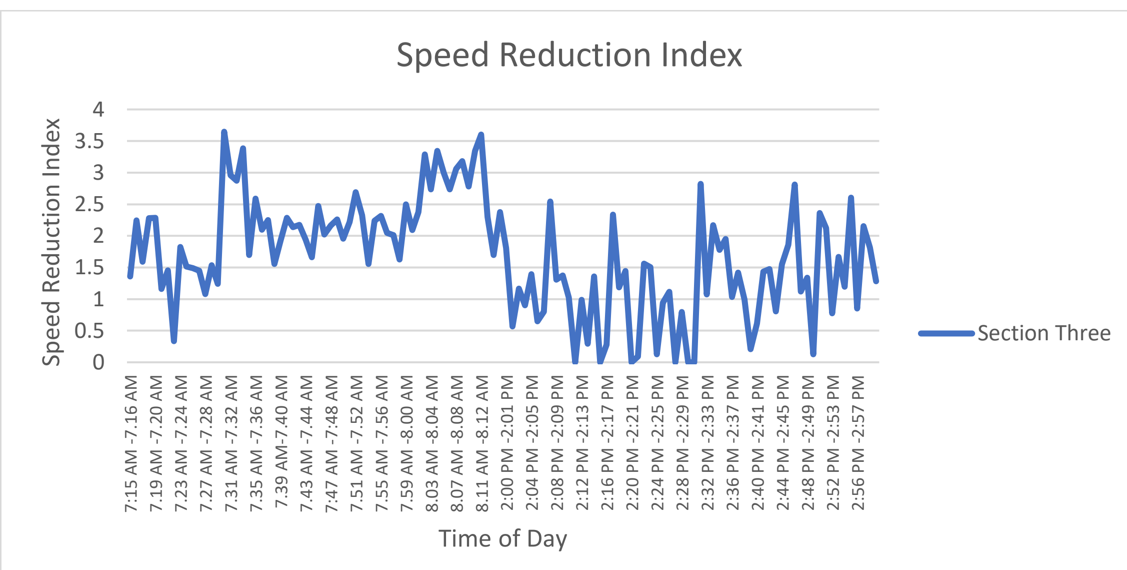


Figure 4-26. Speed Reduction Index for section Three

The graph shows the Speed Reduction Index (SRI) for Section Three over the course of a day. Unlike the previous sections, the SRI values for this section do not exhibit as much variation for the peak and off-peak periods. It can be seen that the SRI fluctuates, but remains relatively moderate, both during the morning peak period and the afternoon off-peak period. There are no dramatic spikes or drops in the SRI as were seen in the previous sections. This suggests that traffic conditions and speeds in Section Three are more consistent and do not experience the same level of unpredictability between high-congestion and free-flow periods compared to the other analyzed road sections.

4.2.12. Travel Time Reliability

Travel time reliability refers to the consistency or dependability of travel times on a transportation network. It is a measure of the variability in travel times experienced by travelers on a given route or mode of transportation. More formally, is the consistency and dependability of travel times across different days or times of day (Seada M.A. et al., 2019). For this analysis the 95th percentile travel time, average travel time and free flow travel time for both periods are show in the table below.

Table 4.8. Values for 95th percentile travel time, Average Travel Time and Free Flow Travel Time

No	Section	Time period	95th percentile travel time	Average Travel Time	Free Flow Travel Time
1	Section One	Peak Hour	55.4	29.31	7.76
		Off-Peak Hour	20.86	12.4	
2	Section Two	Peak Hour	77.66	55.44	9.90
		Off-Peak Hour	21.39	14.06	
3	Section Three	Peak Hour	12.33	9.74	5.93
		Off-Peak Hour	11.80	8.73	

4.2.12.1. Planning Time Index (PTI)

$$\textbf{PTI}_{\text{Section one (Peak Hour)}} = \frac{95\%TT}{FFTT} = \frac{55.4}{7.76} = \mathbf{7.14}$$

$$\textbf{PTI}_{\text{Section one (Off-Peak Hour)}} = \frac{95\%TT}{FFTT} = \frac{20.86}{7.76} = \mathbf{2.69}$$

The result above shows that travelers need to Incorporate an additional time, specificaly 7.14 times the free-flow travel time to ensure on-time arrival 95% of the time during peak hours and need to to Incorporate only 2.69 times the free-flow travel time to ensure on-time arrival 95% of the time. A higher PTI value indicates lower travel time reliability, as travelers need to budget more extra time to account for potential delays and variability in travel times.

PTISection Two (Peak Hour)= $\frac{\mathbf{95\%TT}}{\mathbf{FFTT}}$= $\frac{\mathbf{77.66}}{\mathbf{9.90}}$ **= 7.84**

PTISection Two (Off-Peak Hour)= $\frac{\mathbf{95\%TT}}{\mathbf{FFTT}}$= $\frac{\mathbf{21.39}}{\mathbf{9.90}}$ **= 2.16**

The result above shows that travelers need to Incorporate an additional time, specificaly 7.84 times the free-flow travel time to ensure on-time arrival 95% of the time during peak hours and need to to Incorporate only 2.16 times the free-flow travel time to ensure on-time arrival 95% of the time.

We can see for both sections that travel time reliability is much better during off-peak periods, when there is less congestion and fewer disruptions to the transportation network. The difference between the peak hour and the off-peak hour highlights the significant impact that peak period conditions have on travel time reliability. Travelers during the peak hour must budget nearly three times as much extra time compared to the off-peak hour to ensure they arrive on time.

PTISection Three (Peak Hour)= $\frac{\mathbf{95\%TT}}{\mathbf{FFTT}}$= $\frac{\mathbf{12.33}}{\mathbf{5.93}}$ **= 2.08**

PTISection Three (Off-Peak Hour)= $\frac{\mathbf{95\%TT}}{\mathbf{FFTT}}$= $\frac{\mathbf{11.80}}{\mathbf{5.93}}$ **= 1.99**

Section three shows that travelers need to incorporate 2.08 times the free-flow travel time while incorporating 1.99 times the free-flow travel time to ensure on-time arrival 95% of the time. While this suggests that while there is still some variability in travel times during the peak hour in Section Three, the impact on reliability is not as dramatic as in the other two sections. The relatively smaller gap between peak and off-peak PTI values implies that the travel conditions in Section Three maintains a more consistent level of reliability throughout the day.

4.2.12.2. Buffer Time Index (BTI)

BTISection one (Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{55.4-29.31}}{\mathbf{29.31}} \times 100$= **89%**

BTISection one (Off-Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{20.86-12.4}}{\mathbf{12.4}} \times 100$= **68.23%**

The peak hour BTI of 89% and the off-peak hour BTI of 68.23% for Section One indicates that travelers need to budget an additional 89% and 68.23% of the average travel time to ensure on-time arrival 95% of the time during the peak and off-peak period.

BTISection Two (Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{77.66-55.44}}{\mathbf{55.44}} \times 100$= **40.08%**

BTISection Two (Off-Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{21.39-14.06}}{\mathbf{14.06}} \times 100$= **52.13%**

Compared to Section one, section two recorded a lower BTI with 40.08% in the peak hour and 52.13% in the off-peak hour. Even though the peak period percentage is lower than the off-peak period it doesn’t mean travellers incorporate more time than they do in the peak period. The high BTI values, especially during the peak hours, suggest that travelers need to include a substantial amount of extra time to ensure on-time arrival. Which aligns with the earler findings by the Planning Time Index.

BTISection Three (Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{12.33-9.74}}{\mathbf{9.74}} \times 100$= **26.59%**

BTISection Three (Off-Peak Hour) =$\frac{\mathbf{95\%}\boldsymbol{TT-ATT}}{\boldsymbol{ATT}} \times \mathbf{100}\%$= $\frac{\mathbf{11.80-8.73}}{\mathbf{8.73}} \times 100$= **35.17%**

As previous measures section three recorded lower BTI values, both during the peak and off-peak periods, value suggests that travel time reliability in Section Three is generally better compared to Sections One and Two.

4.2.13. Section level of service

Speed flow curve and flow density curve were used to calculate capacity. In this study flow density curve was developed using the three most widely used traffic flow modeling techniques, the Greenshields, Greenberg and Underwood model. Then a model that best fits the dataset was used to determine capacity.

4.2.13.1. The Greenshields Model

The linear model proposed by Greenshields is represented by Equation as follow

$$u = uf\ (1 - k/kj)$$

Where: U=speed corresponding to density k; uf=free flow speed (km/hr); kj=jam density (veh/km); K= density (veh/km). For this Model, while free-flow speed, uf and jam density, kj, are identified as unknown parameters.

Section one

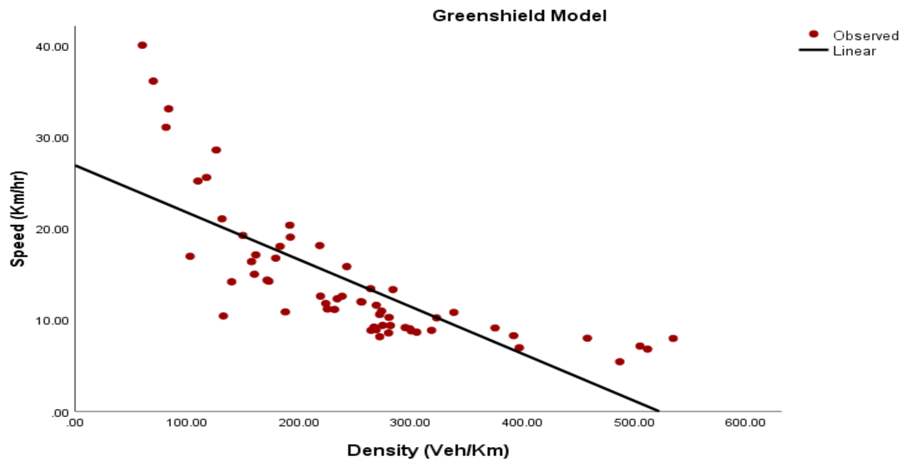


Figure 4-27. Greenshields Speed density relationship for section one

The regression analysis using the above data gave the following results:

u_f = 26.9 kj = 522.0 R^2= 0.577

Table 4.9. Summary of estimated Results using Greenshields model

Sections	Parameters		
	u_f	kj	R^2
Section One	26.9	522	0.577
Section Two	9.87	1,343	0.342
Section Three	46.34	277.68	0.299

4.2.13.2. The Greenberg Model

The Logarithm model proposed by Greenberg is represented by Equation as follow

$$u = u_o \ln\left(\frac{\kappa j}{k}\right)$$

Where: U=speed corresponding to density k; uo = speed corresponding to capacity (km/hr); kj=jam density (veh/km); K= density (veh/km). For this Model, uo and kj are identified as unknown parameters.

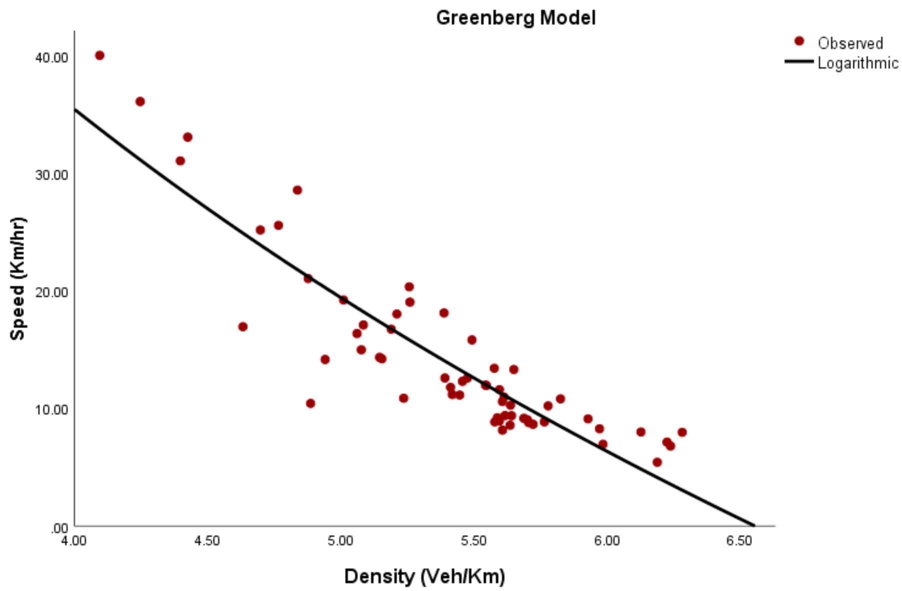


Figure 4-28. Greenbergs Speed density relationship for section one

uo = 13.5 kj = 632.17 R^2 = 0.809

Table 4.10. Summary of estimated Results using Greenberg model

Sections	Parameters		
	uo	kj	R^2
Section One	13.5	632.17	0.809
Section Two	2.78	4,758.9	0.366
Section Three	8.69	3,896.16	0.289

4.2.13.3. The Underwood Model

The Exponential model proposed by Greenberg is represented by Equation as follow

$$u = u_f\, e^{\left(\frac{-k}{k_0}\right)}$$

Where: U=speed corresponding to density k; uf=free flow speed (km/hr); Ko= optimum density (veh/km). For this Model, uf and ko are identified as unknown parameters.

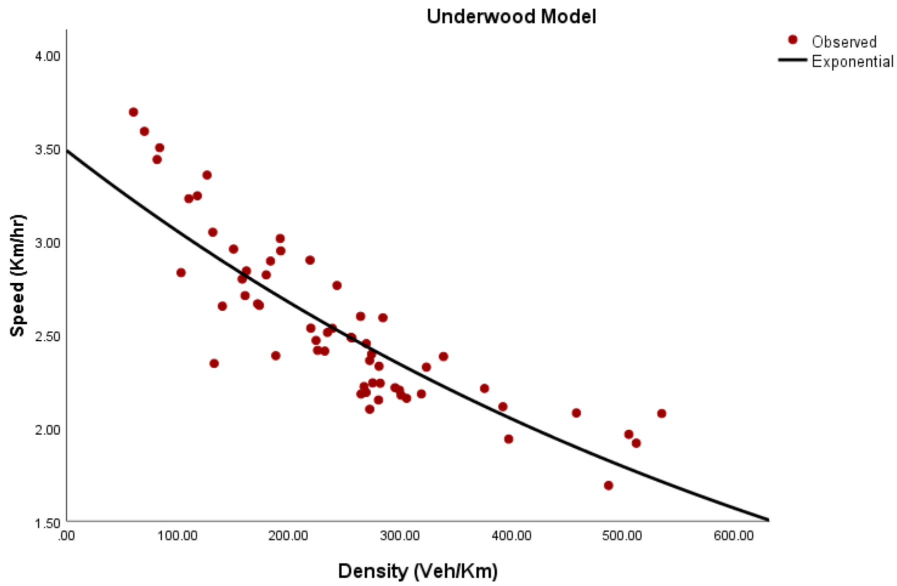


Figure 4-29. Underwood Speed density relationship for section one

u_f = 29.51 ko = 293.76 R^2 = 0.754

Table 4.11. Summary of estimated Results using Underwood model

Sections	Parameters		
	u_f	ko	R^2
Section One	29.51	293.76	0.75
Section Two	10.27	1000.9	0.35
Section Three	47.59	219.4	0.309

From the three traffic flow models used for capacity determination, the Greenberg model had the higher R^2 values when compared to the other two models but gives a value that is not a proper representation of the actual traffic conditions. So, the underwood model was selected to compute the capacity because it can better represent the conditions on the ground and had a higher R^2 than the Greenshields model.

Table 4.12. Capacity of all sections using the underwood model

No	Study Section	Capacity (Veh/hr)
1	Section 1	3,188.87
2	Section 2	3,780.25
3	Section 3	3,840.79

Capacity determination using passenger car unit factors

There is variance in the size and speed of cars in mixed traffic. Consequently, in order to achieve capacity in homogeneous traffic conditions, heterogeneous vehicles must be converted to homogeneous using PCU.

For this study, capacity was calculated using the passenger car unit PCU developed for this study. Table below shows the calculated PCU values.

Table 4.13. PCU values for various vehicles

Vehicle	PCU
Passenger car and Taxi	1
4WD	1.05
Mini Bus	1.24
Medium Bus	2.65
Bus	4.29
Small Truck	1.56
Truck	3.19
Truck & Trailor	7.42

Table 4.14. Capacity in PCU for all sections

No	Study Section	Capacity (pcu/hr)
1	Section 1	3,743.58
2	Section 2	4,393.78
3	Section 3	5,214.87

As we see in the above table, we have three different capacity values calculated and to determine the capacity, the **Indian Roads Congress (IRC:106-1990 Guidelines for capacity of urban-roads)** was referred for determining the capacity that will be used for level of service analysis. According to the IRC, the recommended value for 6-lane Divided Two-way Urban Arterial Road is 4,300 Pcu/hr. By this account, section one is the preferred choice since section two and section three have values higher than the recommended value.

Table 4.15. volume to capacity ratio for all sections

No	Study Section	Peak Hour Volume (pcu/hr)	Capacity (pcu/hr)	V/C	LOS
1	Section 1	3,334	3,743.58	0.891	**D**

2	Section 2	3,029	3,743.58	0.809	**D**
3	Section 3	2,362	3,743.58	0.631	**B**

When we look at the table, we can see section one and two had a level of service D, which shows that the section is operating very close to its capacity, which indicates that the demand is almost equal to the available capacity. At this level, the sections are approaching unstable flow, traffic volume slightly increases, Speeds slightly decrease and delay increases. Freedom to maneuver within the traffic stream is much more limited and driver comfort levels decrease. Which shows that the sections are experiencing congestion and delays during peak hour.

Section three on the other hand had a LOS of B, which shows that the demand is considerably lower compared to the capacity of the road. At this level, the traffic flow is stable, with reasonably free-flowing conditions and little to no delays. The section appears to be operating well within its capacity and is providing a good level of service to drivers during the peak hour.

4.3. Discussion

A decision may be influenced by several metrics of congestion, such as the degree of congestion and whether or not the present traffic situation qualifies as congested. Some of the discussed metrics have a cut off value for the congestion state, out from the different measures used in the data analysis., for example, RSCI indicates a congestion state when its value is close to 0. The SPI and V/C measures provide a set of values to indicate various levels of congestion. While Travel rate, Travel Time index, delay rate and delay ratio, do not explicitly provide a range of value, only a point value, for congested traffic conditions.

Table 4.16. Average Values of Travel Rate, Travel Time Index, Delay Rate and Delay Ratio during peak and off-peak hour

	Average Travel Rate (min/Km)		Average Travel Time Index		Average Delay Rate (min/Km)		Average Delay Ratio	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Section one	5.09	2.05	3.93	1.59	3.80	0.76	0.69	0.31
Section Two	7.88	2.16	5.25	1.44	6.38	0.66	0.80	0.28

Section Three	1.63	1.45	1.65	1.47	0.64	0.47	0.39	0.31

As can be seen from the table, all four measures recorded their highest values in section two morning Peak hour. The travel rate and delay rate recorded their lowest value on section three Off-Peak period while travel time index and delay ratio recorded their lowest values on section two Off-Peak period. All four measures in the above table showed similar trend for sections one and two, all of them recorded their highest value during the morning peak period and their lowest value in the afternoon off-peak period. But when we come to section three all four measures showed a slightly higher values in the morning peak period but uniform value for both periods. One reason behind this variation is the characteristics of the segments. Section one and two are characterized as having an increased road side activity, like pedestrians crossing and vehicles & especially taxis loading and unloading during peak hours. While section three is characterized as having minimum activity during peak hours.

- The time-based measures like the TTI and Travel rate are both measures used to assess congestion, but they differ in their focus. TTI is a rough estimate of how much extra time you have to spend on the road when traffic congestion is higher than if it was in free flow. The TTI can be used to analyze the scale and occurrence of traffic problems in a specific area resulting from congestion. However, TRI is useful for understanding the impact of congestion on travel efficiency (e.g., fuel consumption, emissions etc.).
- The delay-based metrics, such as Delay rate and the Delay ratio are mostly employed to measure the impact of traffic congestion on travel time. The delay rate is more useful when it comes down for determining total or real effect of traffic congestion, such as the total amount of time lost due to delays. While the delay ratio serves as a relative measure because it quantifies the severity of congestion by comparing travel times under congested-to-uncongested conditions.

All four methodologies do not have a range of values to show the congestion range like the SPI, RSCI, SRI or V/C, but they do however allow the general public to understand the main concept except for TTI and the delay ratio, which might be hard for the non-technical user to understand because their measure gives a value with no units. Estimation of the travel rate, delay rate and delay ratio can be compared to a target value that represents unacceptable levels of congestion if there is a stated value for a particular road.

Table 4.17. Average Values of SPI, RSCI and V/C during peak and off-peak hour

	SPI		RSCI		SRI		V/C	
	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
Section one	31.12	66.21	0.088	0.762	6.37	2.27	0.89	0.58
Section Two	17.88	61.37	0	0.480	7.69	2.08	0.81	0.45
Section Three	75.66	86.35	0.312	0.662	2.21	1.10	0.63	0.39

Again, we can see from the table, the three measures the SPI, RSCI and SRI recorded their lowest (highest in case of SRI) values on section two morning peak period and the V/C recorded its highest value on section one morning peak period. The SPI and SRI recorded their highest (lowest in case of SRI) values on section three off-peak period, while the RSCI recorded its highest value on section one Off-peak period. V/C recorded its lowest value on section three Off-peak period. The Four measures, SPI, RSCI and SRI in the above table showed similar trend for section one and two. i.e., All of them recorded their lowest (Highest value in case of SRI and V/C) value during the morning peak period and a Higher (lowest in case of SRI and V/C) value in the afternoon Off-peak period. For Section three all four measures showed a slightly lower (higher in case of SRI and V/C) values in the morning peak period but uniform value throughout the day. One of the reasons behind this has been pointed out previously.

- The speed-based measures like the SPI, SRI and RSCI are all used to assess congestion but they differ in their approach. The SPI provides a measure of how well traffic is moving compared to the optimal or desired speed (Posted Speed) limit. It is useful for evaluating the operational performance of road segments, as it directly quantifies the impact of congestion on vehicle speeds. In contrast the SRI provides a different perspective on the impact of congestion, focusing on the relative change in speed rather than the absolute speed. While the RSCI focuses on showing the degree of the specified problem.

Unlike the pervious measures discussed all four methodologies have a range of values to show the congestion range, but the measures might be hard for the non-technical user to understand because the measure gives a value with no units.

- Other measures like PTI and BTI measure congestion by quantifying the level of travel time uncertainty and unpredictability experienced by drivers.

Table 4.18. Comparison of Travel Time - Based and level of service methods

Travel Time – Based Methods	Level of service method
Provide valuable insights into traffic flow, congestion levels, and operational conditions of the transportation system.	Provide valuable insights into traffic flow, congestion levels, and operational conditions of the transportation system.
Data Requirements	
Travel-time based methods rely heavily on real-time data to directly measure travel times.	LOS often is not dependent on real time data it can use historic data as well.
User's perspective	
Travel-time based analysis is directly related to what a commuter experiences, making it more tangible and relatable for the general public.	LOS Offers a more general understanding by assessing the utilization and capacity of the road infrastructure. which may not always align with the user's perceived experience.
Granularity of Analysis	
Travel Time based measures provide a higher level of detail and granularity in their analysis, as they can capture variations in travel times and congestion levels.	LOS provides a more aggregated assessment of the transportation system.
Temporal Sensitivity	
Travel Time-Based Methods can more effectively capture and respond to real-time changes in traffic conditions.	LOS may be less sensitive to short-term or rapidly changing transportation but useful for long-term planning and evaluation.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Traffic congestion is a major problem worldwide when it comes to creating effective and durable traffic management systems. This thesis examined the travel time-based analysis methods and level of service method on different road sections. For each category, congestion measures were described with their corresponding equations and quantitative ranges for various congestion levels. A set of real-time data was analyzed to evaluate these congestion measures. The study's results showed that:

- The road sections, African union Intersection – Pushkin Square and Mekanisa Abo – Mekanisa Intersection had similar characteristics in both the travel time based and volume to capacity ratio methodologies, they recorded worst traffic conditions during peak hour and a smooth traffic condition during off-peak hour. While the section, Mekanisa Intersection – German Square had a smooth traffic condition on both the peak and Off-peak hour.
- The Travel time-based measures provided a level of detail in their analysis by directly measuring travel times, which identified variations in congestion levels and on the changing traffic conditions.
- Although the level of service methodology did not capture minute-by-minute variations in congestion or delay, it gave overall assessment of the traffic situation in terms of the ability of the road segment to carry the existing volume of traffic.
- While calculating the 85th percentile free flow speed, the speed data was not normally distributed as it was observed from the normality test and five common distributions were used for fitting the speed data. And from those distributions, normal distribution fitted section one well, while logistics and Weibull distributions were a good fit for section two and three respectively.
- From the three models taken for capacity analysis, the underwood model was selected because it was a better fit when compared to the other two models.

- Results from the Travel time reliability analysis shows that travelers need to budget more time, as much as seven times the free flow time or twice the average travel time while travelling on the road segment.

5.2. Recommendation

Traffic congestion is an issue that policymakers and concerned bodies need to properly address. It should be minimized through the implementation of timely and cost-effective traffic management strategies. High-quality, up-to-date, and comprehensive traffic data are essential for providing current and accurate traffic information, as well as for deploying effective traffic management measures. But to do this we must use a congestion analysis measure that will give a value that is a representative of the condition on the ground.

Of the two methods used to conduct performance evaluation, the travel time-based measures provide a more realistic result of the condition on the ground for the following reasons.

- ❖ As they are flexible enough to describe traffic conditions in both space and time.
- ❖ Since most of the travel time-based measures are dimensionless, it helps to compare mobility levels on different roadways.
- ❖ The measures associated with the time or speeds are easy to understand and interpret by both the transportation professionals and the traveling public.
- ❖ Directly Reflects User Experience using the transportation system which provides a more meaningful and tangible assessment of system performance from the user's perspective.

In general, policymakers should appropriately address traffic congestion and minimize it through the implementation of prompt and effective traffic management techniques. The provision of up-to-date and precise traffic information as well as the implementation of traffic management strategies depend on timely, full, and high-quality traffic data. Furthermore, it is evident that Addis Ababa is still developing; therefore, it will need to do more studies, work to ensure that issues arising from its traffic and transportation system won't have an impact on its standing.

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APPENDIX

APPENDIX A

Traffic Volume Data

North Bound

Section One (African Union – Pushkin Square)

Tuesday (Mar 14,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	4	0	294	75	64	11	26	2	1	1
7:15-7:30 AM	0	10	0	432	85	88	7	24	2	1	0
7:30-7:45 AM	0	10	0	457	109	84	3	26	1	2	0
7:45-8:00 AM	0	9	0	465	114	100	6	19	1	1	0
8:00-8:15 AM	0	10	0	565	150	121	6	28	1	2	0
8:15-8:30 AM	0	6	0	376	95	78	7	16	2	0	0
8:30-8:45 AM	0	11	0	358	105	86	7	25	1	0	0
8:45-9:00 AM	0	10	0	495	105	112	7	21	1	1	0
9:00-9:15 AM	0	11	0	510	106	89	3	29	1	2	0
9:15-9:30 AM	0	15	0	380	110	88	7	23	2	0	0
9:30-9:45 AM	0	6	0	432	96	96	7	19	0	2	0
9:45-10:00 AM	0	9	0	375	118	84	8	20	0	1	0
1:00-1:15 PM	0	7	0	270	72	63	1	6	9	7	0
1:15-1:30 PM	0	15	0	288	84	68	2	3	17	11	0
1:30-1:45 PM	0	2	0	318	95	68	2	5	17	9	1
1:45-2:00 PM	0	10	0	278	78	65	3	6	14	11	0
2:00-2:15 PM	0	15	0	253	67	60	6	6	15	7	2
2:15-2:30 PM	0	6	0	299	87	62	0	11	11	12	1
2:30-2:45 PM	0	10	0	306	102	59	5	7	12	9	0
2:45-3:00 PM	0	8	0	298	67	52	2	8	11	8	0
4:00-4:15 PM	0	15	0	302	118	56	1	19	12	11	0
4:15-4:30 PM	0	34	0	346	114	66	3	22	7	6	0
4:30-4:45 PM	0	17	0	375	120	70	3	22	5	7	1
4:45-5:00 PM	0	21	0	366	112	105	4	20	10	5	0
5:00-5:15 PM	0	22	0	337	121	79	1	20	5	1	1
5:15-5:30 PM	0	9	0	321	80	75	8	23	7	0	0
5:30-5:45 PM	0	6	0	305	69	73	3	12	3	0	0
5:45-6:00 PM	0	5	0	302	65	62	2	15	4	0	0
6:00-6:15 PM	0	3	0	279	77	72	6	20	1	1	0
6:15-6:30 PM	0	4	0	270	60	68	5	14	2	2	0
6:30-6:45 PM	0	3	0	175	55	53	4	13	1	1	0
6:45-7:00 PM	0	3	0	177	28	52	3	18	3	1	0

Traffic Volume Data

South Bound

Section One (African Union – Pushkin Square)

Tuesday (Mar 14,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	3	0	125	48	76	9	21	1	6	0
7:15-7:30 AM	1	4	0	124	59	66	10	21	4	2	0
7:30-7:45 AM	1	2	0	185	65	86	14	22	1	1	0
7:45-8:00 AM	0	5	0	206	83	80	9	23	2	1	0
8:00-8:15 AM	0	3	0	215	80	87	13	18	4	3	1
8:15-8:30 AM	1	9	0	231	80	83	12	21	3	1	0
8:30-8:45 AM	0	7	0	247	98	75	5	17	3	3	0
8:45-9:00 AM	0	3	0	278	84	80	4	27	3	1	0
9:00-9:15 AM	0	11	0	272	101	85	3	16	8	2	0
9:15-9:30 AM	1	8	0	263	95	86	7	17	2	1	1
9:30-9:45 AM	1	15	0	278	113	105	7	23	8	0	0
9:45-10:00 AM	0	23	0	256	106	82	6	19	11	6	1
1:00-1:15 PM	0	21	0	290	93	83	2	12	14	7	0
1:15-1:30 PM	0	15	0	305	99	82	3	15	13	8	0
1:30-1:45 PM	1	25	0	283	94	72	3	13	13	7	0
1:45-2:00 PM	0	24	0	338	85	63	2	17	9	8	1
2:00-2:15 PM	0	22	0	285	112	74	3	10	7	11	0
2:15-2:30 PM	0	25	0	273	104	81	3	9	11	5	0
2:30-2:45 PM	1	24	0	315	121	60	3	12	11	10	1
2:45-3:00 PM	0	19	0	306	130	71	3	14	14	6	0
4:00-4:15 PM	2	13	0	332	124	86	4	9	9	4	1
4:15-4:30 PM	0	22	0	422	150	94	2	5	13	6	1
4:30-4:45 PM	2	24	0	387	153	73	6	9	5	2	0
4:45-5:00 PM	0	18	0	434	126	97	7	15	2	3	0
5:00-5:15 PM	2	20	1	375	129	77	4	15	0	1	0
5:15-5:30 PM	3	26	0	381	128	77	6	17	3	4	0
5:30-5:45 PM	0	16	0	474	100	74	7	24	7	2	0
5:45-6:00 PM	0	7	0	482	133	106	12	8	2	1	0
6:00-6:15 PM	0	8	0	447	155	94	7	11	3	3	1
6:15-6:30 PM	0	6	0	426	123	93	7	21	2	2	0
6:30-6:45 PM	1	4	0	443	103	82	5	24	5	1	0
6:45-7:00 PM	0	11	0	374	104	70	4	26	4	2	0

Traffic Volume Data
North Bound
Section One (Africa Union – Pushkin Square)

Thursday (Mar 09,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	0	0	219	78	114	10	41	1	1	0
7:15-7:30 AM	0	6	0	431	109	80	3	26	1	2	0
7:30-7:45 AM	0	11	0	477	111	83	7	33	0	1	0
7:45-8:00 AM	0	12	0	473	106	74	12	18	0	1	0
8:00-8:15 AM	0	6	0	480	119	78	6	24	1	1	0
8:15-8:30 AM	0	12	0	376	93	88	9	15	1	1	0
8:30-8:45 AM	0	12	0	473	106	74	12	18	0	1	0
8:45-9:00 AM	0	6	0	431	109	80	3	26	1	2	0
9:00-9:15 AM	0	11	0	477	111	83	7	33	0	1	0
9:15-9:30 AM	1	0	0	410	106	71	7	33	0	0	0
9:30-9:45 AM	0	11	0	335	102	83	2	17	2	1	0
9:45-10:00 AM	0	8	0	377	107	65	8	15	0	1	0
1:00-1:15 PM	1	5	0	262	75	70	4	10	14	5	2
1:15-1:30 PM	0	10	0	293	92	55	2	7	12	9	0
1:30-1:45 PM	0	1	0	291	76	65	2	5	9	10	0
1:45-2:00 PM	0	15	0	290	81	67	0	9	17	9	0
2:00-2:15 PM	0	13	0	307	73	64	1	13	14	12	1
2:15-2:30 PM	0	1	0	295	100	49	4	8	12	10	0
2:30-2:45 PM	0	8	0	276	102	63	1	11	11	10	0
2:45-3:00 PM	0	7	0	270	81	70	2	9	11	11	0
4:00-4:15 PM	0	11	0	263	97	47	1	15	8	7	0
4:15-4:30 PM	0	30	0	310	93	46	3	24	9	8	0
4:30-4:45 PM	0	21	0	344	127	54	2	18	9	1	0
4:45-5:00 PM	0	17	0	299	102	95	2	12	11	3	0
5:00-5:15 PM	0	20	0	281	92	68	7	11	5	1	1
5:15-5:30 PM	0	8	0	234	76	72	5	15	8	0	1
5:30-5:45 PM	0	8	0	274	59	60	2	9	1	0	0
5:45-6:00 PM	0	8	0	257	63	61	1	7	3	0	0
6:00-6:15 PM	0	10	0	213	64	67	3	23	6	1	0
6:15-6:30 PM	0	7	0	192	68	53	3	10	1	2	2
6:30-6:45 PM	0	3	0	147	46	41	7	10	1	1	0
6:45-7:00 PM	0	1	0	164	41	54	4	10	2	2	0

Traffic Volume Data
South Bound
Section One (Africa Union – Pushkin Square)

Thursday (Mar 09,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	1	0	0	96	54	64	7	24	0	3	0
7:15-7:30 AM	1	3	0	120	62	61	9	18	2	2	0
7:30-7:45 AM	1	2	0	195	77	72	22	30	5	4	0
7:45-8:00 AM	0	1	0	203	74	67	14	30	1	3	0
8:00-8:15 AM	0	6	0	185	68	105	2	20	0	1	0
8:15-8:30 AM	0	3	0	203	76	80	14	15	4	0	1
8:30-8:45 AM	0	4	0	212	94	78	2	11	5	0	0
8:45-9:00 AM	1	9	0	274	75	70	7	21	0	3	0
9:00-9:15 AM	0	8	0	293	93	74	3	16	2	1	0
9:15-9:30 AM	0	14	0	260	97	74	7	23	3	2	0
9:30-9:45 AM	0	16	0	211	132	84	7	31	4	1	0
9:45-10:00 AM	1	16	0	245	87	69	9	19	1	0	1
1:00-1:15 PM	0	17	0	288	89	84	1	6	10	13	0
1:15-1:30 PM	0	17	0	311	93	75	3	10	9	10	0
1:30-1:45 PM	0	22	0	269	106	80	2	8	10	6	1
1:45-2:00 PM	0	20	0	326	98	53	0	13	21	11	0
2:00-2:15 PM	0	17	0	260	98	75	1	6	14	7	0
2:15-2:30 PM	0	28	0	275	93	54	3	15	9	10	1
2:30-2:45 PM	1	29	0	293	109	73	5	11	12	8	0
2:45-3:00 PM	0	24	0	288	128	69	1	8	15	4	0
4:00-4:15 PM	0	12	0	296	106	78	4	8	12	4	1
4:15-4:30 PM	0	14	0	392	126	64	1	6	10	4	0
4:30-4:45 PM	0	17	0	379	125	72	3	9	8	2	0
4:45-5:00 PM	2	22	0	436	127	87	4	11	1	0	1
5:00-5:15 PM	1	22	0	363	123	70	5	14	3	3	1
5:15-5:30 PM	0	21	0	361	118	75	10	10	1	2	0
5:30-5:45 PM	3	17	0	449	87	71	8	9	5	3	0
5:45-6:00 PM	0	6	0	521	112	79	6	15	3	2	0
6:00-6:15 PM	1	3	0	431	148	72	10	9	4	1	0
6:15-6:30 PM	1	8	0	399	128	52	6	13	5	3	1
6:30-6:45 PM	0	7	0	378	82	50	3	19	0	1	0
6:45-7:00 PM	1	13	0	374	97	205	5	17	2	1	0

Traffic Volume Data
North Bound
Section Two (Mekanisa Abo - Mekanisa)

Tuesday (May 16,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	2	0	349	93	83	9	19	7	0	1
7:15-7:30 AM	1	1	0	427	114	79	10	18	7	0	1
7:30-7:45 AM	0	3	0	444	119	103	5	13	1	2	0
7:45-8:00 AM	0	3	0	372	114	115	7	18	2	1	0
8:00-8:15 AM	0	3	0	380	113	117	8	23	1	1	0
8:15-8:30 AM	0	7	0	304	131	79	2	18	2	6	0
8:30-8:45 AM	0	5	0	273	109	73	2	24	5	3	0
8:45-9:00 AM	0	8	0	217	87	68	6	20	5	4	0
9:00-9:15 AM	0	10	0	257	91	88	6	11	3	4	3
9:15-9:30 AM	0	14	0	218	75	71	3	14	4	1	0
9:30-9:45 AM	1	13	0	278	105	99	7	9	6	2	1
9:45-10:00 AM	0	7	0	227	87	69	2	10	6	16	0
1:00-1:15 PM	0	15	0	150	66	47	0	7	21	19	0
1:15-1:30 PM	0	6	0	150	66	72	3	15	32	28	3
1:30-1:45 PM	0	11	0	145	67	61	7	6	14	17	1
1:45-2:00 PM	2	8	0	149	67	50	2	5	21	13	3
2:00-2:15 PM	0	12	0	152	53	45	1	17	15	14	1
2:15-2:30 PM	1	15	0	144	53	53	1	14	11	18	2
2:30-2:45 PM	0	14	0	143	57	58	2	8	13	21	0
2:45-3:00 PM	1	10	0	139	68	60	1	16	13	12	2
4:00-4:15 PM	0	13	0	164	51	53	3	10	6	2	2
4:15-4:30 PM	0	11	0	229	80	87	3	24	3	4	0
4:30-4:45 PM	0	19	0	246	90	106	3	23	7	4	0
4:45-5:00 PM	1	13	0	208	60	82	5	14	0	3	0
5:00-5:15 PM	1	10	0	138	58	50	8	14	6	2	0
5:15-5:30 PM	1	3	0	127	56	61	7	14	2	3	0
5:30-5:45 PM	0	5	0	152	53	67	7	9	3	4	0
5:45-6:00 PM	0	8	0	128	54	53	8	10	0	3	0
6:00-6:15 PM	0	10	0	124	39	54	8	9	1	3	0
6:15-6:30 PM	0	4	0	138	50	59	5	13	1	3	0
6:30-6:45 PM	0	3	0	109	29	62	5	26	1	5	0
6:45-7:00 PM	1	11	0	111	46	36	3	16	1	2	0

Traffic Volume Data

South Bound

Section Two (Mekanisa Abo - Mekanisa)

Tuesday (May 16,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	1	1	0	58	38	59	10	27	3	3	0
7:15-7:30 AM	0	1	0	131	41	79	13	23	1	3	0
7:30-7:45 AM	1	1	0	216	55	72	9	22	2	1	0
7:45-8:00 AM	0	2	0	236	55	90	10	20	1	0	0
8:00-8:15 AM	0	9	0	290	33	69	1	11	2	0	0
8:15-8:30 AM	2	3	0	197	62	72	6	12	7	1	0
8:30-8:45 AM	1	6	0	167	53	45	1	12	3	3	0
8:45-9:00 AM	0	3	0	189	37	54	4	13	2	4	0
9:00-9:15 AM	0	4	0	197	47	51	3	22	3	1	1
9:15-9:30 AM	0	15	0	140	28	52	5	17	5	1	0
9:30-9:45 AM	0	17	1	175	61	71	2	12	5	2	0
9:45-10:00 AM	2	8	0	188	46	60	5	10	15	1	0
1:00-1:15 PM	0	6	0	235	29	46	2	9	23	10	0
1:15-1:30 PM	2	11	0	214	34	55	3	6	16	11	1
1:30-1:45 PM	1	2	0	197	51	54	2	5	17	10	1
1:45-2:00 PM	0	11	0	194	58	66	2	5	21	10	1
2:00-2:15 PM	0	21	0	171	51	42	5	8	16	15	4
2:15-2:30 PM	5	23	0	196	26	49	1	8	20	18	2
2:30-2:45 PM	0	16	0	173	31	42	3	7	14	9	4
2:45-3:00 PM	1	11	0	220	77	69	2	7	17	14	2
4:00-4:15 PM	0	20	0	307	114	84	5	11	6	9	1
4:15-4:30 PM	7	16	0	302	98	81	3	7	7	4	1
4:30-4:45 PM	0	25	0	233	87	76	5	14	6	5	0
4:45-5:00 PM	1	18	0	304	88	74	7	14	10	3	0
5:00-5:15 PM	0	15	0	343	89	62	3	12	0	1	0
5:15-5:30 PM	0	13	0	327	83	56	8	23	5	3	3
5:30-5:45 PM	1	16	0	357	76	63	8	19	5	2	1
5:45-6:00 PM	1	9	0	333	103	93	8	10	9	2	0
6:00-6:15 PM	0	21	0	454	106	102	15	23	9	4	3
6:15-6:30 PM	1	15	0	465	94	117	10	31	10	3	2
6:30-6:45 PM	0	7	0	445	106	94	11	30	8	8	0
6:45-7:00 PM	0	8	0	425	70	66	11	21	9	4	1

Traffic Volume Data
North Bound
Section Two (Mekanisa Abo - Mekanisa)

Thursday (May 18,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	2	1	0	316	89	74	10	24	3	1	1
7:15-7:30 AM	0	1	0	385	114	92	11	23	3	0	0
7:30-7:45 AM	0	4	0	406	144	101	7	21	0	1	1
7:45-8:00 AM	0	4	0	382	130	91	7	19	2	1	0
8:00-8:15 AM	0	2	0	350	98	100	7	23	4	2	0
8:15-8:30 AM	0	5	0	371	132	123	4	17	6	1	1
8:30-8:45 AM	1	4	0	293	119	97	3	13	4	4	1
8:45-9:00 AM	0	7	0	202	92	89	3	16	1	3	0
9:00-9:15 AM	2	13	0	213	88	70	5	11	4	6	0
9:15-9:30 AM	0	14	0	191	96	54	3	14	3	0	0
9:30-9:45 AM	0	14	0	243	92	73	7	9	0	3	0
9:45-10:00 AM	0	13	0	189	85	82	4	13	6	0	0
1:00-1:15 PM	1	11	0	158	56	49	0	8	14	14	4
1:15-1:30 PM	0	10	0	145	66	64	1	7	19	20	2
1:30-1:45 PM	1	7	0	140	65	70	2	10	24	11	4
1:45-2:00 PM	0	15	0	161	73	49	0	10	15	13	5
2:00-2:15 PM	0	12	0	128	79	62	1	13	20	14	3
2:15-2:30 PM	0	8	0	117	61	71	2	17	20	10	3
2:30-2:45 PM	1	11	0	138	52	62	4	15	20	8	1
2:45-3:00 PM	0	11	0	131	68	63	0	12	12	14	0
4:00-4:15 PM	0	10	0	161	61	68	4	10	8	4	0
4:15-4:30 PM	0	11	0	163	74	58	8	20	7	5	0
4:30-4:45 PM	0	6	0	202	71	84	8	30	5	3	0
4:45-5:00 PM	0	17	0	213	90	75	3	22	3	2	0
5:00-5:15 PM	0	5	0	181	82	78	10	16	4	5	3
5:15-5:30 PM	0	7	0	154	61	70	5	15	8	1	0
5:30-5:45 PM	0	11	0	125	70	67	9	9	10	0	0
5:45-6:00 PM	0	6	0	116	65	64	10	13	7	0	1
6:00-6:15 PM	0	9	0	115	66	54	6	14	4	2	2
6:15-6:30 PM	1	2	0	142	62	47	4	17	0	1	1
6:30-6:45 PM	0	0	0	110	66	71	3	24	1	2	0
6:45-7:00 PM	0	1	0	110	52	48	4	19	2	1	0

Traffic Volume Data
South Bound
Section Two (Mekanisa Abo - Mekanisa)

Thursday (May 18,2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	0	1	67	33	59	11	18	3	2	0
7:15-7:30 AM	1	1	0	121	41	93	10	22	3	1	0
7:30-7:45 AM	0	3	0	201	41	78	11	25	5	0	0
7:45-8:00 AM	1	2	0	235	52	62	6	17	3	0	0
8:00-8:15 AM	0	10	0	251	38	67	12	26	3	2	0
8:15-8:30 AM	0	6	0	189	68	66	9	14	2	0	0
8:30-8:45 AM	0	2	0	183	52	44	13	15	3	0	0
8:45-9:00 AM	2	2	0	213	35	36	7	22	2	0	0
9:00-9:15 AM	1	9	0	160	40	47	4	10	3	3	0
9:15-9:30 AM	0	20	0	145	26	47	10	11	2	2	0
9:30-9:45 AM	0	18	1	177	54	50	4	15	5	4	0
9:45-10:00 AM	1	9	0	194	49	57	2	19	13	1	0
1:00-1:15 PM	1	20	0	183	23	53	0	3	16	7	1
1:15-1:30 PM	1	10	0	217	38	57	0	6	16	2	0
1:30-1:45 PM	0	8	0	208	40	46	2	6	14	7	1
1:45-2:00 PM	0	14	0	182	54	55	1	8	21	8	1
2:00-2:15 PM	3	21	0	173	45	42	4	5	19	11	2
2:15-2:30 PM	2	23	0	176	51	42	4	4	18	6	4
2:30-2:45 PM	1	11	0	209	44	46	4	7	22	9	1
2:45-3:00 PM	0	15	0	213	36	42	5	6	20	10	1
4:00-4:15 PM	1	27	0	307	98	74	7	12	7	2	2
4:15-4:30 PM	1	20	0	283	78	48	4	9	8	7	0
4:30-4:45 PM	0	21	0	264	97	67	8	14	13	14	2
4:45-5:00 PM	4	4	0	309	110	72	6	18	6	4	3
5:00-5:15 PM	0	10	0	356	77	66	2	10	5	10	1
5:15-5:30 PM	1	15	0	321	80	54	11	22	7	7	0
5:30-5:45 PM	2	14	0	271	70	61	7	12	9	3	5
5:45-6:00 PM	1	14	0	304	109	73	14	13	6	3	1
6:00-6:15 PM	0	21	0	349	101	87	13	27	2	4	3
6:15-6:30 PM	1	14	0	408	83	131	9	27	0	3	0
6:30-6:45 PM	0	7	0	408	91	73	4	26	3	5	1
6:45-7:00 PM	2	7	0	334	53	68	4	18	7	4	1

Traffic Volume Data
North Bound
Section Three (Mekanisa – German Square)

Tuesday (May 23, 2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	2	0	273	74	62	8	18	5	0	0
7:15-7:30 AM	0	1	0	313	69	58	8	15	7	0	0
7:30-7:45 AM	0	3	0	366	88	92	2	13	1	0	0
7:45-8:00 AM	0	0	0	260	74	89	5	16	1	1	0
8:00-8:15 AM	0	2	0	306	94	96	7	21	1	0	0
8:15-8:30 AM	0	3	0	219	112	60	2	18	2	6	0
8:30-8:45 AM	0	1	0	211	87	60	2	22	4	2	0
8:45-9:00 AM	0	8	0	158	67	51	6	18	4	4	0
9:00-9:15 AM	0	8	0	191	76	76	5	11	1	3	3
9:15-9:30 AM	0	10	0	174	68	58	3	12	4	1	0
9:30-9:45 AM	1	10	0	214	92	88	7	9	5	2	1
9:45-10:00 AM	0	7	0	175	72	63	2	10	5	11	0
1:00-1:15 PM	0	15	0	109	56	42	0	7	21	18	0
1:15-1:30 PM	0	6	0	118	58	64	3	14	30	27	3
1:30-1:45 PM	0	9	0	109	60	56	7	6	14	14	1
1:45-2:00 PM	2	7	0	113	57	43	2	5	21	12	3
2:00-2:15 PM	0	12	0	128	51	41	0	16	14	10	1
2:15-2:30 PM	1	13	0	114	49	48	1	14	10	15	1
2:30-2:45 PM	0	13	0	111	45	52	2	8	13	20	0
2:45-3:00 PM	1	10	0	112	57	55	1	14	13	12	2
4:00-4:15 PM	0	13	0	115	40	45	3	10	6	2	2
4:15-4:30 PM	0	11	0	168	71	74	3	24	3	4	0
4:30-4:45 PM	0	14	0	174	78	86	3	22	6	2	0
4:45-5:00 PM	1	12	0	147	49	74	5	12	0	3	0
5:00-5:15 PM	1	10	0	98	49	41	6	14	6	2	0
5:15-5:30 PM	1	3	0	103	52	56	5	13	2	3	0
5:30-5:45 PM	0	5	0	106	48	58	7	9	3	3	0
5:45-6:00 PM	0	8	0	99	49	47	8	9	0	2	0
6:00-6:15 PM	0	9	0	86	29	51	8	9	1	2	0
6:15-6:30 PM	0	4	0	93	41	50	5	13	1	3	0
6:30-6:45 PM	0	3	0	84	25	53	5	25	0	5	0
6:45-7:00 PM	1	9	0	80	40	33	3	15	0	2	0

Traffic Volume Data

South Bound

Section Three (Mekanisa – German Square)

Tuesday (May 23, 2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	0	0	91	42	66	8	24	2	3	0
7:15-7:30 AM	0	3	0	101	76	88	10	18	4	1	0
7:30-7:45 AM	0	0	0	109	62	68	9	18	2	3	1
7:45-8:00 AM	0	3	0	149	70	75	7	10	3	1	0
8:00-8:15 AM	0	1	0	185	57	85	5	20	4	2	0
8:15-8:30 AM	0	4	0	171	65	82	1	8	3	4	3
8:30-8:45 AM	0	6	0	156	87	73	4	9	5	3	1
8:45-9:00 AM	1	3	0	154	71	54	1	12	3	3	0
9:00-9:15 AM	0	12	0	144	63	64	2	6	1	1	0
9:15-9:30 AM	0	12	0	131	53	58	2	14	3	1	1
9:30-9:45 AM	0	8	0	132	58	58	3	11	4	4	0
9:45-10:00 AM	0	7	0	144	55	59	4	16	9	11	3
1:00-1:15 PM	0	12	0	124	37	57	1	4	14	11	3
1:15-1:30 PM	0	12	1	133	51	63	1	7	17	10	5
1:30-1:45 PM	1	7	1	145	57	63	4	6	19	20	2
1:45-2:00 PM	0	13	0	129	34	47	3	3	13	13	3
2:00-2:15 PM	1	8	0	150	50	56	3	9	20	16	1
2:15-2:30 PM	0	9	0	131	37	43	0	7	25	21	2
2:30-2:45 PM	0	5	0	157	67	60	0	8	22	17	0
2:45-3:00 PM	0	13	0	190	78	64	4	13	20	11	1
4:00-4:15 PM	0	9	2	254	111	85	2	8	10	6	0
4:15-4:30 PM	0	5	0	252	85	106	3	12	9	8	0
4:30-4:45 PM	0	7	1	256	97	71	5	7	5	4	0
4:45-5:00 PM	1	16	0	277	97	76	4	13	6	6	1
5:00-5:15 PM	0	7	0	252	104	77	3	18	5	3	0
5:15-5:30 PM	0	14	0	275	123	62	8	21	5	4	0
5:30-5:45 PM	1	16	0	292	95	67	11	21	3	4	0
5:45-6:00 PM	0	11	0	329	78	86	9	22	3	5	0
6:00-6:15 PM	0	14	0	310	71	91	6	21	3	5	1
6:15-6:30 PM	1	12	0	335	74	97	4	15	6	4	0
6:30-6:45 PM	0	9	0	298	58	67	4	30	1	3	0
6:45-7:00 PM	0	3	0	267	88	83	7	14	3	6	1

Traffic Volume Data

North Bound

Section Three (Mekanisa – German Square)

Thursday (May 25, 2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	1	1	0	238	76	58	9	24	2	1	1
7:15-7:30 AM	0	1	0	294	88	67	7	22	3	0	0
7:30-7:45 AM	0	3	0	308	111	73	4	21	0	1	0
7:45-8:00 AM	0	4	0	281	91	69	5	18	1	1	0
8:00-8:15 AM	0	1	0	263	85	87	6	22	4	2	0
8:15-8:30 AM	0	3	0	274	97	97	3	17	5	0	1
8:30-8:45 AM	1	3	0	210	93	78	3	13	2	4	0
8:45-9:00 AM	0	7	0	138	69	75	2	16	0	2	0
9:00-9:15 AM	2	10	0	156	74	60	5	10	3	3	0
9:15-9:30 AM	0	13	0	146	82	47	3	13	2	0	0
9:30-9:45 AM	0	14	0	196	73	62	6	7	0	2	0
9:45-10:00 AM	0	11	0	136	65	73	4	12	4	0	0
1:00-1:15 PM	1	11	0	120	54	41	0	8	13	14	3
1:15-1:30 PM	0	9	0	112	56	57	1	7	19	20	2
1:30-1:45 PM	1	7	0	108	57	67	2	9	23	10	4
1:45-2:00 PM	0	12	0	119	64	42	0	10	14	12	5
2:00-2:15 PM	0	10	0	96	71	54	1	13	19	14	3
2:15-2:30 PM	0	7	0	87	53	62	2	17	18	10	2
2:30-2:45 PM	1	8	0	109	46	51	3	15	19	8	1
2:45-3:00 PM	0	11	0	106	59	56	0	12	11	14	0
4:00-4:15 PM	0	7	0	112	51	58	3	10	7	4	0
4:15-4:30 PM	0	10	0	126	67	51	7	20	6	3	0
4:30-4:45 PM	0	6	0	164	67	73	8	27	5	3	0
4:45-5:00 PM	0	17	0	146	81	60	2	22	3	2	0
5:00-5:15 PM	0	5	0	136	72	63	8	16	4	5	3
5:15-5:30 PM	0	7	0	120	57	58	4	14	8	1	0
5:30-5:45 PM	0	11	0	96	70	62	9	9	10	0	0
5:45-6:00 PM	0	5	0	85	60	54	10	12	7	0	1
6:00-6:15 PM	0	7	0	82	59	50	6	14	4	1	2
6:15-6:30 PM	1	2	0	112	55	41	4	17	0	1	1
6:30-6:45 PM	0	0	0	87	62	69	3	23	1	2	0
6:45-7:00 PM	0	1	0	92	46	46	4	19	2	1	0

Traffic Volume Data
South Bound
Section Three (Mekanisa – German Square)

Thursday (May 25, 2023)

Time	Two wheels	Motor Cycle	Three wheels	Passenger car & taxi	4WD	Mini bus	Medium Bus	Bus	Small Truck	Truck	Truck and Trailer
7:00-7:15 AM	0	3	0	69	43	56	5	24	3	0	0
7:15-7:30 AM	0	1	0	75	54	68	11	23	0	0	0
7:30-7:45 AM	0	2	0	111	67	65	5	22	0	5	0
7:45-8:00 AM	0	4	0	160	59	72	7	21	2	1	0
8:00-8:15 AM	0	8	0	170	83	97	0	28	1	5	1
8:15-8:30 AM	1	6	0	173	80	66	4	8	1	2	2
8:30-8:45 AM	0	3	0	141	82	60	3	19	5	3	0
8:45-9:00 AM	0	7	0	128	56	50	3	19	2	1	0
9:00-9:15 AM	0	10	0	124	52	54	4	15	1	1	0
9:15-9:30 AM	0	8	0	118	73	62	5	12	5	6	1
9:30-9:45 AM	0	10	0	123	78	58	0	18	3	5	0
9:45-10:00 AM	0	5	0	146	57	53	4	11	5	5	2
1:00-1:15 PM	2	4	0	133	52	47	4	2	22	16	1
1:15-1:30 PM	0	8	0	126	38	47	3	4	18	8	1
1:30-1:45 PM	0	7	0	153	44	58	3	5	11	15	2
1:45-2:00 PM	0	6	0	123	34	38	2	3	13	14	0
2:00-2:15 PM	0	10	0	143	56	38	4	8	18	12	3
2:15-2:30 PM	0	8	0	154	49	37	1	7	21	15	3
2:30-2:45 PM	1	6	0	171	56	60	3	7	18	16	1
2:45-3:00 PM	0	6	0	123	51	40	2	4	15	8	2
4:00-4:15 PM	0	8	1	203	83	66	4	12	11	12	0
4:15-4:30 PM	0	7	0	227	82	67	3	13	3	8	1
4:30-4:45 PM	0	6	0	241	111	79	3	13	8	2	0
4:45-5:00 PM	0	14	0	249	111	88	7	16	7	2	0
5:00-5:15 PM	0	9	0	244	90	75	5	14	2	5	1
5:15-5:30 PM	0	11	0	252	94	69	6	19	2	4	1
5:30-5:45 PM	0	10	0	259	94	80	9	21	1	3	0
5:45-6:00 PM	1	12	0	296	71	75	8	22	4	2	0
6:00-6:15 PM	0	12	0	291	78	69	7	10	1	2	0
6:15-6:30 PM	0	9	0	264	68	81	6	22	0	2	0
6:30-6:45 PM	0	4	0	275	66	74	3	20	4	4	1
6:45-7:00 PM	1	8	0	239	82	66	2	29	3	3	1

APPENDIX B

Average travel speed by vehicle category (Sample representation, Section One)

Time	Segment Name: African Union – Pushkin Square								
	Length: 100 M								
	Moto	Passenger Car	4WD	Minibus Taxi	Medium Bus	BUS	Small Truck	Truck	Truck & Trailer
7:15 AM -7.16 AM		10.79	11.30	8.78		10.49			
7.16 AM -7.17 AM		17.60	17.56	16.61		21.25			
7.17 AM -7.18 AM	20.00	12.75	10.42	11.51		9.23			
7.18 AM -7.19 AM		8.55	8.97	5.90	8.37	9.28			
7.19 AM -7.20 AM		12.49	12.86	11.31	25.71	12.95			
7.20 AM -7.21 AM		8.59	9.93	9.69		11.05			
7.21 AM -7.22 AM		11.21	12.41	9.82		13.85			
7.22 AM -7.23 AM		8.08	6.89	6.91		14.42			
7.23 AM -7.24 AM		11.89	6.00	20.00		14.57			
7.24 AM -7.25 AM		22.17	20.59	23.45		21.18			
7.25 AM -7.26 AM		7.05	7.30	10.01					
7.26 AM -7.27 AM		16.24	17.58	16.25		21.25			
7.27 AM -7.28 AM		9.37	11.99	9.81					
7.28 AM -7.29 AM		9.42	6.66	10.59		9.73			
7.29 AM -7.30 AM	25.71	15.22	13.04	13.90		15.65			
7.30 AM -7.31 AM		10.23	11.19	11.13		18.95			
7.31 AM -7.32 AM		14.64	14.48	13.64					
7.32 AM -7.33 AM		25.91	26.14	25.37		24.07			
7.33 AM -7.34 AM	42.5	31.82	34.74	30.36		24.60			
7.34 AM -7.35 AM		40.82	41.69	41.20		40.50			
7.35 AM -7.36 AM		38.84	36.11	36.85		32.82			
7.36 AM -7.37 AM		24.66	29.53	19.77		24.86			
7.37 AM -7.38 AM		11.17	10.38	8.38		11.61			
7.38 AM -7.39 AM		21.87	22.12	17.18		15.65			
7.39 AM-7.40 AM		10.60	15.21	7.14		10.28			
7.40 AM -7.41 AM	15.00	11.38	12.83	11.79		9.00			
7.41 AM -7.42 AM		11.84	12.26	10.39					
7.42 AM -7.43 AM	22.5	11.15	12.34	13.19		8.78			
7.43 AM -7.44 AM		19.58	20.34	18.96		11.25			
7.44 AM -7.45 AM		26.52	26.66	24.77					
7:45 AM -7:46 AM	45.00	36.49	28.96	33.10					
7:46 AM -7:47 AM	30.42	21.01	18.51	18.20		21.61			
7:47 AM -7:48 AM	36.00	29.44	29.89	29.18		24.11			
7:48 AM -7:49 AM		21.59	17.38	28.00		13.35			
7:49 AM -7:50 AM		14.27	20.38	15.59					
7.50 AM -7.51 AM		17.50	21.25	17.26					
7.51 AM -7.52 AM		8.82	10.30	9.43					
7.52 AM -7.53 AM		18.38	15.32	16.36		15.93			
7.53 AM -7.54 AM		17.30	16.15	14.40		10.11			

7.54 AM -7.55 AM		13.23	11.39	14.71		10.59			
7.55 AM -7.56 AM	13.85	13.11	11.55	13.37		9.99			
7.56 AM - 7.57 AM		15.53	15.23	12.27		13.33			
7.57 AM -7.58 AM		11.80	9.68	10.12		9.87			
7.58 AM -7.59 AM		10.88	10.02	7.93					
7.59 AM -8.00 AM		14.79	13.55	13.82					
8.00 AM -8.01 AM		9.76	8.72	8.22		7.47			
8.01 AM -8.02 AM		10.72	11.35	9.88					
8.02 AM -8.03 AM		10.55	11.91	8.75		15.65			
8.03 AM -8.04 AM		9.42	12.43	9.41		11.25			
8.04 AM -8.05 AM	21.18	13.16	13.48	10.21		10.62			
8.05 AM -8.06 AM		6.75	7.53	8.19		6.55			
8.06 AM -8.07 AM		11.55	11.66	11.47		13.83			
8.07 AM -8.08 AM		14.15	14.68	12.43		12.17			
8.08 AM -8.09 AM		7.89	10.07	7.68		8.18			
8.09 AM -8.10 AM		20.66	26.71	31.14		16.40			
8.10 AM -8.11 AM		11.13	9.34	8.91		7.95			
8.11 AM -8.12 AM	31.36	12.23	14.74	12.83		12.13			
8.12 AM -8.13 AM		9.85	9.06	8.09		13.81			
8.13 AM -8.14 AM		6.31	4.14	5.26		5.07			
8.14 AM -8.15 AM		17.25	13.87	13.18					
2:00 PM -2:01 PM		37.79	37.95	35.80		36.00	36.00		
2:01 PM -2:02 PM		40.10	37.84	42.50					
2:02 PM -2:03 PM	46.29	39.44	40.14	43.50			37.00	36.67	
2:03 PM -2:04 PM		39.22	34.15	36.36	30.00		40.00	51.00	
2:04 PM -2:05 PM	51.43	35.65	36.12	36.69				27.69	
2:05 PM -2:06 PM	38.00	39.08	38.33	42.94			51.43	24.00	
2:06 PM -2:07 PM	51.43	36.30	38.20	36.74			45.00	27.69	
2:07 PM -2:08 PM	55.71	37.28	43.19	40.00		38.43	42.48		
2:08 PM -2:09 PM		32.05	27.65	31.01		36.00			
2:09 PM -2:10 PM	36.36	41.73		35.10			34.36		
2:10 PM -2:11 PM	40.00	49.39	50.48	51.96		30.00			
2:11 PM -2:12 PM	48.21	45.39	49.17	45.00			45.00		
2:12 PM -2:13 PM	42.50	43.44	47.14	42.11				34.91	
2:13 PM -2:14 PM		38.86	36.24	36.40	24.00		30.00	34.24	
2:14 PM -2:15 PM		27.44	35.32	29.80		22.50	27.69	36.00	
2:15 PM -2:16 PM	36.00	35.71	31.74	34.69		20.00			
2:16 PM -2:17 PM		43.45	39.25	36.00		42.50	51.43	38.00	
2:17 PM -2:18 PM	30.00	33.15	33.04	33.68		31.85	31.85	30.00	
2:18 PM -2:19 PM	38.00	39.01	36.69	40.00			38.86		
2:19 PM -2:20 PM	36.00	32.11	33.19	18.00		38.00			
2:20 PM -2:21 PM	45.00	38.88	37.91	41.67			60.00	45.00	
2:21 PM -2:22 PM		34.55	30.62	33.85		36.00			
2:22 PM -2:23 PM		31.17	27.57	37.86			25.71		
2:23 PM -2:24 PM		31.28	35.92	38.96	36.00			27.69	

2:24 PM -2:25 PM		35.48	36.36	33.55	36.00		32.73		
2:25 PM -2:26 PM		36.35	37.75	35.15		40.00	36.00		
2:26 PM -2:27 PM		31.23	28.12	26.25		32.73			
2:27 PM -2:28 PM		25.76	26.72	28.91		21.18	25.71	24.00	
2:28 PM -2:29 PM		26.30	29.20	28.43		32.73	32.73		
2:29 PM -2:30 PM		24.14	24.71	27.04			18.00	40.00	
2:30 PM -2:31 PM		23.08	27.27	32.08		20.00	22.50	26.25	
2:31 PM -2:32 PM		28.03	25.84	36.24		25.71	37.50		
2:32 PM -2:33 PM		13.30	12.67	12.65		16.21	11.61		
2:33 PM -2:34 PM		21.07	24.72	21.48		27.86		25.10	
2:34 PM -2:35 PM		11.12	10.52	12.15		8.78	11.25		
2:35 PM -2:36 PM		21.57	20.47	20.04		17.62			
2:36 PM -2:37 PM	27.69	25.32	26.55	27.00		24.00			
2:37 PM -2:38 PM		17.86	11.74	16.72	12.41	10.29	13.99		
2:38 PM -2:39 PM		27.57	30.57	32.86		15.00	30.00		
2:39 PM -2:40 PM		38.43		51.43		25.71	32.73	25.71	
2:40 PM -2:41 PM		33.58	31.57	39.68			38.00	32.73	
2:41 PM -2:42 PM		39.70	40.50	45.71					
2:42 PM -2:43 PM		34.00	36.18	31.92		45.00	45.00		
2:43 PM -2:44 PM		33.23	37.20	35.41		32.73	25.71		
2:44 PM -2:45 PM		26.84	25.67	24.32		25.82	27.69	22.50	
2:45 PM -2:46 PM		20.97	22.88	23.22		23.45		21.18	
2:46 PM -2:47 PM		31.31	27.53	28.35			27.86		
2:47 PM -2:48 PM	51.43	33.31	33.30	35.18					
2:48 PM -2:49 PM		29.20	28.92	28.85		36.95		34.36	
2:49 PM -2:50 PM		25.41	23.25	25.42			25.85		
2:50 PM -2:51 PM		29.36	33.20			27.61			
2:51 PM -2:52 PM	45.00	41.67	38.79	45.71		36.00			
2:52 PM -2:53 PM	30.00	28.92	30.57	28.78		31.36	32.73		
2:53 PM -2:54 PM		35.22	33.75	30.00		27.69	38.00		
2:54 PM -2:55 PM		35.47	32.00	40.00		36.00			
2:55 PM -2:56 PM	32.73	31.91	34.19	40.00		32.73			
2:56 PM -2:57 PM	51.43	41.49	46.86	51.43		45.00			
2:57 PM -2:58 PM		35.07	35.49	32.29				32.73	
2:58 PM -2:59 PM		40.29	40.42	37.91		45.00			
2:59 PM -3:00 PM		34.46	31.17	35.91		30.00			

APPENDIX C

Performance Analysis (Sample representation, Section One)

Section Name: African Union – Pushkin Square									
Segment Length: 100 M									
Duration	**Travel Time (Sec)**	**Travel Speed (Km/hr)**	**Travel Rate (min/Km)**	**Delay (Sec)**	**Delay Rate (min/Km)**	**Travel Time Index**	**Traffic Volume (Veh)**	**Segment delay (Veh-min)**	**Delay ratio**
7:15 AM -7.16 AM	36.01	10.00	6.00	28.25	4.71	4.64	1380	649.71	0.78
7.16 AM -7.17 AM	20.40	17.65	3.40	12.64	2.11	2.63	1740	366.54	0.62
7.17 AM -7.18 AM	32.43	11.10	5.41	24.67	4.11	4.18	2880	1184.21	0.76
7.18 AM -7.19 AM	46.00	7.83	7.67	38.24	6.37	5.93	2220	1414.81	0.83
7.19 AM -7.20 AM	26.87	13.40	4.48	19.11	3.19	3.46	2880	917.49	0.71
7.20 AM -7.21 AM	39.07	9.21	6.51	31.31	5.22	5.03	2400	1252.43	0.80
7.21 AM -7.22 AM	31.81	11.32	5.30	24.05	4.01	4.10	2040	817.76	0.76
7.22 AM -7.23 AM	41.93	8.59	6.99	34.17	5.70	5.40	3600	2050.21	0.81
7.23 AM -7.24 AM	35.73	10.07	5.96	27.97	4.66	4.60	3300	1538.47	0.78
7.24 AM -7.25 AM	17.34	20.77	2.89	9.58	1.60	2.23	2760	440.48	0.55
7.25 AM -7.26 AM	49.82	7.23	8.30	42.06	7.01	6.42	2760	1934.72	0.84
7.26 AM -7.27 AM	20.76	17.34	3.46	13.00	2.17	2.68	2580	558.93	0.63
7.27 AM -7.28 AM	36.22	9.94	6.04	28.46	4.74	4.67	2820	1337.48	0.79
7.28 AM -7.29 AM	42.30	8.51	7.05	34.54	5.76	5.45	4260	2452.42	0.82
7.29 AM -7.30 AM	24.27	14.83	4.04	16.51	2.75	3.13	3540	973.92	0.68
7.30 AM -7.31 AM	32.71	11.00	5.45	24.95	4.16	4.22	2640	1097.91	0.76
7.31 AM -7.32 AM	29.24	12.31	4.87	21.48	3.58	3.77	3060	1095.46	0.73
7.32 AM -7.33 AM	14.28	25.20	2.38	6.52	1.09	1.84	3000	326.24	0.46
7.33 AM -7.34 AM	11.51	31.27	1.92	3.75	0.63	1.48	2520	157.59	0.33
7.34 AM -7.35 AM	8.92	40.37	1.49	1.16	0.19	1.15	2400	46.29	0.13
7.35 AM -7.36 AM	10.24	35.15	1.71	2.48	0.41	1.32	2520	104.28	0.24
7.36 AM -7.37 AM	21.47	16.77	3.58	13.71	2.28	2.77	3300	753.87	0.64
7.37 AM -7.38 AM	38.24	9.41	6.37	30.48	5.08	4.93	2700	1371.76	0.80
7.38 AM -7.39 AM	20.37	17.68	3.39	12.61	2.10	2.62	3660	768.98	0.62
7.39 AM-7.40 AM	41.26	8.73	6.88	33.50	5.58	5.32	2640	1473.80	0.81

7.40 AM -7.41 AM	31.55	11.41	5.26	23.79	3.96	4.07	3000	1189.36	0.75
7.41 AM -7.42 AM	33.05	10.89	5.51	25.29	4.22	4.26	2520	1062.33	0.77
7.42 AM -7.43 AM	30.47	11.82	5.08	22.71	3.78	3.93	3660	1385.22	0.75
7.43 AM -7.44 AM	22.50	16.00	3.75	14.74	2.46	2.90	3960	972.95	0.66
7.44 AM -7.45 AM	14.48	24.87	2.41	6.72	1.12	1.87	2760	308.99	0.46
7:45 AM -7:46 AM	11.70	30.78	1.95	3.94	0.66	1.51	2760	181.06	0.34
7:46 AM -7:47 AM	17.58	20.47	2.93	9.82	1.64	2.27	3900	638.52	0.56
7:47 AM -7:48 AM	12.45	28.92	2.07	4.69	0.78	1.60	3600	281.19	0.38
7:48 AM -7:49 AM	22.11	16.28	3.69	14.35	2.39	2.85	3840	918.71	0.65
7:49 AM -7:50 AM	25.41	14.17	4.24	17.65	2.94	3.27	3780	1111.97	0.69
7.50 AM -7.51 AM	21.04	17.11	3.51	13.28	2.21	2.71	3000	663.75	0.63
7.51 AM -7.52 AM	41.48	8.68	6.91	33.72	5.62	5.35	2340	1315.16	0.81
7.52 AM -7.53 AM	22.10	16.29	3.68	14.34	2.39	2.85	2760	659.42	0.65
7.53 AM -7.54 AM	27.42	13.13	4.57	19.66	3.28	3.53	2460	806.15	0.72
7.54 AM -7.55 AM	31.00	11.61	5.17	23.24	3.87	3.99	3120	1208.22	0.75
7.55 AM -7.56 AM	31.34	11.49	5.22	23.58	3.93	4.04	2640	1037.48	0.75
7.56 AM - 7.57 AM	26.66	13.51	4.44	18.90	3.15	3.44	2460	774.75	0.71
7.57 AM -7.58 AM	40.70	8.84	6.78	32.94	5.49	5.25	2400	1317.66	0.81
7.58 AM -7.59 AM	42.13	8.54	7.02	34.37	5.73	5.43	2700	1546.80	0.82
7.59 AM -8.00 AM	24.66	14.60	4.11	16.90	2.82	3.18	1980	557.64	0.69
8.00 AM -8.01 AM	43.81	8.22	7.30	36.05	6.01	5.65	2640	1586.09	0.82
8.01 AM -8.02 AM	37.31	9.65	6.22	29.55	4.92	4.81	2880	1418.19	0.79
8.02 AM -8.03 AM	42.09	8.55	7.02	34.33	5.72	5.42	3420	1956.91	0.82
8.03 AM -8.04 AM	36.70	9.81	6.12	28.94	4.82	4.73	2580	1244.45	0.79
8.04 AM -8.05 AM	28.97	12.43	4.83	21.21	3.54	3.73	3000	1060.54	0.73
8.05 AM -8.06 AM	50.62	7.11	8.44	42.86	7.14	6.52	3480	2485.85	0.85
8.06 AM -8.07 AM	31.18	11.55	5.20	23.42	3.90	4.02	2580	1007.11	0.75
8.07 AM -8.08 AM	31.85	11.30	5.31	24.09	4.01	4.10	3060	1228.41	0.76
8.08 AM -8.09 AM	44.06	8.17	7.34	36.30	6.05	5.68	3660	2214.41	0.82
8.09 AM -8.10 AM	17.79	20.23	2.97	10.03	1.67	2.29	2880	481.54	0.56
8.10 AM -8.11 AM	41.26	8.72	6.88	33.50	5.58	5.32	2460	1373.55	0.81
8.11 AM -8.12 AM	24.92	14.44	4.15	17.16	2.86	3.21	2760	789.46	0.69
8.12 AM -8.13 AM	45.63	7.89	7.60	37.87	6.31	5.88	3240	2044.71	0.83

8.13 AM -8.14 AM	70.63	5.10	11.77	62.87	10.48	9.10	2640	2766.28	0.89
8.14 AM -8.15 AM	26.14	13.77	4.36	18.38	3.06	3.37	2400	735.16	0.70
2:00 PM -2:01 PM	10.14	35.49	1.69	2.38	0.40	1.31	1920	76.27	0.23
2:01 PM -2:02 PM	9.10	39.58	1.52	1.34	0.22	1.17	2040	45.40	0.15
2:02 PM -2:03 PM	9.30	38.71	1.55	1.54	0.26	1.20	1800	46.20	0.17
2:03 PM -2:04 PM	9.79	36.77	1.63	2.03	0.34	1.26	1980	67.01	0.21
2:04 PM -2:05 PM	10.10	35.63	1.68	2.34	0.39	1.30	1740	67.97	0.23
2:05 PM -2:06 PM	10.08	35.73	1.68	2.32	0.39	1.30	2100	81.05	0.23
2:06 PM -2:07 PM	9.73	37.00	1.62	1.97	0.33	1.25	1980	65.02	0.20
2:07 PM -2:08 PM	8.76	41.09	1.46	1.00	0.17	1.13	1740	29.03	0.11
2:08 PM -2:09 PM	12.00	29.99	2.00	4.24	0.71	1.55	1620	114.58	0.35
2:09 PM -2:10 PM	9.99	36.05	1.66	2.23	0.37	1.29	2640	97.98	0.22
2:10 PM -2:11 PM	8.57	41.99	1.43	0.81	0.14	1.10	1980	26.81	0.09
2:11 PM -2:12 PM	7.80	46.15	1.30	0.04	0.01	1.01	1800	1.20	0.01
2:12 PM -2:13 PM	8.75	41.12	1.46	0.99	0.17	1.13	1320	21.87	0.11
2:13 PM -2:14 PM	11.20	32.14	1.87	3.44	0.57	1.44	1920	110.11	0.31
2:14 PM -2:15 PM	12.85	28.03	2.14	5.09	0.85	1.66	1680	142.39	0.40
2:15 PM -2:16 PM	12.31	29.24	2.05	4.55	0.76	1.59	1800	136.51	0.37
2:16 PM -2:17 PM	8.83	40.78	1.47	1.07	0.18	1.14	2220	39.49	0.12
2:17 PM -2:18 PM	11.57	31.10	1.93	3.81	0.64	1.49	2340	148.76	0.33
2:18 PM -2:19 PM	9.68	37.18	1.61	1.92	0.32	1.25	1680	53.81	0.20
2:19 PM -2:20 PM	12.60	28.58	2.10	4.84	0.81	1.62	2160	174.16	0.38
2:20 PM -2:21 PM	8.37	43.00	1.40	0.61	0.10	1.08	1680	17.12	0.07
2:21 PM -2:22 PM	11.26	31.96	1.88	3.50	0.58	1.45	1620	94.61	0.31
2:22 PM -2:23 PM	12.87	27.96	2.15	5.11	0.85	1.66	2040	173.89	0.40
2:23 PM -2:24 PM	10.99	32.77	1.83	3.23	0.54	1.42	2040	109.71	0.29
2:24 PM -2:25 PM	10.46	34.41	1.74	2.70	0.45	1.35	2160	97.29	0.26
2:25 PM -2:26 PM	9.79	36.78	1.63	2.03	0.34	1.26	1860	62.83	0.21
2:26 PM -2:27 PM	12.55	28.69	2.09	4.79	0.80	1.62	2220	177.14	0.38
2:27 PM -2:28 PM	14.43	24.94	2.41	6.67	1.11	1.86	1860	206.84	0.46
2:28 PM -2:29 PM	12.25	29.38	2.04	4.49	0.75	1.58	1860	139.29	0.37
2:29 PM -2:30 PM	14.86	24.23	2.48	7.10	1.18	1.91	1800	212.89	0.48
2:30 PM -2:31 PM	15.26	23.59	2.54	7.50	1.25	1.97	1500	187.52	0.49

2:31 PM -2:32 PM	12.85	28.01	2.14	5.09	0.85	1.66	1800	152.74	0.40
2:32 PM -2:33 PM	28.18	12.78	4.70	20.42	3.40	3.63	2100	714.67	0.72
2:33 PM -2:34 PM	15.46	23.28	2.58	7.70	1.28	1.99	2100	269.57	0.50
2:34 PM -2:35 PM	34.55	10.42	5.76	26.79	4.47	4.45	2340	1044.92	0.78
2:35 PM -2:36 PM	18.40	19.57	3.07	10.64	1.77	2.37	2100	372.23	0.58
2:36 PM -2:37 PM	14.18	25.39	2.36	6.42	1.07	1.83	1860	199.00	0.45
2:37 PM -2:38 PM	27.97	12.87	4.66	20.21	3.37	3.60	2100	707.50	0.72
2:38 PM -2:39 PM	15.16	23.75	2.53	7.40	1.23	1.95	1740	214.60	0.49
2:39 PM -2:40 PM	11.35	31.71	1.89	3.59	0.60	1.46	1920	114.97	0.32
2:40 PM -2:41 PM	10.47	34.37	1.75	2.71	0.45	1.35	1980	89.57	0.26
2:41 PM -2:42 PM	8.70	41.38	1.45	0.94	0.16	1.12	2040	31.96	0.11
2:42 PM -2:43 PM	9.82	36.67	1.64	2.06	0.34	1.27	2280	78.19	0.21
2:43 PM -2:44 PM	11.33	31.78	1.89	3.57	0.59	1.46	2280	135.63	0.32
2:44 PM -2:45 PM	14.48	24.86	2.41	6.72	1.12	1.87	1800	201.64	0.46
2:45 PM -2:46 PM	16.28	22.11	2.71	8.52	1.42	2.10	1800	255.58	0.52
2:46 PM -2:47 PM	12.86	28.00	2.14	5.10	0.85	1.66	2220	188.62	0.40
2:47 PM -2:48 PM	9.90	36.36	1.65	2.14	0.36	1.28	2100	74.92	0.22
2:48 PM -2:49 PM	11.69	30.80	1.95	3.93	0.65	1.51	1920	125.74	0.34
2:49 PM -2:50 PM	14.55	24.75	2.42	6.79	1.13	1.87	2100	237.53	0.47
2:50 PM -2:51 PM	12.62	28.52	2.10	4.86	0.81	1.63	1680	136.14	0.39
2:51 PM -2:52 PM	8.90	40.45	1.48	1.14	0.19	1.15	1740	33.06	0.13
2:52 PM -2:53 PM	11.98	30.05	2.00	4.22	0.70	1.54	2160	151.96	0.35
2:53 PM -2:54 PM	11.41	31.55	1.90	3.65	0.61	1.47	1560	94.94	0.32
2:54 PM -2:55 PM	10.37	34.72	1.73	2.61	0.43	1.34	1800	78.29	0.25
2:55 PM -2:56 PM	10.65	33.80	1.78	2.89	0.48	1.37	1680	80.92	0.27
2:56 PM -2:57 PM	7.76	46.39	1.29	0.00	0.00	1.00	1740	0.00	0.00
2:57 PM -2:58 PM	10.78	33.41	1.80	3.02	0.50	1.39	2040	102.51	0.28
2:58 PM -2:59 PM	8.99	40.04	1.50	1.23	0.21	1.16	1740	35.72	0.14
2:59 PM -3:00 PM	11.14	32.31	1.86	3.38	0.56	1.44	1440	81.18	0.30

APPENDIX D

Passenger Car Unit Analysis

Length=105 M

Morning peak period

Time in Sec							
Passenger	4WD	Mini Bus	Medium Bus	BUS	Small Truck	Truck	Truck & Trailer
13	15	13	15	15	12	18	0
16	16	14	13	14	18	21	
12	20	16	18	21	17	16	
23	14	18	19	13	19	19	
13	19	20	17	14	20		
17	19	16	20	27			
16	12	16	14	20			
19	16	14		17			
15	13	13					
13	14	13					
16	15	15					
15	14	19					

Space Mean Speed (Km/hr)							
24.13	**24.26**	**24.26**	**22.81**	**21.45**	**21.98**	**20.43**	**0.00**

Afternoon off peak period

Time: Sec							
Passenger	4WD	Mini Bus	Medium Bus	BUS	Small Truck	Truck	Truck & Trailer
18	16	17	18	17	17	15	25
15	17	18	15	20	16	22	20
16	22	20	16	19	20	18	23
17	21	16	17	22	14	21	30
17	15	21		16	18	21	21
16	13	20		23	17	17	27
15	17	16		16	23	18	19
18	15	15		13	16	35	
15	16	16		17	16		
19	14	19		15	19		
18	21	18			17		
19	20	19			18		

Space Mean Speed (Km/hr)

22.34	**21.91**	**21.10**	**22.91**	**21.24**	**21.50**	**18.11**	**16.04**

Evening peak period

Time in Sec							
Passenger Car	4WD	Mini Bus	Medium Bus	BUS	Small Truck	Truck	Truck & Trailer
18	19	16	16	14	13	20	0
16	12	14	19	18	18	17	
17	14	16	15	19	18	16	
18	15	14	16	14	17	17	
13	22	17	19	12	16		
18	11	14	21	17	19		
15	15	12	15	16			
15	16	14	14	18			
17	14	15	15	21			
14	17	11		16			
14	15	15		20			
16	12	17		15			

Space Mean Speed (Km/hr)							
23.75	**24.92**	**25.92**	**22.68**	**22.68**	**22.46**	**21.60**	**0.00**

Passenger car unit per vehicle

Vehicle	Average Area (M2)	Average Speed (Km/hr)	PCU=((Vc/Vi)/(Ac/Ai))
Passenger car and Taxi	7.42	23.41	1
4WD	7.89	23.69	1.05
Mini Bus	9.38	23.76	1.24
Medium Bus	19.37	22.80	2.65
Bus	29.07	21.79	4.29
Small Truck	11.00	21.98	1.56
Truck	20.39	20.05	3.19
Truck & Trailor	39.6	16.04	7.42

APPENDIX E

Capacity analysis

speed-Flow-Density result made during consecutive One minutes on Section one, Two and Three for peak hour

	Section One			Section Two			Section Three		
Peak Hour	Average Speed (Km/Hr)	Flow (Veh/Hr)	Density (Veh/Km)	Average Speed (Km/Hr)	Flow (Veh/Hr)	Density (Veh/Km)	Average Speed (Km/Hr)	Flow (Veh/Hr)	Density (Veh/Km)
7:15 AM -7.16 AM	10.4	1380	132.48	8.1	1680	207.33	41.4	1620	39.13
7.16 AM -7.17 AM	16.9	1740	102.73	8.0	2220	278.22	36.2	1920	53.05
7.17 AM -7.18 AM	10.6	2880	272.17	6.3	2040	323.05	39.5	1380	34.96
7.18 AM -7.19 AM	8.2	2220	272.21	7.0	2160	310.25	37.0	1620	43.76
7.19 AM -7.20 AM	12.3	2880	234.23	7.7	2100	271.97	35.7	1620	45.41
7.20 AM -7.21 AM	8.6	2400	280.15	6.6	2640	397.59	43.2	1320	30.56
7.21 AM -7.22 AM	10.9	2040	187.85	5.7	2820	497.81	41.8	2100	50.27
7.22 AM -7.23 AM	7.1	3600	505.00	8.1	3240	397.81	44.4	1860	41.89
7.23 AM -7.24 AM	10.2	3300	323.13	6.7	2460	366.83	39.7	1680	42.27
7.24 AM -7.25 AM	21.0	2760	131.23	6.3	1920	305.45	41.6	1980	47.61
7.25 AM -7.26 AM	7.0	2760	397.04	6.6	2580	393.15	40.4	1800	44.57
7.26 AM -7.27 AM	16.4	2580	157.67	6.5	3360	514.43	41.1	2340	56.99
7.27 AM -7.28 AM	8.9	2820	318.63	6.8	3600	528.18	42.9	2520	58.74
7.28 AM -7.29 AM	8.0	4260	534.59	7.7	3180	410.65	41.1	2700	65.75
7.29 AM -7.30 AM	13.4	3540	264.03	7.7	2760	356.85	42.5	2280	53.64
7.30 AM -7.31 AM	9.4	2640	281.68	6.6	2880	434.49	32.3	2400	74.21
7.31 AM -7.32 AM	12.0	3060	255.40	7.0	3060	438.03	32.8	2460	74.99
7.32 AM -7.33 AM	25.6	3000	117.40	6.5	3780	581.32	33.8	2040	60.37
7.33 AM -7.34 AM	31.0	2520	81.20	6.4	3420	536.35	31.7	2640	83.30
7.34 AM -7.35 AM	40.0	2400	60.00	7.2	3060	427.11	40.0	2520	63.00
7.35 AM -7.36 AM	36.1	2520	69.84	9.0	3000	335.06	36.9	1860	50.44
7.36 AM -7.37 AM	18.0	3300	183.14	9.0	2460	273.08	37.9	2100	55.42
7.37 AM -7.38 AM	9.2	2700	295.00	6.2	3180	509.66	37.6	1620	43.13
7.38 AM -7.39 AM	19.0	3660	192.32	6.5	2400	366.49	38.4	2040	53.18
7.39 AM-7.40 AM	8.6	2640	305.35	6.2	2760	445.48	37.9	1860	49.01
7.40 AM -7.41 AM	11.0	3000	273.92	6.5	2940	452.88	37.2	2160	58.00
7.41 AM -7.42 AM	11.2	2520	225.44	6.2	2340	379.36	39.0	2220	56.95
7.42 AM -7.43 AM	10.8	3660	338.52	6.0	1860	307.87	39.8	2340	58.77
7.43 AM -7.44 AM	18.1	3960	218.63	6.6	2160	326.82	37.8	2160	57.07
7.44 AM -7.45 AM	25.2	2760	109.69	6.5	2100	322.54	36.9	2220	60.13
7:45 AM -7:46 AM	33.1	2760	83.50	7.3	2040	278.48	37.2	2220	59.75
7:46 AM -7:47 AM	20.3	3900	191.81	7.1	2280	323.35	38.9	1620	41.67

7:47 AM -7:48 AM	28.5	3600	126.10	7.1	2760	390.71	35.6	1860	52.27
7:48 AM -7:49 AM	15.8	3840	242.79	5.6	2160	383.64	36.6	2160	59.05
7:49 AM -7:50 AM	13.3	3780	284.08	5.2	2280	439.10	38.1	1980	51.97
7.50 AM -7.51 AM	16.7	3000	179.25	8.2	2700	328.06	38.9	2040	52.42
7.51 AM -7.52 AM	8.8	2340	264.47	7.7	2460	319.15	35.6	1860	52.31
7.52 AM -7.53 AM	17.1	2760	161.49	6.6	2700	412.07	35.7	1560	43.74
7.53 AM -7.54 AM	14.2	2460	173.11	5.9	2700	453.93	39.0	1620	41.56
7.54 AM -7.55 AM	11.6	3120	269.19	6.5	2400	372.03	38.7	1560	40.32
7.55 AM -7.56 AM	11.8	2640	224.00	7.8	2640	338.79	38.8	1680	43.31
7.56 AM - 7.57 AM	14.3	2460	171.59	9.0	2880	321.50	38.1	1920	50.39
7.57 AM -7.58 AM	8.9	2400	269.05	6.7	2880	430.23	37.9	1740	45.92
7.58 AM -7.59 AM	9.0	2700	299.06	6.9	2640	382.54	42.2	1860	44.08
7.59 AM -8.00 AM	14.2	1980	139.88	6.7	2580	384.92	37.3	1740	46.68
8.00 AM -8.01 AM	8.8	2640	300.47	8.0	2700	336.69	37.2	2220	59.70
8.01 AM -8.02 AM	10.3	2880	280.57	8.2	2460	299.31	34.8	2160	62.14
8.02 AM -8.03 AM	9.1	3420	375.37	7.9	2700	341.97	32.4	1860	57.45
8.03 AM -8.04 AM	9.4	2580	274.84	8.2	3180	388.52	34.9	2160	61.89
8.04 AM -8.05 AM	12.6	3000	238.62	7.0	2520	361.67	32.4	1800	55.64
8.05 AM -8.06 AM	6.8	3480	511.71	9.1	2400	263.03	35.0	2100	60.05
8.06 AM -8.07 AM	11.1	2580	231.80	10.6	2640	249.55	34.6	2400	69.33
8.07 AM -8.08 AM	11.9	3060	256.25	7.5	2760	368.91	34.7	2220	63.89
8.08 AM -8.09 AM	8.0	3660	457.89	6.3	2400	380.39	33.0	2160	65.37
8.09 AM -8.10 AM	19.2	2880	149.88	7.7	2580	335.41	37.2	2280	61.29
8.10 AM -8.11 AM	9.2	2460	267.14	7.8	2160	277.88	32.9	1980	60.19
8.11 AM -8.12 AM	12.6	2760	219.31	6.4	2400	372.24	31.6	1800	57.05
8.12 AM -8.13 AM	8.3	3240	391.93	7.7	2040	266.10	34.5	1560	45.21
8.13 AM -8.14 AM	5.4	2640	486.85	8.0	1740	217.44	38.3	1500	39.17
8.14 AM -8.15 AM	15.0	2400	160.24	7.9	2460	313.06	36.4	1800	49.47