ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

TRAVEL TIME RELIABILITY TO EVALUATE THE PERFORMANCE OF BUS TRANSPORT SERVICE ALONG MAJOR CORRIDORS OF ADDIS ABABA CITY

MSc Thesis

By: Betselot Kassaw Mekonen

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 with a Focus on Road and Transportation Engineering Stream.

Advisors: Abel Kebede (Ph.D.)

Robeam Solomon (Ph.D.)

October 2024

Addis Ababa, Ethiopia

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Approved by Advisors and Board of Examiners

	Signature	Date
Abel Kebede (Ph.D.) Advisor		27/11/24
Robeam Solomon (Ph.D.) Advisor		25/11/2024
Emnete Tadesse (Ph.D. Candidate) Internal Examiner	for	25/11/2024
Anteneh Afework (Ph.D.) External Examiner		21/11/2024
Chair Person	Abrham Gebre (Dr.) Dean, School of Civil & Environmental Engineering	

Place and Date of Submission: Addis Ababa, Ethiopia, October 2024

UNDERTAKING

I the undersigned declare that this thesis entitled ‘‘***Travel Time Reliability to Evaluate the Performance of Bus Transport Service Along Major Corridors of Addis Ababa City’’*** is my original work performed under the supervision of my research advisors Dr. Abel Kebede and Dr. Robeam Solomonand has not been presented for a degree in any university. All sources of materials used for this thesis have been duly acknowledged.

Signature: ____________

Undertaker’s Full Name: Betselot Kassaw Mekonen
Place of Undertaking: Addis Ababa, Ethiopia

Date: October, 2024

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ABSTRACT

Travel time reliability (TTR) has been progressively considered an important measure of the performance of the transportation system. TTR is related to the travel experience and is significant to both users and public transport operators. The study investigates bus travel time reliability along major corridors in Addis Ababa, focusing on identifying key factors that influence reliability and proposing actionable improvements. As urbanization drives increased travel demand, public transport systems, particularly buses, are crucial for sustainable mobility. However, challenges such as traffic congestion, inadequate infrastructure, and unreliable services undermine their effectiveness. The main objective of the study is to characterize and develop predictive analysis of bus travel time reliability for a major corridors in Addis Ababa: Corridor 1 (Mexico to Haile Garment Square), Corridor 2 (Kara Kore to Wabi Shebelle Hotel/Mexico), and Corridor 3 (Megenagna to Derartu Square). The study aims to assess bus TTR, identify influencing factors and their impact on TTR of bus transport, and assess TTR from the users' perspective. A descriptive research method was used, combining quantitative and qualitative research approaches. Primary and secondary data were collected, including AVL (O-D-based) system data for travel time estimation and TTR modeling, as well as user perspectives gathered through interviews. A multiple linear regression model was applied to identify factors affecting bus TTR. Users were purposively selected at bus waiting stations along the corridors. Index-based analysis with the planning time index was used to measure the reliability of the study corridors, and travel time pattern revealing that peak hours (AM(6:30-9:30) and PM(4:00-7:30)), and weekdays (Monday, and Friday) were particularly unreliable. The regression model fit, using those variables, yielded adjusted R-squared values of 0.79 (79%) without interaction model and 0.8 (80%) with interaction for the study corridors. The analysis indicates that segment length, travel speed, dwell time, bus lanes, number of intersections, number of bus stops, bus frequency, time of the day, and day of the week are significant factors affecting bus travel time reliability across the corridors. Among interviewed users, 67% are unaware of the bus schedule, 50% acknowledged the impact of dwell time on bus TTR. 88% of respondents agreed on the effect of bus frequency and reported long waiting times, with 53% waiting over 30 minutes to get the next bus & 85% believe dedicated bus lanes reduce travel time. Users rated the day of the week and time of day as significant factors in TTR, with average scores of 1.58 and 2.1 out of 5, respectively, indicates the unreliability of travel time over the study corridors that supports the findings of the other numerical analysis. Therefore, the study recommends the need for tailored strategies, including optimizing bus schedules, implementing dedicated bus lanes, and improving communication and frequency, to enhance bus travel time reliability and user satisfaction. These insights offer valuable guidance for policymakers and transport authorities aiming to improve bus public transport services in Addis Ababa.

Keywords: Travel Time Reliability, Bus transport, urban corridors, regression model

TABLE OF CONTENTS

UNDERTAKING i

ACKNOWLEDGMENT ii

ABSTRACT iii

LIST OF FIGURES vii

LIST OF TABLES viii

ACRONYMS ix

CHAPTER ONE: INTRODUCTION 1

1.1 Background of the Study 1

1.2 Statement of the Problem 4

1.3 Research Objective 6

1.3.1 General Objective 6

1.3.2 Specific Objectives 6

1.4 Research Questions 6

1.5 Scope and Limitation of the Study 7

1.6 Significance of the Study 8

1.7 Organization of the Study 8

CHAPTER TWO: LITERATURE REVIEW 9

2.1 Travel Time Reliability in Urban Public Transportation System 9

2.2 Importance of Travel Time Reliability 11

2.3 Travel Time Reliability Measures 12

2.4 Factors Affecting Travel Time Reliability of Urban Corridors 13

2.5 Factors Affecting Bus Transport Travel Time Reliability 14

2.6 Travel Time Reliability and Level of Service (LOS) 15

2.7 Travel Time Reliability from User Perspective 16

2.8 Summary of Literature Review and Research Gap 21

CHAPTER THREE: METHODOLOGY OF THE STUDY 22
3.1 Description of Study Area 22
3.2 Research Methodology Flowchart 24
3.3 Research Approach and Design 24
3.4 Sample Size and Sampling Techniques 25
3.5 Data Requirement 26
3.6 Data Collection 26
3.7 Data Extraction Methods 29
3.8 Data Analysis Methodology 30
3.8.1 Estimation of Travel Time 30
3.8.2 Travel Time Reliability Factors Identification Analysis 31
3.8.3 Index Based Travel Time Reliability Analysis 33
3.8.4 Travel Time Reliability Regression Modeling 34
3.8.5 Interaction in Regression Model 36
3.8.6 One-Way ANOVA 36
3.9 Qualitative Data Analysis 37
CHAPTER FOUR: RESULTS AND DISCUSSIONS 38
4.1 Evaluating Travel Time Reliability of Bus Transport on Study Corridors 38
4.1.1 Index Based Travel Time Reliability Analysis 39
4.1.1.1 Travel Time Reliability Index Analysis for Corridor 1 39
4.1.1.2 Travel Time Reliability Index Analysis for Corridor-2 40
4.1.1.3 Travel Time Reliability Index Analysis for Corridor-3 40
4.2 Descriptive Statistics of Variables for the Study Corridors 42
4.3 Regression Model of Bus Travel Time Reliability 42
4.3.1 Testing Multiple Linear Regression Analysis 43
4.3.2 One-Way ANOVA Analysis 46
4.3.3 Multiple Linear Regression Analysis at Aggregated Level 47

4.3.4 Multiple Linear Regression Analysis at Disaggregated Level 50
4.3.5 Interactions in Regression Analysis at Aggregated Level......................................53
4.3.6 Interactions in Regression Analysis at Disaggregated Level 55
4.4 Travel Time Reliability from User Perspectives..59
CHAPTER FIVE: CONCLUSION AND RECOMMENDATION 64
5.1 Conclusion...64
5.2 Recommendation...65
REFERENCES 68
APPENDICES 74
Annex 1: Segments Along Each Study Corridor 74
Annex 2: Questionnaire...78
Annex 3: Segment level estimated travel time based on time of day and day of week 81
Annex: 4 Corridor level estimated travel time based on time of day and day of week for the study corridors...90
Annex 5: Corridors related data from Addis Ababa Transport Bureau 92

LIST OF FIGURES

Figure 1 Study Corridors map in Addis Ababa City (Own depiction using Google Map) 23
Figure 2 Study methodology flowchart (Source: Author depiction) 24
Figure 3 Travel time pattern for the study corridors based on time of day and day of the week 39
Figure 4 Normality test on the residuals of the model fit for the study corridors....................45
Figure 5 User's socio-demographics data 59
Figure 6 User perspective feedback on bus TTR attributes 60
Figure 7 Pictures during field data collection 61

LIST OF TABLES

Table 1 Presenting literature review based on the title, methodology and study findings 17
Table 2 Variables of travel time reliability and related glossary 32
Table 3 Travel time reliability measure analysis of corridor-1 based on segment and corridor level 39
Table 4 Travel time reliability measure analysis of corridor 2 based on segment and corridor level 40
Table 5 Travel time reliability measure analysis of corridor-3 based on segment and corridor level 41
Table 6 Descriptive Statistics of variables for the study corridors 42
Table 7 Ramsey RESET test for study corridors 43
Table 8 Pearson-correlation matrix between the independent variables 44
Table 9 Variance inflation factor summary of independent variables 44
Table 10 Breusch-Pagan / Cook-Weisberg test for heteroskedasticity 45
Table 11 One-way ANOVA test for travel time over the times of day 47
Table 12 One-way ANOVA test for travel time over the days of the week 47
Table 13 Multiple linear regression analysis result at aggregated level 48
Table 14 Multiple linear regression analysis result at disaggregated level 50
Table 15 Interaction regression analysis results at aggregated level 53
Table 16 Interaction regression analysis results for corridor 1 55
Table 17 Interaction regression analysis results for corridor 2 56
Table 18 Interaction regression analysis results for corridor 3 57
Table 19 Travel time reliability attributes/factors from the user perspective 60

ACRONYMS

ANOVA	Analysis of Variance
AVL	Automatic Vehicle Location
BI	Buffer Index
BRT	Bus Rapid Transit
BT	Buffer Time
DOT	California Department of Transport
C1, C2, & C3	Corridor 1, Corridor 2, and Corridor 3
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
LOS	Level of Service
MOE	Measure of Effectiveness
MSE	Mean Square Error
PTI	Planning Time Index
PT	Planning Time
RMSE	Root Mean Square Error
TTI	Travel Time Index
TTR	Travel Time Reliability
SPSS	Statistical Package for the Social Sciences

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Transportation is essential for the social, economic, and political development of cities worldwide, facilitating the movement of people, goods, and services. Public transport, a key element of urban mobility, plays a crucial role in sustaining urban life by alleviating traffic congestion and reducing the negative impacts of car dependency (Kehinde, 2019; Murad & Sanjaya, 2022). As part of a broader transportation system, public transport services, including buses, contribute to enhanced quality of life by providing affordable, accessible, and environmentally friendly transportation options. However, public transport systems can also contribute to challenges such as delays, traffic congestion, and environmental pollution (Imam, 2019).

Traffic congestion is a widespread issue in cities across the globe, leading to significant delays and inefficiencies in transportation systems (Asfaw, 2018). For deve loping countries, addressing road traffic congestion presents unique challenges due to rapid urbanization, inadequate infrastructure, and limited resources for public transport investment (Alebe et al., 2023). Effective congestion management is critical to improving travel efficiency and reducing delays, particularly in urban public transport systems. Strategies such as optimizing traffic flow, enhancing infrastructure, and encouraging public transport use are essential to mitigating these challenges. Contributing factors traffic congestion include low public transport service quality, inadequate infrastructure for non-motorized transport, rising car ownership, high rates of traffic accidents, roadside parking, and the limited capacity of the road network. This congestion leads to highly unreliable travel times, making travel time reliability an increasingly important performance measure for evaluating traffic conditions. As businesses and households become more dependent on punctual transportation, particularly in public transport systems, the reliability of travel times has emerged as a critical factor Gebremeskel et al. (2023).

Urban communities worldwide heavily depend on transportation systems to sustain their economies and enable the daily movement of people and goods (Vladimir et al., 2021). Urban transport plays a crucial role in advancing sectors like industry, trade, education, and health. As a result, urban transportation and mobility have emerged as key concerns for urban planners and city managers, particularly in developing countries. In these regions, cities often struggle to gather the necessary data for effective urban public transport planning (Cheng et al., 2023). Specifically, bus transport, a common mode of passenger travel within cities, frequently suffers from a mismatch between supply and demand. This imbalance, coupled with inadequate management, aggravates the challenges of meeting the growing mobility needs of people and goods (Toan, 2019). In developed countries, while bus systems benefit from better infrastructure and technology, they often face issues related to congestion, aging infrastructure, and high operational costs, making it difficult to provide efficient and reliable services. On the other hand, developing countries encounter distinct challenges, such as poor road conditions, limited funding for public transport, and outdated fleet management systems, which further hinder the ability to meet increasing travel demands. As economic and population growth drive higher travel demand, both developed and developing cities struggle to balance efficiency, reliability, and accessibility in their transportation systems.

In the case of Addis Ababa, these challenges are even more pronounced. The city, like many in developing countries, is experiencing rapid urbanization and population growth, which has placed immense pressure on its public transport network. Limited infrastructure, inadequate service frequency, and unreliable travel times are common issues. Addressing these challenges, particularly along major bus corridors, is critical to improving mobility and meeting the transportation needs of the growing population. The studies with the case of Addis Ababa city indicated a significant disparity between public transport supply and demand (Alebe et al., 2023; Wubneh, 2013). As the city continues to grow economically, demographically, and geographically, there is an urgent need for expanded mass transport services, supported by advanced technology, to enhance capacity and ensure reliable travel times for users (Gebremeskel et al., 2023).

The reliability of a transport system can be evaluated using TTR measures or indices such as the Buffer Time Index, Planning Time Index, 95th Percentile Travel Time, Travel Time Index, and the Standard Deviation of Travel Time. Travel time reliability is a widely recognized indicator for assessing transportation system performance and traffic conditions. In the past decade, its significance in traffic management, control, and network design has gained significant attention. As a key factor in transportation network efficiency and service quality, travel time reliability has a profound impact on a wide range of stakeholders, including users, service providers, planners, and managers (Jing et al., 2016).Travel time reliability measures, such as the buffer time index, planning time index, and travel time index, provide insights into the certainty of service operation (Maciej et al., 2019). According to FHWA US-DOT (2015), travel time reliability is a crucial aspect of congestion that has historically been overlooked in the congestion management process. As a key performance indicator, travel time reliability reflects the impact of traffic uncertainties on transport services. Accurate predictions of travel time and its reliability assist travelers in making informed decisions about departure times and route choices during pre-trip planning and navigation.

Reliability-based performance measures shift the focus from asking, "How is the traffic today?" to "What is the probability that traffic will be bad today?" (Roger & Elena, 2014). Reliability is concerned with the variation in travel time for any given trip or journey. The travel time reliability of urban corridors is influenced by multiple factors. Specifically, bus transport reliability is affected by departure delays, the number of bus stops, signal intersections, bus lanes, day of the week, weather conditions, time of day, route/corridor length, and dwell time (Hareth et al., 2022). According to the study by Ernest & Laurence (2021) emphasized the growing need for reliable performance measures in urban corridors due to increasing traffic congestion and the high value users place on travel time. Accurate travel time predictions are essential for users as they assist in route selection. Travelers' decisions regarding route choice and departure time hinge on predictable travel times and their reliability. For transport planners, developing appropriate metrics for travel time reliability and ranking different links based on performance is crucial. This prioritization aids in identifying which urban corridors require improvements and in implementing effective mitigation strategies. However, the travel time experienced by a traveler on an urban corridor is influenced not only by their own choices such as destination, mode, route, and speed but also by the decisions of many other travelers, including those not necessarily on the same route.

In Africa, research has primarily concentrated on identifying the factors that influence travel time reliability in bus rapid transit (BRT) corridors. However, these studies have often failed to clearly demonstrate the actual reliability or unreliability of travel time experienced by road users (Mandlate et al., 2023; Prosper et al., 2020). Furthermore, studies by George et al. (2023), Mchome & Nzoya (2023), Yanan et al. (2022), and Olufikayo et al. (2020) have examined travel time reliability in public transport systems across African countries like Ghana, Nigeria, and Tanzania, focusing on BRT systems as case studies. These studies suggest that the introduction of BRT systems has positively influenced commuters' perceptions of public transport. Assen & Quezon (2019) assessed the road network's performance for the case of Addis Ababa, Ethiopia by analyzing travel time reliability and employing reliability modeling to pinpoint the key factors influencing travel time reliability on various road segments. Moreover, Gezahegn (2019) highlighted that travel time reliability across all transport services is heavily impacted by factors like traffic composition, driver behavior, link capacity, speed limits, signal timing, and the geometric design of roads and intersections. Additionally, factors such as adjacent land use, median types, signalized intersection spacing, passenger boarding and payment practices, and conflicting traffic from crossroads all contribute to variations in travel times. Understanding those specific elements is essential for tackling the challenges associated with bus travel time reliability.

While general studies on travel time reliability (TTR) provide valuable insights, they often fail to address the specific challenges faced by bus public transport along major corridors. In Addis Ababa, these corridors serve as the backbone of the city's transport network, handling a majority of the passenger traffic. Studying TTR along these major corridors is essential because these routes typically experience high levels of congestion, varying traffic conditions, and operational inefficiencies. By focusing on these major corridors, this study provides crucial insights into the primary factors affecting bus travel time reliability in the most heavily used parts of the network. These insights will help to identify targeted solutions, such as optimizing bus schedules, improving infrastructure, enhancing user engagement, and implement dedicated bus lanes. Ultimately, improving reliability on these corridors will enhance bus public transport efficiency, reduce delays, and improve the user experience, benefiting both the city's commuters and its wider transportation system. Despite existing research, there's still a gap in exploring bus TTR along these major corridors. Addressing this gap is crucial for optimizing the performance of Addis Ababa's bus public transport system and meeting the growing demand for reliable bus services.

1.2 Statement of the Problem

Travel Time Reliability (TTR) is a crucial metric for assessing the consistency of travel times, which significantly impacts both users and operators. TTR is integral to evaluating transportation system performance, as it affects the overall travel experience. High traffic demand and limited road capacities often lead to extended travel times, with users spending considerably more time on their daily journeys (Sharmili et al., 2021). In urban settings, travel times are influenced by fluctuations in traffic demand, traffic control measures, accidents, and unforeseen events. Research indicates that commuters frequently experience time losses due to traffic congestion and inadequate public transport systems (Anish et al., 2018; Tanzina & Nita, 2020). Issues such as traffic congestion, low service quality, and inadequate public transport led to delays in arriving at workplaces and appointments. In today's fast-paced world, punctuality is crucial for worker efficiency and economic development (Xing & Hao, 2016). Thus, understanding congestion impacts and assessing the reliability of travel times is essential.

Previous studies by Mandlate et al. (2023), George et al. (2023), Yanan et al. (2022), and Krishna (2014) have investigated public transport travel time reliability (TTR), particularly in bus rapid transit corridors within developing African countries. These studies emphasize that traffic congestion and variability in travel times significantly undermine urban transportation systems, reducing overall network performance and efficiency. In Addis Ababa, traffic congestion is a major issue typically assessed using metrics such as delay, travel time, level of service (LOS), density, volume, demand, saturation flow rate, capacity, and average travel speed. While these metrics are useful for evaluating network performance and traffic conditions, they fail to fully capture the impact on users (Dursa & Tune, 2020). Unreliable travel times, driven by inconsistent public transport services, inadequate infrastructure, and poor traffic management, often result in delays that negatively affect worker punctuality and productivity.Factors such as inconsistent public transport services, inadequate infrastructure, and poor traffic management contribute to unreliable travel times, resulting in late arrivals that negatively affect worker punctuality and productivity. Despite existing research on travel time reliability in various contexts, there is a significant gap in targeted studies examining bus travel time reliability along major corridors in Addis Ababa. This study seeks to fill that gap by focusing specifically on these critical issues. While previous studies have modeled travel time reliability of all public transport service for road segments in Addis Ababa (Assen & Quezon, 2019); Gezahegn, 2019). However, there remains a significant gap in research focusing specifically on travel time reliability of bus services along major corridors in the city. The identified gaps from their study included the lack of targeted research on bus travel time reliability along key corridors and insufficient integration of user feedback into reliability analyses. Existing studies often offer generalized solutions that do not address the unique challenges of Addis Ababa's public transport system. This study aims to bridge this gap by investigating the factors influencing bus travel time reliability in major urban corridors and aimed to address those gaps.

This study focuses on bus travel time reliability along major corridors in Addis Ababa and aims to identify key factors affecting bus TTR and provide a comprehensive assessment of user perspective on bus transport TTR that integrates both quantitative and qualitative data. By combining data-driven insights with user feedback, the study offers a well-rounded understanding of reliability factors, ensuring findings are both accurate and reflective of user experiences. Moreover, the aim is to provide actionable recommendations for optimizing bus schedules, reducing delays, minimizing travel time variability, and enhancing overall service reliability. These improvements will benefit daily users' by ensuring a more efficient and dependable bus transport experience. The findings offer valuable guidance for policymakers to implement targeted infrastructure improvements, such as optimized bus schedules and dedicated bus lanes. These strategies can significantly enhance bus travel time reliability, reduce peak-period congestion, and make public transport a more reliable and attractive option. By addressing these factors, the study supports long-term sustainability goals by promoting bus transport and reducing dependence on private vehicles.

1.3 Research Objective

1.3.1 General Objective

The general objective of this study is to characterize and develop predictive analysis of bus travel time reliability for a major urban corridors.

1.3.2 Specific Objectives

The specific objectives of the study are to:

- Assess the travel time reliability of bus transport on major urban corridors.
- Identify the factors and their level of influence on travel time reliability of bus transport service along the major urban corridors.
- Incorporate the users' perspective in evaluating the bus transport travel time reliability.

1.4 Research Questions

To achieve the objectives of the research, the following research questions were formulated:

- How does bus travel time reliability vary by time of day (AM and PM peak hours) and day of the week, and how do these variations impact the service quality of bus transport?
- What are the key factors affecting bus travel time reliability on major urban corridors, and how do those factors interact?
- How do bus users perceive the reliability of bus transport based on their experiences, and what insights can be gained to improve service reliability?

1.5 Scope and Limitation of the Study

This study focuses on the travel time reliability of bus transport along major corridors in Addis Ababa. It does not include other road sections and intersections outside these major corridors. The major corridors under study include those with dedicated spaces for public transport services, such as exclusive bus lanes, cycling lanes, and high-quality pedestrian areas. Service lanes may also be utilized to manage access to adjacent land uses. The service lanes help in organizing traffic flow and reducing congestion on major roads by providing separate routes for accessing nearby businesses or residential areas. In the context of Addis Ababa, major corridors are key arterial routes that facilitate the movement of large volumes of people and goods, connecting high-density residential areas with central business districts, commercial zones, and other significant destinations. These corridors are typically defined by their strategic importance to the city's transportation network, high traffic demand, and frequent use by public transport vehicles, especially buses. The scope of this study aligns with its main objective of assessing bus transport travel time reliability along these major corridors and identifying factors affecting bus travel time reliability in the study area.

The thesis does not address factors affecting the travel time reliability of bus transport under non-recurrent conditions, such as traffic accidents, unexpected events (vehicle malfunctions, special events, debris on the road, and security checks or roadblocks), and weather conditions. Additionally, pedestrian activities, and TTR factor like segment or road width are not considered in this study. Due to time and budget constraints, the study focuses on a selection of major corridors that are more congested and have a higher number of bus stops, rather than including every corridor in the city. Moreover, due to complexity of variables and data availability factors like network design and traffic signal time are not included as a factor of bus transport TTR in this study. The division of these corridors into segments is only based on the spacing of bus stop stations but not based on the spacing of intersections. Moreover, due to the division of corridors based on bus stop stations traffic volume is not considered as a factor in this study.

1.6 Significance of the Study

The significance of the study lies in its potential to address the impact of traffic congestion on urban development in Addis Ababa. By examining the travel time reliability of bus transport along major corridors, the research provides crucial insights for various stakeholders, including transportation planners and decision-makers at the city bus services and the authority, and also planning policies. These insights can help in formulating strategies to enhance public transport reliability, promote its use over private cars, and ultimately alleviate traffic congestion. The study supports evidence-based decision-making and policy planning by offering valuable travel time-related information, thereby helping to improve public transport services and overall service quality.

1.7 Organization of the Study

The thesis is organized into five chapters. Started with this - Chapter one, which introduced the background, problem statement, objectives, scope, and contribution of the study. Chapter two reviews detailed literature on definition of travel time reliability, importance of TTR, reliability measures and TTR factors. Subsequently, chapter three explains the method including the study area, research approach and design, data collection, and analysis techniques. Chapter four explains the results and discusses the main empirical results, and findings. Chapter five draws conclusions and forward recommendations.

CHAPTER TWO: LITERATURE REVIEW

This chapter presents the literature review on travel time reliability, its measures, factors, and related issues. The first three subsections cover the concept of travel time reliability, its suitability for traffic performance analysis, its importance, and its applications in determining route choice. The fourth subsection, which focus on time reliability factors in urban corridors and major transport corridors within large cities Finally, the fifth subsection links travel time reliability to Level of Service (LOS) within the Highway Capacity Manual (HCM) framework for urban roads.

The last subsection serves as a Summary of the Literature Review and presents the research gaps identified from the existing studies. It synthesizes the discussions on travel time reliability, its measures, and factors, and highlights areas where further research is needed to address gaps in the literature, particularly regarding its application to urban corridors and bus transportation in large cities

2.1 Travel Time Reliability in Urban Public Transportation System

Public transport provides a vital service by enabling access to education, employment, medical care, and recreation (Herath et al., 2022). The mobility of people, goods, and services is essential to any society, with a strong correlation to a country's economic vitality. In the developing world, rapid motorization combined with inadequate infrastructure and financial limitations leads to a mismatch between public transport supply and demand, contributing to declining service quality. Addressing this issue requires a focus on improving travel time reliability within the road network to sustain a functional public transport system.

Travel Time Reliability (TTR) has been defined in various ways in the literature. Initially introduced in the early 1950s, the concept of reliability was applied to both communication and transport systems (Murad & Sanjaya, 2022). Higatani et al. (2009) defined reliability as "the probability that a system or component performs its required function at a given time or over a specified period, without the need for repair work." TTR measures the variation in travel times and is crucial for evaluating transport performance. However, no single metric of reliability is universally accepted, easy to understand, and applicable across different locations (Banik et al., 2021).

Emam & Al-deek, (2006) proposed a definition for TTR as "a road segment is considered 100% reliable if its travel time is less than or equal to the travel time at the posted speed limit". Based on this definition, reliability is highly sensitive to the geographical location indicating the level of congestion and bottlenecks. According to (Saptarshi et al., 2019), the study to determine the travel time reliability of various public transportation modes along a specific route in Kolkata city, India. The study by (Mohamed et al., 2021) revealed that buses experience a high signal and congestion delay during peak hours. So, their study overlooked the travel time reliability from the user perspective for bus transport performance and the impact of congestion on travelers.

Sharmili et al., (2021) defined travel time as the time taken to traverse a route between any two points of interest and also it is a fundamental measure in transportation. The travel times for urban areas are susceptible to higher degrees of variability either due to recurring (fluctuations in traffic demand, presence of control features) or non-recurring (traffic incidents or occurrence of any unexpected events) traffic events. In addition, TTR described as the measure of consistency or dependency in travel conditions over time, has been increasingly considered as an important measure of the performance of the transportation system, as it is related to the travel experience and is important to both users and operators. Florida Department of Transportation (FDoT, 2000) referred reliability as the percentage of travel that takes no longer than the expected travel time plus a certain acceptable additional time. California Department of Transport (CalDOT,1998) defined reliability as the level of variability between the expected travel time (based on scheduled or average travel time) and the actual travel time experienced.

According to Narang (2012) a typical definition for travel time reliability is the consistency or dependability in travel times, as measured from day to day and/or across different times of the day. Travel time reliability is a measure of the stability of travel time and is subjected to fluctuation in flow and capacity. Generally, all definitions suggest that reliability is an indicator of the operational constancy of a service over an extended period, measured as some function of the amount of non-recurrent delay and/or recurrent delay that occurs during that period. In conclusion, the value of understanding how much travel time is reliable or not to users has important implication and can be utilized for the development of policies by transport planners and decision makers. Therefore, understanding time reliability for road users have become critical and helps transportation system planners to design and plan accordingly targeted for the users.

2.2 Importance of Travel Time Reliability

Travel time reliability represents the temporal uncertainty practiced by users in their movement between any two nodes in a road network. Transportation planners and decision-makers should consider travel time reliability as their key performance measure (Narang, 2012). The importance of time reliability depends on the penalties incurred by the user's significance of travel time reliability compared to other network reliability measures like connectivity reliability or capacity reliability has resulted in several studies in the area of transport network reliability. Kittelson, & Vandehey (2013) found that the applicable functional hierarchy of roads may be disturbed by travel time uncertainty. The study also suggested that a reliability index of travel time is a useful and important measure to evaluate both the actual LOS and functional hierarchy of roadway networks.

Travel time reliability is significant to many transportation system users, whether they are vehicle drivers, transit riders, freight shippers, or even air travelers. Personal and business travelers value reliability because it allows them to make better use of their own time. Shippers and freight carriers require predictable travel times to remain competitive (FHWA, 2019). Travel time reliability is important in choosing a mode of transport for travelers to decrease travel time, travel cost, and maximum delay (Doohee, 2017). One of the most important qualities of drivers of public transportation is reliability in travel time reliability. To benefit both passengers and operators, many improvements in travel time reliability are required. In addition, the lack of punctuality and certainty of the scheduled departure and arrival times are considered the most important issues that affect the travel time reliability of public transportation (Zhenliang et.al., 2015).

Travel time reliability (TTR) is a crucial index for evaluating the performance of road networks and improving their travel efficiency (Jiang et al., 2016). Traffic professionals value TTR because it captures the benefits of traffic management and operational activities more effectively than simple averages, which only calculate average travel time without considering its variability or consistency. As a result, TTR has become a key performance indicator for transportation systems. While Karami et al. (2021) and Smith (2016) highlighted the importance of TTR to travelers, they did not address the impact of congestion or use TTR as a measure for bus transport performance. Similarly, Anish et al. (2018) focused on TTR measures like the planning time index for Level of Service (LOS), but their study did not consider delays or how reliable travel times are for users. This gap has prompted further research into developing measures to quantify travel time reliability and its variability.

2.3 Travel Time Reliability Measures

Anish et al., (2018) demonstrated how travel time reliability can be used to quantify the level of service (LOS) for urban arterial and inter-urban highway corridors on Indian roadways. Automatic vehicle license plate number data were gathered using the traffic monitoring system to estimate travel times. The researchers fully use the video-base system to analyze what is set in the entry and exit of the section. The travel time analysis showed that the urban uninterrupted and intercity highway routes' respective PTI thresholds for LOS B were 1.37 and 1.01, respectively, which suggested the urban uninterrupted study route has 1.37 times longer travel time than the free-flow corridor.

Sharmili et al. (2021) conducted a case study in Chennai city to explore the applicability of travel time reliability measures using GPS data collected from buses operating along the study corridor. The study compared various statistical range measures, such as buffer time, tardy trip, probabilistic, and congestion measures, which revealed that different measures can indicate varying levels of reliability. Similarly, Saptarshi et al. (2019) assessed the travel time reliability of various public transport modes along a specific route in Kolkata, finding that bus journey time reliability ranged from 45 to 65 percent compared to metro rail. The study estimated parameters like buffer time, buffer index, planning time, and planning time index, providing valuable insights into bus transport reliability. Other key traffic parameters, such as congestion delay and waiting time delay, were also analyzed, with results showing that buses experience significant signal and congestion delays during peak hours.

Harsha & Mulangi (2021) investigated travel time variability by analyzing travel time distributions using temporal (peak and off-peak) and spatial (route and segment) aggregations. They found that the generalized extreme value distribution best characterizes public transit trip time variability in Mysore City, India. Similarly, Tanzina &Nita (2020) reviewed road traffic congestion measures, such as speed, travel time, delay, level of service, and congestion indices, comparing them with real-time traffic data. Their analysis highlighted the strengths and weaknesses of each measure, suggesting improvements for long-term traffic management. Sourabh et al. (2017) predicted travel time by analyzing traffic characteristics like flow, speed, and diversion routes, offering insights into congestion on urban arterial roads with heterogeneous traffic. They combined predicted journey time with free-flow time using a congestion index. Lastly, Sharmili et al. (2021) discussed travel time reliability measures based on daily travel time distributions on specific routes, categorizing them into statistical range, buffer time, tardy trip, probabilistic, and congestion/volume-based measures.

In summary, reliability measures based on different empirical studies, reliability measures are commonly used to measure the reliability of travel time in urban corridors. These reliability measures include travel time index, planning time, buffer time, planning time index, and buffer time index (FHWA 2019), and (Doley D., & Maurya A. 2024).

Planning time: it represents the total time that should be expected or 'planned' when an adequate buffer time is included. It is the 95th percentile of the measured travel time. PT represents travel time on some of the highest traffic days.

Planning time index: it is the ratio of the planning time to the free flow travel time. The PTI indicates the severity of traffic congestion as it represents the worst level of congestion at a given time of the day compared with the free flow traffic condition.

Buffer time: - is the difference between planning time and average travel time. It represents the extra time to ensure on-time travel arrival to the destination. This extra time accounts for any unexpected delay.

Buffer time index: - is defined as the ratio of buffer time to the average travel time.

Therefore, from the empirical studies finding the most effective methods of measuring travel time reliability are 90th or 95th percentile travel times, buffer index, and planning time index. In addition, several statistical measures, such as standard deviation and coefficient of variation, have been used to quantify travel time reliability.

However, the Federal Highway Administration's (FHWA) travel time reliability measures, used in this study, are designed for U.S. traffic conditions and differ from Ethiopia's context.

2.4 Factors Affecting Travel Time Reliability of Urban Corridors

Hojati et al. (2021) inestigated a study on TTR of urban corridors and the finding of the study indicates that work zones, insidents, weather conditions, traffic volume and signal intersections are significant factors of TTR on urban corridors for both recurrent and non-recurrent traffic conditions.

Lohmiller (2012) indicated that surface transportation in urban areas in general experiences a problem of low travel time reliability. Non-recurring traffic congestion is one of the prime factors affecting travel time reliability in the case of surface transportation. Some of the variables affecting reliability such as volume-capacity ratio, route length, number of intersections, passenger loading, etc. (Doohee, 2017). Time reliability depends strongly on traffic congestion, which has many sources such as bottlenecks, traffic incidents, bad weather, work zones, poor signal timing, and special events (Li et al., 2019). The travel time reliability on arterial networks is usually not only a function of traffic flow, driver behavior, traffic composition, roadside parking, link capacity, and speed limit, but also involves numerous other factors such as signal timing, roadway and intersection geometries, adjacent land use and development, median type, signalized intersection spacing, and conflicting traffic from cross streets (Polus, 2012).

A study by Gezahegn (2019) indicated that the travel time reliability on urban corridors is usually not only a function of traffic flow, driver behavior, traffic composition, link capacity, and speed limit, but also involves numerous other factors such as signal timing, roadway, and intersection geometries, adjacent land use and development, median type, signalized intersection spacing, passengers boarding and paying cash, and conflicting traffic from crossroads. On the other hand, TTR factors are categorized into primary and secondary factors. The primary factors are demand, weather conditions, and accidents whereas the secondary factors are heavy goods vehicles, day of week, time of day, local traffic rate, and commuter traffic rate (Lohmiller, 2012). Polus (2012) highlighted that the reliability of urban arterial routes is mainly influenced by traffic volume and average speed. Other critical factors include congestion levels and junction saturation, which are related to traffic and geometric features such as pavement width, segment length, and grade. Similarly, a study by (Ali et al., 2021) identified traffic congestion issues based on stakeholder perceptions in Lahore, Pakistan. Key causes of congestion and extended travel times included illegal roadside parking, poor driver and shopkeeper behavior, encroachments, and conducting business on public streets.

2.5 Factors Affecting Bus Transport Travel Time Reliability

One of the most important drivers of public transportation quality is reliability in travel time reliability. According to (Mohamed et al., 2021), study analysis result and findings show that the travel time reliability of buses is strongly affected by the number of bus stoppings, the number of signalized intersections along the route or corridor, the length of the route or corridor, and passengers boarding and paying cash. The findings show that public bus travel time reliability is strongly affected by the number of bus stop stations, segment or corridor length, day of the week, number of intersections along the corridor or route, passengers boarding and paying cash (dwell time). Traffic congestion creates a major concern for the reliability of the bus travel time. Many factors affect the reliability of bus travel time, such as inadequate green time, pedestrian crossings, and over-development. Although many travelers face traffic delays caused by congestion (Zhu et al., 2021). Improvements in trip-time reliability are essential for benefiting both passengers and operators (Zhenliang et al., 2015).

Punctuality and certainty of scheduled departure and arrival times are key factors influencing the travel time reliability of public bus transportation.

In summary, the factors influencing travel time reliability (TTR) along major urban corridors are specific to the study area but also share a common characteristics. General factors affecting TTR include bottlenecks, traffic incidents, adverse weather, work zones, poor signal timing, traffic composition, speed limits, roadside parking, roadway and intersection geometries, median types, driver behavior, demand, and time of day. For bus transportation, additional factors include the number of bus stops, number of intersections along the corridor, corridor or segment length, departure and arrival delays, weather conditions, traffic volume, average travel speed, bus frequency, bus lane exclusivity, day of the week, time of day, dwell time (passenger boarding patterns, and payment methods).

2.6 Travel Time Reliability and Level of Service (LOS)

Russell (2014) examined the analytical and quantitative relationships between travel time reliability measures and Level of Service (LOS). The researcher recommended using the coefficient of variation as a reliable proxy for several other travel time reliability measures, such as the planning time index, median-based buffer index, and skew statistics, due to its relative stability compared to other measures. In contrast, standard deviation was found to be less stable and, therefore, not recommended as a proxy. However, the study suggested that standard deviation could potentially be replaced by the coefficient of variation (the ratio of standard deviation to the mean) in assessing travel time reliability. Similarly, Swapneel and Srinivas (2019) computed travel time measures, including average travel time, the 95th percentile travel time (planning time), the planning time index (PTI), and the buffer time index (BTI), based on the posted speed limits of selected road links. They examined the relationships between estimated speeds from a regional network model and these travel time measures to develop LOS thresholds at the link level according to posted speed limits.

Other findings are that the buffer index and percent of on-time-arrival would be described based on median, rather than average to avoid underestimating reliability. The study found that travel time reliability generally fails as traffic congestion increases as shown by the relationship between reliability measures and the travel time index. This reliability measure thus may be suitable to measure LOS since under free flow conditions the LOS is maximized at its optimum potential, but if the maximum travel time increases above this, i.e. the travel time index is an increasingly positive number, it indicates congestion (Kittelson & Vandehey, 2013).

2.7 Travel Time Reliability from User Perspective

In developing countries, research indicates that users often experience significant delays due to factors such as traffic congestion, inadequate infrastructure, and inefficient service management. Tirachini & Catalano (2015) found that commuters in Santiago, Chile, expressed concerns about the unpredictability of bus arrival times, which directly impacted their daily planning and overall satisfaction with the transport service. In contrast, research in developed countries reflects a somewhat different user perspective on TTR. For instance, Kearns & Speed (2018) explored user attitudes toward bus services in the UK and found that while reliability is essential, users also value additional factors such as comfort and accessibility. Their findings suggest that improvements in TTR can lead to increased ridership and enhanced public perception of bus services. Moreover, Buehler & Pucher (2011) highlighted that, in many European cities, well-managed bus systems with dedicated lanes and efficient scheduling have resulted in higher user satisfaction regarding travel time reliability. Users in these contexts often expect real-time updates and precise scheduling, reflecting a higher baseline for what constitutes reliable service

Users typically gauge reliability by the likelihood that a bus will arrive and depart as scheduled, minimizing delays and reducing overall waiting time. For passengers, a reliable system means they can plan their trips with confidence and experience minimal disruptions, which is particularly crucial in a congested urban environment like Addis Ababa, where timely arrival is often impacted by unpredictable traffic conditions (Sohail et al. 2006). From a user perspective, travel time reliability in public transport, particularly for bus services in Addis Ababa, is defined as the consistency and predictability of travel times that allow passengers to reach their destinations within a reasonable or expected timeframe. In contrast, an operational perspective of travel time reliability focuses on achieving consistent service performance from the transit agency's side. This includes maintaining headways (time intervals between buses), adhering to schedule adherence, and managing on-time departures and arrivals across different times of the day and week. Operational reliability encompasses factors like managing dwell times, optimizing bus frequencies, and addressing bottlenecks (Gezahegn, 2019).

In Addis Ababa, these two perspectives can diverge due to external factors like traffic congestion, limited infrastructure (e.g., few dedicated bus lanes), and varying demand patterns across peak and off-peak hours. For instance, while operators may prioritize maintaining scheduled headways, users may still experience unreliability due to frequent delays at intersections or prolonged waiting times caused by congestion. As a result, although operators might meet internal metrics for reliability, users may continue to view the service as inconsistent and unreliable (Shah et al. 2020). Overall, while both developing and developed countries recognize the importance of travel time reliability, the specific challenges and user expectations can vary significantly. Addressing the unique needs of users in developing contexts, such as enhancing information systems and improving infrastructure, is essential for improving public transport reliability and increasing user satisfaction.

Therefore, travel time reliability for users emphasizes timeliness and predictability in the context of daily commuting needs, while for operators, it centers on system efficiency and performance consistency. This distinction highlights the need for an integrated approach to improve user-perceived reliability by aligning operational metrics with actual commuter experiences.

The reviewed literatures are presented below in table 1 based on the Authors name, study title, methodology, and study finding.

Table 1 Presenting literature review based on the title, methodology and study findings

Authors	Study Title	Methodology	Findings
Herath et al. (2022)	Identification of Factors Affecting the TTR of Public Bus Transportation	Literature review on public transport's role in accessibility	Highlighted public transport's importance in enabling access to essential services; noted issues in developing countries, with focus on travel time reliability
Murad & Sanjaya (2022)	Public Transport Affordability Evaluation for Addis Ababa City	Definition analysis	Defined TTR as a probability-based concept, noting its application in both communication and transport systems
Higatani et al. (2009)	Empirical analysis of TTR measures in Hanshin expressway network	Definition of reliability	Described reliability as a probability of performance over a specific time period; introduced reliability's relevance in evaluating transport performance
Emam & Al-deek (2006)	Using Real-Life Dual-Loop Detector Data to Develop a New Methodology for Estimating Freeway TTR	Defined TTR by road segment speed limits	Defined a road segment as 100% reliable if travel time is within posted speed limits; highlighted reliability's sensitivity to congestion and bottlenecks

Authors	Study Title	Methodology	Findings
Hojati et al. (2021)	Assessing the major causes of TTR on urban freeways	Investigated TTR on urban corridors, focusing on recurrent and non-recurrent traffic conditions	Work zones, incidents, weather conditions, traffic volume, and signal intersections significantly affect TTR
Lohmiller (2012)	Factors influencing the TTR of motorway section	Analyzed factors affecting TTR in urban roads focusing on non-recurring congestion	Identified volume-capacity ratio, route length, intersections, and passenger loading as factors affecting reliability. Non-recurring traffic congestion is a major factor
Li et al. (2019)	TTR measure based on predictability using the Lempel–Ziv algorithm	Focused on arterial network TTR and its dependency on various factors	TTR is influenced by traffic flow, driver behavior, traffic composition, roadside parking, link capacity, speed limit, signal timing, roadway geometry, land use, and intersection spacing
Polus (2012)	Modelling TT and reliability on urban arterials for recurrent condition	Studied urban arterial routes and factors impacting TTR	Traffic volume, average speed, congestion levels, and junction saturation, road width, segment length, and grade are key influencers on TTR
Zhu et al. (2021)	Capturing the Interaction b/n TTR and Route Choice Behavior Bsed on the Generalized Bayesian Traffic Model	Investigated factors affecting bus TTR	Traffic congestion and inadequate green time influence bus travel reliability, requiring improvements in trip-time reliability for passengers and operators
Saptarshi et al. (2019)	Assessing TTR of Public Transport in Kolkata	Route-based travel time analysis on public transportation modes	Found significant reliability variation between buses and metro rail; assessed buffer time, buffer index, planning time, and planning time index
Mohamed et al. (2021)	Identification of Affecting Factors on the TTR for Bus Transportation.	Observational study on peak-hour bus travel	Identified TTR of buses affected by factors bus stops, intersections, route length, and dwell time, traffic congestion, inadequate green time, and pedestrian crossings and overlooked user perspectives on performance of bus transport TTR
Sharmili et al. (2021)	Case Study in Chennai City	GPS data analysis for buses on study corridor	Demonstrated variability in reliability measures, finding different statistical metrics (buffer time, tardy trip measures) indicated different reliability levels

Authors	Study Title	Methodology	Findings
Anish et al. (2018)	TTR as a Level of service Measure for Urban and Inter-Urban Corridors in India	Used the Planning Time Index as a TTR measure to assess the Level of Service for bus corridors	Found that the PTI provides insights into the general level of service but does not fully capture the nuances of TTR, especially from the user's perspective
Narang (2012)	Introducing reliability and maintainability in engineering and technology	General definition review	Defined TTR as consistency in travel times across days/times; emphasized TTR as critical in policymaking and user satisfaction
Kittelson & Vandehey (2013)	Incorporation of Travel Time Reliability into the HCM	Study on roadway network functionality under travel time variability	Highlighted reliability index as useful in evaluating Level of Service (LOS) and roadway hierarchy disruptions due to time uncertainty
Doohee (2017)	Estimation of the Value of TTR	Examined various sources of congestion affecting TTR	Found that traffic congestion sources include bottlenecks, incidents, adverse weather, work zones, poor signal timing, and special events
Jiang & Chenhui (2016)	Assessing Segment- and Corridor-Based TTR on Urban Freeways	Reviewed TTR as a traffic management metric	Stated that TTR reflects benefits of management activities and is more effective than average travel time in assessing road network performance
Karami et al. (2021)	Empirical Analysis for Measuring TTR on Road Network	Review on TTR's value to travelers	Highlighted travellers' reliance on TTR; did not explore congestion or its impact on bus performance
Harsha & Mulangi (2021)	Probability distributions analysis of TTR for the public transit system	Analyzed public transit time distributions in Mysore, India	Found extreme value distribution best characterized trip time variability; noted significant variations between peak and off-peak periods
Ali et al. (2021)	Understanding Traffic Congestion from Stakeholders' Perceptions in the Central Area of Lahore, Pakistan	Stakeholder-based analysis on congestion in Lahore, Pakistan	Identified main causes of congestion as roadside parking, encroachments, and driver/shopkeeper behavior affecting travel time reliability
Gezahegn (2019)	Travel Time and Reliability Modeling On Urban Road Segments	Using distribution and reliability modelling	Identified key TTR factors as signal timing, traffic volume, roadside parking, intersection geometry, and adjacent land use development

Authors	Study Title	Methodology	Findings
(Assen & Quezon, 2019)	Model-Based Urban Road Network Performance Measurement Using TTR	using reliability modelling to identify factors on road segments	Key factors influencing TTR include traffic composition, driver behavior, link capacity, speed limits, and road/intersection geometry on various segments
Zhenliang et al. (2015)	Modelling bus TTR with supply and demand data from AVL and smart card systems	analysis on TTR factors in public transportation	The study found that punctuality and certainty in scheduled departure and arrival times are critical issues that significantly affect TTR in public transportation
Russell (2014)	TTR and LOS Relationship	Statistical analysis and quantitative measures	Suggested coefficient of variation as a stable proxy for other TTR measures; discouraged standard deviation due to variability
Swapneel & Srinivas (2019)	Link-Level Travel Time Measures-Based Level of Service Thresholds by the Posted Speed Limit	Developed TTR measures by analysing speed and travel time	Computed TTR measures (average travel time, 95th percentile travel time) for LOS assessment, noting speed impact on travel time reliability
Tirachini, & Catalano (2015)	The Impact of Public Transport Supply and Quality on User Satisfaction	Survey of bus users analyzing their experiences and satisfaction levels with transport services	Users expressed concerns about unpredictability in bus arrival times, which negatively impacted their daily planning and satisfaction with the service
Kearns & Speed (2018)	User Experiences of Bus Transport: The Role of Reliability in Service Satisfaction	Surveys and focus groups with bus users in the UK to explore factors influencing satisfaction with bus services	While reliability was essential, users also valued comfort and accessibility, indicating a more nuanced understanding of satisfaction beyond TTR
Buehler& Pucher (2011)	Sustainable Transport in Japan: A Comparative Analysis of Public Transport and Active Travel in Japanese and American Cities	Comparative analysis of transport systems in various cities with a focus on user satisfaction and service quality	Well-managed bus systems in European cities with dedicated lanes and efficient scheduling led to higher user satisfaction regarding travel time reliability

2.8 Summary of Literature Review and Research Gap

In summary, the review of literature on Travel Time Reliability (TTR) highlights its critical role in ensuring a sustainable public transport system, particularly in urban corridors. TTR is defined through various metrics, such as travel time index, planning time, and buffer time, with no universally accepted measure across all locations. Factors affecting bus transport TTR include the number of bus stops, number of intersections, corridor or segment length, departure and arrival delays, weather conditions, traffic volume, average travel speed, bus frequency, bus lane exclusivity, day of the week, time of day, dwell time (passenger boarding patterns, and payment methods). The review underscores the importance of TTR for both users and transport planners, as it influences the overall service quality of public transportation systems and serves as a key performance indicator in transport planning.

Existing literature (Assen & Quezon, 2019); Gezahegn, 2019) on travel time reliability (TTR) in Addis Ababa has largely overlooked the specific context TTR to evaluate the performance of bus transport service and its influencing factors. There is a noticeable absence of empirical studies focusing on TTR from the user perspective both with a focus on Ethiopian and specific to the case of Addis Ababa city. This study aims to address this gap by evaluating bus transport TTR through a detailed investigation on the influencial factors. By employing reliability indices and developing multiple regression models, the research will analyze the interaction between independent variables and TTR, providing a comprehensive understanding of how various factors affect the reliability of bus transport from the user's experience and perception.

CHAPTER THREE: METHODOLOGY OF THE STUDY

This research aims to assess the travel time reliability (TTR) of bus transport along major corridors in Addis Ababa. The study focuses on identifying and evaluating the factors that influence TTR in these corridors. This chapter outlines the research methodology, including a description of the study area, the research design and approach, and the methods used for data collection, extraction, and analysis.

3.1 Description of Study Area

The study area for this research is Addis Ababa, the capital city of Ethiopia. Addis Ababa city is divided into 11 sub-cities and around 130 woredas. The selection of corridors should depend on the purpose of the study, which is carried out using expert consultation, traffic (corridors related) data obtained from the city's Transportation Bureau and Google Map. Google Maps was used to assess traffic intensity on the corridors during peak and off-peak hours, providing a visual representation of congestion levels. Additionally, corridors related information data from the city's transport bureau and researcher observation were utilized, which included information on both mixed-traffic corridors and dedicated bus lanes see (Annex 5). This data was crucial in selecting the study corridors. The selection focused on peripheral areas with significant residential activity, where traffic congestion remains a persistent issue. Three major corridors in Addis Ababa known for their high congestion levels were purposively chosen: Corridor 1 (Mexico, from Federal Police Commission Headquarters to Haile Garment Square on the Mexico-Garment-Gelan route), Corridor 2 (Kara Kore to Mexico Wabi Shebelle Hotel, along the Kara Kore-Torhailoch Hospital-Legehar route), and Corridor 3 (Megenagna to Derartu Square, on the Megenagna-Ayat Chefe route). These corridors are characterized by regular, severe traffic congestion, especially during peak hours, and the analysis of mixed traffic and dedicated lanes along these corridors is essential to understanding travel time reliability and traffic flow patterns. Each corridor is assigned specific bus route codes: Corridor 1 (bus code 27), Corridor 2 (bus code 36), and Corridor 3 (bus code 49). The study also incorporates travel times for additional buses operating along these corridors, including buses with codes 92, 106, 115, 117, and 121 for Corridor 1; codes 61, 74, 83, and 101 for Corridor 2; and codes 3, 58, 66, and 70 for Corridor 3. This broader inclusion of bus data enhances the analysis and allows for comparison with user perspectives gathered qualitatively. The corridors are segmented by bus stop stations, with details like stop names, segment lengths, and coordinates provided in Annex 1. Figure 1 illustrates the selected corridors and locational indicators.

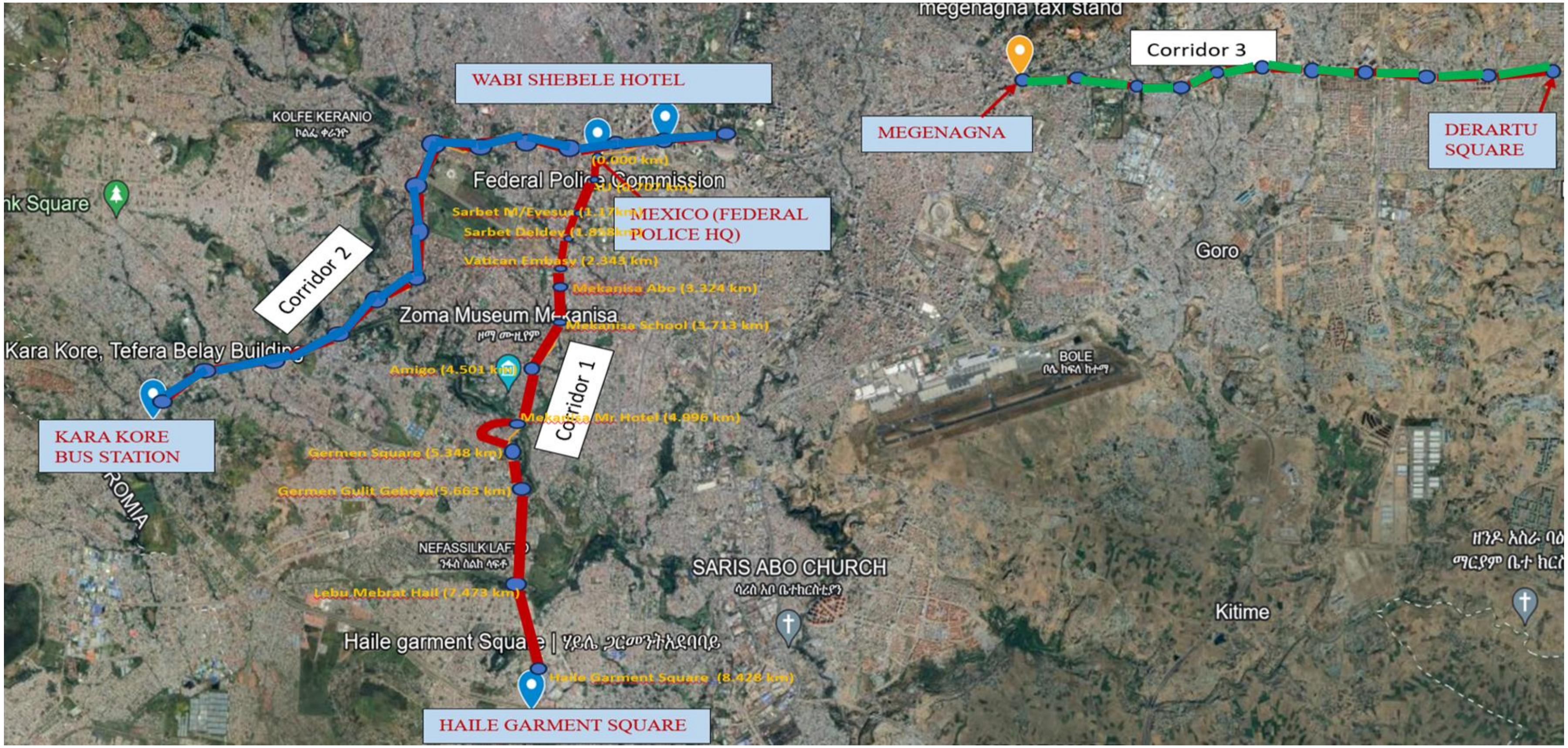

Figure 1 Study Corridors map in Addis Ababa City (Own depiction using Google Map)

Corridor Description

Corridor 1 (from Mexico, Federal Police HQ to Haile Garment Square) : Length = 8.608 km, Bus Code =27

Corridor 2 (from Kara Kore to Wabi Shebelle Hotel, Mexico) : Length = 9.784 km, Bus Code = 36

Corridor 3 (from Megenagna to Derartu Square) : Length = 8.834 km, Bus Code = 49

3.2 Research Methodology Flowchart

The research methodology flowchart outlines the sequential steps of the study's methodology, detailing the research approach and design, followed by data sourcing, collection, processing, extraction, and analysis. It concludes with data presentation, result interpretation, discussions, conclusions, and recommendations. The complete methodology flowchart is shown in Figure 2 below.

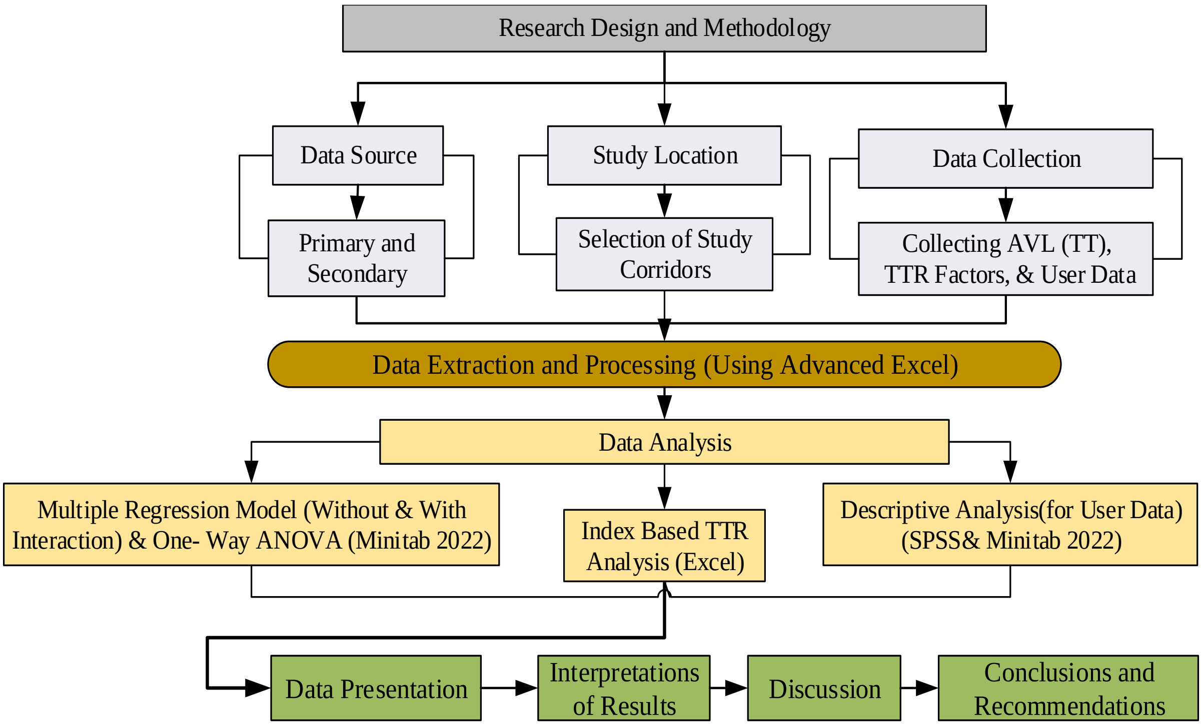

Figure 2 Study methodology flowchart (Source: Author depiction)

3.3 Research Approach and Design

This study employs descriptive research design, integrating a mixed-methods both quantitative and qualitative approaches to comprehensively analyze travel time reliability in bus transportation.

The quantitative aspect of the study focuses on analyzing data collected through an origin-destination (O-D) survey. This survey is enhanced by data from the Automatic Vehicle Locator (AVL) system, which provides precise bus travel time information. The AVL (Automatic Vehicle Locator) system tracks buses in real-time by receiving GPS signal data, which records essential metrics such as travel times between stops, and total journey times. This raw GPS signal data is then processed to provide a detailed analysis of travel time reliability across study corridors and on different times of day. By directly using GPS signals, the system ensures high accuracy in tracking, which is vital for understanding variability in travel times. Additionally, the O-D (origin-destination) survey data complements the AVL system by providing further insights into travel patterns, allowing for a comprehensive assessment of factors affecting bus travel time reliability and helping identify patterns in both peak and off-peak hours. Together, these datasets enable the quantification of the impact of dwell time, segment length, travel speed, bus lane, number of bus stop stations, time of the day, days of the week, number of intersections, and bus frequency factors on the reliability of bus public transport.

The qualitative component of the study complements the quantitative analysis by providing insights into the user experience and perceptions of travel time reliability of bus transport. Data for this approach was collected through direct interviews with bus users along the study corridors. The interview was structured to gather detailed feedback on users' experiences. This qualitative data enriches the study by highlighting the user aspect of travel time reliability, offering context to the numerical findings, and identifying areas for potential improvement from the perspective of bus users. By integrating these two approaches, the study leverages the robustness of quantitative data while capturing detailed qualitative insights into user experience. The quantitative data offers a broad view of travel time reliability, identifying key patterns and factors, while the qualitative data supports these findings by highlighting how significant factors impact users. This mixed-methods approach ensures a comprehensive understanding of the factors influencing travel time reliability in bus transport along the studied corridors.

3.4 Sample Size and Sampling Techniques

The bus transport users along the selected corridors considered as a population. To meet the study objectives, a purposive sampling technique was employed to select bus users for data collection and as mentioned to select the study corridor. The use of purposive sampling technique is mainly due to its advantage to select contributors depending on specific criteria that are related to the nature of the study, and it also allows a more profound investigation into a specific phenomenon (Nyimbili F. & Nyimbili L., 2024).

3.5 Data Requirement

Several factors influence the travel time reliability of bus transport, including segment length, day of the week, number of intersections, delays at bus stops (arrival delays), presence of bus lanes, bus frequency, travel speed, number of bus stop stations, time of day, and dwell time (the time spent on passenger boarding and paying cash). In this study, the methods used to measure and collect data on these variables are detailed below.

Bus travel time data: The travel time data was collected on 7 days (all days of the week) (from 12 February 2024 to 18 February 2024) AVL bus travel time. Bus travel time data extraction was done using an O-D-based survey for the segments along each corridor.

TTR factors identification related data: The factor (dwell time) was measured from AVL data during travel time data extraction and the remaining factors (number of intersections, bus lane, and stop stations) were counted and collected for the study corridors. The factors including the number of intersections, the number of bus stops, bus lane, segment length, time of day, travel speed, day of the week, and dwell time, were collected for each study corridor. Travel speed calculated from travel time and distance between stations (segment length). Dwell time – recording the time at each bus stop station of passenger activity (passenger boarding and paying cash).

Travel Time Reliability (TTR) from a user perspective: To achieve this objective, data was collected through one-on-one interviews with 60 purposively selected respondents at bus waiting stations along the study corridors, focusing on key factors affecting bus travel time reliability, such as scheduling, and user perceptions of the bus transportation system

3.6 Data Collection

The data collected for this study using primary data collection technique , and secondary data was for conducting the research. The bus travel time data first collected using (GPS) AVL data O-D based and obtained from the Addis Ababa City Bus Service Enterprise Head office. On the otherhand,, an interview questionnaire was employed to collect travel time reliability from the user perspective for the study corridors. Moreover, the specific bus schedule for the study corridors during the data collection period based on their code, side number, and plate number were collected from the five branch offices or depo of Addis Ababa City Bus Service Enterprise, namly the ones located in Kality, Mekanisa, Shegole, Summit, and Yeka. The bus code of corridor 1 from Mexico (Federal Police Commission Headquarters) to Haile Garment Square (found in Mexico to Gelan Route) is number 27, corridor 2 from Kara Kore to Mexico-Wabi Shebelle Hotel (found in Kara Kore -Torhailoch Hospital to Legehar Route) is number 36, and corridor 3 from Megenagna to Derartu Square (found in Megenagna to Ayat Chefe Route) is number 49. Moreover, other considered buses pass through corridor 1 (code 106, 115, 117, and 121), corridor 2, (code 61, 74, 83, and 101), and corridor 3 (code 3, 58, 66, and 70).

For this study, the bus license plate number and travel time data on the study area at the origin-destination based on the selected corridors were collected. Moreover, data on travel time reliability factors for the selected corridors were measured and collected during the travel time survey. In addition, travel time reliability from the user perspective was collected using a structured interview questionnaire. Primary data type: bus travel time data extracted from AVL, TTR factors measured & identified, and a questionnaire-based one-to-one interview to assess TTR from the user perspective. For bus travel time the data was taken at the origin and destination of the segment along each corridor for travel time data and TTR factor measured parallel to travel time surveyed data. Day of the week, this research was focused on all days of the week (i.e., from Monday to Sunday, from 12 February 2024 to 18 February 2024). Time of the day used for this study was (peak hours and off-peak hours). The peak hours include AM peak (6:30-9:30), PM peak (4:00-7:30), and off-peak hours (11:00 AM-3:00 PM).

Dividing the corridors into segments for analysis, rather than using the entire corridors, allows for a more detailed measurement of travel time reliability (TTR). By focusing on specific segments between stations, the study can accurately assess TTR using reliability measures and identify the factors affecting bus transportation along each part of the corridor. This approach provides a clearer identification of problematic segment and helps to pinpoint areas needing improvement. In addition, the purpose of the O-D-based corridor survey is to estimate the travel time of the study period. Instead of segments, pairs of origins and destinations must be specified before both O-D–based travel times and TTR measures can be estimated. Therefore, the concept of O-D-based travel time reliability (TTR) is defined as the reliability of your trip from one point to another. Travel time refers to the duration taken to travel between two points of interest. It is a key measure in transportation, widely used in analyses like congestion management, transportation planning, and providing user information.

The literature review and local domain knowledge were used to identify the factors affecting travel time reliability (TTR) for urban corridors and bus transport along major routes. These factors include traffic flow and volume, driver behavior, traffic composition, average travel speed, link capacity, speed limit, roadway and intersection geometries, median type, road or segment width, segment length, traffic signal timing, network design, signalized intersection spacing, dwell time, work zones, weather conditions, day of the week, time of day, number of bus stop stations, number of intersections, presence of bus lanes, and bus frequency.

Based on time and budget constraints, the independent variables used for this study to identify the TTR of bus transport are presented in Table 2, which includes the number of bus stoppings, the number of intersections along the corridor, the segment length (the length between stop stations in the study corridors), the day of the week, time of the day, bus lane, bus frequency, travel speed and dwell time.

Dwell time is the time a bus or bus stops to either drop off or pick up passengers at each station including ticketing. Dwell time is crucial in determining the total amount of time spent travelling on public buses. Mostly, the determinants of dwell time for this study include passenger activities (passengers boarding and paying cash).

Time of the day consists peak hours (morning and evening rush hours) typically involve more traffic congestion, leading to increased travel times and greater travel time variability. Off-peak periods, such as late morning or early afternoon, often have lighter traffic, resulting in more consistent and faster travel times.

A dedicated bus lane is a traffic lane reserved exclusively for buses, which helps them avoid congestion from regular traffic. The presence of a bus lane usually improves travel time reliability by reducing delays caused by general traffic conditions, allowing buses to move more freely.

Day of the week means days from Monday to Sunday and may experience varying levels of traffic and demand for bus services. For instance, weekdays generally have higher traffic volumes and bus ridership due to work and school schedules, while weekends might see lighter traffic but different travel patterns. This factor affects the travel time reliability due to changing traffic conditions.

Segment length is the distance between two consecutive bus stop stations along a corridor. Longer segments allow buses to travel uninterrupted for a greater distance, often improving speed and reducing stop-related delays. Shorter segments, on the other hand, can increase the frequency of stops and deceleration, which may contribute to travel time variability.

Travel speed is the average speed at which a bus travels along the corridor. Higher travel speeds generally result in shorter travel times, while lower speeds can lead to increased travel times and reduced reliability.

Number of bus stops refers to the total number of designated bus stop stations along the corridor. More stops generally result in longer travel times, as the bus needs to decelerate, stop, load/unload passengers, and accelerate again, which can also affect travel time variability.

Number of intersections are points where different roads meet, often controlled by traffic signals or signs. The number of intersections along a corridor can significantly impact travel time, as buses may face delays due to signal timings, traffic congestion, or cross-traffic at these junctions. More intersections typically increase travel time and reduce travel time reliability.

Bus frequency refers to how often buses are scheduled to run along a corridor. Higher bus frequency can reduce passenger wait times and improve service quality.

The other type of data collected focused on the perspectives of bus users regarding travel time reliability (TTR). An interview questionnaire was designed to gather this data, structured in a clear and easily understandable format with unambiguous questions categorized into three parts: purpose, socio-demographic details, and travel time reliability. A one-on-one interview survey was conducted to obtain in-depth insights and complement the quantitative findings. The questionnaire included a total of 17 questions, as detailed in Annex 2. A pilot survey with 30 bus users from the study corridors was conducted, which prompted the amendment of existing questions and the addition of new questions for the final data collection, based on the feedback and analysis of the pilot responses. This process aimed to enhance the relevance and clarity of the questions, ensuring they effectively captured users' experiences and perceptions related to TTR.

3.7 Data Extraction Methods

Travel time data was extracted from the AVL data collection sheet using advanced Excel techniques. The origin-destination (O-D) bus time records at each station were used to compute travel time by calculating the difference in arrival times. The reliability of the study corridors was then assessed using reliability index, including buffer time, planning time index (PTI), buffer time index (BTI), and the 95th percentile, all derived from the extracted travel time data. To identify factors affecting bus travel time reliability and their significance for the selected corridors, data extraction involved several steps. The steps include collecting raw travel time data for city buses, filtering by bus plate and code numbers, converting Unix time to AM and PM data, recording travel time data at each stop station by coordinates, and estimating travel time at both segment and corridor levels using the extracted data. Dwell time is extracted from the AVL data at each bus stop stations for the study corridors. Moreover, number of bus stops, bus lanes, number of intersections counted along the study corridors. Segment length is measured in kilometer the distance between two bus stop stations, and travel speed is calculated from dividing segment length by travel time for each study corridors.

3.8 Data Analysis Methodology

This section defines the overall data analysis methodology of the research. Minitab 22 and SPSS software package and advanced Excel were utilized as major data analysis and manipulation tools. The primary data was collected from selected major corridors and the researcher used AVL bus travel time data for the study purpose. The assessment of the travel time reliability of the selected corridors was performed based on the descriptive research method of analysis using the collected travel time data and reliability measures were computed. In this study, a multiple linear regression model and one-way analysis of variance (ANOVA) were used to identify factors of bus travel time reliability of the study corridors. Besides, travel time reliability from the user perspective was assessed through descriptive analysis. The analysis was done using the SPSS and Minitab 22 software packages.

3.8.1 Estimation of Travel Time

To estimate travel time, bus codes with plate numbers and their arrival times at the origin and destination points of each station along the study corridors were recorded. Subsequently, bus codes with license plates at the origin and destination points were matched and travel time was calculated from the difference in arrival times at these two points. Then, the average travel time for weekdays and weekend on all the study corridors was presented. To further explore more about travel time distributions, the study corridors were divided into segments based on the spacing of bus stops.

The travel time data is aggregated into spatial and temporal dimensions. Spatial aggregation involves both corridor and segment levels, while temporal aggregation focuses on various time periods, including morning/AM peak, evening/PM peak, and off-peak hours. Each corridor is analyzed at the segment level across these different time periods to assess travel time data distribution. Specifically, corridor one consists of 12 segments, corridor two includes 14 segments, and corridor three has 10 segments, with analyses conducted for each direction of travel during the specified time periods. To encircle or enclose the bus stop region, a radius of 50m was considered from the center of the bus stop for dwell time revording. Each segment consisted of the distance between the two consecutive bus stops up to the end of the downstream bus stop.

3.8.2 Travel Time Reliability Factors Identification Analysis

Time reliability depends strongly on traffic congestion, which has many sources. Hence, the factors for travel time reliability of bus transportation include the number of bus stoppings, the number of intersections along the route/corridor, the length of the segment/corridor/route (length between bus stop stations), the day of the week, time of the day, bus lane, travel speed, bus frequency, and dwell time (passengers boarding and paying cash). The focus of the study is to investigate the level of influence of those travel time factors for bus transport.

To identify the TTR factor using the measured collected data multiple regression model was employed. The dependent variable in the regression model is TTR, and independent variables are factors like the number of bus stop stations, number of intersections, length between stop stations which is segment length, day of the week, time of the day, bus lane (bus lane only), travel speed (bus travel speed on the segment), bus frequency (bus frequency per specific time at stop stations), and dwell time (passengers boarding and paying cash). The dependent variable is denoted by Y and the independent variables are denoted by X's (X1, X2, X3,…..Xn). The detail description of the variables with their characterstics is presented in the table below.

The model equation becomes; $Y= \beta0+\beta1X1 + \beta2X2 + \beta3X3 + \beta nXn + \varepsilon$………………. Eq (1)

Where Y= Travel time (in minute), and X1-Xn= Independent variables

β0= constant, other β's are coefficients of independent variables, and ε= error term

Table 2 Variables of travel time reliability and related glossary

Variables	Type	Description	Type	Unit
Travel Time	Dependent	Time spent to travel from origin to destination	Continuous	Minutes
No. of bus stops	Independent	Number of bus stops during the trip	Continuous	Count (no. of bus stops along the corridor)
Segment length	Independent	Distance covered during the trip for each segment	Continuous	Kilometre
Day of the week	Independent	How the day of the week (weekday and weekend classified days) affects the travel time	Categorical	Monday to Sunday
Dwell time	Independent	Times of passengers boarding and alighting at every stop	Continuous	Minutes
No. of intersections	Independent	Number of intersections on every trip in the study corridors	Continuous	Count (the number of intersections along the corridor)
Bus lanes	Independent	Number of bus lanes in each trip	Nominal	Count bus lanes of roadways along the corridor
Time of the day	Independent	Effect of times within a day on bus transportation	Categorical	AM peak, PM peak, off-peak
Bus frequency	Independent	In terms of buses per hour or within a specified time	Continuous	Count (buses within a specified time)
Travel speed	Independent	The average speed of the bus measured between two stop stations	Continuous	Km/hr

3.8.3 Index Based Travel Time Reliability Analysis

The reliability of travel time is important for measuring transportation systems and for increasing the quality of life for public transport users to produce less delay for their daily trips. In addition, it can also be used as an indicator for improving the overall system operations and management to reduce traffic congestion. Based on the federal highway administration (FHWA), the travel time reliability measures of urban corridors were discussed and computed from the extracted data. The travel time reliability measures include planning time, buffer time, planning time index, buffer time index, and 95th percentile (Sharmili et al, 2021). Buffer time is defined as a reliability measure that is recommended by USDOT, NCHRP, and SHRP2. The buffer time represents the extract time (buffer or cushion time) that most users add to their average travel time when planning trips to confirm on-time arrival.

The buffer time index, another reliability measure, is expressed as a percentage and its value increases as reliability gets worse. Based on previous studies, the coefficient of variance, standard deviation, PTI, TTI, BT, and BTI are the most widely used travel time reliability measures. The coefficient of variance and buffer index have limitations because their values are tied to the average travel time, which can fluctuate over time. This means that as the average travel time changes, the calculated values of these measures may also change, making them less reliable or consistent as indicators of travel time reliability.

In this study, the free flow time was obtained from the off-peak bus travel time of the day. The off-peak bus travel time of the day chosen to determine the free flow time in the study because it represents the time when traffic is least congested, allowing buses to travel at their optimal speed. By using off-peak travel times, the researcher could establish a baseline for the fastest possible travel time under normal conditions, which is crucial for measuring TTR and identifying delays during peak hours. This approach ensures that the free flow time reflects the best-case scenario for bus travel along the corridors.

Therefore, the planning time index was selected as the TTR measure because it provides a consistent and robust indication of how much extra time travelers need to plan for to ensure on-time arrival, making it a reliable metric for assessing travel reliability across different segments. The PTI indicates the severity of traffic congestion as it represents the worst level of congestion at a given time of the day compared with the free flow traffic condition, which lead to unreliability. Therefore, planning time index, PTI is chosen as a primary travel time reliability measure in this study. The rating ranges of travel time reliability which are given based on the PTI values are: (1) reliable (PTI < 1.5); (2) moderately to heavily unreliable (1.5 < PTI < 2.5) and (3) extremely unreliable (PTI > 2.5) (Zhen & Wei, 2019).

The travel time index (TTI) is the ratio of the average travel time to the mean free-flow travel time.

$$TTI = \frac{\text{Average Travel Time}}{\text{Free Flow Travel Time}} \quad \text{Eq (2)}$$

Buffer time and Buffer time index can be computed as.

Buffer time (sec)= 95th percentile travel time (sec) – Average travel time (sec)………. Eq (3)

$$\text{Buffer index (BI)} = \frac{\text{95th percentile travel time (sec) – Average travel time (sec)}}{\text{Average travel time (sec)}} \quad \text{Eq (4)}$$

Where; 95th percentile travel time (sec) indicates how bad the delay will be on the heaviest travel days. From the above equations, the travel time reliability threshold (in seconds) for this research is deducted as;

Travel time reliability or threshold ≤ Buffer time + Average travel time………………. Eq(5)

The planning time index is described as

$$PTI = \frac{\text{95th percentile travel time (sec)}}{\mathit{Free\ flow\ travel\ time}} \quad \text{Eq (6)}$$

Index based reliability analysis measures are calculated for each study corridor based on segment level and presented in the result parts.

3.8.4 Travel Time Reliability Regression Modeling

Multiple linear regression was emplyed to model the bus travel time reliability of the study corridors. The explanatory variables contain continuous and categorical variables, as given in Table 1 above. The continuous variables are segment length, travel speed, dwell time, number of intersections, number of bus stop stations, bus lane, and bus frequency per specific time. The categorical variables are time of the day and day of the week. The multiple linear regression is the most widely applicable statistical and economic technique to develop predictive models using various sets of variables employing parametric setups. The tests and assumptions that should be checked before heading to calibrate the regression model are discussed below.

Model specification: Ramsey Regression Equation Specification Equation Test (RESET) test is used to test the specific of multiple regression models (Gunawan R., & Hutter S. 2017). Ramsey RESET test evaluates the correctness of the specification of a regression model by testing for omitted variables, and incorrect functional form specifically it tests whether a non-linear combination of the explanatory variables helps to explain the response variable. Ramsey test is not actually a general test for omitted variables bias, rather it is a test for misspecifications. The Ramsey RESET test (model specification test) has two hypothesis:- null hypothesis (H0); the model has no omitted variable or non-linear form of variables (the model is correctly specified), and alternate hypothesis (H1); the model suffers from an omitted variable problem or non-linear variables (the model is not correctly specified).

Correlation and Multicollinearity: The common concept between correlation and multicollinearity is the presence of relationships between variables. Both concepts involve understanding interdependencies among variables, though multicollinearity highlights the problem that arises when those relationships are excessively strong within a regression context. Therefore, correlation simply measures how strongly and in what direction (positive or negative) two variables move together, giving an indication of a linear relationship. Multicollinearity, on the other hand, is a specific problem in regression analysis where two or more independent variables are highly correlated, making it hard to isolate the effect of each variable on the outcome.

To check multicollinearity commonly two methods were employed; variance inflation factor (VIF) and Pearson-correlation coefficient values. The assumption for multicollinearity assumes that for the independent variables, there is little or no high correlation with each other. To check correlation coefficients, make a correlation matrix using the pearson correlation method and look for coefficients magnitude of less than 0.80 or higher. If the variables shows multicollinearity, they will be highly correlated and can inflate the t-value (or model fit) which is undesirable. Similarly, VIF values were examined for each independent variable, with a high VIF value (>10) indicating multicollinearity.

Heteroskedasticity/Homoscedasticity: The Breusch Pagan test is designed to test for heteroskedasticity in the linear regression model. This test can be checked using the command estat hettest. The hettest uses the predict command to compute the predicted values ($\hat{y}$) and the residuals (e). If there is no heteroskedasticity, then the squared residuals should neither increase nor decrease in magnitude as $\hat{y}$ increases, and the test statistic should be insignificant (Richard, 2020). The Breusch Pagan / Cook-Weisberg test follows two hypothesis which are the null hypothesis that the error variances are all equal versus the alternative hypothesis that the error variances are a multiplicative function of one or more variables.Null Hypothesis (H_0): the null hypothesis states that the residuals are homoskedastic, meaning that the variance of the residuals is constant across all levels of the independent variables. Alternative Hypothesis (H_1): the alternative hypothesis states that the residuals are heteroskedastic, meaning that the variance of the residuals changes with the level of the independent variables.

Normality: In regression analysis, one key assumption is that the residuals (or errors) of the regression model are approximately normally distributed. This assumption is crucial for the validity of statistical inferences and hypothesis tests associated with the regression model. The final assumption is to check the residuals of the regression line are approximately normally distributed. In this normality test, the error term is normally distributed. There are two common methods to check this assumption using a histogram (with a normal curve) or a normal probability Q-Q plot. For this study normal probability plot using Anderson Darling test is used to check the normality of the residuals. Normality refers to the distribution of residuals following a normal (Gaussian) distribution. Residuals are the differences between the observed values and the values predicted by the regression model. Specifically, the assumption of normality means that if the plot of the residuals, they should form an indicative of a normal distribution. Null Hypothesis (H_0): The residuals are normally distributed. Alternative Hypothesis (H_1): The residuals are not normally distributed.

3.8.5 Interaction in Regression Model

Interaction in a regression model represents a combined or synergistic effect of two or more variables. That is the dependent variable depends on the joint value of two or more variables. A second-order effect is an interaction between two variables, typically denoted as X1X2. A third–order effect is an interaction between three variables, and so on. Therefore, the researcher wants to check the synergetic effect of two independent variables.

3.8.6 One-Way ANOVA

The objective of using one-way ANOVA is to compare the means of a continuous dependent variable across different categorical independent variables to identify statistically significant differences. In this study, one-way ANOVA is used to determine if there are significant differences in travel time based on factors such as the time of day and days of the week. There are two hypothesis for this test. Null hypothesis (H_0): there are no significant differences in the means of the groups and the alternative hypothesis (H_1): at least one group mean is significantly different from the others.

3.9 Qualitative Data Analysis

Data that is relevant to the accomplishment of the study objective was collected through an interview questionnaire. A total of 17 questions were prepared: three focusing on the socio-demographics of the passengers and 14 close-ended questions designed to gather perceptions of travel time reliability from corridor users. For more details, refer to Annex 3. A total of 60 one-to-one interviews were conducted with bus users along the study corridors which is equally 20 respondants per corridor, using purposive sampling at bus stops to ensure relevance to the research. This approach aimed to gather a manageable yet diverse dataset for qualitative analysis. The sample provides valuable insights into travel time reliability within the corridors. Six age categories were used : 14 and below, 15-19, 20-24, 25-34, 35-44, and 45 and above. Descriptive statistics, including percentages, frequencies, and means, were used to analyze the bus users data.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

The chapter is divided into three parts: travel time reliability using travel time pattern and index based analysis, regression modelling (with and without interaction), and travel time reliability from user perspective.

4.1 Evaluating Travel Time Reliability of Bus Transport on Study Corridors

To achieve the first objective of the study, travel time reliability (TTR) is evaluated and characterized by analyzing travel time patterns across different times of day and days of the week, along with index-based analysis. Travel time for the study corridors is estimated at both segment and corridor levels, with detailed results provided in Annexes 3 and 4. Across all study corridors, the highest estimated travel times occur on Monday and Friday during peak hours, as shown in Figure 3. The Addis Ababa Traffic Management Agency excludes these two days from traffic counts due to the exceptionally high traffic volumes along the corridors and intersections. While this exclusion is intended to preserve the integrity of the traffic data, it may lead to inaccurate assessments of travel time reliability. Therefore, the study emphasizes that including these two days in the TTR analysis offers valuable insights into understanding reliability for users and provides important information for transportation planners to design and implement user-focused systems. The reason for higher commuter traffic on Monday and Friday is due to the start and end of the work week leading to congested roadways. On Friday, individuals may be heading out for social activities, events, vacations, and shopping after work contributes to increased traffic congestion and travel time leading to reliability being lower. After the weekend, many people return to work on Monday, causing another surge in traffic as everyone is back on the road/corridor.

On other working days of the week travel time is slightly differs across each study corridor which is medium or average level on Tuesday and Thursday, and lowest on Wednesday. Therefore, travel time on weekends is smaller than Weekdays. This is highly related to traffic intensity. Traffic intensity on working days is higher than on off-working days, as the travel time result of each study corridor is shown in figures 3 below. Travel time reliability fluctuates throughout the week and at different times of the day, which highlights the effects of traffic congestion. Understanding these variations helps in developing strategies to improve travel time reliability. By addressing the factors that cause longer travel times during peak periods, transport authorities can enhance overall reliability and improve the user experience.

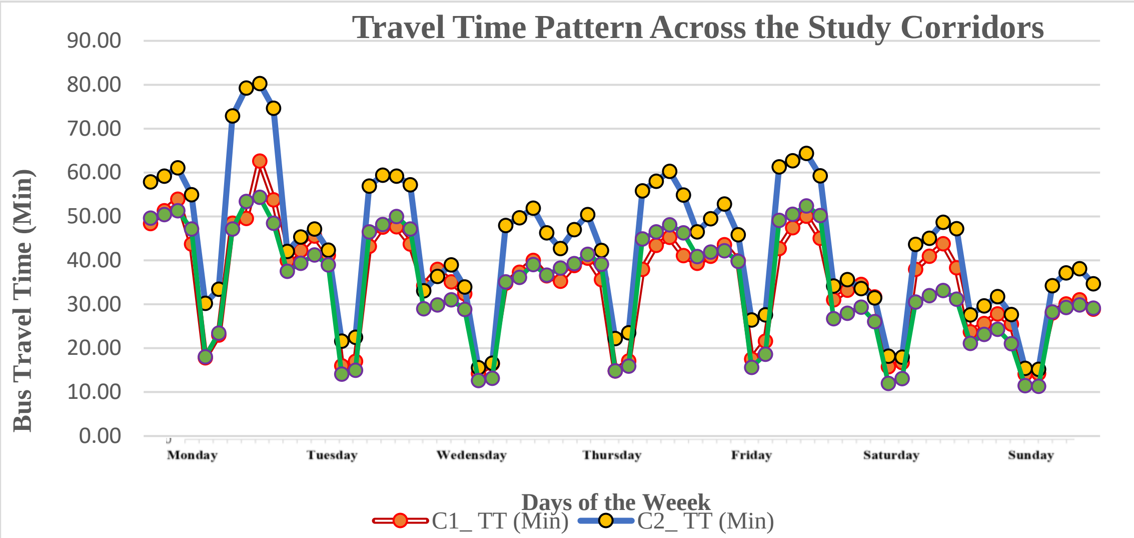

Figure 3 Travel time pattern for the study corridors based on time of day and day of the week

4.1.1 Index Based Travel Time Reliability Analysis

The Index-Based Travel Time Reliability analysis for the study corridors is presented in the following subsections. This analysis aims to quantify how consistently travel times on the studied corridors perform, offering insights into their reliability. By detailing the results in the subsequent subsections, the study highlights the specific reliability indices used and their implications for each corridor.

4.1.1.1 Travel Time Reliability Index Analysis for Corridor 1

TTR for corridor-1 was calculated at both the segment and corridor levels, covering 12 segments. The PTI, as a measure of TTR, shows that segment 5 has the highest PTI value of 4.80, while the overall PTI for corridor one is 4.17, indicating unreliability based on PTI ranges. An increase in the PTI value reflects greater unreliability of the segment or corridor.

Table 3 Travel time reliability measure analysis of corridor-1 based on segment and corridor level

Segment Level						
Seg. No	Length (km)	ATT (Sec)	BT (Sec)	BTI (Sec)	95% (Sec)	PTI (Sec)
1	0.707	186.48	47.79	0.26	234.27	3.79
2	0.415	173.4	63.72	0.37	237.12	3.95
3	0.688	156.14	17.91	0.08	230.85	3.85
4	0.452	181.46	49.96	0.28	231.42	3.86
5	0.495	153.8	136.9	0.89	290.7	4.8
6	0.788	138.85	119.36	0.86	258.21	4.3
7	0.589	150	89.97	0.6	239.97	3.96
8	0.981	150.45	94.65	0.63	245.1	4.04
9	0.485	146.73	94.95	0.65	241.68	4.03
10	1.395	212.94	76.99	0.49	233.13	3.77
11	0.463	160.1	128.32	0.8	288.42	3.88
12	1.15	183.29	52.12	0.28	235.41	3.22
Corridor Level						
1	8.608	2114	1410.31	0.67	3524.31	4.17

4.1.1.2 Travel Time Reliability Index Analysis for Corridor-2

TTR measures were calculated based on segment and corridor level (comprising 14 segments) and the results are shown in Table 4. The highest PTI value of 4.87 found in segment 14, and from PTI ranges all segments along the corridor were found under unreliable and the also unreliable.

Table 4 Travel time reliability measure analysis of corridor 2 based on segment and corridor level

Segment Level						
Seg. No	Length (km)	ATT (Sec)	BT (Sec)	BTI (Sec)	95% (Sec)	PTI (Sec)
1	0.673	204.19	56.87	0.28	216.06	4.27
2	1.292	185.58	68.07	0.37	253.65	4.23
3	1.024	185.6	56.65	0.31	242.25	4.04
4	0.511	187.22	64.72	0.35	251.94	4.2
5	0.992	187.4	72.52	0.39	259.92	4.29
6	0.999	179.89	16.76	0.09	196.65	3.28
7	0.625	144.39	59.67	0.41	204.06	3.33
8	0.568	149.43	79.14	0.53	228.57	3.81
9	0.733	151.85	84.7	0.56	236.55	3.83
10	0.352	155.9	48.16	0.31	204.06	3.37
11	0.381	173.14	73.67	0.43	246.81	4.11
12	0.631	184.69	65.54	0.35	250.23	4.17
13	0.44	191.52	58.14	0.3	249.66	4.16
14	0.563	195.81	96.6	0.49	292.41	4.87
Corridor Level						
1	9.784	2596.29	96.6	0.76	4576.53	5.02

4.1.1.3 Travel Time Reliability Index Analysis for Corridor-3

As presented in Table 5 below, the reliability measures for all segments on corridor-3 are calculated. The highest PTI value of segments along the corridor is segment 9 which is PTI= 5.29 and the corridor PTI value is 4.55 which indicates the unreliabilty. Therefore, the high value in PTI indicates an increase in unreliability condition on the segment or along the corridor. Moreover, based on the results the study corridors were indicating unreliable because the PTI rating values of segment and corridor level are greater than 2.5. Therefore, the high PTI values for segments and the overall corridor highlight significant unreliability in bus travel times. This result calls for focused interventions to reduce travel time variability, and make the bus system a more viable and dependable mode of transportation.

Table 5 Travel time reliability measure analysis of corridor-3 based on segment and corridor level

Segment Level						
Seg. No	Length (km)	ATT (Sec)	BT (Sec)	BTI (Sec)	95% (Sec)	PTI (Sec)
1	0.594	189.68	70.24	0.37	259.92	4.13
2	1.709	193.74	55.92	0.29	249.66	4.12
3	0.927	187.96	55.43	0.29	243.39	3.86
4	0.845	178.46	60.94	0.34	239.40	3.69
5	0.595	191.74	113.78	0.59	305.52	4.59
6	1.127	170.86	90.77	0.53	261.63	4.19
7	0.417	203.69	105.25	0.52	308.94	4.90
8	1.239	204.41	108.52	0.53	312.93	5.01
9	0.746	193.31	122.47	0.63	315.78	5.26
10	0.635	179.77	80.15	0.45	259.92	4.17
Corridor Level						
1	8.834	2040.04	1061.33	0.52	3101.37	4.55

Therefore, this study evaluated bus travel time reliability on days of the week and times of day (AM peak, PM peak, and off-peak) along major corridors. The study demonstrated that travel time is least reliable during AM and PM peaks and on weekdays (Monday, Friday, Thursday, Tuesday, and Wednesday), whereas weekends (Saturday and Sunday) show more reliable travel times due to lower traffic flow compared to weekdays. These result findings align with the study by Zhen & Wei (2019) Charlotte, North Carolina, in United States, and Saptarshi et al., (2019), conducted a study in Kolkata the capital of the state of West Bengal, who also reported unreliable travel times during peak hours of weekdays.This study employed TTR measures such as BT, BTI, 95th percentile travel time, and PTI to assess reliability at segment and corridor levels, with PTI chosen to measure worst-case reliability. This approach differs slightly from Gezahegn (2019), conducted in Addis Ababa which primarily focused on buffer time index for assessing reliability.

4.2 Descriptive Statistics of Variables for the Study Corridors

Descriptive statistics are used to describe the basic features of the data in the study. The descriptive statistics of the dependent variable and independent variables are given in Table 6. Generally, low standard deviation indicates that the data points tend to be close to the mean, whereas a high standard deviation indicates that the data are spread out over a large range of values. Therefore, for the dependent variable and independent variables for the study corridors, the standard deviation is close to the mean value.

The descriptive statistics reveal variations across the study corridors in travel time, speed, dwell time, and other factors. Notably, travel time and speed exhibit significant variability, which may be influenced by segment length, the presence of intersections, and bus stop stations. These differences offer valuable insights into the factors influencing travel time reliability across corridors. Additionally, variables such as the number of intersections, bus frequency, and bus lanes vary among corridors, reflecting their unique characteristics that may impact bus transport travel time reliability.

Table 6 Descriptive Statistics of variables for the study corridors

Descriptive Statistics of Variables for Study Corridors					
Variables	**No. Obs**	**Mean**	**StDev**	**Min**	**Max**
Travel Time (TT)	2520	2.67	1.13	0.56	6.30
Segment Lebgth (SL)	2520	0.75	0.32	0.35	1.71
Travel Speed (TS)	2520	22.25	6.79	15.00	40.00
Dwell Time (DWT)	2520	0.63	0.37	0.00	2.27
No.of Intersections (No In)	2520	0.50	0.50	0.00	1.00
No. of Bus Stop Stat. (No.BSS)	2520	0.99	0.10	0.00	1.00
Bus Lane (BL)	2520	0.72	0.45	0.00	1.00
Bus Frequency (Bus Freq)	2520	2.81	1.05	1.00	6.00
Time of Day (ToD)	2520	1.80	0.75	1.00	3.00
Day of Week (DoW)	2520	4.00	2.00	1.00	7.00

4.3 Regression Model of Bus Travel Time Reliability

A multiple linear regression technique was used to develop a mathematical model for bus travel time data on the study corridors. The aggregated-level regression model analysis was conducted using 2,520 observations. At the disaggregated level, the total travel time data for Corridor 1 was 840 observations (70 trips for each of the 12 segments along the corridor over seven days). Similarly, for Corridor 2, the total observed travel time data was 980 observations (70 trips for each of the 14 segments), and for Corridor 3, the total observed data was 700 (70 trips for each of the 10 segments).

Developing a TTR regression model at both aggregated and disaggregated levels is essential for users and transportation planners/policymakers. For users, a disaggregated model provides detailed insights, such as time-of-day or corridor-specific reliability, helping them plan trips more efficiently, avoid delays, and improve their overall experience. For planners and policymakers, an aggregated model reveals broader patterns and trends, supporting effective policy decisions and infrastructure investments. Disaggregated models allow for targeted interventions at specific locations or times, leading to more precise resource allocation and improved system performance.

4.3.1 Testing Multiple Linear Regression Analysis

The regression analysis in the context of sensitivity analysis, encompasses fitting a linear regression to the model response and using standardized regression coefficients as a direct measure of sensitivity. Before calibrating the regression analysis, the model assumptions should be checked first. These assumptions include model specification, linear relationship, autocorrelation, multicollinearity, heteroskedasticity, and normality tests. With a recall to the study methodology section, multiple linear regression analysis were developed using variables in Table 1. The following assumptions of multiple linear regression were checked for violation or sensitivity analysis before performing the main analysis.

Assumption One:- Ramsey RESET Test for Model Specification

The Ramsey RESET test assesses whether a regression model is correctly specified or if there are omitted variables or unaccounted non-linear relationships. In this analysis, with p-values exceeding 0.05, there is insufficient evidence to reject the null hypothesis that the models are correctly specified. This suggests no significant presence of misspecification or omitted variables. The test results further indicate that the regression models for the corridors are correctly specified, with no notable signs of misspecification or non-linearity. The fitted values (_hat) and their square (_hatsq) have coefficients that are not statistically significant at the 0.05 level, with p-values of 0.068 and 0.073, respectively. The overall probability (Prob = 0.089) also exceeds 0.05, further supporting that the model does not exhibit significant signs of misspecification.

Table 7 Ramsey RESET test for study corridors

Fitted values	**Coef.**	**Std. Err.**	**t**	**P**	
_hat	0.245	0.088	1.69	0.068	Number of obs = 2520
_hatsq	0.153	0.017	1.89	0.073	F(2, 2517) = 187.08
_cons	0.825	0.107	1.58	0.066	Prob = 0.089

Assumption Two:- Multicollinearity

In the Pearson correlation table 8, all correlation coefficients are less than 0.80, with their signs indicating the direction of the linear relationships between independent variables. Positive coefficients suggest that as one variable increases, the other tends to increase, while negative coefficients indicate that as one variable increases, the other tends to decrease. Near-zero coefficients suggest little to no linear relationship. As shown in table 9, the VIF values for all variables are below 10, confirming that multicollinearity is not a concern. This implies that the independent variables are not highly correlated, ensuring a stable and reliable regression model without multicollinearity issues.

Table 8 Pearson-correlation matrix between the independent variables

Correlation									
	Segment Length	Travel Speed	Dwell Time	No of Inter.	No of Bus Stops	Bus Lane	Bus Freq	Time of Day	Day of Week
Segment Length	1								
Travel Speed	0.412	1							
Dwell Time	0.002	-0.303	1						
No of Inter.	-0.297	-0.097	0.030	1					
No of Bus Stop	-0.025	-0.059	-0.060	0.020	1				
Bus Lane	-0.371	-0.181	0.020	-0.002	-0.027	1			
Bus Frequency	-0.005	-0.374	0.295	0.033	-0.015	-0.055	1		
Time of Day	0.023	0.399	-0.228	-0.058	0.000	0.075	-0.519	1	
Day of Week	0.000	0.201	-0.086	0.000	-0.104	-0.002	-0.139	0.000	1

Table 9 Variance inflation factor summary of independent variables

Variables	Segment Length	Travel Speed	Dwell Time	No of Intersection	No.Bus Stop Stations	Bus Lane	Bus Frequency	Time of Day	Day of Week
VIF	1.70	1.35	1.17	1.12	1.03	1.21	1.26	1.26	1.72

Assumption Three:- Breusch Pagan Test for Heteroskedasticity

As presented in Table 10 below, the p-value for the Breusch-Pagan test is above the 0.05 significance level. This indicates that fail to reject the null hypothesis of constant variance, suggesting no significant evidence of heteroskedasticity in the model. The results imply that the assumption of homoskedasticity (constant variance) is satisfied, and the model's residuals have constant variance across all levels of the independent variables, thereby supporting the validity of the regression model. In summary, the results indicate that the regression models for the study corridors exhibit a linear relationship while adhering to the assumption of constant residual variance. This reinforces the reliability of the model's standard errors and subsequent inferences, as there is no strong evidence of heteroskedasticity affecting the results.

Table 10 Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

hettest = Breusch-Pagan / Cook-Weisberg test for heteroskedasticity	
Ho: Constant variance =	Variables: fitted values
chi^2	3.63
P	**0.605**

Assumption Four:- Normality Test

The Anderson-Darling (AD) test results, as shown in Figure 4, indicate that the p-value for assessing the normality of the residuals in the model fit is greater than 0.05. This provides insufficient evidence to reject the null hypothesis that the residuals are normally distributed, suggesting that the residuals for the study corridors adhere to the normality assumption required for linear regression models. Consequently, this supports the appropriateness of the models and the reliability of the results. In summary, the satisfactory normality of the residuals reinforces the validity of the regression models utilized in the analysis.

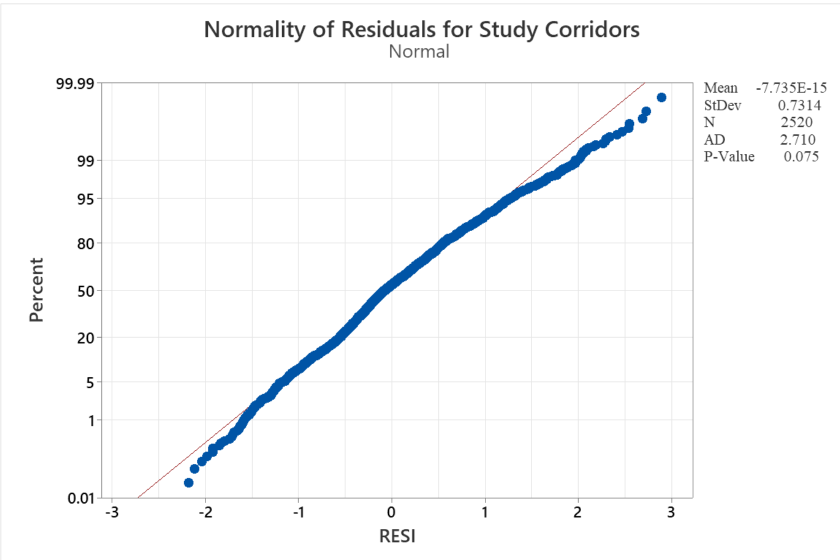

Figure 4 Normality test on the residuals of the model fit for the study corridors

4.3.2 One-Way ANOVA Analysis

The independent variables consist of six continuous variables, one nominal variable and two categorical variables. One-way ANOVA (Analysis of Variance) for categorical variables was employed. The reason for applying one-way ANOVA (Analysis of Variance) for categorical variables is to compare the means of travel time reliability across different categories or groups. This statistical method determine if there are significant differences in travel time reliability among the various groups, such as time of day, and day of the week. A statistical hypothesis test was performed to determine if bus travel time differs across various times of the day (AM Peaks, PM Peaks, and Off-Peaks) and days of the week (Monday to Sunday). A one-way ANOVA test was used to evaluate whether these factors have a statistically significant impact on bus travel time along the study corridors.

Null Hypothesis (H0): There is no statistically significant variation in travel time based on the time of day (AM Peaks, PM Peaks, and Off-Peaks) or the day of the week (from Monday to Sunday).

Alternative Hypothesis (H1): There is a statistically significant difference in travel time based on the time of day (AM Peaks, PM Peaks, and Off-Peaks) or the day of the week (from Monday to Sunday).

A p-value ≤ 0.05 indicates that the differences between some of the means are statistically significant. Therefore, if the p-value is less than or equal to the significance level, we reject the null hypothesis and conclude that not all group means are equal. Conversely, a p-value > 0.05 indicates that the differences between the means are not statistically significant. If the p-value is greater than the significance level, then there is no enough evidence to reject the null hypothesis that the group means are all equal. For this analysis, time of day is coded as follows: 1 for AM Peaks, 2 for PM Peaks, and 3 for Off-Peaks. The days of the week are coded as: 1 for Monday, 2 for Tuesday, 3 for Wednesday, 4 for Thursday, 5 for Friday, 6 for Saturday, and 7 for Sunday.

The one-way ANOVA results for travel time based on the time of day are shown in Table 11. The degrees of freedom (DF) for time of day is 2. The p-value associated with the F-statistic is ≤ 0.000 for the study corridors, indicating that the observed F-values are statistically significant. This leads us to reject the null hypothesis, showing significant differences in travel time across different times of the day. Thus, time of day is a significant factor affecting bus travel time reliability in the study corridors.

Table 11 One-way ANOVA test for travel time over the times of day

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ToD	2	1038	519.17	597.49	0.00
Error	2517	2187	0.87		
Total	2519	3225			

The one-way ANOVA results for travel time based on the day of the week are shown in Table 12. The p-value for the day of the week is 0.000 for each corridor, which is below the 0.05 significance level. This indicates significant differences in travel times across different days of the week, demonstrating that the day of the week has a highly significant effect on travel time. Thus, day of the week is a significant factor in bus travel time reliability along the study corridors.

Table 12 One-way ANOVA test for travel time over the days of the week

Source	DF	Adj SS	Adj MS	F-Value	P-Value
DoW	6	436.1	72.68	65.48	0.00
Error	2513	2789.3	1.11		
Total	2519	3225.4			

4.3.3 Multiple Linear Regression Analysis at Aggregated Level

Based on the results of a one-way ANOVA test, both the time of day and the day of the week have a significant effect on travel time, indicating an interaction between these variables. Consequently, these variables are also incorporated into the multiple linear regression model to better understand and predict bus travel time reliability along the study corridors. The results of the multiple linear regression analysis at aggregated level is presented in Table 13. The p-value is used to identify significant predictor variables, while the adjusted R-squared, mean square error (MSE), and root mean square error (RMSE) are used to assess the model fit. Lower MSE and RMSE values (less than 1) suggest the model is performing well, as the predictions closely match the actual values. Additionally, high adjusted R-squared values (ranging from 0.7 to 1.0) indicate that the model explains a large proportion of the variability in the dependent variable. Based on the regression results shown in the table, this model is considered a good fit, with adjusted R-squared values falling between 0.7 and 1.0.

Table 13 Multiple linear regression analysis result at aggregated level

Model (Travel Time Reliability)	**Coefficients**		**Significance**	
	Coef	**SE Coef**	**t-Value**	**P-Value**
Constant	3.51	0.19	8.36	0.00
Segment Length	1.14	0.06	7.90	0.00
Travel Speed	-0.07	0.00	-10.93	0.00
Dwell Time	0.43	0.04	9.95	0.00
No of Intersections	0.06	0.03	1.95	0.03
No of Bus Stop Stations	0.08	0.15	0.53	0.01
Bus Lane	-0.08	0.04	-2.17	0.03
Bus Frequency	-0.02	0.02	1.26	0.01
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	0.23	0.03	6.74	0.00
Off- Peak = 3	-0.62	0.06	-4.53	0.00
Day of Week (1= Monday, Base reference)				
Tuesday= 2	-0.35	0.05	-6.31	0.00
Wednesday = 3	-0.55	0.06	-9.83	0.00
Thursday= 4	-0.19	0.05	-3.47	0.00
Friday = 5	0.05	0.05	1	0.03
Saturday = 6	-0.55	0.06	-9.71	0.00
Sunday = 7	-0.79	0.06	-13.43	0.00
R-Square	80.22%			
Adjusted R- Square	79.14 = 79%			
MSE	0.53			
RMSE	0.73			

TTR_{bus}= 3.51+1.14SL-0.07TS+0.43DWT+0.06No.of Int+0.08No.of BSS-0.08BL-0.02BFreq +0.23PM-Peak-0.62Off-Peak-0.35Teus-0.55Wedn-0.19Thurs+0.05Fri-0.55Satur-0.79Sun

Where, SL= Segment Length, TS= Travel Speed, DWT= Dwell Time, No,of Int= Number of intersections, No.of BSS= Number of Bus Stop Stations, BL= Bus Lane, BFreq= Bus Frequency, PM& Off-peak (Time of Day categories by taking AM-Peak as a base reference), Tues =Tuesday, Wedn= Wednesday, Thurs= Thursday, Fri=Friday, Satur= Saturday, & Sun=Sunday (days of week categories by taking Monday as a base reference).

Interpretation of regression model at aggregated level without interaction

The results in Table 13 highlight significant factors affecting bus travel time reliability, including segment length, travel speed, dwell time, number of intersections, bus lanes, bus stop stations, day of the week, time of day, and bus frequency. All predictor variables have a p-value below the 0.05 significance level, indicating that they significantly predict travel time reliability, with an adjusted R-squared value of 0.7914. Segment length has a strong positive effect on unreliability, while higher travel speed and the presence of bus lanes reduce unreliability. Dwell time, the number of intersections, and bus stop stations all increase travel time unreliability, though intersections and bus stops have a smaller effect. Higher bus frequency slightly improves reliability by reducing unreliability. For time of day, travel time increases during PM peak (compared to AM peak) and decreases during off-peak hours. Regarding the day of the week, travel time decreases on Tuesday, Wednesday, Thursday, Saturday, and Sunday compared to Monday, while it increases on Friday. The model explains 79% of the variance in travel time reliability, with a good fit as indicated by low MSE and RMSE values (<1).

Therefore, based on the analysis results, the factors with the highest impact on bus transport travel time reliability the study corridors are segment length, dwell time, number of bus stop stations, number of intersections, bus frequency, bus lanes, day of the week, and time of day.

This study identified segment length, travel speed, dwell time, number of intersections, number of bus stop stations, bus lanes, bus frequency, time of day, and days of the week as significant factors affecting travel time reliability. These findings align with the study (Mohamed et al., 2021), conducted in Malaysia, who similarly highlighted the impact of factors like bus stoppings, segment length, intersections, and dwell time on bus travel time reliability. However, this study differ from Gezahegn (2019), and Assen & Quezon (2019), who focused primarily on road segment travel time reliability in Addis Ababa rather than bus transport travel time reliability factors. Additionally, while some research, such as (Zhu et al., 2021), conducted in United States and China stated factors like inadequate green time, pedestrian crossings, and over-development as significant contributors to bus travel time reliability, these factors were not identified in the this study.

4.3.4 Multiple Linear Regression Analysis at Disaggregated Level

Table 14 Multiple linear regression analysis result at disaggregated level

Corridor 1				
Model (Travel Time Reliability)	**Coefficients**		**Significance**	
	Coef	**SE Coef**	**t-Value**	**P-Value**
Constant	2.85	0.17	16.49	0.00
Segment Length	1.54	0.10	15.56	0.00
Travel Speed	-0.08	0.004	-17.66	0.00
Dwell Time	0.27	0.06	4.23	0.00
No of Intersections	0.21	0.04	-5.18	0.00
No of Bus Stop Stations	0.62	0.09	7.14	0.00
Bus Lane	-0.15	0.06	-2.56	0.84
Bus Frequency	-0.01	0.03	-0.20	0.01
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	0.07	0.05	-1.49	0.13
Off- Peak = 3	-0.53	0.09	-6.11	0.00
Day of Week (1= Monday, Base reference)				
Tuesday= 2	-0.18	0.08	-2.24	0.03
Wednesday = 3	-0.32	0.08	-3.95	0.00
Thursday= 4	-0,23	0.08	-2.81	0.00
Friday = 5	0.62	0.08	-1.54	0.12
Saturday = 6	-0.23	0.08	-2.85	0.00
Sunday = 7	-0.49	0.09	-5.42	0.00
R-Square	0.8124 (81.24%)			
Adjusted R- Square	0.8035 (80.35%)			
MSE	0.38			
RMSE	0.61			
Corridor 2				
Constant	3.31	0.25	13.01	0.00
Segment Length	0.46	0.12	3.99	0.00
Travel Speed	-0.17	0.01	-9.41	0.00
Dwell Time	0.36	0.09	3.95	0.00
No of Intersections	0.03	0.05	0.6*	0.54
No of Bus Stop Stations	0.29	0.10	2.83	0.00
Bus Lane	-0.42	0.06	-7.58	0.00
Bus Frequency	-0.01	0.03	-0.42	0.00
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	0.39	0.05	7.73	0.00
Off- Peak = 3	-0.66	0.09	-7.15	0.00
Day of Week (1= Monday, Base reference)				
Tuesday= 2	-0.38	0.08	-4.54	0.00
Wednesday = 3	-0.50	0.09	-5.86	0.00
Thursday= 4	-0.21	0.08	-0.48	0.00
Friday = 5	0.42	0.08	1.03	0.01
Saturday = 6	-0.49	0.09	-5.70	0.00
Sunday = 7	-0.76	0.09	-8.71	0.00
R-Square	0.7958 (79.58%)			

Adjusted R- Square	0.7888 (78.88%)			
MSE	0.48			
RMSE	0.69			
Corridor 3				
Constant	4.23	0.20	21.53	0.00
Segment Length	0.29	0.08	3.46	0.00
Travel Speed	-0.03	0.01	-5.04	0.00
Dwell Time	0.38	0.08	4.94	0.00
No of Intersections	0.04	0.05	0.86	0.39
No of Bus Stop Stations	0.12	0.06	-1.97	0.04
Bus Lane	-0.26	0.04	5.87	0.00
Bus Frequency	-0.08	0.03	-2.35	0.02
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	0.04	0.05	8.39	0.00
Off- Peak = 3	-1.54	0.11	-14.32	0.00
Day of Week (1= Monday, base reference)				
Tuesday= 2	-0.61	0.08	-7.51	0.00
Wednesday = 3	-1.18	0.08	-14.03	0.00
Thursday= 4	-0.41	0.08	-5.00	0.00
Friday = 5	0.53	0.08	-2.44	0.02
Saturday = 6	-1.41	0.09	-15.85	0.00
Sunday = 7	-1.75	0.09	-18.81	0.00
R-Square	0.8095 (80.95%)			
Adjusted R- Square	0.8053 (80.53%)			
MSE	0.32			
RMSE	0.56			

Interpretation of regression model without interaction

Corridor One

As presented in Table 14 above the independent variables have a p-value of less than the significance level **(0.05)** and significantly predict travel time with an Adj. R-square value of 0.8035. The Adj. R-square interpreted as all the selected variables segment length, travel speed, dwell time, number of intersections, number of bus stop stations, bus frequency per specific time, time of the day, and day of the week are significant explainers of the travel time (dependent variable) and explain 80% of the varience in the observed data. For an increase in segment length. dwell time, number of intersections, number of bus stop and presence of bus lane causes an increase in the travel time, and the reverse with the increase in travel speed causes a decrease in the travel time. For each unit increase in bus frequency, the travel time decreases holding other variables constant. For time of the day (ToD_1 =AM peak, as a reference category), ToD_2 (PM peak) travel time increases, and for ToD_3 (Off-Peak) travel time decreases compared to AM peak. Similarly, for day of the week, DoW_1 = Monday is the base reference category day of the week. Travel time decreases on Tuesday, Wednesday, Thursday, Saturday, and Sunday compared to the base category, while on Friday travel time increases.

Corridor Two

The explanatory variables segment length, travel speed, dwell time, number of bus stop stations, bus lanes, bus frequency, day of the week, and time of day were found to have p-values less than the significance level of 0.05, indicating that they significantly predict travel time, with an Adjusted R-square value of 0.7888 (78.88%). From the regression coefficients, an increase in segment length, dwell time, number of intersections, and the number of bus stop stations leads to an increase in corridor travel time. Conversely, the negative coefficient for travel speed suggests that higher speeds reduce travel time. Similarly, the presence of bus lanes and increased bus frequency along the corridor also reduce travel time. Time of day is a categorical variable, with the AM Peak (ToD_1) as the base reference category. During the PM peak (ToD_2), travel time increases compared to the AM peak, while during the Off-Peak period (ToD_3), travel time decreases. For the day of the week, Monday (DoW_1) is the base reference category. Travel time decreases on Tuesday, Wednesday, Thursday, Saturday, and Sunday compared to Monday, but increases on Friday.

Corridor Three

The independent variables with segment length, travel speed, dwell time, number of bus stop stations, bus lane, bus frequency per time, time of day and day of the week have a p-value less than the significance level **(0.05)** and these variables significantly predict travel time with an Adjusted R square value of 0.8053 (80.53%). An increase in Segment length, dwell time, the number of bus stop stations, and the number of intersections results in an increase in travel time which becomes an unreliability outcome on the corridor. Besides, travel speed, bus lane, and bus frequency have an inverse relationship depending on the result. The negative sign of the coefficients can be interpreted as an increase in travel speed, bus lane, and bus frequency indicating a decrease in travel time and this result matches with the expected signs of those variables with the travel time reliability of the corridor. Time of the day and day of the week are categorical variables. For ToD_1 =AM Peak and day of the week, DoW_1 =Monday is the base reference category. ToD_2 (PM Peak) during this specific time of day travel time increases, and ToD_3 (Off-Peak) travel time decreases compared to AM peak. Travel time decreases on Tuesday, Wednesday, Thursday, Saturday, and Sunday compared to Monday but on Friday travel time increases.

Therefore, the parameters or factors that has the highest impact on bus transport TTR described as; segment length, number of bus stop stations, dwell time, number of intersections, bus frequency, bus lane, days of the week and time of the day respectively. This model provides a robust framework for predicting TTR across other major corridors in Addis Ababa. By considering the variability of these factors in different corridors in Addis Ababa, city planners can strategically target improvements such as adding dedicated bus lanes, optimizing bus frequency, or reducing dwell times to enhance reliability. The model emphasizes that a holistic approach, addressing both infrastructure and operational efficiencies, is crucial for elevating bus transport reliability in Addis Ababa's transit network.

4.3.5 Interactions in Regression Analysis at Aggregated Level

Adding interaction terms to the regression model enhances the understanding of how variables are related. The interaction between two independent variables predicts their combined impact on the dependent variable. Specifically, when a categorical variable interacts with a continuous variable, the interaction term shows how the effect of the continuous variable on the dependent variable changes across different categories. In this research, interactions between the time of day and variables like travel speed, dwell time, and bus frequency were included in the regression model. This means the effect of interaction between two independent variables translate to affect the dependent variable.

Table 15 Interaction regression analysis results at aggregated level

Model (Travel Time Reliability)	**Coefficients**		**Significance**	
	Coef	**SE Coef**	**t-Value**	**P-Value**
Constant	3.70	0.22	6.89	0.00
Segment Length	1.16	0.06	9.43	0.00
Travel Speed	-0.08	0.00	-7.38	0.00
Dwell Time	0.62	0.06	9.62	0.00
No of Intersections	0.06	0.03	1.97	0.04
No of Bus Stop Stations	0.08	0.15	-0.53	0.00
Bus Lane	-0.14	0.04	-3.87	0.01
Bus Frequency	-0.01	0.03	0.45	0.00
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	0.60	0.20	3.04	0.00
Off- Peak = 3	-1.38	0.23	-6.03	0.00
Day of Week (1= Monday, Base reference)				
Tuesday= 2	-0.36	0.05	-6.67	0.00
Wednesday = 3	-0.55	0.06	-7.95	0.00
Thursday= 4	-0.20	0.05	-3.73	0.00
Friday = 5	0.06	0.05	1.07	0.02
Saturday = 6	-0.53	0.06	-9.60	0.00

Model (Travel Time Reliability)	Coefficients		Significance	
	Coef	**SE Coef**	**t-Value**	**P-Value**
Sunday = 7	-0.76	0.06	-5.97	0.00
TS (KM/hr)*ToD	(1= AM Peak, as a reference)			
PM Peak= 2	-0.01	0.01	-1.87	0.052
Off- Peak = 3	0.04	0.01	5.87	0.00
DWT (Min)*ToD	(1= AM Peak, as a reference)			
PM Peak= 2	-0.38	0.09	-4.11	0.00
Off- Peak = 3	-0.23	0.17	-1.32	0.1
Bus Freq*ToD	(1= AM Peak, as a reference)			
PM Peak= 2	0.04	0.04	1.13	0.11
Off- Peak = 3	-0.05	0.06	-0.80	0.05
R-Square	81.12%			
Adjusted R- Square	80.34 = 80%			
MSE	0.52			
RMSE	0.72			

Interpretation of regression model witht interaction

The results from table 15 above reveal significant factors impacting travel time reliability. Segment length has a strong positive effect on unreliability, indicating that longer segments increase travel time unreliability. In contrast, higher travel speeds improve reliability. Dwell time and the number of intersections contribute to increased unreliability, while the presence of bus lanes helps reduce it. Time of day also plays a crucial role, with PM peak travel times higher than AM peak, while off-peak travel times are lower. Variations across days of the week indicate decreased unreliability from Tuesday to Sunday compared to Monday, with Friday showing a slight increase. The interaction terms suggest that travel speed and dwell time vary across times of day. The model demonstrates a strong fit, explaining 80% of the variance in travel time reliability, with low Mean Squared Error (MSE) of 0.52 and a Root Mean Squared Error (RMSE) of 0.72, confirming the model's effectiveness in predicting travel time reliability.

4.3.6 Interactions in Regression Analysis at Disaggregated Level

Table 16 Interaction regression analysis results for corridor 1

Corridor 1				
Interaction regression model terms	**Coefficients**		**Significance**	
	Coef	**SE Coef**	**T-Value**	**P-Value**
Constant	3.10	0.22	13.93	0.00
Segment Length	1.56	0.01	16.09	0.00
Travel Speed	-0.10	0.01	-12.72	0.00
Dwell Time	0.41	0.09	4.69	0.00
No of Intersections	0.22	0.04	-5.3	0.00
No of Bus Stop Stations	0.58	0.09	6.8	0.00
Bus Lane	-0.22	0.06	0.94*	0.35
Bus Frequency	-0.04	0.04	-3.62	0.00
Time of Day (1= AM Peak, as a reference)				
PM Peak= 2	0.61	0.28	1.59*	0.11
Off- Peak = 3	-1.36	0.32	-4.25	0.00
Day of Week (1= Monday, as a reference)				
Tuesday= 2	-0.19	0.08	-2.4	0.02
Wednesday = 3	-0.32	0.08	-4.12	0.00
Thursday= 4	-0.21	0.08	-2.72	0.01
Friday = 5	0.28	0.08	-1.5*	0.13
Saturday = 6	-0.26	0.08	-3.25	0.00
Sunday = 7	-0.47	0.09	-5.33	0.00
TS*ToD	(1= AM Peak, as a reference)			
2	-0.005	0.01	-0.48*	0.63
3	0.04	0.01	4.84	0.00
DWT*ToD				
2	-0.30	0.13	-2.29	0.02
3	-0.11	0.24	-0.46*	0.65
Bus Freq*ToD				
PM Peak= 2	-0.10	0.05	-1.84*	0.06
Off- Peak = 3	-0.13	0.09	-1.50*	0.13
R-Squared	0.8290			
Adjusted R-Square	0.8222			
MSE		0.35		
RMSE		0.59		

Table 17 Interaction regression analysis results for corridor 2

Corridor 2				
Interaction regression model terms	**Coefficients**		**Significance**	
	Coef	**SE Coef**	**T-Value**	**P-Value**
Constant	3.27	0.33	9.91	0.00
Segment Length	0.57	0.12	4.50	0.00
Travel Speed	-0.06	0.01	-8.15	0.00
Dwell Time	0.68	0.15	4.51	0.00
No of Intersections	0.05	0.05	1.07*	0.28
No of Bus Stop Stations	0.23	0.10	2.23	0.03
Bus Lane	-0.52	0.06	-8.59	0.00
Bus Frequency	-0.04	0.04	1.01	0.03
Time of Day (1= AM Peak, Base reference)				
PM Peak= 2	1.28	0.37	3.43	0.00
Off- Peak = 3	-0.79	0.37	-2.13	0.03
Day of Week (1= Monday, Base reference)				
Tuesday= 2	-0.40	0.08	-4.88	0.00
Wednesday = 3	-0.50	0.08	-5.92	0.00
Thursday= 4	-0.05	0.08	-0.64*	0.52
Friday = 5	0.57	0.08	0.91*	0.36
Saturday = 6	-0.49	0.08	-5.80	0.00
Sunday = 7	-0.75	0.08	-8.66	0.00
TS*ToD (1= AM Peak, Base reference)				
2	-0.005	0.01	-0.39*	0.70
3	0.03	0.01	3.35	0.00
DWT*ToD				
2	-0.69	0.20	-3.48	0.00
3	-0.34	0.30	-1.13*	0.26
Bus Freq*ToD				
PM Peak= 2	-0.08	0.06	-1.32*	0.19
Off- Peak = 3	-0.17	0.09	-1.86	0.06
R-Squared	0.8123			
Adjusted R-Square	0.8027			
MSE		0.46		
RMSE		0.68		

Table 18 Interaction regression analysis results for corridor 3

Corridor 3				
Interaction regression model terms	Coefficients		Significance	
	Coef	SE Coef	T-Value	P-Value
Constant	4.34	0.25	17.28	0.00
Segment Length	0.28	0.08	3.47	0.00
Travel Speed	-0.04	0.01	-6.50	0.00
Dwell Time	0.82	0.12	7.03	0.00
No of Intersections	0.04	0.05	-0.79*	0.43
No of Bus Stop Stations	0.09	0.06	-1.5	0.13
Bus Lane	-0.20	0.04	4.46	0.00
Bus Frequency	-0.11	0.04	-2.38	0.02
Time of Day	1=AM Peak, Base reference			
PM Peak= 2	0.89	0.33	2.69	0.01
Off- Peak = 3	-2.43	0.38	-6.33	0.00
Day of Week	1=Monday, Base reference			
Tuesday= 2	-0.61	0.08	-7.77	0.00
Wednesday = 3	-1.15	0.08	-14.09	0.00
Thursday= 4	-0.41	0.08	-5.18	0.00
Friday = 5	0.53	0.08	-2.32	0.02
Saturday = 6	-1.32	0.09	-15.15	0.00
Sunday = 7	-1,64	0.09	-17.85	0.00
TS*ToD	1= Am Peak, Base reference			
2	-0.01	0.01	-0.69*	0.49
3	0.04	0.01	4.68	0.00
DWT*ToD				
2	0.79	0.16	-4.91	0.00
3	-0.71	0.34	-2.09	0.04
Bus Freq*ToD				
PM Peak= 2	0.09	0.06	1.45*	0.15
Off- Peak = 3	0.09	0.11	0.85	0.02
R-Squared	0.8239			
Adjusted R-Square	0.8185			
MSE	0.29			
RMSE	0.54			

Interpretation of regression model at disaggregate level with interaction

The interaction model result is presented in Table 16-18 above and the significant predictor variables are similar to the initial multiple regression results for the study corridors. Therefore, the interpretation of interaction terms of travel speed and time of day on off-peak is significant compared with the base category AM peak. This indicates during an off-peak time of the day travel speed is increased which results in a decrease in travel time, the interaction term is significant for the study corridors. In addition, the interaction of travel speed and PM peak time of the day is not significant compared to AM peak time of the day. Similarly, the interaction term of dwell time and PM peak time of day is significant compared to AM peak time of the day, dwell time increases at PM peak time which results in an increased travel time for the study corridors.

Moreover, the interaction term of bus frequency and PM peak time of the day is significant compared to AM peak time, an increase in bus frequency results decrease in travel time which translates to travel time reliability for the study corridors. Therefore, the findings from the interaction model are crucial for understanding how different factors interact with each other to affect travel time and can help in planning and optimizing public transport systems for better efficiency and reliability.

In summary, the findings from the interaction model are critical for understanding how various factors, such as travel speed, dwell time, and bus frequency, interact with the time of day to influence travel time. These insights are valuable for planning and optimizing public transport systems, ultimately improving their efficiency and reliability. A positive coefficient for the variables indicates an increase in travel time (decrease in reliability), while a negative coefficient indicates a decrease in travel time. However, both increases and decreases in travel time can impact travel time reliability. A decrease in travel time due to certain factors might make the bus service less reliable by causing longer waiting times for users at stations or disrupting the schedules. The model helps to understand the significant factors that influence bus travel time reliability on the study corridors.

4.4 Travel Time Reliability from User Perspectives

Respondents were purposively selected from those waiting at bus stations along the selected corridors. The interview results, as presented in Figure 5, revealed a male majority, with most participants in the prime and mature working age groups (25-44 years). This suggests that their travel behavior and perceptions of reliability can give a significant finding. Given their experience with bus transport services, these respondents are likely well-equipped to assess bus travel time performance at stops and along the corridor. The majority of interviewed users primarily utilized the bus for work-related travel, with a notable concentration of these users employed in government and private sectors. A substantial proportion of users traveled by bus more than four days a week, indicating regular reliance on bus transportation. However, a significant issue observed was that most users were unaware of the bus schedule information. This lack of awareness about bus schedules contributes to unreliable travel times, potentially leading to increased frustration and inefficiencies in the public bus transportation system.

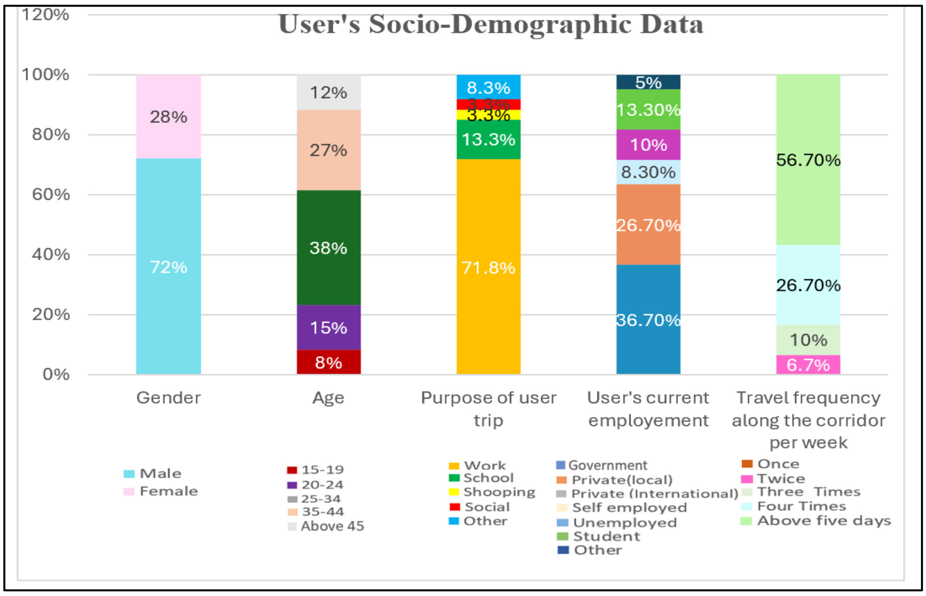

Figure 5 User's socio-demographics data

As it is presented in Figure 6 below, the results reveal that 88% of respondents reported long waiting times at bus stop stations, while 12% experienced no issues with bus frequency, highlighting a widespread concern about bus frequency. Additionally, 53% of users waited over 30 minutes for the next bus, 28% waited 21-30 minutes, 7% waited 11-20 minutes, and 12% had no long waiting times. Regarding boarding and alighting, 50% of users felt it affected their travel time, while the other 50% did not. Furthermore, 85% of users agreed that dedicated bus lanes significantly reduce travel time, whereas 15% disagreed. Overall, the majority of users see the benefit of dedicated bus lanes in improving travel time reliability. These findings from the qualitative study complement the initial objectives, linking user perspectives on travel time reliability with the identified factors affecting bus travel time in the study corridors.

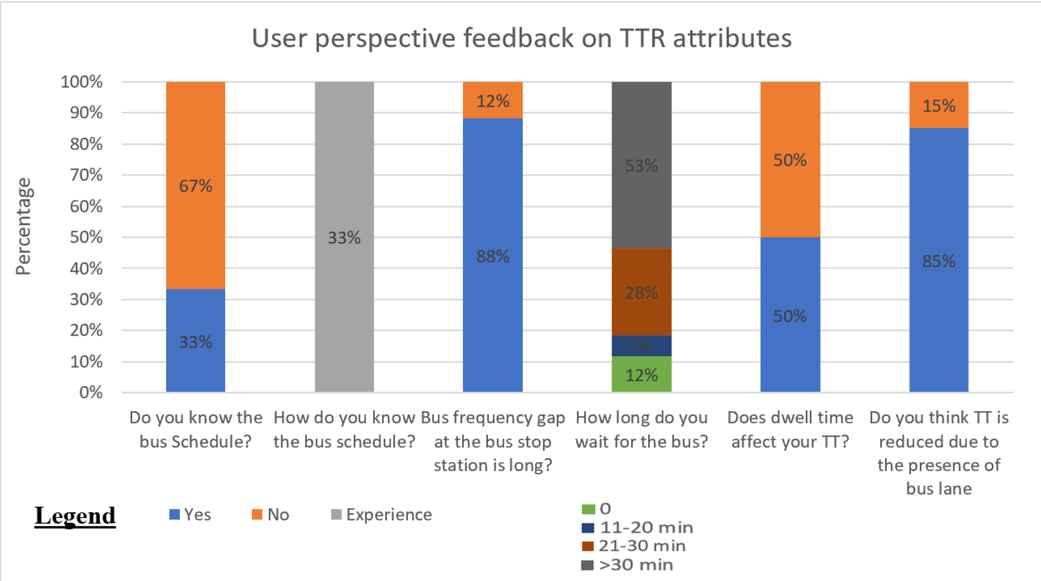

Figure 6 User perspective feedback on bus TTR attributes

To assess user perspectives on travel time reliability, a Likert-scale form interview questionnaire was developed covering attributes such as, time of day, day of the week, bus frequency, number of bus stops, arrival delay, and number of intersections. The results show that higher mean values indicate minimal impact on travel time reliability, whereas lower mean values suggest significant effects. Specifically, the day of the week and time of day, with mean values of 1.58 and 2.1 respectively, are identified as key factors affecting travel time reliability. Additionally, a greater number of intersections along the corridors tends to increase travel time, while adequate bus frequency improves reliability.

Table 19 Travel time reliability attributes/factors from the user perspective

Variables		Arrival Delay	Bus frequency	Time of day	No.of intersections	Day of the week	No. of bus stops
N		60	60	60	60	60	60
Average		2.1	3.8	2.1	4.03	1.58	3.27
Std. Dev.		0.877	0.777	0.796	0.736	0.591	0.756

Figure 7 Pictures during field data collection

In summary, the study's findings address three objectives related to bus travel time reliability. The analysis revealed that travel times are highest on Mondays and Fridays, particularly during AM and PM peaks. The PTI values for the study corridors indicate varying levels of reliability, with PTI showing that travel time reliability is significantly affected by the time of day and day of the week. Multiple linear regration, and interaction regression models identified several key factors influencing travel time reliability, including segment length, travel speed, dwell time, number of intersections, bus lanes, number of bus stop stations, and bus frequency. Notably, interaction terms involving travel speed, dwell time, and bus frequency with time of day were significant. User feedback highlighted that travel time reliability is strongly affected by the time of day, day of the week, number of bus stop stations, number of intersections, bus frequency, bus lanes, and dwell time. The mean values and feedback from users align with the quantitative results, reinforcing the critical factors impacting travel time reliability. Overall, the study emphasizes that improving travel time reliability requires addressing time-of-day and day-of-week effects, optimizing segment length, travel speed, and bus frequency, and managing dwell time and bus lane allocation effectively.

The findings of this study on travel time reliability (TTR) in Addis Ababa align with similar challenges identified in studies from other developing countries. Research by Mandlate et al. (2023), George et al. (2023), Yanan et al. (2022), and Krishna (2014) highlights recurring issues in urban transportation systems, particularly in bus rapid transit (BRT) corridors, where traffic congestion and travel time variability are major obstacles to efficient public transit. In Addis Ababa, as in other African cities, traffic congestion during peak hours and the lack of dedicated bus lanes on major corridors contribute to inconsistent travel times. This study shows that, similar to findings by Mandlate et al. (2023) and George et al. (2023), heavy dependence on mixed-traffic lanes for buses reduces TTR, especially during peak periods. Moreover, users in Addis Ababa report long waiting times and a lack of accessible schedule information, which parallels findings from other developing cities, where inadequate communication of transit schedules further reduces user satisfaction and perceived reliability.

However, one notable difference lies in the level of infrastructure development. Some developing cities with established BRT systems, like those studied by Yanan et al. (2022), have partially mitigated TTR issues by implementing exclusive bus lanes and regular schedules, whereas Addis Ababa is still in the early stages of incorporating such infrastructure widely across its major corridors. This lack of infrastructure in Addis Ababa exacerbates the issues observed in these other studies, underscoring a stronger need for dedicated lanes and improved transit management systems to enhance reliability. The challenges of TTR in Addis Ababa reflect those found in similar urban environments in developing countries, the need for targeted infrastructure improvements, such as expanding dedicated bus lanes and better communication tools, appears particularly urgent.

Therefore, the most significant challenge in achieving reliable travel time for bus transport service in Addis Ababa is managing peak hour (AM peak, 6:30-9:30 and PM peak 4:00-7:30) demands particularly high traffic weekdays (on Monday and Friday). Moreover, insufficient dedicated bus lanes with low enforcements mean buses share road space with general traffic, leading increasing delays during peak periods. Lack of accessible bus sckedules and real time information compounds this issue by leaving passengers uninformed about expected delays or changes, reducing reliability. Thus, a combination of operational and infrastructural interventions is need to undertake the challenges during peak periods effectively

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study addressed gaps in understanding how various factors affect travel time reliability across different times of the day and days of the week. Previous studies lacks a comprehensive analysis of bus TTR factors and did not sufficiently incorporate user's perceptions in their analysis. The study estimated travel time at both segment and corridor levels, evaluated bus TTR using index-based analysis, applied one-way ANOVA and multiple regression, and incorporated user feedback through qualitative analysis.

The findings show that travel time is consistently higher on weekdays, especially Mondays and Fridays, and during peak hours, AM peak (6:30-9:30), and PM peak (4:00-7:30). Key factors affecting TTR include time of day, day of the week, segment length, travel speed, dwell time, intersections, bus lanes, bus stops, and bus frequency. User feedback emphasizes the importance of bus frequency, bus stop stations, and dedicated lanes, which supports the significant impact of weekdays and peak periods on reliability. Moreover, a substantial number of users were unaware of bus schedules, indicating a gap in information that affects travel time reliability.

The results suggest that optimizing bus schedules to manage peak times and high-traffic weekdays could enhance travel time reliability. Implementing dedicated bus lanes and reducing the number of bus stops and intersections help minimize delays. Improved communication of bus schedules and increased frequency are crucial for enhancing reliability. The study effectively linked travel time reliability with significant factors and user perceptions. The results indicates actionable insights for city planners and transport authorities to enhance bus travel time reliability through both infrastructural and operational improvements, ensuring more reliable and user-friendly services.

The findings suggest several policy implications for improving bus transport travel time reliability. Authorities should focus on optimizing bus schedules during peak periods AM peak (6:30-9:30), and PM peak (4:00-7:30), particularly on high-traffic weekdays like Mondays and Fridays, to reduce delays. Policies promoting the implementation of dedicated bus lanes, and increasing bus frequency are essential to enhance efficiency and reliability. Additionally, addressing the gap in user awareness of bus schedules through better communication tools, display boards, should be prioritized to improve overall user satisfaction and reduce unreliability in travel time.

Therefore, the study finding highlights that peak hour congestion on weekdays, the bus frequency, and insufficient bus lanes are primary challenges for bus transport service reliability in Addis Ababa. Based on the study's key findings, it is concluded that, on average, an additional hour is needed to ensure reliable travel times for users of the bus transport service across the study corridors.

5.2 Recommendation

Based on the study findings, the following recommendations are provided for practitioners, policymakers, and decision-makers in public institutions, and particularly relevant to Addis Ababa City Bus Service Enterprise and the Addis Ababa Traffic Management Agency. Implementing these recommendations can significantly improve bus transport travel time reliability, resulting in more efficient, reliable, and user-friendly public transport services.

1. Optimize Bus Schedules

The study findings reveal that 67% of respondents indicated that users are generally unaware of bus schedule information, which contributes to the perception of unreliability in bus transport services, particularly during peak periods on weekdays along the study corridors. This can be achieved by adjusting bus schedules to better accommodate AM (6:30-9:30) and PM (4:00-7:30) peak periods, as travel time is significantly higher during these times focusing on Monday and Friday, which show the highest travel times. Besides, implement dynamic scheduling based on real-time traffic conditions and demand patterns to reduce delays and improve travel time reliability.

2. Enhance Implementation of Dedicated Bus Lanes

Expand and enforce dedicated bus lanes on major corridors to minimize delays caused by mixed traffic. This will help in reducing travel time variability and enhance overall reliability. Moreover, ensure strict enforcement of bus lane usage and monitor their effectiveness regularly to maintain their efficiency. Based on the study's findings, dedicated bus lanes emerge as a crucial factor in enhancing travel time reliability (TTR) for bus transport services. User feedback further underscores this need, with 85% of respondents advocating for the expansion of dedicated bus lanes along major corridors, recognizing their contribution to improved service reliability. This strong user support highlights the importance of prioritizing dedicated lanes as an effective strategy to reduce delays, minimize congestion impacts, and provide a more dependable transit experience for daily commuters.

3. Increase Bus Frequency

Increase bus frequency or number of buses, particularly during peak hours, to accommodate higher passenger volumes and reduce waiting times. This will enhance both travel time reliability and user satisfaction. Additionally, make sure that bus frequency aligns with demand patterns, especially during high-traffic periods on weekdays, to prevent overcrowding and associated delays. The study findings indicate that most users reported waiting over 30 minutes for the next bus after the first one leaves the departure stop. To improve reliability in high-demand corridors, a target bus frequency with headways between 5–10 minutes is recommended, though the optimal interval may vary depending on the specific corridor.

4. Improve Communication of Bus Schedules

Improving communication of bus schedules involves ensuring that accurate, real-time information about bus arrival and departure times is easily accessible to users. This can be achieved through digital displays at bus stops. By providing real-time updates, passengers can plan their trips more effectively, reducing uncertainty and waiting times. Clear communication also helps users adjust to delays or changes in service, contributing to better travel time reliability and overall user satisfaction. This recommendation aims to bridge the information gap identified in the study, ensuring passengers are well-informed and can make more efficient travel decisions.

Future Research

- In this study, corridors were segmented based on bus stop spacing, and travel time data was aggregated into two different scales: spatial (corridor level and segment level) and temporal (AM peak, PM peak, and off-peak periods). The travel time distribution of each aggregation case was analyzed. For future research, it is recommended to segment corridors based on the spacing of intersections in addition to the bus stops.
- This study developed a multiple regression model using nine independent variables under recurrent conditions, both with and without interaction effects. Future studies could explore:
  - Factors affecting bus travel time reliability in non-recurrent conditions (e.g., traffic incidents, unexpected events).
  - Segment or road width as a factor in bus transport TTR
  - The impact of signal timing quality (good coordination versus poor coordination).
  - Traffic flow and volume at mid-blocks and intersections (vehicles per hour per lane).

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APPENDICES

Annex 1: Segments Along Each Study Corridor

Segments along corridor 1

Path	Name	Latitude	Longitude	Distance (Km)	Segments
From Mexico-Federal Police Commission Headquarters to Haile Garment Square					
		Bus Stop Stations in Corridor 1			
A	Federal Police Commission Headquarters Mexico	9.00878	38.74382	0	
	Africa Hibret / □□□□ □□□□	9.00298	38.74112	0.707	1
	Sarbet Mekaneyesus / □□ □□ □□□ □□□□	8.99915	38.73943	1.17	2
	Sarebet Deldey / □□ □□ □□□□	8.99310	38.73822	1.858	3
	Vatican Embassy / □□□□ □□□□	8.98883	38.73750	2.343	4
	Mekanisa Abo Mazoria / □□□□ □□ □□□□	8.98212	38.73432	3.324	5
	Mekanissa School /	8.97883	38.73398	3.713	6
	Amigo / □□□	8.97287	38.73110	4.501	7
	Mekanissa Mr Hotel /	8.96842	38.73132	4.996	8
	Germen Adebabay / □□□□ □□□□□	8.96559	38.73270	5.348	9
	Germen Gulit Gebeya / □□□□ □□□ □□□	8.96326	38.73291	5.663	10
	Lebu Mebrat Hail / □□ □□□□ □□□	8.94715	38.73394	7.473	11
	Haile Garment Adebabay / □□□ □□□□□ □□□□□	8.93871	38.73454	8.428	12
From Haile Garment Square to Mexico-Federal Police Commission Headquarters					
B	Haile Garment Square / □□□ □□□□□ □□□□□	8.94011	38.73516	0	
	Lebu Mebrat Hail / □□ □□□□ □□□	8.95177	38.73282	1.333	12
	Kidist Arsema Betekrstian / □□□□ □□□□ □□ □□□□□□	8.96170	38.73307	2.441	11
	Germen Adebabay / □□□□ □□□□□	8.96506	38.73298	2.820	10
	Mekanissa Mekaneysuse / □□□□ □□□ □□□□	8.96871	38.73145	3.267	9
	Mekanissa / □□□□	8.97402	38.73241	3.915	8
	Mekanissa School /	8.97786	38.73413	4.410	7
	Mekanissa Abo Mazoria / □□□□ □□ □□□□	8.98207	38.73454	4.896	6
	Gibsen School /	8.98546	38.73767	5.506	5
	Vatican Embassy / □□□□ □□□□	8.99061	38.73819	6.088	4
	Sarebet Deldey / □□ □□ □□□□	8.99306	38.73838	6.359	3
	Africa Hibret / □□□□ □□□□	9.00294	38.74136	7.516	2

	Federal Police Commission Headquarters Mexico	9.00901	38.74414	8.253	1

Segments along corridor 2

From Kara Kore to Wabi Shebelle Hotel (Mexico)					
Path	**Name**	**Bus Stop Stations in Corridor 2**			**Segments**
		Latitude	**Longitude**	**Distance (Km)**	
A	Kara Kore / □□ □□	8.97526	38.68079	0	
	Ayer Tena Girar / □□□ □□ □□□	8.97929	38.68516	0.673	1
	Ayer Tena Mesalemiya / □□□ □□ □□□□□	8.98249	38.69628	1.965	2
	Zenebe Worq / □□□ □□□ □□□□	8.98500	38.70520	2.989	3
	Alert Square / □□□□ □□□□□	8.98756	38.70895	3.5	4
	Total 3 Kuter Mazoria /	8.99262	38.71589	4.492	5
	Minaye Buiding / □□□□ □□□	8.99993	38.71915	5.491	6
	Augusta / □□□□	9.00557	38.71889	6.116	7
	Torhayloch / □□ □□□□	9.01011	38.72113	6.684	8
	Mekoninoch Kibeb |Torhayloch /	9.01127	38.72662	7.417	9
	Coca-Cola Mazoria / □□ □□ □□□□	9.01186	38.72961	7.769	10
	Lideta Federal Court /	9.01159	38.73306	8.15	11
	Lideta / □□□	9.01086	38.73867	8.781	12
	Tegbared Tvet School / □□□□ □□	9.01034	38.74263	9.221	13
	Wabi Shebele Hotel / □□ □□□ □□□	9.01191	38.74681	9.784	14
From Wabi Shebelle Hotel (Mexico) to Kara Kore					
B	Wabi Shebele Hotel / □□ □□□ □□□	9.01283	38.74786	0	
	Tegbared Tvet School / □□□□ □□	9.01060	38.74307	0.611	14
	Lideta / □□□	9.01112	38.73870	1.094	13
	Lideta Federal Court /	9.01182	38.73318	1.715	12
	Coca-Cola Mazoria / □□ □□ □□□□	9.01217	38.72945	2.127	11
	Mekoninoch Kibeb |Torhayloch /	9.01127	38.72620	2.513	10
	Shewa Supermarket / □□□ □□□	9.00847	38.71959	3.547	9
	Augusta / □□□□	9.00561	38.71856	3.884	8
	Minaye Building / □□□□ □□□	8.99997	38.71886	4.51	7
	Total 3 Kuter Mazoria /	8.99283	38.71588	5.412	6
	Alert Square / □□□□ □□□□□	8.98665	38.70780	6.603	5
	Zenebe Worq / □□□ □□□	8.98525	38.70510	6.968	4
	Ayer Tena Damot College / □□□ □□ □□□ □□□	8.98257	38.69588	8.032	3
	Ayer Tena Girar / □□□ □□ □□□	8.97948	38.68530	9.259	2
	Kara Kore / □□ □□	8.97544	38.68069	9.968	1

Segments along corridor 3

From Megenagna to Derartu Square					
Path	Name	Bus Stop Stations in Corridor 3			Segments
		Latitude	Longitude	Distance (Km)	
	Megenagna Terminal / □□□□ □□□□□	9.02059	38.80217	0	
	Zerfeswale School (Tapu) /	9.01966	38.80392	0.594	1
	Gurd Shola / □□□ □□	9.01909	38.81930	2.303	2
	Salitemihiret / □□□□□□□	9.02029	38.82733	3.23	3
	Civil Service / □□□ □□□□	9.02159	38.83473	4.075	4
A	Cmc Michael /	9.02134	38.84014	4.67	5
	Cmc Apartment /	9.02082	38.85038	5.797	6
	Yetebaberut / □□□□□□	9.02066	38.85386	6.214	7
	Meri / □□	9.02074	38.86511	7.453	8
	Ayat Babur Tabiya / □□□ □□□ □□□	9.02104	38.87189	8.199	9
	Derartu Square / □□□□ □□□□□	9.02121	38.87733	8.834	10
From Derartu Square to Megenagna					
	Derartu Square / □□□□ □□□□□	9.02154	38.87736	0	
	Ayat Babur Tabiya / □□□ □□□ □□□	9.02146	38.87423	0.374	10
	40/60 Apostelic /	9.02104	38.86736	1.132	9
	Meri / □□	9.02076	38.86048	1.889	8
B	Yetebaberut / □□□□□□	9.02089	38.85377	2.628	7
	Cmc Apartment /	9.02114	38.85045	3.028	6
	Cmc Michael /	9.02166	38.84014	4.163	5
	Civil Service / □□□ □□□□	9.02194	38.83317	4.93	4
	Salitemihiret / □□□□□□□	9.02030	38.82660	5.686	3
	Gurd Shola / □□□ □□	9.01936	38.81936	6.528	2
	Megenagna Terminal / □□□□ □□□□□	9.02059	38.80217	8.451	1

Annex 2: Questionnaire

Addis Ababa University
Addis Ababa Institute of Technology
School of Civil and Environmental Engineering
MSc. program in Road and Transportation Engineering Stream

Questionnaire for assessing Travel Time Reliability (TTR) from the user perspective on the study corridors (Mexico to Haile Garment Square, Kara Kore to Mexico Wabe Shebelle Hotel, and Megenagna to Derartu Square).

Part one: Background

Dear respondents,

This questionnaire is prepared for data collection of research on Travel Time Reliability (TTR) of Bus Transport performance for the selected corridors in Addis Ababa City. Thus, your responses to these questions are kept **confidential** and be used only for academic purposes. Therefore, please be helpful and give your precise and correct answers to these questions.

Part two: General information of respondents

1. What is your age?

1. 14 and below ☐	2. 15 - 19 ☐	3. 20-24 ☐
4. 25-34 ☐	5. 35-44 ☐	6. above 45 ☐

2. Gender of the respondent

1. Male ☐	2. Female ☐

3. Can you please state your current employment?

1. Government ☐	2. Private (local) ☐	3. Private (international) ☐
4. Self-employed ☐	5. Unemployed ☐	6. Student ☐
7. Other ☐		

Part three: Assess travel time reliability from the user's perspective across study corridors.

This interview questionnaire has been prepared to get responses from the user on travel time reliability (TTR) information related to the bus schedule, stop waiting time, and dwell time. Moreover, the **questionnaire has been prepared to get responses from the user on travel time reliability attributes** namely arrival delay, time of the day, day of the week, bus frequency per specific time, number of bus stops, and number of intersections. The questions are grouped into two categories yes or no under (A) to collect bus schedule-related information and Likert Scale (B) to collect TTR attributes.

Accordingly, please give your precise answer from your perception of travel time reliability of the study corridors using yes or no and the respective numbers presented using the Likert Scale method list of questions in the table below.

No	A = Yes or No Questions	Yes		No		
1	How often do you travel this corridor per week?	Once	Twice	Three times	Four times	Above five days
2	What is the purpose of your trip (use the bus to attend activity)?	Work	School	Shopp ing	Social	Other
3	Do you know the bus schedule of the route/ corridor bus stop station departure or arrival time?					
4	If you answer yes, how do you know the bus schedule information?	Experience		Display on information boards		Other
5	The gap in bus frequency at your departure stop station is long (waiting time for the second bus after the first bus travel/operation)					
6	If you answer yes, how long are you waiting at the stop station to get a bus?	Minutes				
		<10	11-20	21-30		>30
7	Does the time taken by boarding and alighting the bus at the stop station affect your trip travel time?					
8	Do you think travel time is reduced due to using the allocated bus lane of your corridor for bus transport?					

For the following Likert Scale questions each number stands for 1. Strongly Disagree, 2. Disagree, 3. Neutral, 4. Agree, and 5. Strongly Agree with the below table.

No	**B= Likert Scale Questions**	**1=SD**	**2=D**	**3=N**	**4=A**	**5=SA**
1	Buses always arrive on time for their route/corridor departure					
2	Bus frequency per specific time at bus stop station reduces long waiting time					
3	Enough buses are allocated during times of work entry and exit.					
4	Your journey isn't affected by the various traffic lights across the corridor.					
5	The corridor you use can be characterized by slower speeds, longer travel time, and an increased no. of vehicles from Monday to Sunday.					
6	The number of bus stops in the corridor interrupts your journey so often, which leads to a longer travel time					

Annex 3: Segment level estimated travel time based on time of day and day of week

Corridor 1: Estimated travel time

Corridor 1: AM Peaks Travel Time														
Days	**No. of Trips**	**Sta 13**	**Sta 12**	**Sta 11**	**Sta 10**	**Sta 9**	**Sta 8**	**Sta 7**	**Sta 6**	**Sta 5**	**Sat 4**	**Sta 3**	**Sta 2**	**Sta 1**
Monday	1	2.08	4.25	3.16	5.09	4.11	2.45	3.24	4.10	3.12	3.46	4.51	4.36	4.43
	2	2.15	4.28	3.32	5.14	4.20	2.48	3.29	4.13	3.25	3.50	5.06	5.06	5.38
	3	1.58	5.05	3.51	5.34	5.20	2.52	3.36	4.24	3.45	3.58	5.16	5.14	5.41
	4	1.36	4.13	3.01	4.48	3.41	2.23	3.01	3.52	2.54	3.13	4.01	4.28	4.36
Tuesday	5	1.88	3.26	3.17	4.28	4.27	2.34	2.38	2.50	2.58	2.49	3.34	3.24	4.17
	6	2.20	3.41	3.31	5.01	4.39	2.43	2.42	2.54	2.36	3.03	3.47	3.35	4.37
	7	1.82	4.43	5.56	5.48	5.01	3.28	2.54	2.42	2.53	2.29	2.14	3.56	4.49
	8	1.68	4.11	4.22	4.34	4.51	3.02	2.46	2.34	2.49	2.23	2.10	3.28	4.38
Wednesday	9	1.95	3.14	3.21	4.41	3.52	2.06	2.00	2.28	2.01	2.03	2.08	2.36	3.21
	10	2.07	3.34	3.42	4.58	3.56	2.28	2.19	2.38	2.11	2.14	2.37	3.54	4.02
	11	1.90	3.26	3.38	4.52	2.34	2.16	2.11	2.19	2.03	2.00	2.28	3.34	3.58
	12	1.77	3.13	3.16	4.22	2.14	2.03	2.01	2.09	1.56	1.58	2.13	3.11	3.46
Thursday	13	2.23	3.31	3.33	4.36	2.28	1.56	2.09	3.32	1.58	2.00	2.53	3.11	3.54
	14	2.42	3.45	3.56	5.07	2.50	2.17	2.16	3.37	2.06	2.03	2.54	3.46	4.05
	15	2.30	4.21	4.36	4.54	2.41	2.31	2.34	3.51	2.21	2.13	3.01	3.16	4.01
	16	2.02	3.51	3.38	4.28	2.34	2.11	2.11	2.53	2.11	2.03	2.59	3.01	3.58
Friday	17	2.32	4.08	3.36	4.39	2.16	2.15	2.34	3.48	2.39	2.09	3.17	3.38	4.08
	18	2.45	4.38	3.42	4.47	2.32	2.19	2.55	3.58	2.44	2.21	3.28	3.46	4.19
	19	2.35	4.51	3.51	4.58	2.56	2.38	3.05	4.03	2.53	2.35	3.41	4.07	4.26
	20	2.22	4.11	3.23	4.4	2.28	2.23	2.44	3.54	2.48	2.18	3.21	3.54	4.11
Saturday	21	2.05	3.09	3.03	3.46	2.51	1.58	1.58	2.01	1.57	2.05	2.45	2.55	3.13
	22	2.20	3.32	3.05	3.54	2.56	2.01	2.03	2.07	2.1	2.08	2.53	2.59	3.15
	23	2.08	3.48	2.55	4.01	3.57	2.43	2.00	2.36	2.09	2.11	1.50	3.00	3.36
	24	1.88	3.23	2.49	3.53	3.52	2.21	1.56	2.17	2.04	2.01	1.43	2.54	3.07
Sunday	25	1.40	2.31	2.18	2.41	2.52	1.28	1.26	1.40	1.24	1.36	2.01	2.12	2.25
	26	1.53	2.43	2.24	2.57	2.59	1.51	1.39	1.53	1.42	1.49	2.14	2.28	2.49
	27	1.45	2.58	2.33	3.09	3.09	1.58	1.58	2.00	1.53	1.58	2.09	2.37	2.52
	28	1.30	2.27	2.48	3.01	3.01	1.49	1.43	1.57	1.37	1.39	1.57	2.40	2.17

Corridor 1: PM Peaks Travel Time														
Days	**No.of Trips**	**Sta 1**	**Sta 2**	**Sta 3**	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sat 10**	**Sta 11**	**Sta 12**	**Sta 13**
Monday	1	2.42	4.00	3.13	4.00	4.30	4.43	3.00	2.58	5.23	4.41	4.56	3.13	3.31
	2	3.05	4.34	3.30	4.11	4.25	4.54	3.30	3.10	5.31	4.30	3.20	3.23	3.51
	3	3.20	5.11	5.01	5.36	6.25	6.19	6.30	6.10	5.20	4.30	3.20	3.30	3.10
	4	2.77	4.52	4.37	5.01	5.00	5.10	5.16	5.26	4.53	4.00	2.58	3.01	2.52
Tuesday	5	2.88	3.00	3.11	3.54	3.43	3.51	2.42	2.32	3.13	3.46	4.19	4.13	4.11
	6	3.08	3.08	3.18	4.11	3.57	4.23	2.51	2.45	4.12	4.46	4.59	4.13	4.11
	7	2.62	5.10	5.11	5.04	3.36	4.07	4.03	4.01	3.41	3.01	2.32	2.38	3.21
	8	2.55	4.16	4.24	4.46	3.36	4.07	4.03	4.01	3.41	3.01	2.32	2.00	2.11
Wednesday	9	2.38	3.08	2.51	3.05	3.13	3.20	2.28	2.03	2.59	3.04	3	2.11	2.43
	10	2.60	3.23	2.57	3.17	3.2	3.32	2.42	2.13	3.12	3.16	3.08	2.25	3.03
	11	2.48	3.54	3.14	3.23	3.32	3.46	3.06	2.58	3.19	3.24	3.28	2.39	3.13
	12	2.20	3.41	3.02	3.09	3.21	3.24	2.34	2.08	3.02	3.09	3.08	2.28	2.48
Thursday	13	2.73	3.11	2.58	4.05	4.09	3.42	2.48	2.58	2.58	3.02	2.47	2.32	2.54
	14	2.87	3.42	3.26	4.38	4.24	4.11	3.26	3.36	3.08	3.08	3.08	2.30	3.00
	15	2.68	4.08	3.38	4.51	4.36	4.17	3.34	3.42	3.24	3.14	3.45	2.45	3.02
	16	2.57	3.58	3.18	4.14	4.24	3.51	3.18	3.57	3.01	3.04	2.54	2.24	2.34
Friday	17	3.10	3.39	3.53	4.16	3.14	4.49	2.54	2.17	4.39	3.56	3.19	2.49	2.54
	18	3.20	3.45	4.11	4.35	4.38	4.58	3.23	2.54	4.44	4.18	3.36	2.51	3.14
	19	2.97	4.10	4.38	4.58	4.47	5.09	3.55	3.17	4.51	4.07	3.42	2.57	3.20
	20	2.73	3.53	4.21	4.28	4.04	4.51	3.45	2.32	4.29	3.50	3.09	2.53	2.57
Saturday	21	2.42	2.58	2.38	3.41	3.32	3.43	2.21	2.26	3.24	3.16	4.02	2.43	3.08
	22	2.38	3.47	2.57	3.49	3.59	3.54	2.49	2.53	3.49	3.45	4.15	2.52	3.27
	23	2.55	4.01	3.24	3.58	4.03	2.58	3.13	3.41	3.55	3.57	4.33	2.49	3.36
	24	2.10	3.38	2.46	3.51	3.44	2.58	2.38	2.42	3.31	3.21	4.10	2.29	3.12
Sunday	25	1.58	2.14	2.28	2.36	2.41	2.49	1.56	2.04	2.38	2.37	2.21	2.04	2.16
	26	1.63	2.57	2.47	2.52	2.56	2.37	2.02	2.16	2.47	2.54	2.41	2.11	2.22
	27	1.53	2.52	3.01	3.09	3.16	2.11	2.22	2.34	2.41	2.21	2.16	2.17	2.09
	28	1.43	2.45	2.57	3.01	3.06	2.04	2.11	2.24	2.32	2.16	2.01	1.51	2.02

Corridor 1: Off-Peaks Travel Time														
Days	No. of Trips	Sta 1/13	Sta 2/12	Sta 3/11	Sta 4/10	Sta 5/9	Sta 6/8	Sta 7/7	Sta 8/6	Sta 9/5	Sat 10/4	Sta 11/3	Sta 12/2	Sta 13/1
Monday	1	1.00	1.58	1.14	1.26	1.06	1.30	1.03	1.54	1.10	1.04	1.46	2.00	2.30
	2	1.00	2.24	2.11	3.30	2.28	1.08	1.30	1.30	1.30	1.30	1.00	2.24	2.53
Tuesday	3	0.97	1.07	1.05	1.15	1.09	1.06	1.03	1.12	1.25	1.01	1.1	2.03	2.06
	4	0.95	1.39	1.50	1.58	1.58	1.00	1.19	1.26	1.06	1.02	1.00	1.48	2.01
Wednesday	5	1.10	1.06	1.02	1.05	1.01	1.04	1.02	1.09	1.03	1.05	1.09	1.24	1.46
	6	1.12	1.24	1.58	2.16	1.13	1.00	1.11	1.03	1.09	1.07	1.00	1.35	1.59
Thursday	7	0.98	1.11	1.01	1.00	1.00	1.03	1.00	1.11	1.05	1.04	1.06	1.36	2.08
	8	1.03	1.34	1.59	2.27	1.12	1.00	1.13	1.06	1.18	1.15	0.59	1.56	2.07
Friday	9	1.03	1.38	1.00	1.32	1.01	1.03	1.00	1.52	1.02	1.04	1.26	2.41	2.54
	10	1.07	2.41	2.31	2.51	2.03	1.00	1.23	1.15	1.26	1.19	1.01	2.00	2.47
Saturday	11	1.05	1.11	1.00	1.04	1.00	1.03	1.01	1.31	1.00	1.02	1.12	2.01	2.06
	12	1.00	1.19	2.00	1.56	1.49	1.00	1.02	1.04	1.01	1.04	1.00	1.41	2.00
Sunday	13	1.00	1.03	1.00	1.02	1.00	1.01	1.00	1.08	1.00	1.00	1.01	1.48	1.51
	14	1.00	1.00	1.26	1.32	1.21	1.00	1.00	1.01	1.01	1.00	1.00	1.24	1.22

Corridor 2: Estimated travel time

Corridor 2: AM Peaks Travel Time															
Days	Sta 1/15	Sta 2/14	Sta 3/13	Sta 4/12	Sta 5/11	Sta 6/10	Sta 7/9	Sta 8/8	Sta 9/7	Sat 10/6	Sta 11/5	Sta 12/4	Sta 13/3	Sta 14/2	Sta 15/1
Monday	2.63	4.13	4.27	4.10	4.24	4.33	3.26	3.24	3.42	3.36	3.42	4.20	4.09	4.13	5.24
	2.38	4.47	4.34	4.18	4.36	4.48	3.33	3.34	3.53	3.45	3.51	4.29	4.21	4.24	5.35
	2.07	4.58	4.45	4.25	4.42	4.56	3.45	3.40	4.01	4.15	3.58	4.33	4.35	4.38	5.43
	1.70	4.22	4.19	3.55	4.09	4.21	3.11	3.16	3.36	3.28	3.32	4.11	3.56	4.01	5.08
Tuesday	1.93	4.21	2.24	2.40	3.35	3.05	2.26	3.48	3.36	3.03	2.41	2.43	2.43	2.48	3.01
	2.27	4.28	2.36	3.06	3.48	3.45	2.48	3.52	3.42	3.12	2.49	2.58	2.54	3.08	3.18
	1.90	4.39	2.45	3.17	3.57	3.58	3.26	3.58	3.48	3.22	2.56	3.01	2.58	3.19	3.21
	1.80	4.06	2.17	2.45	3.24	3.11	2.32	3.38	3.24	3.16	2.46	2.38	2.46	3.01	3.11
Wednesday	2.02	3.13	2.24	2.09	2.22	2.24	2.18	2.24	2.28	1.42	1.53	2.18	2.38	2.58	2.35
	2.07	3.27	2.34	2.19	2.39	2.32	2.34	2.47	2.51	2.02	2.05	2.34	2.53	3.09	2.46
	1.93	3.39	2.43	2.36	2.48	2.43	2.41	2.56	3.00	2.38	2.36	2.49	3.04	3.16	2.54
	1.82	3.26	2.15	2.00	2.11	2.09	2.26	2.33	2.38	2.11	2.18	2.22	2.31	2.51	2.21
Thursday	2.30	4.48	3.41	3.04	3.08	3.05	2.54	1.51	2.04	1.54	2.04	2.47	4.11	3.51	3.56
	2.47	4.56	3.49	3.22	3.28	3.18	3.11	2.24	2.19	2.26	2.13	2.55	4.21	4.03	4.07
	2.37	5.03	4.12	3.36	3.35	3.27	3.32	2.55	2.40	2.49	2.36	3.04	4.39	4.22	4.18
	2.10	4.26	3.32	3.00	2.51	2.58	3.01	2.19	2.01	1.54	2.47	2.32	4.02	3.38	3.58
Friday	2.38	4.08	3.44	3.47	3.34	3.36	3.06	2.12	2.34	2.26	2.34	3.34	3.42	3.53	4.04
	2.52	4.23	4.09	3.53	3.48	3.52	3.23	2.46	2.56	2.52	2.43	3.45	3.49	3.59	4.43
	2.45	4.29	4.16	4.00	3.55	4.00	3.37	2.51	3.13	3.09	2.56	3.57	3.57	4.05	4.56
	2.33	3.57	3.54	3.38	3.22	3.27	3.01	2.24	2.18	2.26	2.30	3.25	3.33	3.48	4.45
Saturday	2.13	3.10	2.45	2.20	2.11	2.03	2.12	1.38	1.59	1.30	1.34	2.01	3.54	3.49	3.36
	2.25	3.21	2.51	2.26	2.16	2.12	2.18	1.46	2.07	1.39	1.42	2.04	3.58	3.51	3.45
	2.12	3.48	1.54	2.11	2.28	2.38	2.43	3.06	3.01	2.15	1.45	1.38	1.41	2.26	2.53
	1.97	3.35	1.48	2.04	2.22	2.31	2.36	2.54	2.51	2.11	1.36	1.34	1.34	2.16	2.42
Sunday	1.43	2.34	2.11	2.04	2.03	2.09	1.58	1.48	1.50	1.36	1.41	1.56	2.23	2.11	2.33
	1.57	2.39	2.17	2.09	2.10	2.15	2.03	1.57	1.55	1.56	1.47	2.01	2.35	2.26	2.38
	1.58	2.45	2.25	2.17	2.18	2.23	2.06	2.04	2.02	2.03	1.52	2.07	2.46	2.32	2.41
	1.38	2.41	2.08	2.01	2.07	2.03	1.54	1.53	1.48	1.40	1.43	1.58	2.25	2.18	2.33

Corridor 2: Off- Peaks Travel Time																
Days	No. Trips	Sta 1/15	Sta 2/14	Sta 3/13	Sta 4/12	Sta 5/11	Sta 6/10	Sta 7/9	Sta 8/8	Sta 9/7	Sat 10/6	Sta 11/5	Sta 12/4	Sta 13/3	Sta 14/2	Sta 15/1
	1	1.07	2.06	2.02	2.00	2.04	2.10	2.13	2.05	2.04	2.11	2.05	2.08	2.07	2.18	2.21
Monday	2	1.12	1.55	2.09	2.21	2.34	2.23	2.32	2.15	2.38	2.49	2.57	2.25	2.15	2.55	3.01
	3	1.08	1.58	1.41	1.48	1.50	1.47	2.04	1.42	1.36	1.43	1.50	1.23	1.39	1.54	1.17
Tuesday	4	1.03	1.38	1.38	1.46	1.44	1.36	1.51	1.46	1.58	2.04	2.13	1.48	1.43	2.07	2.11
	5	1.13	1.31	1.11	1.10	1.12	1.05	1.09	1.10	1.11	1.06	1.09	1.08	1.10	1.11	`1.10
Wednesday	6	1.17	1.08	1.06	1.09	1.07	1.10	1.12	1.13	1.09	1.11	1.09	1.08	1.11	1.14	1.17
	7	1.05	2.38	1.18	1.21	1.16	1.24	1.47	1.54	2.00	2.00	2.02	1.19	1.30	1.28	1.19
Thursday	8	1.08	1.36	1.19	1.34	1.40	1.30	1.50	1.53	2.01	2.08	1.58	1.53	1.55	2.01	2.08
	9	1.08	2.01	1.42	1.50	1.54	1.59	2.06	1.38	1.53	2.10	2.00	2.01	2.00	2.14	2.10
Friday	10	1.10	1.41	1.36	1.58	2.10	2.06	2.24	2.02	2.11	2.34	2.14	2.05	2.03	2.18	2.34
	11	1.08	1.50	1.24	1.28	1.41	1.46	1.39	1.32	1.26	1.34	1.38	1.41	1.03	1.11	`1.26
Saturday	12	0.97	1.13	1.18	1.26	1.45	1.49	1.36	1.42	1.18	1.22	1.13	1.10	1.00	1.02	1.10
	13	1.05	1.16	1.00	1.00	1.00	1.01	1.00	1.02	1.04	1.06	1.00	1.00	1.01	1.05	1.01
Sunday	14	1.08	1.02	1.00	1.00	1.02	1.01	1.00	1.02	1.00	1.03	1.01	1.00	1.00	1.01	1.00

Corridor 2:PM Peaks Travel Time																
Days	No. Trips	Sta 1/15	Sta 2/14	Sta 3/13	Sta 4/12	Sta 5/11	Sta 6/10	Sta 7/9	Sta 8/8	Sta 9/7	Sat 10/6	Sta 11/5	Sta 12/4	Sta 13/3	Sta 14/2	Sta 15/1
Monday	1	2.47	5.01	5.08	5.17	5.26	5.38	5.45	4.12	4.18	4.56	5.31	5.07	5.18	5.26	5.38
	2	3.08	5.35	5.41	5.22	5.34	5.43	5.51	4.17	4.25	5.08	5.39	6.26	6.17	6.29	6.34
	3	3.23	5.39	5.48	5.33	5.39	5.48	5.58	4.28	4.37	5.38	5.48	6.23	6.11	6.24	6.32
	4	2.85	5.17	5.15	5.28	5.37	5.46	5.51	4.24	4.33	5.07	5.13	5.43	5.53	5.03	5.12
Tuesday	5	2.90	4.56	4.36	4.38	4.41	4.52	4.43	2.22	2.38	2.51	3.32	4.07	4.12	4.47	4.31
	6	3.03	5.08	4.57	4.49	4.54	4.59	5.03	2.28	2.47	2.58	3.42	4.17	4.20	4.54	4.41
	7	2.72	5.14	5.07	5.52	5.16	3.54	5.13	2.43	2.58	3.02	3.59	4.37	4.50	4.56	4.59
	8	2.63	4.51	4.45	4.39	4.48	4.51	4.53	2.32	2.43	2.41	3.42	4.17	4.27	4.44	4.26
Wednesday	9	2.42	3.52	4.16	4.41	4.08	4.24	4.03	2.25	2.08	2.07	2.18	3.05	3.14	3.19	3.14
	10	2.63	3.59	4.23	4.47	4.17	4.42	4.11	2.36	2.25	2.23	2.34	3.18	3.24	3.24	3.23
	11	2.52	4.26	4.54	4.58	4.24	4.51	4.22	2.47	2.38	2.37	2.51	3.34	3.31	3.28	3.36
	12	2.27	3.47	4.32	4.33	3.58	4.06	3.49	2.16	2.03	2.24	2.29	3.01	3.02	3.00	3.04
Thursday	13	2.80	4.38	4.32	4.43	4.21	4.16	4.23	2.18	2.36	2.55	3.29	4.02	4.12	4.34	4.43
	14	2.97	4.53	4.45	4.52	4.37	4.27	4.34	2.27	2.43	3.26	3.42	4.12	4.23	4.41	4.47
	15	2.75	5.11	4.57	5.01	4.46	4.36	4.48	2.41	2.54	3.41	3.58	4.26	4.34	4.48	4.52
	16	2.63	4.23	4.29	4.36	4.12	4.04	4.12	2.21	2.24	3.14	3.31	3.56	4.02	4.24	4.36
Friday	17	3.07	4.14	4.23	4.08	4.25	4.08	4.13	4.03	4.06	4.28	4.36	4.09	4.18	4.25	4.12
	18	3.13	4.23	4.30	4.22	4.34	4.18	4.22	4.15	4.18	4.36	4.44	4.23	4.25	4.30	4.18
	19	3.02	4.37	4.47	4.37	4.47	4.33	4.36	4.23	4.27	4.42	4.54	4.47	4.32	4.41	4.33
	20	2.82	4.01	4.18	3.54	4.12	4.01	4.05	3.56	4.01	4.21	4.32	4.17	4.11	4.13	4.03
Saturday	21	2.47	2.55	3.11	3.24	3.21	3.39	3.14	2.07	2.29	2.11	3.06	3.11	3.28	3.34	3.32
	22	2.50	3.05	3.18	3.30	3.28	3.45	3.19	2.16	2.34	2.18	3.11	3.16	3.33	3.40	3.38
	23	2.62	3.58	3.51	3.55	3.18	3.24	3.21	3.04	3.00	3.07	3.24	3.09	3.32	3.45	3.58
	24	2.20	3.49	3.43	3.42	3.12	3.16	4.13	2.58	2.56	3.00	3.15	3.01	3.26	3.34	3.41
Sunday	25	1.70	2.45	2.54	3.01	3.04	3.07	2.31	1.59	1.55	1.58	2.11	2.23	2.33	2.34	2.41
	26	1.68	2.48	3.07	3.03	3.07	3.10	2.36	2.23	2.11	2.26	2.28	2.28	2.38	2.39	2.47
	27	1.58	2.59	3.10	3.07	3.13	3.24	2.51	2.30	2.19	2.34	2.29	2.35	2.45	2.47	2.52
	28	1.55	2.43	2.51	2.58	2.53	2.52	2.23	2.01	2.21	2.10	2.41	2.47	2.41	2.28	2.46

Corridor 3 AM Peaks Travel Time												
Days	No. of Trips	Sta 11	Sta 10	Sta 9	Sta 8	Sta 7	Sta 6	Sta 5	Sta 4	Sta 3	Sat 2	Sat 1
Monday	1	3.07	4.12	4.19	4.14	4.15	5.11	4.43	5.30	5.28	5.48	4.35
	2	2.95	4.23	4.32	4.27	4.20	5.22	4.54	5.42	5.39	5.51	4.42
	3	3.15	4.56	4.34	4.10	4.04	5.36	4.59	5.56	5.49	5.59	4.56
	4	2.72	4.01	4.00	3.54	3.56	4.48	4.38	5.29	5.32	5.40	4.47
Tuesday	5	2.97	3.08	3.14	2.57	2.51	3.51	3.41	4.24	4.41	3.53	4.17
	6	3.00	3.38	3.19	3.04	2.58	3.58	3.49	4.33	4.51	4.05	4.21
	7	3.08	3.56	3.41	3.11	3.07	4.01	3.55	4.40	4.58	4.16	4.30
	8	2.80	3.42	3.28	3.07	2.54	3.50	3.43	4.27	4.48	4.07	4.12
Wednesday	9	2.68	2.01	2.11	2.03	2.21	3.01	2.34	3.24	3.13	3.14	3.11
	10	2.63	2.38	2.32	2.27	2.14	3.09	2.45	3.38	3.29	3.38	2.54
	11	2.82	2.58	2.49	2.36	2.27	3.28	2.54	3.46	3.37	3.44	2.43
	12	2.57	2.27	2.23	2.21	2.13	3.11	2.21	3.29	3.19	3.14	2.49
Thursday	13	2.78	3.28	3.41	3.06	2.37	4.11	3.50	4.33	4.26	4.05	3.08
	14	2.70	3.43	3.49	3.11	2.48	4.24	3.55	4.43	4.37	4.17	3.28
	15	2.85	4.14	3.58	3.23	2.59	4.36	4.01	4.51	4.46	4.28	3.39
	16	2.63	3.56	3.51	3.15	2.40	4.07	3.42	4.46	4.40	4.21	3.31
Friday	17	2.87	3.36	4.01	3.24	3.41	4.01	4.01	4.39	4.34	4.11	3.14
	18	2.75	3.44	4.26	3.31	3.47	4.12	4.09	4.47	4.45	4.19	3.36
	19	2.92	3.57	4.38	3.51	3.56	3.55	3.56	4.57	4.55	4.48	3.54
	20	2.63	3.41	4.12	3.36	3.36	3.48	3.47	4.31	4.25	4.21	3.21
Saturday	21	2.73	2.51	2.24	2.00	2.14	2.58	2.52	2.52	2.41	2.58	2.52
	22	2.67	2.56	2.28	2.05	2.19	3.01	2.56	2.56	2.49	3.01	2.57
	23	2.80	3.01	2.33	2.09	2.28	3.06	2.59	2.59	2.52	3.07	3.01
	24	2.52	2.42	2.19	2.02	2.14	2.51	2.51	2.48	2.33	2.51	2.43
Sunday	25	2.58	1.53	1.55	1.49	1.38	1.49	2.06	2.32	2.21	2.18	2.34
	26	2.63	2.06	2.03	1.57	1.43	2.00	2.12	2.38	2.29	2.26	2.40
	27	2.78	2.04	2.10	2.00	1.56	2.02	2.21	2.43	2.35	2.33	2.52
	28	2.52	1.51	1.58	1.52	1.50	1.53	2.00	2.24	2.11	2.14	2.41

Corridor 3: PM Peaks Travel Time												
Days	No.of Trips	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10	Sta 11
Monday	1	3.08	4.00	4.38	4.57	4.49	4.35	4.07	4.09	4.59	4.51	5.01
	2	3.20	4.04	5.26	5.34	5.28	5.22	4.46	5.04	5.11	5.40	5.08
	3	2.98	4.10	5.36	5.42	5.35	5.43	5.04	5.10	5.41	5.11	5.11
	4	2.90	4.07	4.58	5.01	4.53	5.02	4.11	4.16	5.00	4.06	5.03
Tuesday	5	3.03	5.10	5.06	5.11	4.50	4.02	3.36	3.58	4.24	4.30	4.18
	6	3.15	5.11	5.12	5.17	4.58	4.21	3.54	4.24	4.38	4.34	4.32
	7	2.93	5.24	5.36	5.28	5.03	4.38	4.07	4.33	4.46	4.42	4.51
	8	2.87	5.14	5.21	5.12	4.53	4.04	3.48	4.20	4.30	4.08	4.21
Wednesday	9	2.82	3.51	3.49	3.54	3.38	3.23	2.34	3.42	3.18	3.09	3.11
	10	2.87	3.58	3.56	3.58	3.43	3.34	2.47	3.56	3.27	3.24	3.21
	11	2.62	4.11	4.04	4.13	3.54	3.56	2.58	4.01	3.49	3.46	3.56
	12	2.60	3.54	3.52	4.01	3.46	3.42	2.52	3.49	3.41	3.34	3.37
Thursday	13	2.85	4.56	4.46	5.12	4.34	4.04	3.45	4.24	4.32	4.38	3.17
	14	2.93	5.01	4.54	5.35	4.49	4.10	3.57	4.36	4.41	4.45	3.26
	15	2.67	5.26	5.04	5.23	4.56	4.31	4.02	4.51	4.54	4.56	3.41
	16	2.70	5.11	4.56	5.12	4.51	4.13	3.51	4.42	4.46	4.42	3.31
Friday	17	2.88	5.09	5.21	5.04	5.19	4.36	3.47	5.31	5.01	4.19	3.39
	18	2.97	5.13	5.34	5.24	5.38	4.49	3.53	5.43	5.10	4.36	3.53
	19	2.72	5.36	5.41	5.39	5.49	4.57	4.11	5.56	5.23	4.55	4.01
	20	2.75	5.19	5.26	5.27	5.21	4.28	4.01	5.34	5.07	4.41	3.41
Saturday	21	2.80	3.14	3.25	3.11	3.03	2.59	2.00	2.51	3.03	2.49	2.54
	22	2.85	3.19	3.32	3.34	3.16	3.08	2.23	2.59	3.08	2.54	2.57
	23	2.60	3.22	3.36	3.39	3.22	3.31	2.36	3.01	3.10	2.57	3.01
	24	2.63	3.11	3.19	3.21	3.09	3.14	2.24	2.51	3.02	2.51	2.51
Sunday	25	2.70	3.05	3.01	3.00	2.51	2.41	2.42	2.33	2.41	2.09	2.31
	26	2.78	3.08	3.10	3.04	2.54	2.49	2.56	2.47	2.55	2.26	2.40
	27	2.53	3.11	3.12	3.09	3.07	3.04	2.36	2.54	2.47	2.09	2.45
	28	2.57	3.02	3.10	3.01	3.00	2.56	2.45	2.49	2.40	2.06	2.48

Corridor 3: Off-Peaks Travel Time											
Days	No.of Trips	Sta 1/11	Sta 2/10	Sta 3/9	Sta 4/8	Sta 5/7	Sta 6/6	Sta 7/5	Sta 8/4	Sta 9/3	Sat 10/2	Sat 11/ 1
Monday	1	1.30	1.51	1.46	1.43	1.52	1.48	1.56	2.10	2.12	1.40	2.17
	2	1.18	2.08	2.14	2.11	2.19	2.32	2.26	2.31	2.42	2.03	2.40
Tuesday	3	1.07	1.18	1.13	1.17	1.29	1.32	1.38	1.51	1.49	1.24	1.36
	4	0.87	1.41	1.47	1.34	1.48	1.39	1.40	1.51	1.56	1.30	1.26
Wednesday	5	1.12	1.13	1.10	1.13	1.18	1.15	1.14	1.16	1.19	1.14	1.19
	6	0.92	1.26	1.31	1.16	1.19	1.21	1.18	1.24	1.33	1.17	1.21
Thursday	7	1.03	1.26	1.37	1.24	1.36	1.41	1.49	1.58	1.52	1.20	1.39
	8	0.83	1.54	2.01	1.41	1.55	1.38	1.53	1.56	1.58	1.24	1.32
Friday	9	1.20	1.32	1.26	1.29	1.35	1.40	1.52	2.01	1.54	1.28	1.46
	10	1.12	1.57	2.03	2.05	2.00	1.54	1.58	2.00	2.01	1.34	1.40
Saturday	11	0.87	1.11	1.10	1.05	1.16	1.12	1.04	1.14	1.11	1.13	1.20
	12	0.83	1.18	1.28	1.15	1.21	1.31	1.26	1.33	1.25	1.16	1.11
Sunday	13	0.90	1.05	1.01	1.06	1.08	1.11	1.08	1.13	1.05	1.00	1.04
	14	0.80	1.09	1.07	1.05	1.09	1.04	1.05	1.05	1.04	1.00	1.08

Annex: 4 Corridor level estimated travel time based on time of day and day of week for the study corridors

Days of the Week	Time of the Day	C1_ TT (Min)	C2_ TT (Min)	C_3 TT (Min)
Monday	AM Peaks	48.41	57.86	49.62
		51.34	59.17	50.47
		53.93	61.11	51.29
		43.71	54.95	47.17
	Off-Peaks	17.81	30.21	18.05
		22.98	33.41	23.44
	PM Peaks	48.50	72.88	47.14
		49.54	79.29	53.43
		62.62	80.29	54.41
		53.83	74.67	48.47
Tuesday	AM Peaks	39.90	42.07	37.54
		42.29	45.31	39.36
		45.55	47.15	41.23
		41.16	42.35	38.98
	Off-Peaks	15.99	21.60	14.14
		17.02	22.50	14.99
	PM Peaks	43.23	56.96	46.48
		47.62	59.40	48.16
		47.67	59.20	50.01
		43.73	57.22	47.18
Wedensday	AM Peaks	34.26	33.08	29.01
		38.00	36.39	29.87
		35.09	38.96	31.04
		32.39	33.94	28.84
	Off-Peaks	14.26	15.56	12.63
		16.47	16.61	13.18
	PM Peaks	34.83	47.96	35.11
		37.28	49.69	36.11
		40.04	51.89	39.10
		36.54	46.31	36.68
Thursday	AM Peaks	35.24	42.68	38.23
		38.84	46.99	39.25
		40.50	50.45	41.40
		35.60	42.29	39.12
	Off-Peaks	14.83	22.21	14.85
		17.09	23.54	15.95
	PM Peaks	37.97	55.82	44.93
		43.44	58.06	46.47
		45.24	60.28	48.11
		41.14	54.87	46.25

Days of the Week	Time of the Day	C1_ TT (Min)	C2_ TT (Min)	C_3 TT (Min)
Friday	AM Peaks	39.39	46.52	40.89
		40.94	49.53	41.91
		43.59	52.86	42.19
		39.97	45.81	39.81
	Off-Peaks	17.56	26.46	15.63
		21.64	27.58	18.64
	PM Peaks	42.69	61.35	49.14
		47.47	62.71	50.50
		50.08	64.38	52.40
		45.05	59.27	50.20
Saturday	AM Peaks	31.06	34.15	26.75
		33.23	35.61	27.95
		34.54	33.59	29.35
		31.68	31.51	26.06
	Off-Peaks	15.76	18.21	12.03
		16.76	18.01	13.07
	PM Peaks	37.94	43.69	30.49
		40.94	45.01	31.95
		43.83	48.68	33.15
		38.30	47.26	31.16
Sunday	AM Peaks	23.74	27.60	21.13
		25.61	29.65	23.17
		27.79	31.79	24.34
		25.46	27.70	21.06
	Off-Peaks	14.14	15.41	11.51
		14.27	15.20	11.36
	PM Peaks	28.02	34.26	28.24
		30.05	37.19	29.27
		31.02	38.13	29.87
		28.93	34.70	29.14

Annex 5: Corridors related data from Addis Ababa Transport Bureau

ሠንጠረዥ 4.20፡ አዲስ የሆኑና መሰራት ያለባቸው ለአውቶቡስ ብቻ ተብለው የተለዩ መስመሮች

ተ.ቁ	የተመረጡ የስምሪት መስመር	የመስመሩ የተለያዩ ክፍፍሎች	በቀን አገልግሎት የሚሰጡ አማካይ አውቶቡስ ብዛት	ዕለታዊ የተሳፋሪ ብዛት	በመስመሩ ላይ የተደረገ ምልልስ	በአንድ አቅጣጫ ያለው የትራፊክ መስመር (Traffic Lane)	ምርመራ
1	1ኛ ደረጃ	ከሾላ ገበያ - መገናኛ	96	1,303,680	18,629	4	
		ከመገናኛ - ላምበረት	146	2,003,120	28,616	3	
		ከብሄራዊ - ሜክሲኮ	96	1,391,040	19,872	3	
		ከሜክሲኮ - ሳር ቤት	102	1,085,280	15,504	3	የተሰራ
		ከኮካ ኮላ አደባባይ - ጦር ኃይሎች	86	993,300	14,190	3	በከፊል LRT
		ከ3 ቁጥር ማዞርያ - ዘነበወርቅ	86	1,011,360	14,448	3	
2	2ኛደረጃ	ከዘነበወርቅ - አየርጤና	68	628,320	8,976	3	
		ከ5 ኪሎ - አንበሳ ግቢ (ፔፕሲ)	63	639,450	9,135	3	
		ከግቢ ገብርኤል - አራት ኪሎ	64	667,520	9,536	4	
		ከብሄራዊ - ለገሃር	78	900,900	12,870	3	የተሰራ ነገር ግን የብዙሃን ትራንስፖርት የማይጠቀሙበት
		ከሳር ቤት - መካኒሳ	98	960,400	13,720	3	የተሰራ
		ከመገናኛ - መሪ /የተባበሩት/	84	846,720	12,096	4	LRT እና Tidal Flow ያለበት
		ሜክሲኮ - ልደታ	80	996,800	14,240		LRT ያለበት
		ጦር ሀይሎች -3 ቁጥር ማዞሪያ	76	728,840	10,412	3	
3	3ኛ ደረጃ	ከፒያሳ - ሳንሱሲ	64	304,640	4,352	3	
		ከቀበና - ሾላ	68	514,080	7,344	4	
		ከላምብረት - ገደራ	86	493,640	7,052	3	ከላምበረት እስከ ካራ የተሰራ

ገፅ| 38

ተ.ቁ	የተመረጡ የስምሪት መስመር	የመስመሩ የተለያዩ ክፍፍሎች	በቀን አገልግሎት የሚሰጡ አማካይ አውቶቡስ ብዛት	ዕለታዊ የተሳፋሪ ብዛት	በመስመሩ ላይ የተደረገ ምልልስ	በአንድ አቅጣጫ ያለው የትራፊክ መስመር (Traffic Lane)	ምርመራ
		ካሳንቺስ - ፍልውሃ ብሄራዊ	61	538,020	7,886	3	
		ከፒያሳ - 4 ኪሎ	64	618,240	8,832	2	
		4 ኪሎ - 5 ኪሎ	57	530,670	7,581	3	
		ከፒያሳ - ጥቁር አንበሳ	47	322,290	4,747	3	የተሰራ
		ከአውቶቡስ ተራ - አብነት	34	202,300	2,890	3	LRT ያለበት
		ከልደታ - ኮካ ማዞርያ	63	626,220	8,946	3	LRT ያለበት
		ከመካኒሳ - ጀሞ	72	443,520	6,336	3	በከፊልየተሰራ
		ስታዲየም - ለገሃር	45	299,250	4,275	3	የተሰራ
		ከመሪ/የተባበሩት/ - አያት	60	436,800	6,240	4	LRT እና Tidal Flow ያለበት
4	4ኛ ደረጃ	አየር ጤና -ካራ ቆሬ	32	127,680	1,824	3	
		አብነት -ጦር ሃይሎች	24	82,320	1,176	3	
		ፒያሳ-አዲሱ ገበያ	29	140,070	2,001	3	
		ፒያሳ-6ኪሎ ምንይልክ	32	15,680	2,240	3	
		ከካርል አደባባይ-ብስራተ ገብርኤል	20	75,600	1,080	3	
		ከቦሌ ድልድይ-ማሞ ድልድይ	20	58,800	840	3	
		ከቄራ - ጎፋ ገብረኤል	21	94,080	1,344	3	
		ከ 6 ኪሎ- ስፔን አምባሲ	30	96,600	1,380	3	
		ከግቢ ገብርኤል-በእስቲፋኖስ-ደንበል ሚፍ	20	61,600	880	3	
		ከግቢ ገብርኤል - ካዛንቺስ	24	120,960	1,728	3	

ምንጭ፡በጥናት ቡድኑ የጂ አይ ኤስ ሶፍትዌር አማካኝነት የተለዩ መስመሮች (2013 ዓ.ም)