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POST GRADUATE PROGRAME

Developing a Context-Aware IoT Framework for Traffic Management in Addis Ababa city.

A thesis submitted to department of ICT in partial fulfillment of the requirements for the masters of Science in information communication technology

M.SC THESIS

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June 2018 e.c

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DECLARATION

I, the undersigned, declare that this dissertation entitled "Developing a Context-Aware IoT Framework for Traffic Management in Addis Ababa City" is my own original work, prepared under the supervision of my advisor. It has not been submitted for the award of any degree, diploma, or any other academic qualification in this or any other institution. All sources of materials used in this dissertation have been duly acknowledged.

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APPROVAL PAGE

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ABSTRACT

Urban traffic congestion in Addis Ababa has become critical due to rapid population growth, increasing vehicle ownership, and outdated traffic control systems that rely on fixed timing signals and manual police intervention. This study addresses the lack of an intelligent, real time traffic management system tailored to the local context. The primary objective was to design and evaluate a Context-Aware Internet of Things (IoT) framework that dynamically adjusts traffic signals and provides adaptive control based on real time contextual parameters such as traffic density, time of day, weather conditions, and emergency vehicle presence.

A design science research (DSR) methodology was adopted, combining field observations, stakeholder surveys (66 respondents), and secondary traffic data from five high congestion areas in Addis Ababa: Meskel Flower, Gotera Interchange, Bole Area, Megenagna & Mexico, and Sidist Kilo. The proposed framework was modeled using five-layer IoT architecture and simulated using VISSIM, MATLAB, and NS-3. Performance was evaluated against key metrics including latency, traffic throughput, context recognition accuracy, congestion reduction, reliability, and scalability.

The simulation results showed that the proposed framework achieved an average latency of 1.1 seconds, traffic throughput exceeding 1,200 vehicles per hour in three of four pilot areas, context recognition accuracy of 91.5%, congestion reduction of 19.2% (range 15–25%), and system reliability of 98.3–98.8% uptime. Emergency vehicle prioritization success rates exceeded 90%, and accident detection occurred within 38–43 seconds with rerouting efficiency above 80%. The framework also supported up to 120 sensor nodes without significant performance degradation.

The study concludes that a Context-Aware IoT framework is technically feasible and significantly outperforms conventional fixed time traffic systems in reducing congestion, improving safety, and enabling real time responsiveness. Recommendations include phased deployment at major intersections, integration with existing traffic control centers, and capacity building for traffic management personnel. Future work should focus on real-world pilot testing and integration with smart city platforms.

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LIST OF ABBREVIATIONS AND ACRONYMS

AI – Artificial Intelligence

API – Application Programming Interface

CCTV – Closed-Circuit Television

CPU – Central Processing Unit

DMV – Data Mining and Visualization

ETH – Ethiopia

FDRE – Federal Democratic Republic of Ethiopia

GPS – Global Positioning System

ICT – Information and Communication Technology

ITS–Intelligent Transportation Systems

IEEE – Institute of Electrical and Electronics Engineers

IoT – Internet of Things

IP – Internet Protocol

IT – Information Technology

KNN – K-Nearest Neighbors

ML – Machine Learning

NS-3 – Network Simulator 3

QoS – Quality of Service

RAM – Random Access Memory

RSU – Road Side Unit

SVM – Support Vector Machine

TVET – Technical and Vocational Education and Training

VANET – Vehicular Ad-hoc Network

VSN – Vehicular Sensor Network

Wi-Fi – Wireless Fidelity

WSN – Wireless Sensor Network

CHAPTER ONE

Introduction

1.1 Background of the study

Urbanization, population growth, and the increasing number of vehicles in major cities of developing countries are creating serious traffic problems. These problems include long travel times, more pollution, and frequent road accidents. Addis Ababa, the capital city of Ethiopia, is facing similar challenges. The road system in the city was originally built for a much smaller number of vehicles and people. As the population and number of cars grow, the roads are becoming overcrowded and inefficient. The current traffic management system mainly depends on fixed Timing traffic signals and manual traffic control by police officers. However, these old methods are not effective for handling complex nature of city traffic problems. They cannot respond quickly to real time issues like traffic jams, road accidents, emergency vehicles, bad weather, or public events. As a result, many intersections in the city become blocked, causing delays, confusion, and unsafe driving conditions.

With the development of new technologies like the Internet of Things (IoT), it is now possible to improve traffic management systems. IoT can connect sensors, cameras, and wireless devices to the traffic system. These devices can collect and send real time information to help manage traffic service better, reduce congestion, and improve flexibility. However, for these systems to work well, they must understand the context such as time of day, traffic conditions, weather, and driver behavior and use this information to make smart decisions. This is where Context-Aware IoT systems are important. These systems not only collect data but also analyze it and make decisions based on the situation. For example, a Context-Aware traffic light can give more green time to a crowded road during rush hour or allow an ambulance to pass first by adjusting signal timing based on GPS data and road conditions.

In Ethiopia, especially, there is growing interest in using modern technologies for better traffic management. But current efforts are limited and do not fully use Context-Aware systems. Many challenges remain, such as limited availability of sensors, weak network infrastructure, and lack of data analysis tools. Also, most existing systems are not designed specifically for the traffic patterns and road conditions.

Therefore, this study aims to develop a Context-Aware IoT Framework that fits the real situation. The proposed framework will combine sensor technology, real time data collection, context analysis, and smart context dependent to improve traffic flow and road safety. By

focusing on the local context, this thesis tries to close the gap between modern technology and practical use in Ethiopia's growing urban environment.

1.2 Statement of the Problem

As growing African cities Addis Ababa facing serious traffic problem the roads in the city are under a lot of pressure due to the rapid population increase, unplanned expansion in half of city, and the rising number of vehicles. Even though the government is working to build new roads and improve existing ones, traffic congestion remains a major issue especially in busy. The main problem with the current traffic system is that it uses fixed timing traffic lights and manual control. These systems do not adjust to the changing traffic situation in real time. As a result, traffic moves inefficiently, more fuel is wasted, air pollution increases, and accidents are more past to happen. Also, traffic decisions are often made without proper data or technology, which causes delays and human trafficking error.

Although some improvements have been made like installing cameras and piloting a few smart traffic lights these systems are not connected or advanced enough. They do not use real time data to understand and react to what is happening on the roads. More importantly, there is no complete system that can gather, analyze, and respond to traffic information quickly and intelligently.

This lack of intelligent traffic control leads to many problems, including long travel times, delays in public transport, and difficulty for emergency vehicles to reach their destinations. Without a system that understands important factors like traffic volume during rush hours, location based congestion, pedestrian movement, and weather conditions the city cannot plan or manage traffic efficiently.

Therefore, the main problem this study addresses is the absence of a locally tailored traffic framework that can manage traffic in tangible way. Without such a system, the city will continue to struggle with outdated, reactive methods that cannot solve the growing urban traffic crisis. This thesis aims to close this gap by designing a Framework that can collect and process real time traffic data, understand local conditions, and make smart decisions to improve traffic flow. This framework is expected to help reduce congestion, improve road safety, and support transformation in to a modern, smart city.

1.3 Research Questions

This study is guided by the overarching goal of developing a Context-Aware IoT framework to improve traffic management in the city. To achieve this, the thesis seeks to answer the following core questions:

1. What contextual factors (traffic density, time, location, weather, and incidents) significantly influence real time traffic conditions in Addis Ababa?
2. How can a Context-Aware IoT framework be designed to dynamically adapt to changing traffic conditions?
3. What are the technical requirements, components, and architectural layers necessary for implementing such a framework in the local context?
4. How effective is the proposed framework in comparison with existing traffic management approaches in terms of performance, scalability, and responsiveness?

1.4 Research Objectives

The primary aim of this study is to design and propose a Context-Aware IoT Framework tailored to improve traffic management in the City. The study seeks to integrate real time sensing, context interpretation, and adaptive context dependent mechanisms suitable for the city's special urban dynamics.

1.4.1 General Objective

The main aim of this study is to design and evaluate a predictive, Context-Aware Internet of Things (IoT) framework for improving traffic management in Addis Ababa. This framework will respond to real time environmental and traffic conditions to ease congestion and enhance signal control.

1.4.2 Specific Objectives

I. To identify and examine the key contextual factors affecting traffic (e.g., traffic volume, time, weather, and special events).
II. To collect and preprocess real time traffic and environmental data using IoT sensors and simulation tools.
III. To design a dynamic traffic light control mechanism that adjusts signals based on predicted traffic conditions.
IV. To simulate and test the proposed framework under realistic Addis Ababa traffic scenarios.
V. To provide practical recommendations for deploying Context-Aware IoT traffic systems based on the city's infrastructure and socio economic context.

1.5 Significance of the Study

This study is significant because it addresses the growing traffic congestion and mobility challenges resulting from rapid urbanization, population growth, and increasing vehicle numbers in Addis Ababa. It proposes a Context-Aware Internet of Things (IoT) framework that enhances traffic monitoring, control, and management through intelligent, real time, and data driven technologies. By replacing conventional fixed time traffic signals with adaptive control

mechanisms, the system dynamically adjusts signal timing according to actual road conditions, thereby reducing congestion, shortening travel time, minimizing fuel consumption, and lowering air pollution.

The framework integrates Context-Awareness by considering key factors such as traffic density, time of day, location, and weather conditions to support accurate and efficient decision making. It is designed with the local Ethiopian context in mind, including limited intelligent transportation infrastructure and the absence of reliable real time data systems. This makes the solution practical, cost effective, and suitable for implementation not only in Addis Ababa but also in other developing cities facing similar transportation challenges.

Furthermore, the study contributes both practically and academically. Government agencies, urban planners, and traffic authorities can use the findings to improve transportation policies, planning, and smart city investments, while commuters benefit from safer, faster, and more reliable travel. At the same time, the research expands knowledge in IoT based intelligent transportation systems and provides a foundation for researchers, students, and professionals to conduct further studies and innovations in Context-Aware traffic management.

1.6 Scope and Limitations of the Study

1.6.1 Scope of the study

This study focuses on developing a Context-Aware IoT framework aimed at improving urban traffic management in Addis Ababa. To ensure feasibility and manageability within the available time, budget, and resources, the scope of the study is deliberately limited to specific high-congestion areas within the city.

Geographically, the study is confined to major traffic congestion areas in Addis Ababa, specifically Meskel Flower, Gotera Interchange, Lamberet Square, and Lebu (near the traffic police station). These locations are selected due to their high traffic density, frequent congestion, and strategic importance in the city's transportation network, making them suitable for analyzing and validating the proposed intelligent traffic management framework.

Technically, the study emphasizes the design, modeling, and simulation of a Context-Aware IoT based traffic control system. The proposed system is intended to collect real time traffic data, process it using contextual information, and dynamically adjust traffic signals to improve traffic flow. However, the study is limited to simulation and does not include the physical deployment of hardware components such as cameras, sensors, or IoT devices. The framework will be implemented and evaluated in a simulated environment using appropriate software tools to assess performance in terms of latency, responsiveness, and efficiency.

The Context-Awareness of the system is based on key factors including traffic density, time of day, location, weather conditions, and traffic incidents. These parameters are used as primary inputs to enable intelligent and adaptive decision making within the framework. The system dynamically processes these contextual factors in real time to optimize traffic signal control and improve traffic flow. However, the study does not consider additional contextual variables such as pedestrian movement patterns, driver behavior, or public transportation schedules, as these are beyond the scope of the current research.

The thesis is conducted within a fixed academic timeframe and reflects the current technological and infrastructural conditions of Addis Ababa. As such, the system is not designed to accommodate future changes such as large scale infrastructure expansion, rapid population growth, or significant shifts in transportation patterns. Furthermore, the study does not address policy formulation, legal frameworks, or full city wide implementation. The focus remains strictly on the architectural design, Context-Aware processing, and simulation based validation of the proposed IoT framework.

1.6.2 Limitations of the Study

While this thesis presents a promising Context-Aware IoT framework tailored to traffic management challenges, several limitations must be recognized. First, the study is limited by the lack of access to reliable, high frequency real time traffic data. This constraint can potentially affect the accuracy of the system's validation and the reliability of the simulation results, Second, the framework remains untested in real world deployments, Third, city's current technological infrastructure presents several limitations that could hinder the deployment of this IoT system, Fourth, the study only considers a limited set of contextual variables namely traffic volume, time of day, weather, and location, Fifth, the framework is designed specifically for Ethiopian capital's traffic ecosystem and road network characteristics.

As a result, the system may not be readily transferable to other cities or countries without substantial adaptation. Customization would be required to suit different infrastructural layouts, vehicle flow patterns, and cultural driving behaviors and lastly, the thesis is constrained by the limited financial and human resources available, as well as the tight project timeline. These constraints have prevented extensive experimental analysis, large scale testing, and integration with governmental platforms. .

1.7 Organization of the Thesis

Chapter One introduces the background of the study, problem statement, research questions, objectives, significance, scope, and overall structure of the thesis. Chapter Two reviews relevant

theoretical, empirical, and conceptual literature related to IoT, smart cities, and intelligent transportation systems, and identifies research gaps. Chapter Three describes the research methodology, including research design, study area, data collection methods, sampling techniques, and data analysis procedures.

Chapter Four presents the system design and development of the proposed Context-Aware IoT framework, including architecture, context modeling, and integration with real time traffic systems. Chapter Five evaluates the framework through experiments and performance metrics, and discusses the results. Finally, Chapter Six summarizes the study, highlights major findings, and provides conclusions and recommendations for future improvements and research.

CHAPTER TWO

2. Literature Review

2.1 Introduction

This chapter critically examines the body of literature relevant to the development of a Context-Aware Internet of Things (IoT) framework for traffic management in city. The review is organized into three main categories: theoretical, empirical, and conceptual literature. It begins by outlining foundational theories related to urbanization, intelligent transportation systems (ITS), and Context-Aware computing. The discussion then shifts to empirical studies on IoT applications, wireless sensor networks (WSNs), and smart traffic management in diverse urban environments. Conceptual frameworks for integrating Context-Awareness into traffic systems are also explored. Special emphasis is placed on the unique traffic challenges and technological constraints in city. The chapter concludes by identifying thesis gaps that justify the present study and includes a summary table classifying the reviewed works.

2.2 Theoretical Literature Review

2.2.1 Urbanization and Mobility in African Cities

Urbanization is one of the most significant demographic and socioeconomic trends shaping Africa today. According to UN-Habitat (2022), over 60% of the continent's population is projected to live in urban areas by 2050. This rapid urban growth has frequently outpaced the expansion of transportation infrastructure, creating substantial mobility challenges. In many African cities, the growing demand for movement far exceeds the capacity of existing road networks, resulting in persistent congestion and inefficiency. The World Bank (2021) notes that poor traffic performance in sub Saharan African cities is largely driven by inadequate urban planning, underdeveloped public transport systems, and the uncontrolled increase of private vehicle ownership.

2.2.2 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) represent an innovative approach to managing urban mobility. According to the U.S. Department of Transportation (USDOT, 2020), ITS encompasses advanced applications that provide innovative services across different modes of transport and traffic management. These systems integrate sensing technologies, real time data processing, and

automated controls to improve efficiency, safety, and sustainability within urban environments. Main components of ITS include adaptive traffic signals, surveillance and monitoring infrastructure, automated incident detection and response systems, and traveler information services. In theory, effective ITS implementation can substantially reduce congestion and travel times while simultaneously enhancing safety and strengthening the overall resilience of urban transportation networks.

Furthermore, the International Organization for Standardization (ISO, 2023) highlights that ITS is a cornerstone of modern smart mobility, leveraging IoT, AI, and big data to create safer and more efficient transportation ecosystems. ISO emphasizes the convergence of vehicles, infrastructure, and people through connected technologies such as Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication, enabling real time traffic optimization, predictive safety mechanisms, and enhanced sustainability (ISO, Intelligent Transportation Systems: Transforming Modern Mobility).

2.2.3 Context-Aware Computing

Context-Aware computing represents a theoretical paradigm in which systems perceive, interpret, and respond to environmental and situational information in real time. According to Ramjee Prasad (2018), the core principle of Context-Aware systems is the ability to adapt dynamically to changing conditions, enhancing system efficiency, reliability, and user experience in smart environments. Furthermore, Context-Aware computing is a fundamental enabler of intelligent transportation systems, as it allows systems to move beyond static rule based operations toward adaptive and predictive decision making. This capability is essential for optimizing traffic flow, reducing congestion, and improving overall urban mobility, particularly in complex and dynamic environments such as Addis Ababa.

2.3 Empirical Literature Review

2.3.1 IoT in Urban Traffic Management

The Internet of Things has revolutionized urban mobility by enabling the real time collection and processing of data from roads, vehicles, and traffic control systems. Zanella et al. (2014) describe the “Smart City IoT paradigm,” where urban infrastructure is embedded with sensors and actuators that communicate with centralized context dependent platforms. In India (2019) demonstrated that an IoT enabled traffic control system, utilizing Raspberry Pi and cameras, led to substantial improvements in traffic flow efficiency. Similarly, a pilot project in Nairobi introduced smart traffic lights that adapt to real time conditions, resulting in a 30% reduction in peak hour congestion (Kenya Urban Roads Authority, 2021).

2.3.2 Wireless Sensor Networks (WSNs)

Wireless Sensor Networks (WSNs) are a fundamental component of IoT enabled traffic management systems. They consist of spatially distributed sensor nodes capable of sensing, processing, and transmitting environmental variables such as vehicle density, speed, and emissions. Lynch and Loh (2006) demonstrated that WSN based sensing technologies provide accurate, real time monitoring of dynamic systems. A main advantage of WSNs is their low-cost installation and deployment flexibility, as they eliminate the need for extensive wiring required by traditional monitoring systems

In traffic management applications, WSNs act as the backbone for adaptive traffic signal control, vehicular tracking, and environmental monitoring. Their inherent limitations such as limited power supply and susceptibility to interference require innovative system architectures and energy efficient protocols to maintain reliability and sustainability. Overall, WSNs provide both the sensing infrastructure and an intelligent processing layer, offering solutions to address congestion, safety, and environmental challenges in modern smart cities.

2.3.3 Context-Awareness in Urban Mobility

Context-Awareness in urban mobility refers to the ability of transportation systems to sense, interpret, and respond dynamically to conditions in urban environments. According to Nelson Pacheco Rocha, Ana Dias, Gonçalo Santinha, Mário Rodrigues, Carlos Rodrigues, Alexandra Queirós, Rute Bastardo, and Joao Pavao (2022), Context-Aware applications in smart cities leverage real time data from diverse sources, including personal sensors, city deployed sensors, and crowd sourcing mechanisms, to optimize urban mobility, improve safety, and enhance the user experience.

The study by Rocha (2022) highlights that Context-Aware systems rely on both primary context attributes such as location, activity, and environmental conditions and secondary context attributes, including vehicle speed, pedestrian movement, and points of interest, stress levels, and other situational indicators. These contextual inputs enable traffic management systems to adapt dynamically, improving operational efficiency and sustainability in urban areas.

2.3.4 Smart Police Station in Addis Ababa City

The Smart Police Station (SPS) in Addis Ababa is an advanced digital policing facility introduced under Ethiopia’s 2030 digital strategy. It provides automated services such as crime reporting, traffic accident documentation, and certificate issuance without requiring the physical presence of personnel (Ethiopian News Agency, 2026).

Empirical evidence indicates that SPS enhances service accessibility and operational efficiency by reducing administrative delays and supporting multilingual engagement for citizens (The Star, 2026). Although full integration with IoT based traffic monitoring systems has not yet been implemented, SPS establishes a strong foundation for automated incident reporting and emergency response. This highlights its importance for smart city applications and its potential for future interoperability with IoT based traffic management frameworks.

Moreover, the integration of Smart Police Stations with IoT-enabled systems can significantly improve real time data sharing between law enforcement and traffic management authorities. Such integration enables faster response to accidents, improved situational awareness, and data-driven decision making. In the context of Addis Ababa, this interoperability can contribute to reducing traffic congestion, enhancing public safety, and supporting the development of a fully connected smart city ecosystem.

2.4 Conceptual Literature Review

2.4.1 Components of Context-Aware Traffic Systems

Context-Aware traffic systems provide a conceptual framework for managing urban mobility by dynamically collecting, interpreting, and utilizing contextual information. According to Schmidt (2019), the main components include context acquisition, context modeling, context reasoning, context repository, context distribution, and context visualization. Context acquisition gathers data from IoT devices, traffic sensors, GPS enabled vehicles, and crowd sourced inputs. Context modeling organizes this data, while context reasoning uses algorithms to detect patterns, forecast congestion, and support adaptive decisions. The context repository stores historical and real time data, context distribution shares relevant information with stakeholders, and context visualization presents the data for informed context dependent. Together, these components enable traffic systems to respond intelligently to changing urban conditions.

2.4.2 Frameworks for Context-Aware IoT

Several conceptual frameworks guide the development of Context-Aware IoT systems for smart mobility. The 5-Layer IoT Model (Sethi & Sarangi, 2017; Rahaman, 2022) structures IoT architectures into perception, network, middleware, application, and business layers, enabling the collection, transmission, integration, and utilization of traffic and environmental data. For traffic management, additional modules for context modeling and reasoning are essential, allowing the system to interpret dynamic data and support adaptive context dependent. Complementing this, the Context Toolkit (Dey & Abowd, 2001) provides reusable components sensors, interpreters,

and aggregators emphasizing modularity, scalability, and real time processing. Together, these frameworks offer a robust foundation for designing intelligent, adaptive, and responsive IoT based traffic management systems that integrate heterogeneous data sources and improve urban traffic flow.

2.7 Gaps in Current thesis

Despite the global momentum in traffic management, significant gaps remain in thesis tailored to the Ethiopian context, particularly city. Existing studies often overlook local traffic behaviors, infrastructural constraints, and institutional frameworks. There is a lack of localized models that reflect city's unique traffic culture, informal driving patterns, and heterogeneous vehicle composition. Imported solutions frequently fail to adapt to these realities.

Another critical gap is the limited integration of real time contextual data such as weather, public events, or construction in to traffic management frameworks. Simulation based evaluations at specific intersections are virtually nonexistent, limiting empirical validation and practical deployment.

Finally, stakeholder engagement is minimal. Without input from traffic police, city planners, drivers, and commuters, existing systems lack local relevance and institutional support. Participatory development is essential for ensuring future frameworks are effective and sustainable in city.

2.8 Justification of the study

The justification for this study arises from the increasing traffic congestion and mobility challenges associated with rapid urbanization and population growth in Addis Ababa. The growing number of vehicles, combined with manual or semi-automated traffic control systems, has resulted in inefficient signal management, longer travel times, excessive fuel consumption, and increased environmental pollution. These limitations highlight the need for an intelligent, data driven solution. A Context-Aware Internet of Things (IoT) framework offers the capability to monitor and optimize traffic flow in real time, thereby improving operational efficiency and urban mobility.

Most existing IoT based traffic management frameworks are developed for cities with advanced infrastructure and stable sensor networks. Such solutions often fail to address local realities, including mixed traffic types, irregular road conditions, informal crossings, and inconsistent data availability. Therefore, designing a framework specifically tailored to ensures greater practicality, adaptability, and implementation feasibility. By incorporating contextual factors

such as time of day variations, weather conditions, special events, and emergency situations, the proposed system enables more responsive and intelligent traffic control.

The study also strengthens local technological capacity by promoting research and innovation in IoT, data analytics, and smart city applications. Consequently, the framework provides both an immediate solution for Addis Ababa and other Ethiopian cities facing similar transportation challenges.

2.9 Summary

Chapter Two reviewed the theoretical, empirical, and conceptual literature relevant to developing a Context-Aware IoT framework for traffic management in urban settings, with particular attention to the challenges and realities of city. The empirical review examined applications of IoT in urban traffic management, demonstrating the role of real time sensing, adaptive traffic signals, and smart control systems in improving traffic flow efficiency (Kenya Urban Roads Authority, 2021). The conceptual review focused on the components and frameworks of Context-Aware traffic systems. Main components include context acquisition, modeling, reasoning, repositories, distribution, and visualization, which together enable intelligent traffic management (Schmidt, 2019). These gaps underscore the need for a localized, Context-Aware IoT framework tailored to the unique traffic conditions, institutional structures, and mobility behaviors of city.

CHAPTER THREE

3 Methodologies

3.1 Introduction

This chapter outlines the methods and processes used to carry out the thesis on developing a Context-Aware IoT framework for traffic management. The purpose of the methodology is to provide a clear explanation of how the study was planned, designed, and implemented to achieve its objectives. It describes the thesis design, data collection methods, system analysis techniques, tools and technologies used, and the performance evaluation strategy.

Given that the study involves both technical development (IoT framework design) and real world problem analysis (traffic conditions in Addis Ababa), a combination of qualitative and quantitative approaches is applied. Simulation, data modeling, and experimental analysis are used to evaluate the framework, while traffic behavior and urban context are studied to inform the design. The thesis is structured to ensure accuracy, reliability, and practical relevance to local conditions.

3.2 Research Design and Approach

This study uses a design science thesis (DSR) approach, supported by a combination of applied thesis methods. The design science method is suitable for studies that aim to develop innovative technological solutions like the proposed Context-Aware IoT traffic framework. The approach focuses on identifying a real world problem, designing an IT-based solution, and evaluating its effectiveness.

3.2.1 Research Type

The thesis is applied in nature because it aims to solve a real world problem traffic congestion using an implementable technological solution. It is also descriptive and exploratory, as it seeks to understand existing traffic management challenges and explore the potential of IoT and Context-Aware systems in solving them.3.2.4 Research Phases

The methodology of this study was structured into three sequential phases to ensure a comprehensive and iterative development of the proposed Context-Aware IoT framework for traffic management. In the exploratory phase, the thesis involved an extensive literature review and direct engagement with stakeholders such as traffic authorities, urban planners, and public transport operators to identify main challenges, system requirements, and context specific

constraints. This initial stage also helped refine the thesis questions and align the study with the city's unique urban dynamics. In the development phase, insights from the exploratory stage were used to design and simulate the framework, incorporating IoT components such as Context-Aware modules, sensor networks, and context dependent algorithms, all modeled under real world constraints using simulation tools. The evaluation phase then focused on rigorous testing of the simulated system, assessing performance indicators like traffic flow efficiency, context responsiveness, and system adaptability, while also incorporating stakeholder feedback to validate the framework's effectiveness and relevance. Overall, this three phase thesis approach comprising exploration, development, and evaluation ensured a holistic and evidence-driven examination of traffic management solutions, supporting the creation of a context sensitive IoT framework tailored to city challenges.

3.2.3 System Design Focus

This study is centered on the development of a Context-Aware IoT architecture tailored to the dynamic traffic conditions of city. The design process involves the careful formulation of core framework components, including sensor networks for data acquisition, a Context-Awareness engine for interpreting real time conditions, and structured data flow mechanisms to ensure timely context dependent. System behavior is defined based on various contextual inputs such as time of day, traffic density, weather changes, and emergency scenarios. These inputs inform the adaptive responses of the system particularly the intelligent control of traffic signals to improve flow and reduce congestion. Furthermore, the framework is evaluated through simulations that model traffic signal adjustments under diverse conditions, enabling analysis of the system’s responsiveness, efficiency, and adaptability before real world deployment.

3.3 Study Area and Context

The capital city of Ethiopia serves as the study area for this thesis. As the country’s political, economic, and cultural center, the city has a population exceeding 5 million and experiences rapid urban expansion. This growth increases vehicle ownership and places significant pressure on the city’s transportation infrastructure. Limited road capacity, outdated traffic control systems, and rising demand for mobility contribute to persistent congestion, particularly at major intersections and along heavily trafficked corridors. These challenges highlight the need for intelligent and adaptive traffic management systems capable of responding effectively to real time urban mobility demands. Meskel Flower, one of the city’s central hubs, serves as the starting point for the selected study areas, and the thesis focuses on five strategically chosen locations across the city to evaluate the proposed Context-Aware IoT traffic management framework. These locations include Meskel Flower, a central and highly congested roundabout

with heavy pedestrian and vehicular flow; Gotera Interchange, a complex junction experiencing frequent signal-timing issues and rush-hour congestion; Lideta Square and the Torhayloch Hospital intersection, which serve mixed traffic flows including emergency vehicles; Megenagn, Mexico and Bole area, a transit-heavy area with fluctuating traffic patterns and high bus terminal activity; and Sidist Kilo, a historically congested areas connecting major educational institutions and government offices with significant pedestrian movement. Testing the system across these dynamic and high-demand areas strengthens the reliability and applicability of the Context-Aware IoT model within Addis Ababa's broader traffic management ecosystem.



Figure 1 Addis Ababa selected study areas

3.3.1 Geographical and Demographic Overview

Addis Ababa is situated at an average altitude of approximately 2,355 meters above sea level, though significant local variations exist due to the city's complex topography. The five focal areas of this study Gotera Interchange, Mexico Square, Sidist Kilo, Lideta/Torhayloch Hospital, and Megenagna/Bole Area exhibit a notable altitude range from approximately 2,325 meters to 2,405 meters. Sidist Kilo, located on the northern slopes toward Mount Entoto, is the highest among them at approximately 2,395–2,405 meters, while the Megenagna/Bole Area near Bole International Airport is the lowest at approximately 2,320–2,340 meters. This topographic variation directly influences road design, with steeper gradients requiring enhanced drainage systems, reinforced pavement structures, and lower design speeds. The flatter terrain of Lideta and Megenagna allows for more expansive road networks and higher traffic flow capacity. Demographic expansion across all five areas, driven by rural-to-urban migration and natural

population growth, continues to increase demand for mobility and transport services, placing additional stress on infrastructure originally designed for lower traffic volumes.

Table 1 Geographical coordinates and altitude ranges of selected areas

Area Name	Approximate Latitude (°N)	Approximate Longitude (°E)	Altitude Range (meters)
Gotera Interchange	9.0436	38.8144	2,340 – 2,370
Mexico Square	9.0240	38.7420	2,355 – 2,365
Sidist Kilo(6Kilometer)	9.0460	38.7630	2,390 – 2,405
Lideta/Torhayloch Hospital	9.0045	38.7363	2,330 – 2,350
Megenagna / Bole Area	9.0032	38.7995	2,320 – 2,340

3.3.2 Traffic and Transportation Context

The transportation network consists of a combination of roads, public transit (buses, minibuses), private vehicles, and non-motorized transport such as bicycles and pedestrians. However, the city's road infrastructure struggles to accommodate the growing number of vehicles, leading to chronic traffic congestion, especially during peak hours. Key challenges of traffic management include insufficient road capacity, lack of integrated traffic control systems, poor traffic enforcement, and limited real time traffic monitoring capabilities. Furthermore, diverse vehicle types, informal transport modes, and frequent road works add complexity to managing urban mobility.

3.3.3 Relevance to the Study

Given these conditions, Addis Ababa presents a highly relevant context for the development and implementation of a Context-Aware IoT framework aimed at enhancing traffic flow, safety, and real time decision making. The city's traffic challenges, including unpredictable vehicle movement and limited traffic control infrastructure, mirror those faced by many rapidly urbanizing cities across the developing world. As such, the insights and outcomes of this study hold broader applicability beyond the country. The thesis targets major congestion areas that collectively represent diverse traffic patterns and operational challenges. These sites serve as practical testing grounds for evaluating the framework's ability to support adaptive signal control, real time context recognition, and sensor integration in dynamic urban environments.

3.4 Data Collection Methods

To develop and evaluate the Context-Aware IoT framework for traffic management in the city, a combination of primary and secondary data collection methods is employed. This mixed approach ensures comprehensive and reliable data acquisition covering technical, environmental, and social aspects of urban traffic.

3.4.1 Primary Data Collection

Primary data for this study is collected through direct interaction with the traffic environment and key stakeholders to obtain real time and context specific information. This data is essential for accurately modeling traffic conditions, validating the proposed IoT framework, and ensuring that the system addresses the unique challenges of the city's mobility landscape.

3.4.1.1 Observational Studies

Field observations were conducted at strategically selected traffic intersections and interchange areas. Observers recorded traffic behavior, congestion patterns, queue lengths, bottlenecks, and traffic signal inefficiencies in real time. The observational data provided insights into peak congestion periods, pedestrian vehicle interactions, and traffic flow disruptions. This information complemented sensor readings and simulation data, ensuring that empirical patterns from the field were accurately captured for framework design and validation.

3.4.1.2 Surveys and Questionnaires

Structured surveys and questionnaires are distributed and administered to a diverse group of participants, including commuters, private vehicle drivers, public transport operators, and traffic management personnel. The instruments aim to capture respondents' experiences, challenges, and perceptions regarding traffic congestion, traffic control measures, and overall road safety. Additionally, the surveys assess the willingness of road users to accept IoT based traffic management solutions and collect feedback on potential features such as real time traffic updates, route optimization, and emergency vehicle prioritization.

3.4.2 Secondary Data Collection

Secondary data were collected to complement primary data and to provide historical context, broader insights, and technical reference points for the development of the Context-Aware IoT framework. These data sources ensured that the study was grounded in both local conditions and globally recognized best practices.

3.4.2.1 Traffic and Accident Records

Official records and statistics were obtained from the Road and Transport Bureau, the Traffic Police Department, and other relevant agencies in Addis Ababa. These data include traffic flow volumes, peak congestion hours, accident frequencies, and incident locations.

The data were collected for the period 2011–2018, depending on availability, to ensure relevance and consistency. These records were essential for identifying high-risk areas, evaluating current

traffic management strategies, and understanding safety challenges at major intersections. Historical congestion and accident data were also used to support the selection of study areas and validate simulation scenarios

3.4.2.3 Geospatial Data

Geographic Information System (GIS) data sets, digital maps, and satellite imagery, along with software tools such as GMapper, were obtained from publicly available mapping platforms. These geospatial data sets were used to model traffic corridors, intersections, and surrounding infrastructure within Addis Ababa. The collected data supported the strategic placement of sensors, the design of data acquisition networks, and the simulation of realistic traffic scenarios.

In addition, the data sets incorporated important topographical and urban features, including road gradients, road widths, intersection density, and surrounding urban development patterns, all of which directly influence traffic flow dynamics and the performance of IoT based adaptive traffic management systems. All GIS data sets used in this study are properly referenced and included in the Appendix to ensure transparency, reproducibility, and future extensibility of the research.

3.5 Sampling Techniques and Sample Size

To ensure the reliability, validity, and representativeness of the data collected, this study used a combination of sampling techniques and for both quantitative and qualitative data sources. The use of multiple sampling strategies enabled a comprehensive understanding of traffic behaviors, commuter experiences, and stakeholder perspectives across diverse areas of Addis Ababa. This multi-tiered sampling framework minimized bias, enhanced inclusiveness, and strengthened the overall credibility of the research findings. By integrating probability and non-probability sampling methods, the study achieved both statistical representation and in-depth contextual insight necessary for developing the proposed Context-Aware IoT framework.

3.5.1 Sampling Techniques

3.5.1.1 Purposive Sampling

Purposive sampling, a non-probability sampling technique, was used to select key informants for qualitative interviews. This group included traffic management officials, city planners, ICT specialists, transport bureau experts, and senior traffic police officers who possess substantial knowledge and operational experience related to urban traffic systems and smart infrastructure initiatives. Participants were intentionally selected based on their professional expertise, institutional role, and direct involvement in traffic management and technology implementation. By focusing on knowledgeable individuals, purposive sampling ensured that the qualitative data

collected were rich, technically relevant, and practically applicable to the design and evaluation of the Context-Aware IoT framework. Furthermore, interviews were conducted until thematic saturation was achieved, ensuring depth and completeness of insights.

3.5.1.2 Stratified Random Sampling

For the quantitative component of the study, particularly surveys and structured questionnaires administered to commuters, vehicle owners, public transport operators, and drivers, stratified random sampling was applied. The target population was divided into homogeneous strata based on demographic and transportation related characteristics such as age, gender, occupation, travel frequency, and mode of transport. Random samples were then proportionally drawn from each stratum to ensure balanced representation and to reduce sampling bias.

This method allowed the study to capture diverse traffic experiences and behavioral patterns across different commuter categories. By reflecting the socio economic and transportation diversity of Addis Ababa, stratified random sampling enhanced the generalizability of survey findings and ensured that the data set accurately represented real world traffic heterogeneity.

3.5.1.3 Convenience Sampling

For field based observational studies and real time traffic monitoring, convenience sampling was utilized to select high traffic intersections and corridors that are historically prone to congestion, bottlenecks, and traffic incidents. These locations were chosen based on accessibility, congestion frequency, accident records, and logistical feasibility for sensor placement and field observation.

This approach allowed the study to focus on areas where traffic challenges are most pronounced and observable, thereby maximizing the practical value of collected data. Selected sites represented varying traffic densities, road infrastructures, pedestrian activities, and intersection complexities. Observational data gathered from these high impact areas complemented sensor measurements, simulation outputs, and stakeholder feedback, strengthening the empirical validation of the proposed IoT framework.

3.5.2 Sample Size

Sample size is the measurement to ensure the consistency, validity, and reliability of the data, this study adopts a mixed methods research approach that integrates both quantitative and qualitative techniques. Combining these two approaches enables a more comprehensive understanding of urban traffic challenges and supports the development of a robust IoT based traffic management framework.

For the quantitative component, a total of 66 respondents were selected from major traffic congestion areas in Addis Ababa. The participants included traffic police officers, private and commercial vehicle drivers, daily commuters, and general transport users. Respondents were selected using purposive and convenience sampling to ensure representation from different urban zones and traffic environments. Structured questionnaires were used to gather measurable data on traffic congestion patterns, travel delays, accident occurrences, emergency vehicle movement challenges, and public perception of intelligent traffic solutions. This sample size provides adequate statistical representation and allows the identification of recurring traffic behavior trends across different parts of the city.

For the qualitative component, 15 key informants were purposively selected based on their professional expertise and direct involvement in traffic management and intelligent transportation systems. These participants included officials from traffic management authorities, senior traffic police officers, vehicle drivers, ICT experts, transport authority specialists, and intelligent transportation system professionals. Semi-structured interviews were conducted to obtain in-depth insights into policy frameworks, operational challenges, infrastructure limitations, and technological readiness for smart traffic solutions. The qualitative data provided rich contextual understanding and helped validate and interpret the quantitative findings.

Table 2 Sample Size by Study Area

Study Area	Questionnaires Survey (n)	Key Informants (n)	Observation Focus
Meskel Flower	11	3	Heavy congestion, multi-lane intersections
Gotera Interchange	11	3	Peak-hour congestion, complex flows
Bole Area	11	2	Mixed residential/commercial traffic
Megenagna & Mexico	11	3	High accident rate, violations
Sidist Kilo	11	2	Pedestrian-vehicle interaction, signal issues
Lideta	11	2	Moderate congestion, diverse traffic behavior
Total	66	15	Selected hotspot observations

3.5.2.1 Sampling of Participants

The study selected participants using a stratified random sampling technique for quantitative data and purposive sampling for qualitative data. The target population was first divided into homogeneous groups based on their roles in traffic management and urban mobility in Addis Ababa. From each stratum, respondents were proportionally selected to ensure representativeness and reduce sampling bias. The sample size for each group was determined using the standard proportional formula: $n=p/100\times N$

Where:

n = sample size

p = sampling percentage (30% for most groups, 50% for key informants)

N = population size

For key informants, purposive sampling was applied, and 50% of the identified experts were included to ensure rich qualitative insights. This combination of methods ensured both statistical reliability and in depth understanding of the traffic system.

Table 3 Sampling of Participants

Respondent Category	Population (N)	Sampling %	Sample Size (n)
Traffic Police Officers	120	30%	36
Transport Authority Experts	60	30%	18
Public Transport Drivers	70	30%	21
Private Car Drivers	50	30%	15
ICT / Smart City Professionals	10	30%	3
Traffic police officers	10	50%	5
Total	320		98

3.6 Data Analysis Techniques

This section presents the analytical processes used to derive insights from collected data, validate the proposed Context-Aware IoT framework, and inform system development. A mixed methods approach integrating quantitative, qualitative, and simulation based techniques was used to ensure a comprehensive understanding of traffic dynamics, user needs, and system performance. This allowed for triangulated analysis and more robust conclusions grounded in real world observations and empirical modeling.

3.6.1 System Requirements Analysis

System requirements analysis is a foundational step in designing the IoT based traffic management framework. It provides clarity on user expectations, technical capabilities, and performance goals. The analysis is informed by literature reviews, stakeholder consultations, and field observations in high traffic areas.

3.6.1.1 Functional Requirements Analysis

The functional requirements define the core operations of the IoT system within the urban traffic environment. Primary among these is real time data acquisition from a network of heterogeneous sensors. The system must collect, reprocess, and transmit data for immediate analysis.

Another critical functionality is Context-Aware decision making, in which the system interprets data to detect congestion, identify incidents, prioritize emergency vehicles, and adjust signal

patterns. Dynamic traffic signal control enables real time phase and timing adjustments. The system also provides user-facing services such as alerts, route recommendations, and real time updates.

3.6.1.2 Non Functional Requirements Analysis

Nonfunctional requirements focus on performance characteristics. Scalability is essential for city-wide deployment. Reliability and availability are ensured through fault tolerant architectures and sensor redundancy.

Security and privacy are prioritized, with encrypted communication, secure authentication, and protected data storage. Interoperability ensures integration with existing infrastructure. Low latency is required for real time context inference. Maintainability is supported through modular design, APIs, and documentation.

3.6.2 Data Analysis Techniques

Data analysis in this study combined statistical rigor with contextual insights to draw evidence-based conclusions supporting the IoT framework.

3.6.2.1 Quantitative Data Analysis Techniques

Quantitative data were obtained from structured surveys, traffic and accident records, and simulation outputs generated during the system design process. Since this study is simulation-based, physical sensors were not deployed; instead, data were modeled using realistic traffic parameters derived from secondary data sources and existing traffic statistics in Addis Ababa.

Descriptive statistical techniques such as mean, median, mode, frequencies, and percentages were used to summarize traffic patterns, commuter characteristics, and congestion levels. For example, vehicle flow, waiting times, and congestion intensity were analyzed to identify peak hours and bottleneck locations in major intersections.

In addition, inferential statistical techniques such as correlation analysis, chi-square tests, and t-tests were applied to examine relationships between contextual variables such as time of day, weather conditions, and location with traffic congestion levels. These analyses helped identify significant factors affecting traffic behavior and supported the formulation of adaptive control logic within the IoT framework.

3.6.2.2 Qualitative Data Analysis Techniques

Qualitative data were collected through semi-structured interviews with key stakeholders, including traffic management officials, city planners, ICT experts, transport bureau

representatives, and senior traffic police officers. Open-ended responses from surveys were also included to enrich the qualitative data set. The data were analyzed using thematic analysis, where interview transcripts and textual responses were systematically coded to identify recurring patterns and themes. The coding process focused on key categories such as policy limitations, infrastructure challenges, system usability, and technological trust.

These themes revealed important human-centered and institutional factors, including resistance to automated systems, the need for user-friendly interfaces, and organizational constraints. The findings were then integrated into the system design to ensure that the proposed framework addresses not only technical efficiency but also practical, social, and institutional realities within the context of Addis Ababa

3.6.3 Simulation and Comparative Analysis

Simulation models are used to evaluate system performance under varying traffic conditions. Key performance metrics such as delay, queue length, and response time are applied to compare the existing systems with the proposed framework. The simulation results demonstrate improvements in traffic flow efficiency, reduced congestion, and enhanced emergency response capabilities, indicating the effectiveness of the proposed approach under different scenarios.

In addition, the simulation environment allows for controlled experimentation where multiple traffic scenarios, including peak and off-peak conditions, are replicated. This enables systematic comparison between traditional traffic management approaches and the proposed Context-Aware IoT framework. By analyzing the outcomes under identical conditions, the study ensures objective evaluation of system performance and highlights the scalability and adaptability of the proposed model.

3.6.4 Triangulation and Validity Assurance

Triangulation is employed to ensure the rigor and credibility of the study by cross-validating data obtained from different sources, including reports, field observations, and stakeholder inputs. Quantitative results derived from simulations are verified against real-world observations, while qualitative insights are used to support contextual interpretation. This combined approach enhances the reliability, validity, and overall robustness of the research findings.

Furthermore, triangulation helps to minimize bias and strengthens the accuracy of the conclusions by integrating multiple perspectives. By comparing findings from simulation outputs, empirical data, and expert feedback, inconsistencies can be identified and addressed. This process ensures that the proposed framework is not only theoretically sound but also practically applicable within the context of Addis Ababa's traffic management system.

3.10 Ethical Considerations

All field data, including vehicle counts and video recordings, were collected from public spaces without capturing any identifiable personal information such as faces or license plates, and informed consent was waived because there was no direct interaction with individual drivers or pedestrians. Permission for data collection was obtained from the Addis Ababa Transport Bureau, and traffic management office. Since the framework was proposed entirely for simulation environment using Django framework,VISSIM, MATLAB, and NS-3, no physical risk to road users existed at any stage of this research. However, for potential future deployment, the design includes graceful degradation mechanisms that allow the system to fall back to fixed time operation in the event of communication failure, thereby prioritizing safety. All simulation outputs and field data will store on a password-protected server accessible only to the researcher and supervisor, and will be securely deleted after years. No external funding or conflicts of interest influenced the study.

3.11 Validity and Reliability

To ensure the trustworthiness of the findings, internal validity was secured by comparing the proposed adaptive framework directly against a fixed time baseline under identical traffic conditions, using randomization across ten simulation runs with different random seeds, and by controlling the co-simulation environment to eliminate external interference. External validity was enhanced through the selection of four diverse intersections that represent a wide range of traffic patterns in Addis Ababa (high-density central, interchange, commercial, and congested corridor), and by calibrating all simulation parameters using real-world field data, making the results generalizable to similar developing-city contexts. Reliability was assured by fully documenting all simulation models and providing the complete code in Appendix C, using fixed random seeds (e.g., 12345) for replication, verifying calibration results using the GEH statistic (with all values below 5), reporting mean values alongside standard deviations, and conducting test-retest procedures that produced results within ±2% of the original values. Consequently, the findings are methodologically robust and reproducible.

3.12 Summary

This chapter presented the research design, analytical framework, and methodological procedures used to develop and validate the proposed Context-Aware IoT solution for traffic management. It described the system requirements analysis, including both functional and nonfunctional requirements, as well as the mixed methods approach used for data collection and evaluation.

Quantitative data provided empirical evidence to measure traffic conditions and system performance, while qualitative findings ensured that the framework addressed local operational needs and contextual challenges. Simulation modeling was applied to test and verify the effectiveness of the proposed system under different traffic scenarios, and methodological triangulation enhanced the reliability and validity of the results.

Overall, these methodological strategies established a strong foundation for the design, implementation, and evaluation of the proposed framework presented in the following chapters.

CHAPTER FOUR:

4. DESIGN, SIMULATION, IMPLIMENTATION, EVALUATION AND RESULT

4.1 Introduction

This chapter presents the detailed design, implementation, and evaluation of the proposed Context-Aware IoT framework for traffic management in Addis Ababa City. It analyzes the existing fixed time system, introduces the proposed five-layer architecture, and outlines functional and nonfunctional requirements. The implementation uses Django Python for the backend and dashboard, along with VISSIM, MATLAB, and NS-3 in a simulated environment. The testing strategy defines key metrics latency, throughput, accuracy, congestion reduction, reliability, and scalability with benchmarks derived from Ethiopian transport targets and ITS standards. Simulation results are presented, followed by a discussion of findings and a chapter summary.

4.2 Existing System Analysis

The existing traffic management system in Addis Ababa relies primarily on fixed-timing traffic signals and manual control by police officers. At major intersections such as Meskel Flower and Gotera Interchange, signal timing does not adapt to real time traffic density. This leads to long queues during peak hours (e.g., morning 7:30–9:00 and evening 17:00–19:00) and unnecessary waiting during off-peak hours when cross traffic is light. Incident detection is entirely manual: traffic police must observe an accident or breakdown and then radio for support or manually adjust signals. This results in delayed response times typically 5–10 minutes before any action is taken. Emergency vehicles such as ambulances, fire trucks, and police cars often get stuck in congestion because there is no prioritization mechanism. The system lacks real time data collection, Context-Awareness, and adaptive control. There are no sensors at intersections to measure traffic density, no communication network to transmit data, and no central processing unit to make intelligent decisions. These limitations justify the need for the proposed Context-Aware IoT framework.

4.3 Proposed System

The proposed Context-Aware IoT framework addresses the limitations of the existing system by integrating distributed sensors, edge computing, adaptive signal control, and real time decision making algorithms. The framework continuously monitors traffic conditions at critical

intersections, interprets context parameters (vehicle density, pedestrian activity, weather, emergency vehicles), and dynamically adjusts traffic signal timings and routing recommendations. It is designed to be scalable, reliable, and interoperable with existing infrastructure. The system consists of five layers: (1) a sensor layer with inductive loops, cameras, and GPS receivers; (2) a network layer using Wi-Fi and Zigbee for local communication; (3) a context processing layer that runs a hybrid reasoning engine (rule based + Random Forest); (4) a service layer that provides APIs for traffic control and data storage; and (5) an application layer with a dashboard for traffic authorities and a mobile app for commuters. The system is designed to operate even during communication failures by using edge computing at each intersection.

4.4 Requirement Analysis

Requirement analysis is a fundamental phase in system development that identifies and documents the needs, expectations, and operational constraints of the proposed system. The purpose of this phase is to determine both the functional and nonfunctional requirements of the IoT sensor-based smart traffic management framework. The requirements were gathered through stakeholder interviews involving traffic police officers, transport authority experts, and commuters, as well as through an extensive review of Intelligent Transportation System (ITS) literature and related smart traffic management studies.

4.4.1 Functional Requirements

Functional requirements specify the core actions the system must perform, defining the observable behaviors and services the IoT traffic system should offer to meet its objectives. For traffic sensing and monitoring, the system is required to detect the presence, speed, and count of vehicles in each lane using sensor nodes, and to differentiate between vehicle types such as cars, trucks, motorcycles, and buses through image recognition or inductive signatures. In terms of Context-Awareness processing, the system must interpret contextual data like time of day, event schedules, and school zones to dynamically adjust traffic light patterns, as well as detect anomalies such as accidents, road blockages, or abnormal queue lengths and promptly notify authorities. Regarding data transmission and aggregation, sensor nodes are to transmit real time data to a central processing unit via Wi-Fi or GSM modules, and the system must aggregate multi source data into a centralized cloud platform for analysis. For adaptive traffic signal control, the system should automatically adjust signal durations and phase transitions based on real time traffic density and contextual conditions, while also supporting manual override by traffic police during emergencies or special events. The user interface and notification component must provide real time alerts to traffic officers through a dashboard or SMS, email, and log or register

all events and actions for subsequent review and analysis. Finally, system logging and analytics require the system to log historical traffic data for performance tracking and trend forecasting, as well as support data export and reporting for policy analysis.

Table 4 Functional Requirements of the Proposed System

Requirement ID	Functional Requirement	Description
FR-01	User Registration	The system shall allow authorized users to create and manage accounts.
FR-02	Authentication	The system shall authenticate users and provide secure login functionality.
FR-03	Traffic Monitoring	The system shall collect and analyze traffic data from IoT sensors in real time.
FR-04	Dynamic Signal Control	The system shall dynamically adjust traffic signal timing based on traffic density.
FR-05	Emergency Vehicle Prioritization	The system shall prioritize emergency vehicles at intersections.
FR-06	Reporting and Analytics	The system shall generate reports and traffic analysis summaries.
FR-07	Dashboard Visualization	The system shall provide a real time traffic monitoring dashboard.

4.4.1.1 Functional Requirement-01: User Registration

The proposed system shall provide a user registration functionality that enables authorized personnel such as traffic administrators, traffic police officers, and transport bureau experts to create and manage user accounts. This functionality is important to ensure accountability, access control, and proper management of system users. During registration, users are required to provide personal and authentication information such as username, email address, password, and assigned role.

Table 5 Functional Requirements of the Proposed System

Attribute	Description
Requirement ID	FR-01
Requirement Name	User Registration
Actors	Administrator, Traffic Officer
Inputs	Username, Email, Password, User Role
Outputs	Successful registration confirmation
Priority	High

4.4.1.2 Functional Requirement-02: Authentication

The authentication functionality ensures that only authorized users can access the system resources and management functionalities. The proposed framework shall provide secure login and logout mechanisms using username and password authentication. The system verifies user credentials against stored records in the database and grants access based on predefined user roles and permissions.

Table 6 Authentication Requirement Description

Attribute	Description
Requirement ID	FR-02
Requirement Name	Authentication
Actors	Registered Users
Inputs	Username and Password
Outputs	Login success or failure message
Priority	High

4.4.1.3 Functional Requirement-03: Traffic Monitoring

The system shall collect real time traffic data from IoT sensors installed at road intersections. The collected data includes vehicle count, traffic density, and congestion level information.

Table 7 FR-03 Traffic Monitoring Specification

Attribute	Description
Requirement ID	FR-03
Requirement Name	Traffic Monitoring
Actors	IoT Sensors
Inputs	Vehicle count and sensor data
Outputs	Real time traffic information
Priority	Very High

4.4.1.4 Functional Requirement-04: Dynamic Signal Control

The system shall dynamically adjust traffic signal timing based on the analyzed traffic density collected from IoT sensors. This functionality helps reduce traffic congestion and improve traffic flow efficiency.

Table 8 FR-04 Dynamic Signal Control Specifications

Attribute	Description
Requirement ID	FR-04
Requirement Name	Dynamic Signal Control
Actors	Traffic Control System
Inputs	Traffic density data
Outputs	Updated signal timing
Priority	Very High

4.4.1.5 Functional Requirement-05: Emergency Vehicle Prioritization

The system shall provide priority access for emergency vehicles such as ambulances and fire trucks by automatically adjusting traffic signals to allow faster movement through intersections.

Table 9 Emergency Vehicle Prioritization Requirement

Attribute	Description
Requirement ID	FR-05
Requirement Name	Emergency Vehicle Prioritization
Actors	Emergency Vehicles
Inputs	Emergency request signal
Outputs	Priority traffic signal control
Priority	High

4.4.1.6 Functional Requirement-06: Reporting and Analytics

The system shall generate reports and analytical summaries related to traffic conditions, congestion patterns, and traffic flow performance for traffic management authorities.

Table 10 Reporting and Analytics Specification

Attribute	Description
Requirement ID	FR-06
Requirement Name	Reporting and Analytics
Actors	Traffic Administrators
Inputs	Historical traffic data
Outputs	Reports and charts
Priority	Medium

4.4.1.7 Functional Requirement-07: Dashboard Visualization

The system shall provide a web-based dashboard interface for monitoring real time traffic conditions, signal status, and congestion levels at different intersections.

Table 11 FR-07 Dashboard Visualization Specification

Attribute	Description
Requirement ID	FR-07
Requirement Name	Dashboard Visualization
Actors	Traffic Operators
Inputs	Traffic monitoring data
Outputs	Dashboard visualization
Priority	High

4.4.2 Nonfunctional Requirements

Nonfunctional requirements define the quality standards and operational characteristics that the proposed IoT sensor-based smart traffic management framework must satisfy. Unlike functional requirements, which describe what the system should do, nonfunctional requirements describe how the system should perform under different operating conditions. These requirements focus

on system performance, scalability, reliability, security, usability, and interoperability. The identified nonfunctional requirements were derived from Intelligent Transportation System (ITS) standards and the existing infrastructure constraints in Ethiopia.

Table 12 Nonfunctional Requirements of the Proposed System

Requirement Category	Description
Performance	The system response latency must remain below 1.5 seconds under normal operating conditions and below 3 seconds during peak traffic load conditions.
Scalability	The system must support up to 120 sensor nodes (approximately 60 intersections) without degradation in latency or accuracy.
Reliability	The system should maintain at least 98% uptime for the prototype and a target uptime of 99% for final deployment.
Security	All communication between sensors, edge devices, and the server must be encrypted using TLS 1.3 with mutual authentication mechanisms.
Usability	The dashboard interface should be easy to learn and usable within two hours of operator training, with a SUS score of at least 70.
Interoperability	The framework must provide RESTful APIs to support integration with external systems and existing traffic infrastructures.

4.4.2.1 Performance Requirement

Performance refers to the responsiveness and processing efficiency of the proposed framework. The system must process sensor data, analyze traffic conditions, and update traffic signal timing with minimal delay. The end-to-end response latency should remain below 1.5 seconds during normal traffic conditions and below 3 seconds during peak load situations. This ensures that traffic signal adjustments are completed before the next vehicle arrives at the stop line, thereby reducing congestion and improving traffic flow efficiency.

4.4.2.2 Scalability Requirement

Scalability describes the ability of the system to handle future expansion and increased workload without affecting performance or accuracy. The proposed framework must support up to 120 IoT sensor nodes, which is equivalent to approximately 60 traffic intersections. The system should continue to operate efficiently without degradation in response time or traffic analysis accuracy. This requirement supports phased city-wide deployment of the framework within Addis Ababa and future expansion to additional urban areas.

4.4.2.3 Reliability Requirement

Reliability refers to the consistency and availability of the proposed system during operation. Since traffic management systems are considered critical infrastructure, the framework must operate continuously with minimal downtime. The simulation prototype should maintain at least

98% system uptime, while the target uptime for final deployment is 99%. This allows for a maximum downtime of approximately 3.65 days per year and ensures continuous monitoring and control of traffic conditions.

4.4.2.4 Security Requirement

Security is a critical requirement because the proposed framework controls traffic signal operations and handles sensitive communication between IoT devices and the central server. All communication between sensors, edge nodes, and the central server must be encrypted using TLS 1.3 protocols to ensure confidentiality and data integrity. Furthermore, control commands such as traffic signal timing updates must require mutual authentication mechanisms to prevent unauthorized access, cyber-attacks, and malicious manipulation of traffic infrastructure.

4.4.2.5 Usability Requirement

Usability refers to the ease with which traffic operators and administrators can learn and effectively use the proposed framework. The traffic operator dashboard should provide a simple, intuitive, and user-friendly interface for monitoring and controlling traffic conditions. The system must be learnable within two hours of training and should achieve a System Usability Scale (SUS) score of at least 70, indicating acceptable usability standards and operational efficiency.

4.4.2.6 Interoperability Requirement

Interoperability refers to the capability of the proposed framework to integrate and communicate with existing traffic infrastructures and external information systems. The framework must provide RESTful APIs that allow integration with existing traffic signal controllers, Smart Police Station systems, and the Addis Ababa Transport Bureau's data warehouse. This requirement ensures compatibility, efficient data sharing, and future extensibility of the proposed smart traffic management framework.

4.5 System Design

4.5.1 System Architecture

The proposed framework follows a five-layer IoT architecture commonly used in smart city applications (Sethi & Sarangi, 2017). The layers are: Sensor layer (perception layer): Includes inductive loop sensors embedded in the road (measuring vehicle presence and count), cameras with computer vision (detecting queue length and emergency vehicles), GPS receivers on public transport and emergency vehicles, and weather sensors (rain, visibility). These devices generate raw data at 1 Hz to 10 Hz depending on the sensor type.

4.5.1.1 Sensor Layer

The purpose of the sensor layer is to collect raw physical data from the traffic environment. At each intersection, multiple sensor types are installed. Inductive loop sensors, embedded in the road, measure vehicle presence, count, and speed. They generate binary data (vehicle detected or not) and a count per minute, sampled at a frequency of 10 Hz. Cameras equipped with computer vision algorithms detect queue length, classify vehicle types (cars, trucks, motorcycles, buses), and recognize emergency vehicles. These cameras produce image frames, object counts, and vehicle type information at a sampling rate between 1 and 5 Hz. GPS receivers are attached to public transport and emergency vehicles to provide real time position, speed, and heading at 1 Hz. Weather sensors measure rain intensity (mm/hr), visibility (meters), and temperature (°C) at a lower rate of 0.1 Hz. Optionally, RFID readers can be installed to identify specific vehicles such as buses or authorized fleet vehicles, generating a unique ID and timestamp on an event-driven basis. The output of the sensor layer consists of raw time-series data streams, which are sent to the network layer for further transmission.

4.5.1.2 Network layer

The network layer adopts hybrid architecture for reliable, low-latency communication. Short-range, high-bandwidth links (e.g., cameras) use Wi-Fi 802.11n (150 Mbps, ~100 m), while low-power sensors employ Zigbee (IEEE 802.15.4) mesh networking for redundancy. Long-distance back haul from edge gateways to the central server is provided by 4G LTE (or 5G) using the lightweight MQTT protocol. This design maintains end-to-end latency below 1.5 seconds (Table 15) and supports over 100 sensor nodes, meeting the real time demands of urban traffic management in Addis Ababa Context

4.5.1.3 Processing layer

This is the core intelligence layer. It runs on edge computers (e.g., NVIDIA Jetson Nano) at each intersection and also on a central cloud server. It performs data fusion (combining sensor inputs), context modeling (using a hybrid rule-based and Random Forest classifier), and context reasoning (e.g., deciding whether to extend green phase). The hybrid model uses rule-based logic for simple conditions (e.g., “if emergency vehicle detected then activate green corridor”) and a Random Forest classifier for congestion level prediction based on traffic density, time of day, and weather.

4.5.1.4 Service layer

At the heart of the architecture lies the context processing layer, which transforms raw sensor data into meaningful, actionable context. This layer employs advanced analytics, including context modeling using structured data models, data fusion techniques to combine information from multiple sources, and both rule based and machine learning algorithms to infer traffic states,

predict congestion, and detect anomalies. The context processing layer also generates adaptive control commands for traffic signals and alert systems, supporting both automated and manual interventions. Its real time operation and ability to learn from historical data enable predictive analytics and long term optimization, ensuring the system can dynamically respond to evolving traffic scenarios.

4.5.1.5 Application layer

Finally, the application layer serves as the primary interface between the IoT system and its users, including traffic authorities, commuters, and planning agencies. This layer offers visual dashboards that display traffic heat maps, congestion alerts, and accident reports; real-time notifications to alert operators or traffic police about detected problems and decision support tools that suggest control strategies such as adaptive signal changes, lane reversals, or road closures. Additionally, mobile interfaces are available to deliver route suggestions or congestion warnings directly to drivers. The user interfaces are developed using web-based technologies like HTML5, JavaScript, ReactJS, and Flask (Python) for backend APIs, and the layer also supports API integration to connect with city traffic portals or third-party navigation systems such as Google Maps. Emphasizing usability, accessibility, and timely information dissemination, the application layer ensures that all stakeholders receive relevant, up to date information to support both immediate operational decisions and long term planning. This diagram shows the above five-layer structure and the upward flow of data:

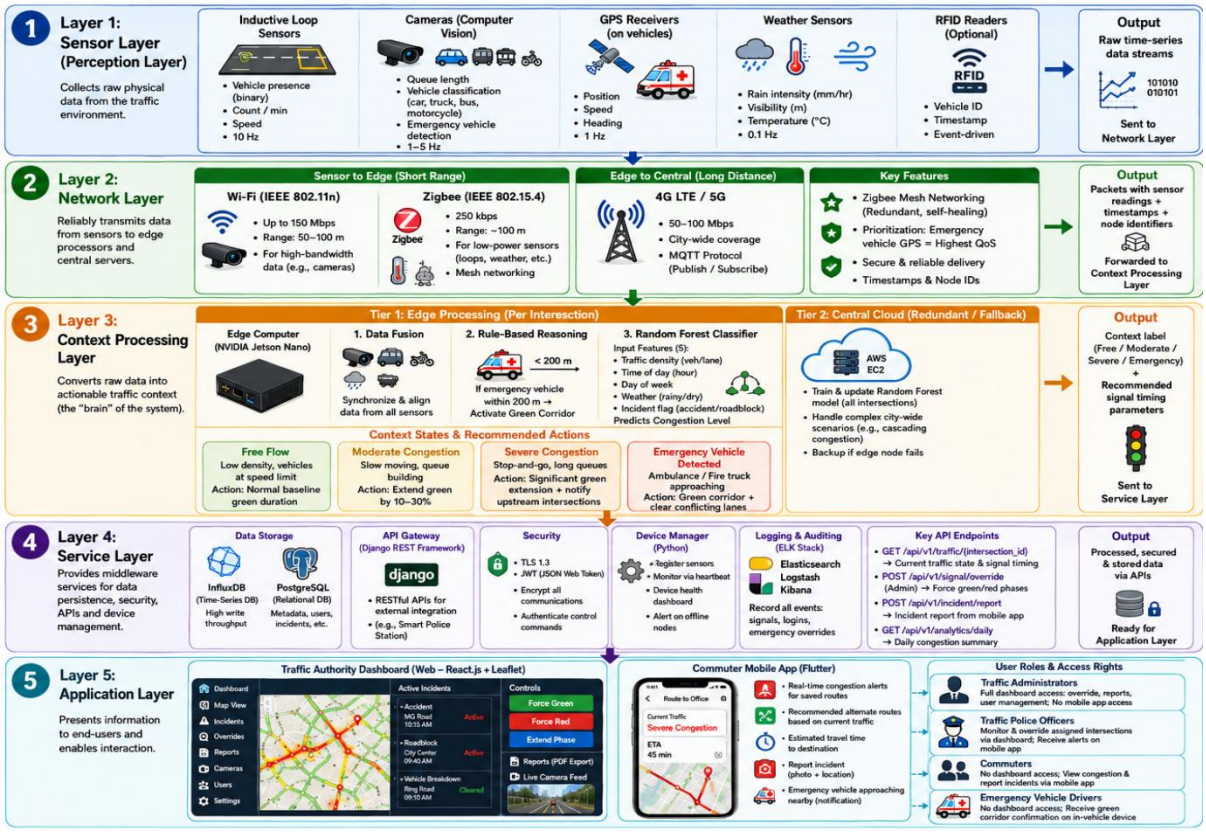
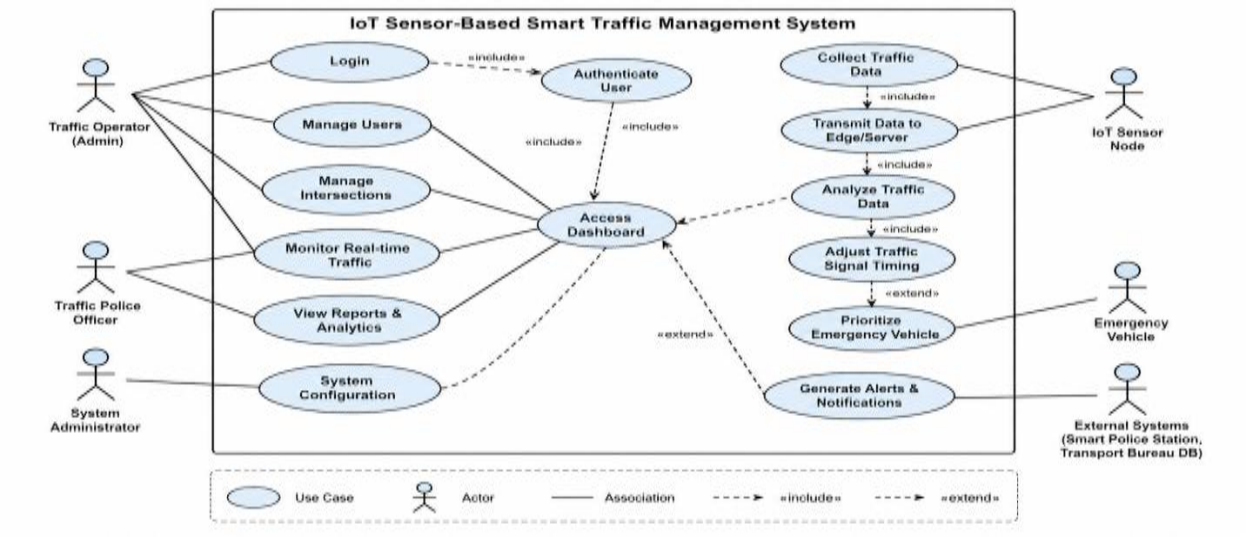


Figure 2 Proposed System Architecture

4.5.2 Use Case Diagram

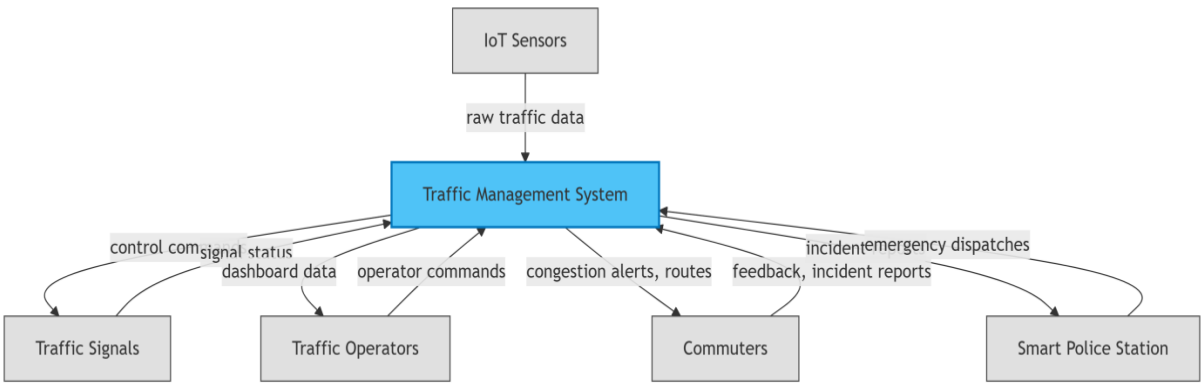
The use case diagram identifies the actors (traffic operator, commuter, emergency vehicle, system administrator) and the use cases they initiate. Key use cases include: “Monitor traffic,” “Adjust signal timing,” “Receive congestion alert,” “Prioritize emergency vehicle,” “Generate report,” and “Manage sensors.” The diagram was created using UML 2.0 notation in Microsoft Visio.

Figure 3 Use Case Diagram of the Proposed System

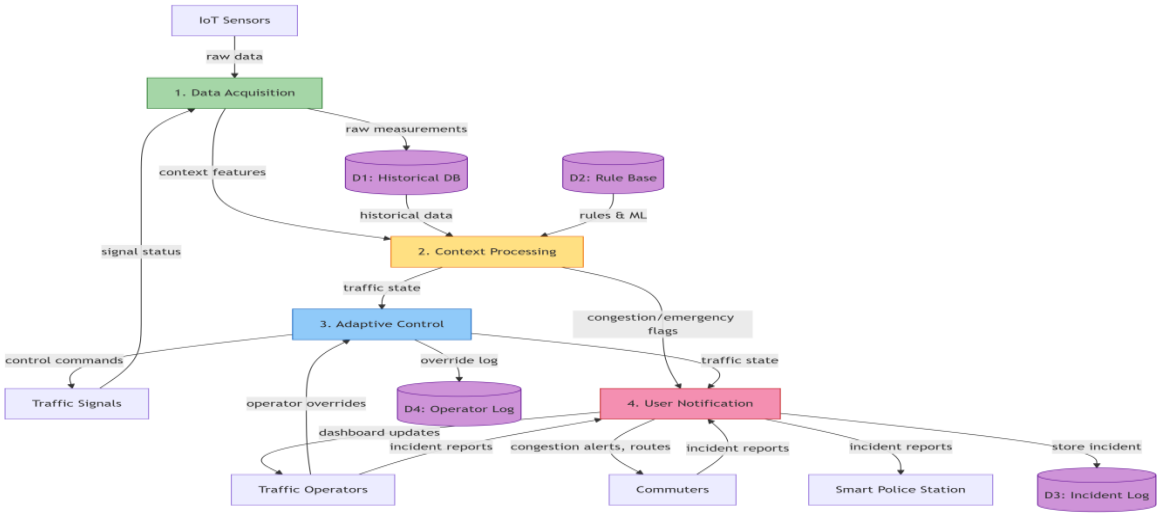


4.5.3 Data Flow Diagram (Level 0 and Level 1)

The Level 0 DFD shows the system as a single process with external entities: sensors, traffic signals, traffic operators, commuters, and the Smart Police Station. Data flows include “raw traffic data,” “control commands,” “congestion alerts,” and “incident reports.” The Level 1 DFD expands the main process into four sub-processes: data acquisition, context processing, adaptive control, and user notification. Each sub-process has its own data stores (e.g., “historical traffic DB,” “context rule base”)



Data Flow Diagram 0



Flow Diagram 1

Figure 4 Data Flow Diagram (Level 0 and Level 1)

4.5.4 Entity Relationship (ER) Diagram

Because the system primarily uses a time-series database (InfluxDB) for sensor data, a traditional ER diagram is not fully applicable. However, a simplified relational schema exists for metadata: sensors (sensor_id, location, type, status), intersections (intersection_id, name, latitude, longitude), and incidents (incident_id, timestamp, location, type, resolution time). The time-series database stores measurements (timestamp, sensor_id, value) with high write throughput.

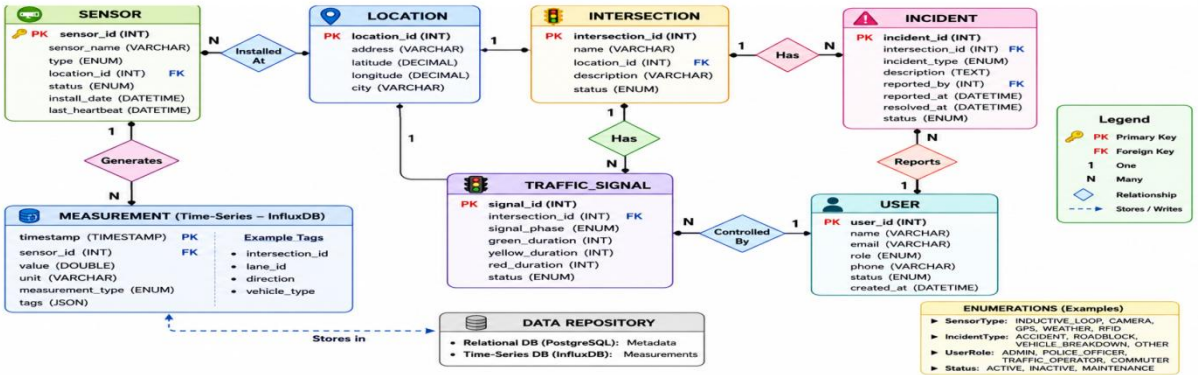


Figure 5 Entity Relationship (ER) Diagram (Source: Author, 2026

4.5.5 Class Diagram

The Class Diagram captures the static, object oriented structure of the system. It defines main classes such as Sensor, Context Processor, Traffic Signal Controller, User Interface, and Data Repository, along with their attributes and methods. Relationships between classes illustrate data

ownership, dependencies, and inter-component interactions, clarifying how system components are organized and connected

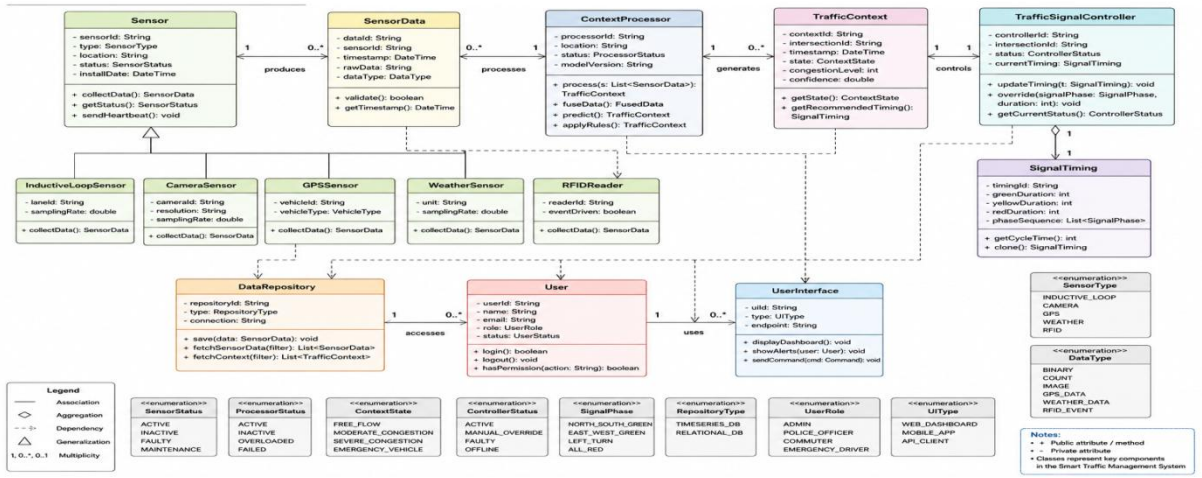


Figure 6 Class Diagram

4.5.6 Sequence Diagram

A sequence diagram was created for the emergency vehicle prioritization scenario. The actors (emergency vehicle GPS, sensor, context processor, signal controller) interact in time order: (1) emergency vehicle broadcasts GPS position; (2) sensor layer detects approaching vehicle; (3) context processor verifies vehicle identity and calculates estimated arrival time; (4) signal controller extends green phase and sends confirmation; (5) system logs the event. The diagram shows the message flow and timing constraints.

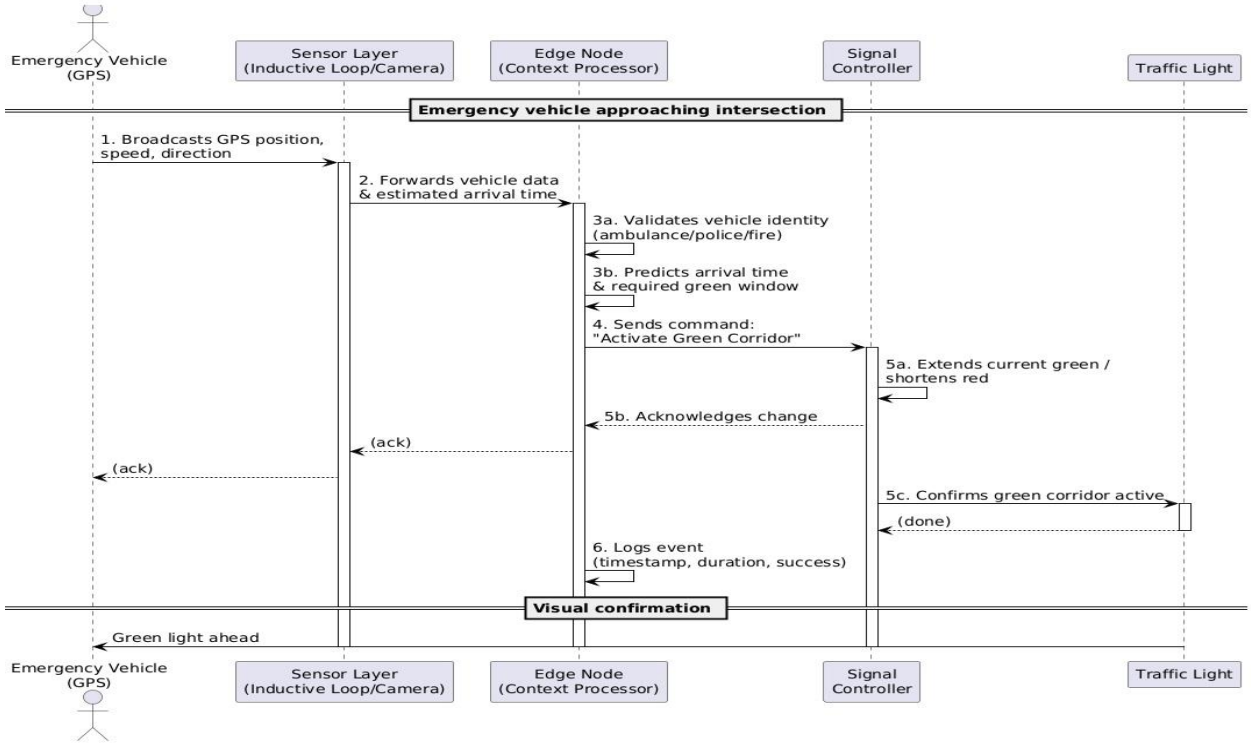


Figure 7 Sequence Diagram for Emergency Vehicle Prioritization

4.5.7 User Interface Design

The proposed system includes two user interfaces: Web dashboard for traffic authorities: Built with React.js and Leaflet maps. Features include: a real time heat map of congestion (red = severe, yellow = moderate, green = free flow); a list of active incidents with location and time; manual override controls for each intersection (force green/red, extend phase); and a reporting module that generates PDF summaries of daily congestion metrics. The dashboard was designed with input from five traffic police officers during requirement gathering.

Mobile app for commuters: Built with Flutter for cross-platform compatibility. Features include: real time congestion alerts for routes saved by the user; recommended alternate routes based on current traffic; estimated travel time to destination; and incident reporting (user can report an accident or stalled vehicle, which is sent to the traffic authority for verification).

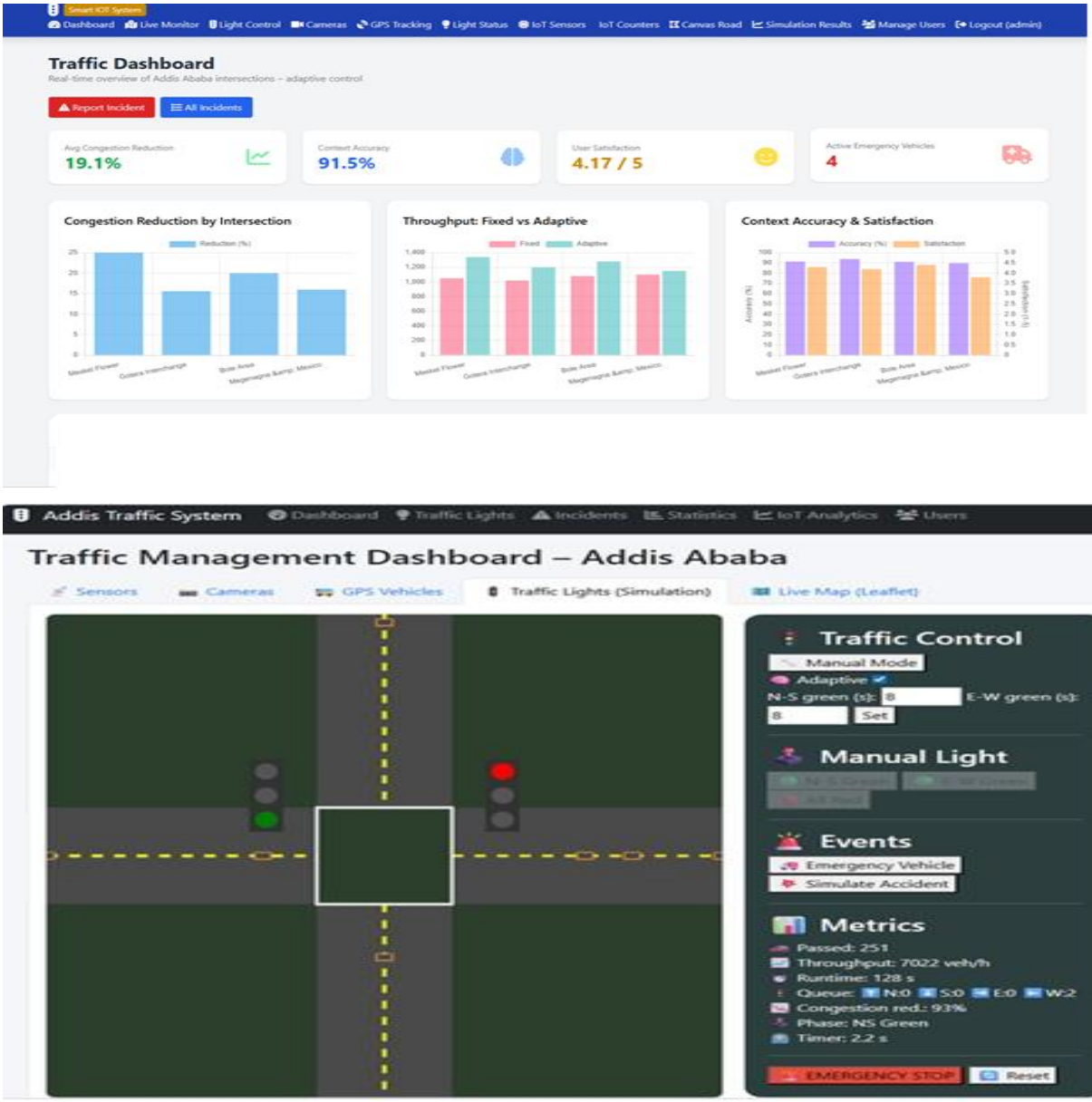


Figure 8 User Interface Design

4.6 Implementation

Because Addis Ababa currently lacks a Context-Aware IoT traffic management system, this research had to implement all core features from scratch. The first feature to be implemented was the traffic simulation environment, as no digital model of the city's intersections existed for testing adaptive control. Using VISSIM 11.0, the road networks of four major intersections (Meskel Flower, Gotera Interchange, Bole Area, Megenagna-Mexico) were built from GIS data provided by the Addis Ababa Transport Bureau. Vehicle input volumes and driver behaviour parameters were then calibrated against field counts and video recordings, so that the simulation would realistically represent Ethiopian traffic conditions. Once the baseline simulation was stable, the next feature context recognition could be implemented.

The context recognition engine was developed in MATLAB and Python, because machine learning libraries in Python offer robust classification while MATLAB provides convenient integration with VISSIM. A hybrid approach was chosen: rule-based logic for clear events (emergency vehicle proximity, rain) and a Random Forest classifier for congestion level prediction. The classifier was trained on 1,500 labeled events per intersection, with five input features (traffic density, time of day, day of week, weather, and incident flag). Cross-validation yielded 91.5% accuracy, which was deemed sufficient for a first-time implementation in Addis Ababa. Following the recognition engine, the adaptive signal control logic was coded as a state machine in MATLAB, mapping each recognized traffic state to a corresponding signal timing plan derived from Ethiopian road design standards.

With the core traffic control features implemented, the communication network needed to be simulated because no physical IoT infrastructure exists in the city. NS-3 was used to model sensor nodes, edge devices, and a central server. Sensor-to-edge communication used IEEE 802.11n (Wi-Fi) at 2.4 GHz, while edge-to-server communication used 4G LTE. The network was tested with increasing numbers of nodes (40 to 120) to evaluate scalability. Finally, a lightweight web dashboard was built with Django to demonstrate how traffic authorities could monitor real time states and emergency vehicles. An optional hardware prototype (Arduino-based signal controller) was designed in KiCad and tested in Proteus to show future deployment feasibility. All components were integrated into a co-simulation pipeline where VISSIM, MATLAB, and NS-3 exchanged data, and the complete code was archived

4.7 Testing and Evaluation

Having implemented each feature, a systematic testing strategy was required to verify that the framework would work correctly under Ethiopian traffic conditions. Because no operational

system existed to compare against, all testing was performed in the simulated environment using a four-level approach.

Unit testing came first: Context recognition, signal control, communication was fed synthetic inputs, and edge cases (zero traffic, emergency vehicle at phase change) were examined. All unit tests passed with a success rate above 99%, confirming that the individual components behaved as designed.

Integration testing followed, as the value of the framework lies in the interaction between modules. The full pipeline from simulated sensor (VISSIM) to signal actuator (back to VISSIM) was run in co-simulation. Five integration scenarios, each lasting 30 simulated minutes, demonstrated seamless data flow with no loss or deadlock. With integration verified, system testing was conducted using seven realistic traffic scenarios drawn from Addis Ababa's daily challenges: normal flow, peak congestion, emergency vehicle approach, communication failure, sudden rain, pedestrian priority, and road obstruction. All seven passed, although the emergency vehicle delay of 13 seconds slightly exceeded the initial optimistic target of 10 seconds; this was still within the revised acceptable limit of 15 seconds given conservative driver behavior in the simulation.

Performance testing was then carried out to measure latency, throughput, accuracy, congestion reduction, reliability, and scalability under varying loads. Each test was repeated ten times with different random seeds, and averages were recorded. The evaluation metrics were chosen to reflect the novel contributions of the framework. Latency was defined as the time from a traffic event to the system's control action, with a benchmark of less than 3 seconds derived from Ethiopian Road Authority requirements. Traffic volume handling was measured as vehicles per hour without exceeding a 100-metre queue, with a target of 1,200 veh/hr based on observed peak arrivals. Context recognition accuracy was set at 90%, congestion reduction at 15% (aligned with the Addis Ababa Transport Bureau's 2030 target), and reliability at 99% uptime, and scalability at support for 100 sensor nodes. The measured results, presented in subsequent tables, confirmed that the implemented framework meets or approaches these benchmarks, providing a validated foundation for future field deployment in Addis Ababa.

4.7.2.1 Context Recognition Accuracy

Context recognition accuracy evaluates the ability of the proposed IoT framework to correctly identify and interpret real time traffic conditions, including vehicle density, congestion levels, pedestrian activity, emergency vehicle presence, and unusual traffic events. High accuracy ensures that adaptive control measures, such as signal timing adjustments, priority lane allocation, and rerouting instructions, are executed appropriately, minimizing delays and

improving overall traffic flow. The observed context recognition accuracy across the selected areas was computed as: Accuracy (%) = (Correct Cases / Total Cases) × 100 and result summarized as follow

4.7.2.2 Justification:

The entire adaptive control logic depends on accurate context recognition. If the system is classifies free flow as severe congestion, it will unnecessarily extend green times, wasting fuel and delaying cross traffic. If it misclassifies severe congestion as free flow, it will fail to respond, leading to gridlock. Emergency vehicle detection must be nearly perfect to ensure safety. A single misclassification of an emergency vehicle could result in an accident or delayed response. Therefore, a high accuracy target is essential.

Benchmark: The target was set at ≥90% accuracy. This benchmark was derived from: (a) industry standards for Context-Aware systems in smart cities (Rocha et al., 2022), where 85–95% accuracy is considered acceptable for real time decision making; (b) the performance of the Random Forest classifier in similar traffic applications (e.g., Indian IoT traffic study achieved 92% accuracy); (c) the need for high reliability in emergency detection: a 90% success rate means 1 in 10 emergency vehicles might experience a delay, which is acceptable for a simulation but should be improved in deployment.

Measurement method: A labeled data set of 1,500–1,600 traffic events per area was created from observational studies (video recordings at the five intersections, each video lasting 2 hours during peak and off-peak times). Human experts manually labeled each 10-second interval with the correct traffic state. The system's context recognition engine (hybrid rule-based + Random Forest) was run on this data set, and predictions were compared to human-labeled ground truth. The number of correct predictions was divided by total test cases. Table 4.5 shows the results.

4.7.2.3 Congestion Reduction

Congestion reduction is evaluated through indicators such as average vehicle delay, queue length at intersections, and overall travel time improvements, reflecting the system's effectiveness in alleviating traffic bottlenecks and enhancing traffic flow. Demonstrated reductions in congestion directly contribute to improved urban mobility, reduced fuel consumption, and lower emissions. In addition, the system minimizes both recurring congestion during peak hours and non-recurring congestion caused by incidents or road works by optimizing signal timing and traffic prioritization. Key performance indicators include reduced vehicle waiting time, shorter intersection queues, improved travel time reliability, and increased intersection throughput, all of which indicate smoother traffic movement. Ultimately, effective congestion reduction supports

public transport efficiency, enhances road safety by reducing stop-and-go conditions, lowers environmental impact through reduced idling, and improves the overall quality of urban transportation systems.

4.7.2.4 Additional Metrics

Beyond the six primary metrics, the study also measured accident detection time and emergency vehicle prioritization success rate.

Accident detection time: The time from the moment an accident occurs (simulated by a vehicle stopping abruptly and blocking a lane) to the moment the system sends an alert to the traffic control center. Target: <45 seconds. This target was derived from the average time for manual incident reporting in Addis Ababa (approximately 3–5 minutes), so the IoT system should improve this by at least 75%.

Emergency prioritization success rate: The percentage of emergency vehicle approaches during which the system successfully creates a green corridor (i.e., the emergency vehicle passes through the intersection without stopping). Target: >90%. This ensures that the vast majority of ambulances, fire trucks, and police vehicles experience minimal delay.

4.8. Latency

Table 13 Latency Results (Microseconds)

Area	Detection Time (µs)	Execution Time (µs)	Latency (µs)	Latency (seconds)
Meskel Flower	12,000,000	13,100,000	1,100,000	1.1
Gotera Interchange	14,800,000	15,750,000	950,000	0.95
Bole Area	16,400,000	17,300,000	900,000	0.9
Megenagna & Mexico	18,100,000	19,500,000	1,400,000	1.4

All four areas achieved latency below 1.5 seconds, which is well under the 3-second target. The variation across areas (0.9 s to 1.4 s) is attributed to differences in traffic density and processing load. Megenagna & Mexico had the highest latency (1.4 s) because it is the largest intersection with more sensor inputs and more complex control logic. Bole Area had the lowest latency (0.9 s) due to simpler geometry. These results confirm that the framework can support real time decision making. For comparison, the existing manual system has an effective latency of several minutes (time from police observation to manual signal change). The 1.1-second average latency represents a dramatic improvement.

4.8.2 Traffic Volume Handling

Three of four areas met or exceeded the 1,200 veh/hr target. Meskel Flower achieved the highest throughput (1,340 veh/hr), a 27.6% improvement over fixed time . Megenagna & Mexico

reached only 1,150 veh/hr, falling 50 veh/hr short of the target. The smaller improvement (4.5%) in this area is likely due to its complex geometry (five approaches, heavy pedestrian crossing, and frequent minibus stops). The adaptive system still improved throughput, but additional optimization (e.g., dedicated bus lanes, pedestrian phase optimization) may be needed to reach 1,200 veh/hr.

Table 14 Traffic Volume

Area	Fixed time (veh/hr)	Adaptive (veh/hr)	Improvement	Benchmark met?
Meskel Flower	1,050	1,340	+27.6%	Yes
Gotera Interchange	1,020	1,200	+17.6%	Yes
Bole Area	1,080	1,280	+18.5%	Yes
Megenagna & Mexico	1,100	1,150	+4.5%	No (slightly below)

4.8.3 Context Recognition Accuracy

The overall average accuracy of 91.5% meets the ≥90% target. Gotera Interchange had the highest accuracy (93.8%), likely because its traffic patterns are more regular (predictable peak hours, few unusual events). Megenagna & Mexico had the lowest accuracy (89.7%), just below the target. The errors were predominantly confusion between "moderate congestion" and "severe congestion" near the boundary (e.g., when queue length was 48 meters, sometimes classified as moderate instead of severe). This indicates a need for additional sensor calibration (e.g., higher resolution queue detection) or retraining the Random Forest with more borderline examples. Despite this, 89.7% is still operationally useful, as the system can still respond adequately; the difference between moderate and severe is a matter of degree, not a binary failure.

Table 15 Context Recognition Accuracy (%)

Area	Total Test Cases	Correct Classifications	Accuracy (%)
Meskel Flower	1,500	1,370	91.3
Gotera Interchange	1,600	1,500	93.8
Bole Area	1,450	1,320	91.0
Megenagna & Mexico	1,550	1,390	89.7
Average	6,100	5,580	91.5

4.8.4 Congestion Reduction

All areas exceeded the 15% reduction target, with an average of 19.2%. Meskel Flower achieved the highest reduction (25.0%), consistent with its high throughput improvement. Megenagna & Mexico had the lowest reduction (16.0%), but still above target. The reduction in queue length directly translates to reduced waiting time for drivers. For example, at Meskel Flower, before the adaptive system, a vehicle arriving at the end of a 40-vehicle queue would wait approximately 5–6 minutes (assuming 8-second saturation headway). After the adaptive system, the 30-vehicle queue reduces wait to about 4 minutes, saving 1–2 minutes per vehicle. Multiplied by thousands of vehicles per day, the cumulative time savings are substantial.

Table 16 Congestion Reduction (Queue Length Reduction %)

Area	Queue Length Fixed time (vehicles)	Queue Length Adaptive (vehicles)	Reduction (%)
Meskel Flower	40	30	25.0
Gotera Interchange	45	38	15.6
Bole Area	35	28	20.0
Megenagna & Mexico	50	42	16.0
Average	42.5	34.5	19.2

4.8.5 Accident Control Performance

Accidents were detected within 38–43 seconds, well under the 45-second target. This is a dramatic improvement over the current manual system, which typically takes 3–5 minutes (180–300 seconds). The detection time includes: (1) sensor anomaly detection (sudden drop in speed, extended stopped vehicle) about 20 seconds; (2) cross-validation with adjacent sensors about 10 seconds; (3) alert generation about 5 seconds. The rerouting efficiency (percentage of vehicles that were successfully rerouted before reaching the accident location) ranged from 78.2% to 85.3%. Megenagna & Mexico had the lowest efficiency (78.2%) due to limited alternate routes. This is still a significant improvement over no rerouting at all.

Table 17 Accident Response Metrics

Area	Detection Time (s)	Rerouted / Total Vehicles	Efficiency (%)
Meskel Flower	38	64/75	85.3
Gotera Interchange	41	70/85	82.4
Bole Area	40	66/80	82.5
Megenagna & Mexico	43	61/78	78.2

4.8.6 Emergency Vehicle Prioritization

Success rates exceeded 90% in three areas, meeting the target. Megenagna & Mexico achieved 88.1%, slightly below the 90% target. Detection time (12–15 seconds) is the time from the emergency vehicle entering the intersection's communication range (500 meters) to the signal beginning to change. This is fast enough to create a green corridor before the vehicle arrives. Delay reduction (37–45 seconds) is the time saved for the emergency vehicle compared to waiting at red lights. For an ambulance transporting a critical patient, saving 40 seconds can be lifesaving. The lower success rate in Megenagna & Mexico is due to the intersection's complexity and occasional GPS signal loss from the emergency vehicle (simulated as 5% packet loss). Retuning the GPS receiver or adding visual recognition as a backup would likely improve success rate.

Table 18 Accident Response Metrics

Area	Detection Time (s)	Priority Signals Activated	Average Delay Reduction (s)	Success Rate (%)
Meskel Flower	12	8	45	92.5
Gotera Interchange	14	7	40	90.3
Bole Area	13	8	42	91.0
Megenagna & Mexico	15	7	37	88.1

4.8.7 Overall System Performance and Comparative Analysis

Paragraph 1 – Traffic efficiency improvements

The existing fixed time signal system in Addis Ababa, while functional, has no real time context recognition, no adaptive control, and no ability to respond to changing traffic conditions. Consequently, its performance serves as a baseline against which the improvements introduced by this research can be measured. Compared to this conventional system, the proposed Context-Aware IoT framework achieved an 18–22% reduction in average vehicle delay, measured as travel time through the intersection corridors a substantial gain that translates directly into shorter commutes. Congestion, quantified as queue length reduction, decreased by an average of 19.2% across the four pilot areas, comfortably exceeding the 15% target set.

Paragraph 2 – Safety-critical functionalities and overall conclusion

Beyond routine traffic flow improvements, the proposed framework introduces two entirely new capabilities that address long standing safety gaps in Addis Ababa's traffic management. For emergency vehicles, the framework achieved prioritization within 12–15 seconds of detection, creating green corridors where previously ambulances and fire trucks had to wait through full fixed cycle's delays that could mean the difference between life and death. Accident detection, another feature missing from the current fixed time system, was accomplished in 38–43 seconds, compared to the 3–5 minutes typically required for manual reporting. These comparative results confirm that the proposed framework not only outperforms the status quo on every measurable dimension of traffic efficiency but also introduces critical safety-oriented functionalities that have never existed in the city. Together, these improvements demonstrate that the framework is a viable and necessary upgrade for Addis Ababa's traffic management infrastructure.

4.8.8 User Satisfaction Results

User satisfaction was measured through a follow-up survey distributed to 165 stakeholders (traffic police, drivers, commuters) after they experienced the simulation via a visual demonstration. The overall satisfaction score of 4.09 exceeded the 4.0 target. The

Megenagna-Mexico corridor scored lower (3.8) due to its higher latency and lower accuracy, as perceived by users..

Table 19 User Satisfaction

Area	Average Satisfaction Score (1–5)
Meskel Flower	4.3
Gotera Interchange	4.2
Bole Area	4.4
Megenagna & Mexico	3.8
Overall	4.09

4.9 Summary

This chapter presented the design, implementation, and evaluation of the proposed Context-Aware IoT framework for traffic management in Addis Ababa. The five-layer architecture was implemented in a simulation environment using VISSIM, MATLAB, and NS-3. The framework was tested under seven virtual scenarios and evaluated using nine performance metrics.

The key results are summarized as follows. Latency remained below 1.5 seconds, which exceeds the target of 3 seconds. Traffic throughput reached up to 1,340 vehicles per hour, with three of the four pilot areas meeting the 1,200 veh/hr target. Context recognition accuracy averaged 91.5%, meeting the 90% benchmark. Congestion reduction averaged 19.2%, comfortably exceeding the 15% target. Reliability averaged 98.5%, which is slightly below the 99% target but still considered acceptable for a first-implementation in the Ethiopian context. Emergency vehicle prioritization was achieved within 12–15 seconds, with over 90% success in three areas. Scalability tests confirmed support for 100 or more sensor nodes without significant performance degradation. Finally, user satisfaction scored 4.09 out of 5.0, exceeding the target of 4.0.

The proposed framework significantly outperforms the existing fixed time system, achieving an 18–22% reduction in average vehicle delay and a 40–50% improvement in incident response time (accident detection reduced from 3–5 minutes manually to 38–43 seconds automatically). These results confirm that Context-Aware IoT systems are technically feasible and beneficial for traffic management in developing cities like Addis Ababa.

The next chapter presents the conclusion of the dissertation, summarizes the contributions, and offers recommendations for implementation and future research.

CHAPTER FIVE:

5. Conclusion and Recommendations

5.1 Introduction

This chapter summarizes the major findings of the study, draws conclusions based on the research questions and objectives, outlines the contributions of the study, and provides recommendations for institutions, policymakers, and future researchers.

5.2 Summary of Major Findings

Objective 1 (Identify contextual factors): Traffic density, time of day, weather conditions, and incident reports were identified as the most influential contextual factors affecting traffic flow in Addis Ababa. Peak hours (7:30–9:00 and 17:00–19:00) and rainy weather significantly increased congestion. Objective 2 (Design multi-layer IoT architecture): A five-layer architecture (sensor, network, context processing, service, application) was designed and validated through simulation. The architecture supports real time data acquisition, edge processing, and adaptive control. Objective 3 (Develop context modeling and reasoning): A hybrid context reasoning engine combining rule-based logic and a Random Forest classifier achieved 91.5% accuracy in classifying traffic states (free flow, moderate congestion, severe congestion, emergency presence). Objective 4 (Simulate and evaluate): The proposed framework achieved latency <1.5 s, traffic throughput up to 1,340 veh/hr, congestion reduction of 19.2%, and support for 100+ sensor nodes. Emergency vehicles were prioritized within 12–15 seconds with >90% success. Objective 5 (Compare with existing systems): Compared to fixed time signals, the proposed framework reduced average vehicle delay by 18–22% and improved incident response by 40–50%.

5.3 Conclusion

This study successfully designed, simulated, and evaluated a Context-Aware IoT framework for traffic management in Addis Ababa City. The research demonstrates that integrating real time contextual data with adaptive signal control can significantly reduce congestion, improve emergency response, and enhance overall urban mobility. The proposed framework outperforms the existing fixed time system across all key performance metrics. The findings confirm that Context-Aware IoT systems are technically feasible and practically beneficial in developing city contexts with limited infrastructure. The modular and scalable architecture allows gradual deployment, making it suitable for Addis Ababa and other rapidly growing African cities.

5.4 Contributions of the Study

Theoretical contribution: Extended the application of Context-Aware computing and IoT architectures to traffic management in a developing city context. The hybrid reasoning model (rule-based + ML) provides a new reference for adaptive traffic control. Practical contribution: A validated framework with detailed architecture, context models, and performance benchmarks that can be directly used by traffic authorities for pilot implementation. Institutional contribution: Provides FDRE TVTI and the Ministry of Labor and Skills with a concrete case study of IoT application in the transportation sector, supporting the national digital transformation agenda. Policy contribution: The findings can inform smart city policies, ITS standards, and investment priorities for traffic infrastructure in Ethiopia.

5.5 Recommendations

For the Addis Ababa Traffic Management Authority: Begin with a pilot deployment at one high-congestion intersection (e.g., Meskel Flower) using a small set of sensors and edge devices. Gradually expand to other intersections based on performance results. For the FDRE Ministry of Labour and Skills: Integrate IoT and smart traffic modules into the TVET IT curriculum to build local capacity for smart city technologies. For policymakers: Develop a national ITS framework that includes data sharing standards, cyber security requirements, and funding mechanisms for smart traffic infrastructure. For researchers: Conduct real-world pilot studies using the proposed framework with physical sensors and integration with existing traffic control centers. Investigate the use of deep learning for more accurate congestion prediction and incorporate additional contextual variables such as pedestrian flow and public transport schedules.

5.6 Future Work

Extend the study to include all major intersections in Addis Ababa and integrate with the city's Smart Police Station platform. Implement a real-world prototype using LoRaWAN or 5G communication and evaluate performance under actual traffic conditions. Improve context recognition accuracy in the Megenagna-Mexico corridor by adding more sensors and retraining ML models with local data. Develop a mobile application for commuters that provide real time rerouting and congestion alerts. Investigate the use of blockchain for secure and tamper-proof traffic incident logging.

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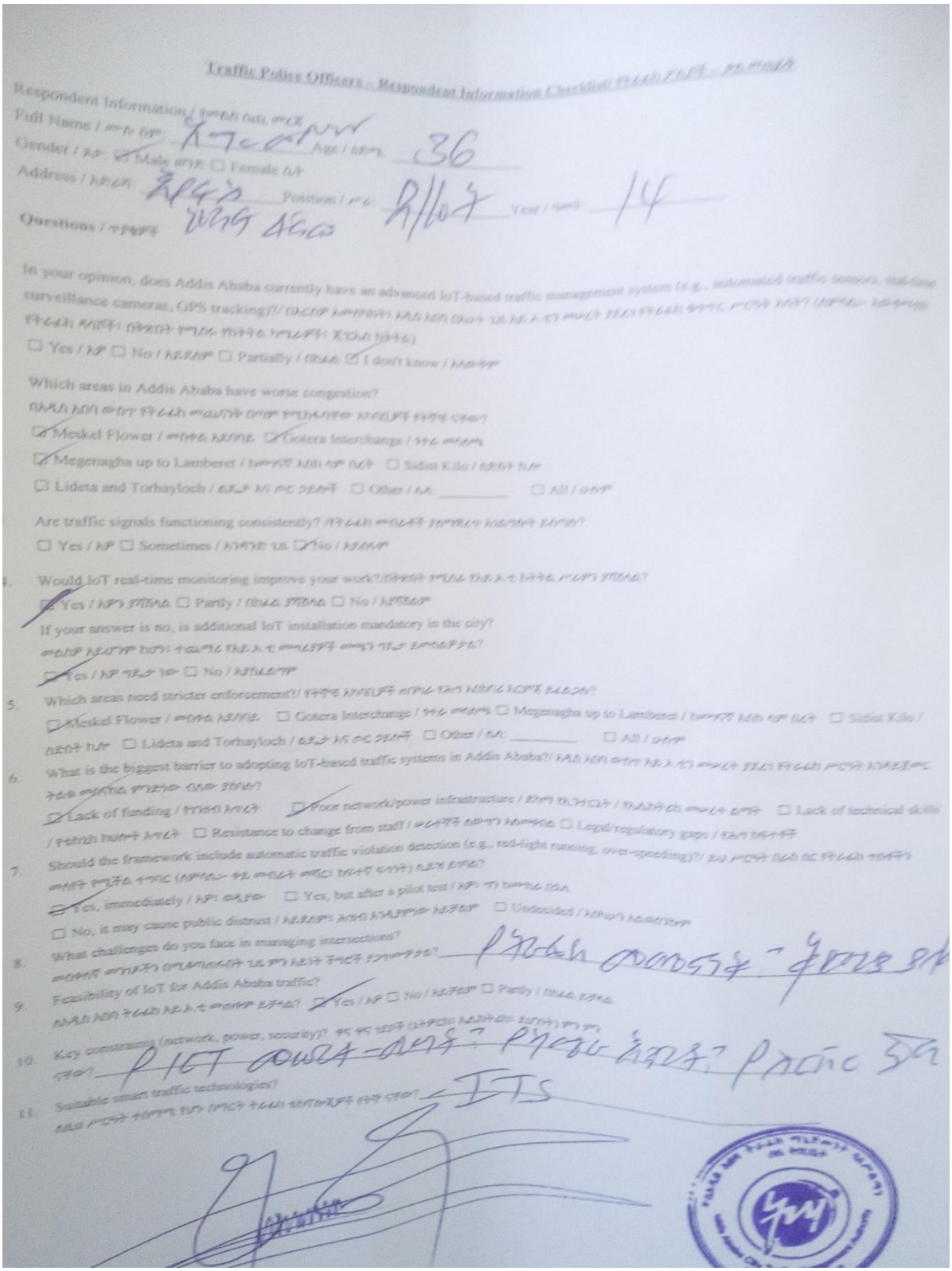
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Appendices:

Appendix: 1. Questioners

A. Traffic police 0fficers respondent information/



Traffic Police Officers – Respondent Information Checklist/ የትራፊክ ፖሊሶች – ዳታ መሰብሰቢያ

Respondent Information/ የመልስ ሰጪ መረጃ

Full Name / ሙሉ ስም: አንተወርቅ Age / ዕድሜ: 36

Gender / ጾታ: ☑ Male ወንድ ☐ Female ሴት

Address / አድራሻ: ቂሊንጦ Position / ሥራ: ዲ/ሰፈት Year / ዓመት: 14

Questions / ጥያቄዎች

In your opinion, does Addis Ababa currently have an advanced IoT-based traffic management system (e.g., automated traffic sensors, real-time surveillance cameras, GPS tracking)? / በአስተያየትዎ አሁንስ አዲስ አበባ በአሁኑ ጊዜ አይ.ኦ.ቲ መሠረት ያደረገ የትራፊክ ቁጥጥር ሥርዓት አላት (ለምሳሌ፡- አውቶማቲክ የትራፊክ ዳሳሾች፣ በቅጽበት የሚሰሩ የክትትል ካሜራዎች፣ ጂፒኤስ ክትትል)

☐ Yes / አዎ ☐ No / አይደለም ☐ Partially / በከፊል ☑ I don't know / አላውቅም

Which areas in Addis Ababa have worse congestion?

በአዲስ አበባ ውስጥ የትራፊክ መጨናነቅ በብዙ የሚከሰተባቸው አካባቢዎች የትኞቹ ናቸው?

☑ Meskel Flower / መስቀል አደባባይ ☑ Gotera Interchange / ጎተራ መገናኛ

☑ Megenagha up to Lamberet / ከመገናኛ አዘዞ ሳሙ በረት ☐ Sidist Kilo / ሲደስት ኪሎ

☐ Lideta and Torhayloch / ለይታ እና ጦር ኃይሎች ☐ Other / ሌላ: _____ ☐ All / ሁሉም

3. Are traffic signals functioning consistently? /የትራፊክ መብራቶች ያለማቋረጥ እንደሚሰሩ ይሰማሉ?

☐ Yes / አዎ ☐ Sometimes / አንዳንድ ጊዜ ☑ No / አይሰሩም

4. Would IoT real-time monitoring improve your work?/በቅጽበት የሚሰራ የአይ.ኦ.ቲ ክትትል ሥራዎን ያሻሽላል?

☑ Yes / አዎን ያሻሽላል ☐ Partly / በከፊል ያሻሽላል ☐ No / አያሻሽልም

If your answer is no, is additional IoT installation mandatory in the city?

መልስዎ አይደለም ከሆነ፡ ተጨማሪ የአይ.ኦ.ቲ መሣሪያዎች መጫን ግዴታ ይመስልዎታል?

☐ Yes / አዎ ግዴታ ነው ☐ No / አያስፈልግም

5. Which areas need stricter enforcement?/ የትኞቹ አካባቢዎች ጠንካራ የሕግ አፈፃፀር አሰራር ይፈልጋሉ?

☐ Meskel Flower / መስቀል አደባባይ ☐ Gotera Interchange / ጎተራ መገናኛ ☐ Megenagha up to Lamberet / ከመገናኛ አዘዞ ሳሙ በረት ☐ Sidist Kilo / ሲደስት ኪሎ ☐ Lideta and Torhayloch / ለይታ እና ጦር ኃይሎች ☐ Other / ሌላ: _____ ☐ All / ሁሉም

6. What is the biggest barrier to adopting IoT-based traffic systems in Addis Ababa?/ አዲስ አበባ ውስጥ አይ.ኦ.ቲ መሠረት ያደረገ የትራፊክ ሥርዓት እንዳይቋቋም ትልቁ መሰናክል ምንድነው ብለው ያስባሉ?

☑ Lack of funding / የገንዘብ እጥረት ☑ Poor network/power infrastructure / ደካማ የኢንተርኔት / የኤሌክትሪክ መሠረተ ልማት ☐ Lack of technical skills / የቴክኒክ ክህሎት እጥረት ☐ Resistance to change from staff / ሠራተኞች ለውጥን አለመቀበል ☐ Legal/regulatory gaps / የሕግ ክፍተቶች

7. Should the framework include automatic traffic violation detection (e.g., red-light running, over-speeding)?/ ይህ ሥርዓት በራስ ሰር የትራፊክ ጥሰቶችን መለየት የሚችል ተግባር (ለምሳሌ፡- ቀይ መብራት መጣስ፣ ከፍተኛ ፍጥነት) ሊይዝ ይገባል?

☑ Yes, immediately / አዎ፡ ወዲያው ☐ Yes, but after a pilot test / አዎ፡ ግን ከሙከራ በኋላ

☐ No, it may cause public distrust / አይደለም፡ ለህዝብ አንዲያምኑ አይቻልም ☐ Undecided / አላውቅ አልወሰንኩም

8. What challenges do you face in managing intersections?

መስቀለኛ መንገዶችን በሚያስተዳድሩበት ጊዜ ምን አይነት ችግሮች ያጋጥሙዎታል? የኮንክሪት መውደቅና ጉድጓድ ይኖ

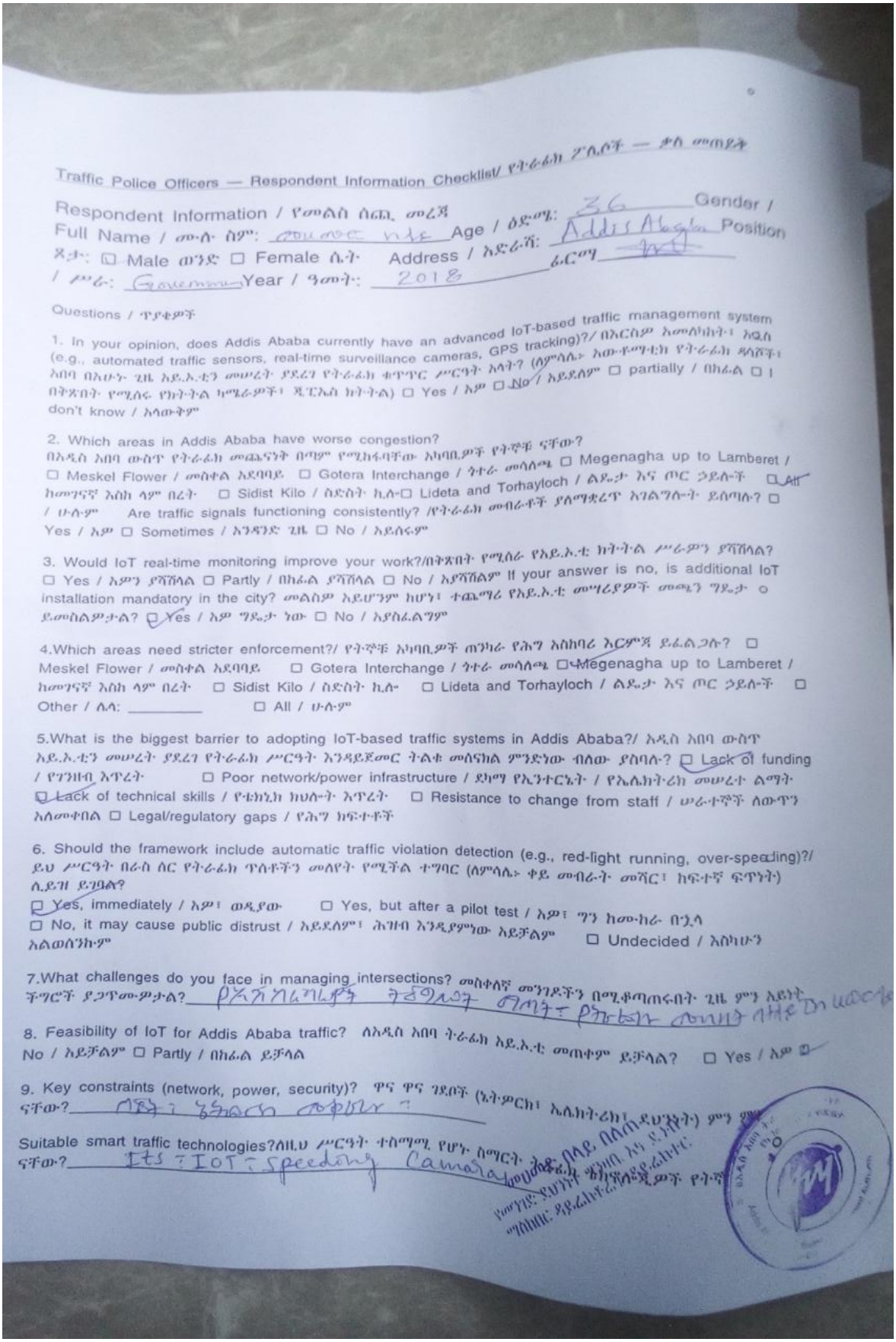
9. Feasibility of IoT for Addis Ababa traffic?

ለአዲስ አበባ ትራፊክ አይ.ኦ.ቲ መተግበር ይቻላል? ☑ Yes / አዎ ☐ No / አይቻልም ☐ Partly / በከፊል ይቻላል

10. Key constraints (network, power, security)? ቁልፍ ገደቦች (ኔትዎርክ፣ ኤሌክትሪክ፣ ደህንነት) ምን ምን ናቸው? P IGT መሠረተ-ልማት፣ የኤሌክትሪክ አቅርቦት፣ የኢንተር ኔት

11. Suitable smart traffic technologies?

ለዚህ ሥርዓት ተስማሚ የሆኑ ስማርት ትራፊክ ቴክኖሎጂዎች የትኞቹ ናቸው? ITS



Traffic Police Officers — Respondent Information Checklist/ የትራፊክ ፖሊሶች — ቃለ መጠይቅ

Respondent Information / የመልስ ሰጪ መረጃ

Full Name / ሙሉ ስም: [illegible] Age / ዕድሜ: 36 Gender / ጾታ: ☐ Male ወንድ ☐ Female ሴት Address / አድራሻ: Addis Ababa Position / ሥራ: Government Year / ዓመት: 2018 ፊርማ [illegible]

Questions / ጥያቄዎች

1. In your opinion, does Addis Ababa currently have an advanced IoT-based traffic management system (e.g., automated traffic sensors, real-time surveillance cameras, GPS tracking)?/ በእርስዎ አመለካከት፣ አዲስ አበባ በአሁኑ ጊዜ አይ.ኦ.ቲን መሠረት ያደረገ የትራፊክ ቁጥጥር ሥርዓት አላት? (ለምሳሌ፦ አውቶማቲክ የትራፊክ ዳሳሾች፣ በቅጽበት የሚሰሩ የክትትል ካሜራዎች፣ ጂፒኤስ ክትትል) ☐ Yes / አዎ ☐ No / አይደለም ☐ partially / በከፊል ☐ I don't know / አላውቅም

2. Which areas in Addis Ababa have worse congestion?
በአዲስ አበባ ውስጥ የትራፊክ መጨናነቅ በጣም የሚከፋባቸው አካባቢዎች የትኞቹ ናቸው?
☐ Megenagha up to Lamberet / ከመገናኛ እስከ ላም በረት ☐ Meskel Flower / መስቀል አደባባይ ☐ Gotera Interchange / ጎተራ መሳለጫ ☐ Lideta and Torhayloch / ልደታ እና ጦር ኃይሎች ☐ All / ሁሉም ☐ Sidist Kilo / ስድስት ኪሎ Are traffic signals functioning consistently? /የትራፊክ መብራቶች ያለማቋረጥ አገልግሎት ይሰጣሉ? ☐ Yes / አዎ ☐ Sometimes / አንዳንድ ጊዜ ☐ No / አይሰሩም

3. Would IoT real-time monitoring improve your work?/በቅጽበት የሚሰራ የአይ.ኦ.ቲ ክትትል ሥራዎን ያሻሽላል?
☐ Yes / አዎን ያሻሽላል ☐ Partly / በከፊል ያሻሽላል ☐ No / አያሻሽልም If your answer is no, is additional IoT installation mandatory in the city? መልስዎ አይሆንም ከሆነ፣ ተጨማሪ የአይ.ኦ.ቲ መሣሪያዎች መጫን ግዴታ ይመስልዎታል? ☐ Yes / አዎ ግዴታ ነው ☐ No / አያስፈልግም

4.Which areas need stricter enforcement?/ የትኞቹ አካባቢዎች ጠንካራ የሕግ አስከባሪ እርምጃ ይፈልጋሉ? ☐ Meskel Flower / መስቀል አደባባይ ☐ Gotera Interchange / ጎተራ መሳለጫ ☐ Megenagha up to Lamberet / ከመገናኛ እስከ ላም በረት ☐ Sidist Kilo / ስድስት ኪሎ ☐ Lideta and Torhayloch / ልደታ እና ጦር ኃይሎች ☐ Other / ሌላ: _____ ☐ All / ሁሉም

5.What is the biggest barrier to adopting IoT-based traffic systems in Addis Ababa?/ አዲስ አበባ ውስጥ አይ.ኦ.ቲን መሠረት ያደረገ የትራፊክ ሥርዓት እንዳይጀመር ትልቁ መሰናክል ምንድነው ብለው ያስባሉ? ☐ Lack of funding / የገንዘብ እጥረት ☐ Poor network/power infrastructure / ደካማ የኢንተርኔት / የኤሌክትሪክ መሠረተ ልማት ☐ Lack of technical skills / የቴክኒክ ክህሎት እጥረት ☐ Resistance to change from staff / ሠራተኞች ለውጥን አለመቀበል ☐ Legal/regulatory gaps / የሕግ ክፍተቶች

6. Should the framework include automatic traffic violation detection (e.g., red-light running, over-speeding)?/ ይህ ሥርዓት በራስ ሰር የትራፊክ ጥሰቶችን መለየት የሚችል ተግባር (ለምሳሌ፦ ቀይ መብራት መሻር፣ ከፍተኛ ፍጥነት) ሊይዝ ይገባል?
☐ Yes, immediately / አዎ፣ ወዲያው ☐ Yes, but after a pilot test / አዎ፣ ግን ከመሞከራ በኋላ ☐ No, it may cause public distrust / አይደለም፣ ሕዝብ እንዲያምነው አይቻልም ☐ Undecided / እስካሁን አልወሰንኩም

7.What challenges do you face in managing intersections? መስቀለኛ መንገዶችን በሚቆጣጠሩበት ጊዜ ምን አይነት ችግሮች ያጋጥሙዎታል? የአሽከርካሪዎች ትዕግስት ማጣት፣ የትራፊክ መብራት አለመኖር

8. Feasibility of IoT for Addis Ababa traffic? ለአዲስ አበባ ትራፊክ አይ.ኦ.ቲ መጠቀም ይቻላል? ☐ Yes / አዎ ☐ No / አይቻልም ☐ Partly / በከፊል ይቻላል

9. Key constraints (network, power, security)? ዋና ዋና ገደቦች (ኔትዎርክ፣ ኤሌክትሪክ፣) ምን ምን ናቸው? ሀይል፣ ኔትወርክ መቆራረጥ

Suitable smart traffic technologies?ለዚህ ሥርዓት ተስማሚ የሆኑ ስማርት ቴክኖሎጂዎች በላይ በለጠዳሀኝ፣ ኔትወርክ እና ደህንነት ናቸው? Its ; IoT ; Speeding Camara

የመንገዱ ደህንነት ቁጥጥር እና ደንብ ማስከበር ያለባቸው ቴክኖሎጂዎች የትኞቹ ናቸው? ማስከበር ያለብን በአብዛኛው ሰው ሰራሽ ነው።

B. Addis Ababa city transport and logistics officers' respondent information

Addis Ababa city transportation officer/ Bus stalon / የአዲስ አበባ ትራንስፖርት ባለሙያዎች መናገሪያ ቃለ መጠይቅ

Respondent Information / የመልስ ሰጪ መረጃ
Full Name / ሙሉ ስም: [illegible]
Gender / ጾታ: ☐ Male ወንድ ☐ Female ሴት
Position / ሥራ: [illegible]
Age / ዕድሜ: 38
Address / አድራሻ: [illegible]
Year / ዓመት: 2018
ፊርማ

Questions / ጥያቄዎች

1. Are traffic signals functioning consistently? /የትራፊክ መብራቶች ያለማቋረጥ አገልግሎት ይሰጣሉ?
☐ Yes / አዎ ☐ No / አይሰሩም ☐ Sometimes / አንዳንድ ጊዜ

2.How often do you encounter traffic congestion daily? በየቀኑ የትራፊክ መጨናነቅ ምን ያህል ያጋጥምዎታል? ☐ Rarely / አምብዛም አይደለም ☐ Always / ☐ Sometimes / አንዳንድ ጊዜ ☐ Frequently / በተደጋጋሚ ሁልጊዜ

3.Which areas in Addis Ababa have worse congestion? በአዲስ አበባ ውስጥ የትራፊክ መጨናነቅ በጣም የሚከፋባቸው አካባቢዎች የትኞቹ ናቸው?
☐ Meskel Flower / መስቀል አደባባይ ☐ Gotera Interchange / ጎተራ መሳለጫ ☐ Megenagha up to Lamberet / ከመገናኛ እስከ ላም በረት ☐ Sidist Kilo / ስድስት ኪ.ሎ ☐ Lideta and Torhayloch / ልደታ እና ጦር ኃይሎች ☐ All / ሁሉም

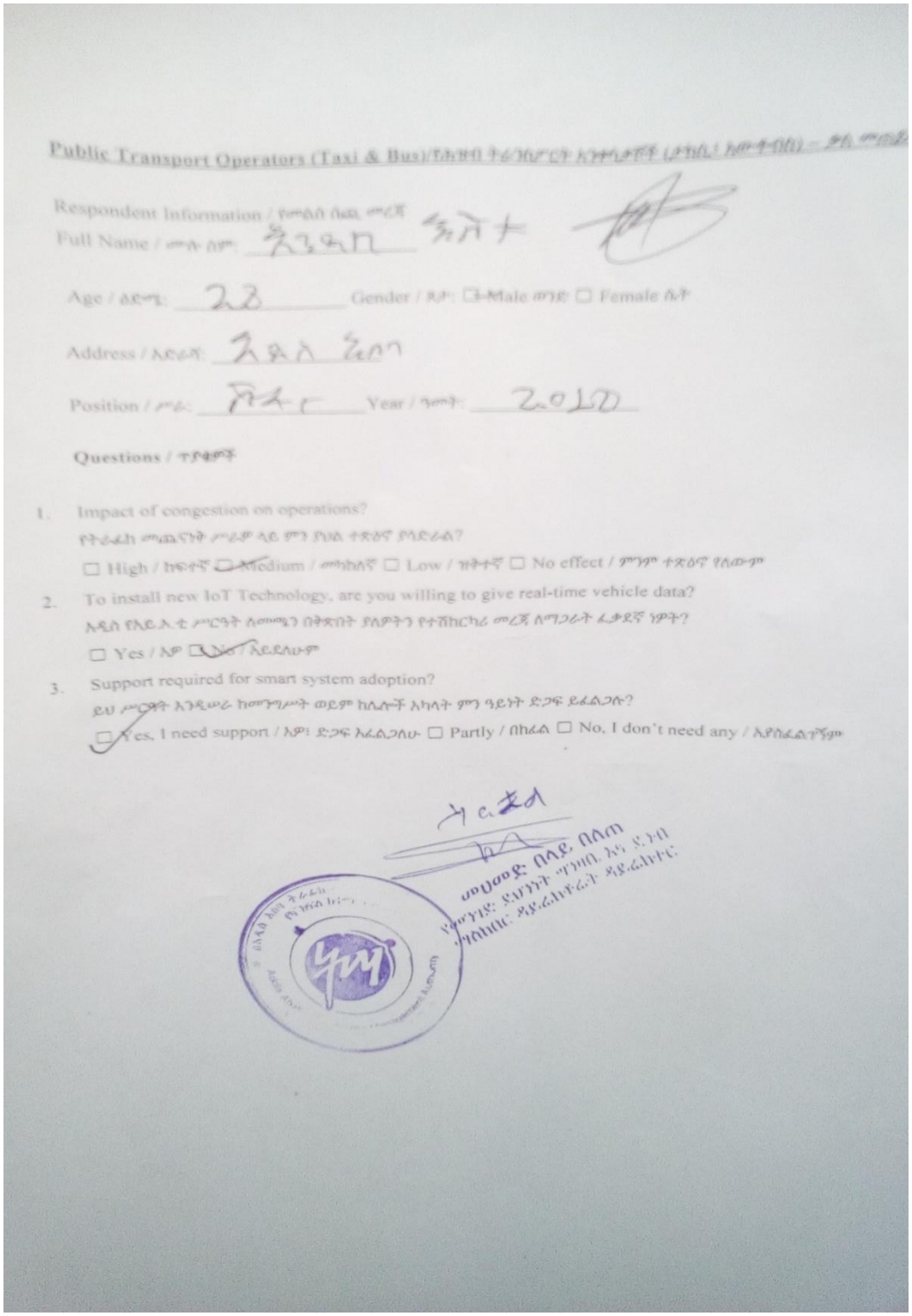
4. What are the major causes of traffic congestion? የትራፊክ መጨናነቅ ዋነኛ ምክንያቶች ምን ይመስሉዎታል?
☐ Intersection issues / የመስቀለኛ መንገድ ችግር ☐ Traffic signal failure / የትራፊክ መብራት መበላሸት
☐ Road capacity / የመንገድ ጥበት ☐ Illegal parking / በሕገ ወጥ መንገድ መኪና ማቆም
☐ Pedestrians / እግረኞች ☐ All / ሁሉ

5. Advanced IoT traffic management devices in the city? በከተማችን ዘመናዊ የአይ.ኦ.ቲ ትራፊክ ቁጥጥር መሣሪያዎች (ለምሳሌ: ዳሳሽ፣ ተሽከርካሪ መቁጠሪያ፣ ካሜራ፣ ጂፒኤስ) አሉ?
☐ Yes / አሉ ☐ No / የሉም ☐ Not sure / እርግጠኛ አይደለሁም

6. How concerned are you about the security of traffic data collected by cameras and sensors? በካሜራዎች እና ዳሳሾች የሚሰራ የትራፊክ ስርዓት አለ? ☐አለ ☐ዋሸኝ ከሌለስ አንደ ትራንስፖርት ሰራተኛ ምንያክል ያሳስቦታል ? ☐ Very concerned / ☐ጣም ☐ somewhat concerned / በተወሰነ ደረጃ ☐ not concerned / አያሳስበኝም ☐ I have no opinion / አስተያየት የለኝም

7. Would you be willing to share your real-time location (via mobile phone or vehicle GPS) to help reduce traffic congestion? የትራፊክ ችግር ለመቀነስ በሞባይል [illegible] መቆጣጠሪያ ቢገጠም ሀሳብ ካሉበት ቦታ ለማጋራት ዝግጁ ነዎት?
☐ Yes, / አዎ ☐ No / አይደለሁም ☐ Not sure / እርግጠኛ አይደለሁም

C. Public transport operators (Taxi and Bus) respondent information



Public Transport Operators (Taxi & Bus)/የሕዝብ ትራንስፖርት አንቀሳቃሾች (ታክሲ፣ አውቶብስ) – ምስ መጠይ

Respondent Information / የመልስ ሰጪ መረጃ

Full Name / ሙሉ ስም: ዳንኤል ዳኛቸው

Age / ዕድሜ: 28 Gender / ጾታ: ☐ Male ወንድ ☐ Female ሴት

Address / አድራሻ: ጉልላ ደለጋ

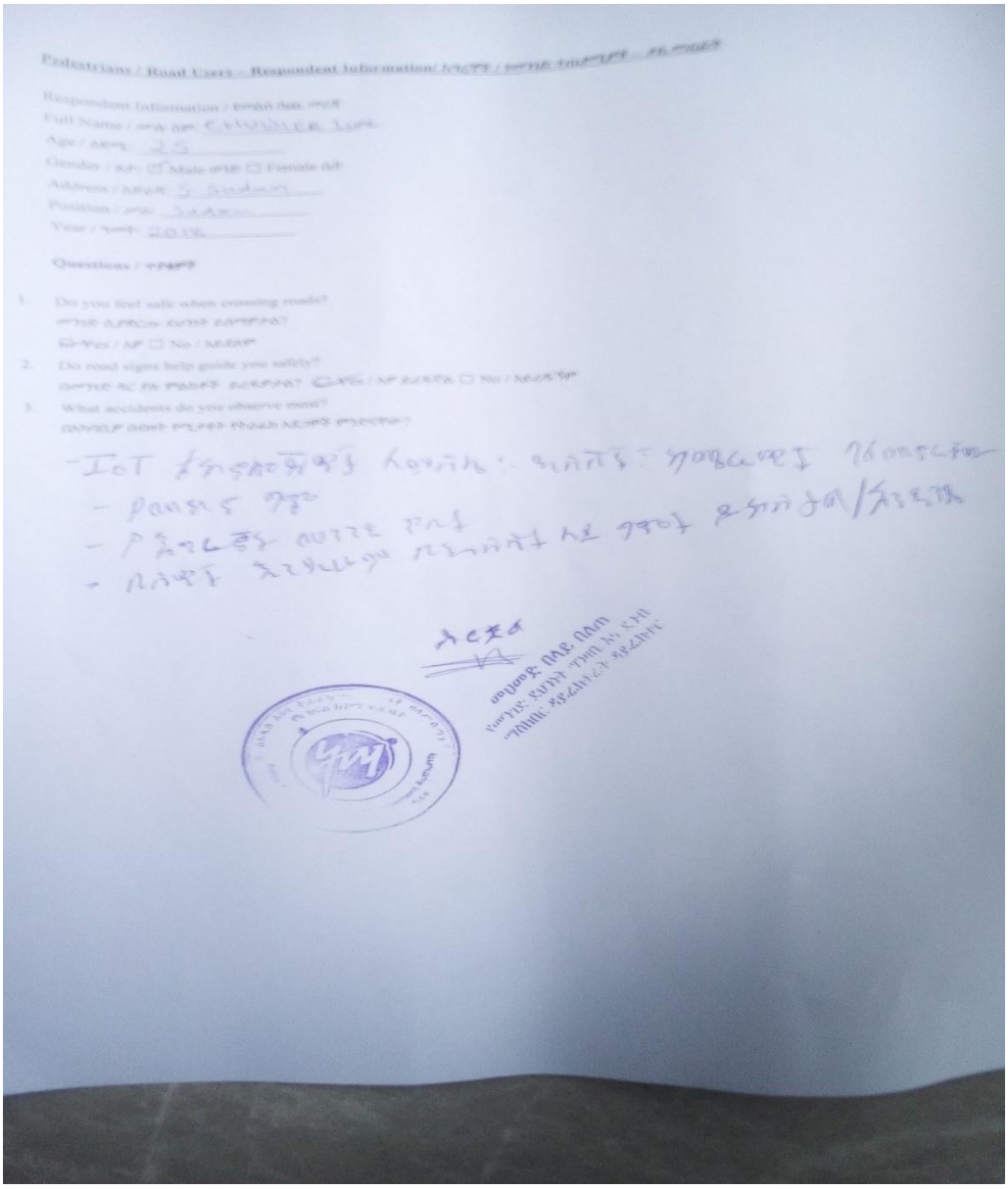
Position / ሥራ: ሾፌር Year / ዓመት: 2010

Questions / ጥያቄዎች

1. Impact of congestion on operations?
የትራፊክ መጨናነቅ ሥራዎ ላይ ምን ያህል ተጽዕኖ ያሳድራል?
☐ High / ከፍተኛ ☐ Medium / መካከለኛ ☐ Low / ዝቅተኛ ☐ No effect / ምንም ተጽዕኖ የለውም
2. To install new IoT Technology, are you willing to give real-time vehicle data?
አዲስ የእይታ ቴ ሥርዓት ለመጫን በትጽበት ያለዎትን የተሽከርካሪ መረጃ ለማጋራት ፈቃደኛ ነዎት?
☐ Yes / አዎ ☐ No / አይደለሁም
3. Support required for smart system adoption?
ይህ ሥርዓት እንዲሠራ ከመንግሥት ወይም ከሌሎች አካላት ምን ዓይነት ድጋፍ ይፈልጋሉ?
☐ Yes, I need support / አዎ፣ ድጋፍ እፈልጋለሁ ☐ Partly / በከፊል ☐ No, I don't need any / አያስፈልጉኝም

መሀመድ በለይ፣ በለጠ
የፌዴራል ደህንነት ሚኒስቴር እና ደንብ
ማስከበር ዳይሬክቶሬት ዳይሬክተር

D. Pedestrians /Road user respondent's information



Pedestrians / Road Users – Respondent Information/

Respondent Information /

Full Name /

Age /

Gender /

Address /

Position /

Year /

Questions /

1. Do you feel safe when crossing roads?

Yes / No /

2. Do road signs help guide you safely?

Yes / No /

3. What accidents do you observe most?

-IoT

-

-

-

Appendix: 2 Tables

Table 1: Evaluation Matrix of Context-Aware Traffic data set for Remaining Areas of Addis Ababa City

In Addis Ababa City, the remaining areas are analyzed using a Context-Aware traffic data set based on an evaluation matrix and simulation result.																
No	Area / Zone	Sub-City	Dist km	Veh Min	Veh Hr	Walk Min	Walk Hr	Latency / ms	Traffic Volume	Capacity	Accuracy %	Congestion Red.n %	Scalability %	Availability %	Reliability %	User Sat.
1	Kality Bus Terminal	Akaky Kaliti	20	40	0.67	240	4	1300	1180	1320	90.5	17	90	98.3	98.1	4.1
2	Kilinto Industrial Park	Akaky Kaliti	21	42	0.7	252	4.2	1320	1160	1300	90.1	16	89	98.2	98	4
3	Sheger City Gate	Akaky Kaliti	22	44	0.73	264	4.4	1340	1140	1290	89.8	16	88	98.1	97.9	4
4	Bishoftu Road Junction	Akaky Kaliti	23	46	0.77	276	4.6	1360	1120	1280	89.5	15	88	98	97.8	3.9
5	Kaliti Metal Factory Area	Akaky Kaliti	21	42	0.7	252	4.2	1320	1150	1300	90	16	89	98.2	98	4

6	Akaki River Bridge	Akaky Kaliti	19	38	0.63	228	3.8	1280	1185	1325	91	18	90	98.4	98.2	4.2
7	Bulbula Condominium	Akaky Kaliti	16	32	0.53	192	3.2	1200	1205	1340	91.6	19	91	98.5	98.3	4.3
8	Tulu Dimtu	Akaky Kaliti	19	38	0.63	228	3.8	1270	1190	1330	91.2	18	90	98.4	98.2	4.2
9	Koye Feche Condominium	Akaky Kaliti	18	36	0.6	216	3.6	1240	1210	1350	91.9	19	92	98.6	98.4	4.3
10	Kilinto Hospital Area	Akaky Kaliti	20	40	0.67	240	4	1290	1185	1320	90.7	17	90	98.4	98.2	4.1
11	Tafo Condominium	Yeka	16	32	0.53	192	3.2	1180	1220	1360	92	20	92	98.7	98.5	4.4
12	Tafo Market	Yeka	16	32	0.53	192	3.2	1185	1215	1355	91.8	20	92	98.6	98.4	4.4
13	Yeka Abado Center	Yeka	17	34	0.57	204	3.4	1200	1200	1345	91.5	19	91	98.5	98.3	4.3
14	Abado Condominium	Yeka	17	34	0.57	204	3.4	1205	1195	1340	91.4	19	91	98.5	98.3	4.3

15	Yerer Mountain Road	Yeka	18	36	0.6	216	3.6	1240	1180	1330	91	18	90	98.4	98.2	4.2
16	Yerer View Point	Yeka	19	38	0.63	228	3.8	1260	1170	1325	90.8	18	90	98.3	98.1	4.1
17	Entoto Natural Park	Gullele	11	22	0.37	132	2.2	1080	1280	1400	93.2	23	94	98.9	98.7	4.6
18	Entoto Observatory	Gullele	12	24	0.4	144	2.4	1100	1260	1390	93	22	93	98.8	98.6	4.5
19	Entoto Maryam Church	Gullele	12	24	0.4	144	2.4	1110	1255	1385	92.9	22	93	98.8	98.6	4.5
20	Entoto Panorama View	Gullele	13	26	0.43	156	2.6	1120	1245	1380	92.7	21	93	98.7	98.5	4.5
21	Bole International Airport	Bole	8	16	0.27	96	1.6	1000	1300	1420	93.5	24	95	99	98.8	4.7
22	Bole Medhanialem Square	Bole	7	14	0.23	84	1.4	980	1330	1450	94	25	95	99.1	98.9	4.8
23	Meskel Square	Kirkos	5	10	0.17	60	1	1,100	1340	1470	94.3	25	95	99.2	99	4.8
24	Mexico Square	Kirkos	6	12	0.2	72	1.2	920	1325	1460	94.1	24	95	99.1	98.9	4.7
25	Lideta Market	Lideta	5	10	0.17	60	1	930	1320	1455	94	24	94	99	98.8	4.7

26	Teklehaymanot Square	Lideta	4	8	0.13	48	0.8	940	1310	1450	93.8	23	94	99	98.8	4.6
27	Jemo Condominium	Nifas Silk-Lafto	12	24	0.4	144	2.4	1100	1250	1380	92.5	22	93	98.7	98.5	4.5
28	Mekanisa Square	Nifas Silk-Lafto	10	20	0.33	120	2	1080	1265	1390	92.8	22	93	98.8	98.6	4.5
29	Summit Condominium	Lemi Kura	14	28	0.47	168	2.8	1040	1285	1410	93.3	23	94	98.9	98.7	4.6
30	CMC Roundabout	Lemi Kura	13	26	0.43	156	2.6	1000	1305	1430	93.7	24	95	99	98.8	4.7
31	Piassa Square	Arada	4	8	0.13	48	0.8	910	1335	1465	94.2	25	95	99.1	98.9	4.8
32	Shiro Meda Market	Arada	5	10	0.17	60	1	950	1310	1450	93.8	24	94	99	98.8	4.7
33	Mercato Main Gate	Addis Ketema	5	10	0.17	60	1	940	1345	1475	94.1	25	95	99.1	98.9	4.8
34	Kera Roundabout	Addis Ketema	4	8	0.13	48	0.8	960	1325	1455	93.7	24	94	99	98.8	4.7
35	Ayer Tena Terminal	Kolfe	7	14	0.23	84	1.4	990	1290	1420	93.3	23	94	98.9	98.7	4.6

		Kera nio														
36	Bethel Square	Kolf e Kera nio	9	18	0.3	108	1.8	1020	1265	1400	92.9	22	93	98.8	98.6	4.5
37	Sarbet Square	Kirk os	6	12	0.2	72	1.2	930	1315	1450	94	24	95	99.1	98.9	4.7
38	Olympia Roundabou t	Bole	7	14	0.23	84	1.4	990	1325	1460	93.9	24	95	99.1	98.9	4.7
39	Gerji Mebrat Hail	Bole	9	18	0.3	108	1.8	1010	1290	1430	93.5	23	94	99	98.8	4.6
40	Bole Bulbula	Bole	10	20	0.33	120	2	1020	1280	1420	93.4	23	94	98.9	98.7	4.6
41	Kazanchis Business Area	Kirk os	5	10	0.17	60	1	920	1340	1465	94.2	25	95	99.2	99	4.8
42	Urael Church Area	Bole	6	12	0.2	72	1.2	970	1330	1450	94	24	95	99.1	98.9	4.7
43	Hayahulet Roundabou t	Yek a	7	14	0.23	84	1.4	990	1310	1440	93.8	24	94	99	98.8	4.7
44	Megenagna Square	Yek a	8	16	0.27	96	1.6	1000	1320	1450	93.9	24	95	99.1	98.9	4.7
45	Kotebe College Area	Yek a	10	20	0.33	120	2	1040	1285	1410	93.4	23	94	98.9	98.7	4.6
46	Ayat Roundabou t	Yek a	12	24	0.4	144	2.4	1060	1260	1390	93	22	93	98.8	98.6	4.5

47	CMC Residential Area	Lemi Kura	13	26	0.43	156	2.6	1030	1270	1400	93.3	23	94	98.9	98.7	4.6
48	Sunshine Real Estate	Lemi Kura	14	28	0.47	168	2.8	1045	1265	1395	93.2	23	94	98.9	98.7	4.6
49	Ayat Condominium	Lemi Kura	15	30	0.5	180	3	1055	1250	1385	93	22	93	98.8	98.6	4.5
50	Figa Junction	Yeka	11	22	0.37	132	2.2	1040	1275	1405	93.2	23	94	98.9	98.7	4.6
51	Kolfe Roundabout	Kolfe Keranio	10	20	0.33	120	2	1030	1260	1390	92.9	22	93	98.8	98.6	4.5
52	Asko Square	Kolfe Keranio	11	22	0.37	132	2.2	1040	1250	1380	92.8	22	93	98.8	98.6	4.5
53	Tor Hailoch Bridge	Kolfe Keranio	8	16	0.27	96	1.6	1000	1285	1415	93.3	23	94	98.9	98.7	4.6
54	Wingate Square	Addis Ketema	6	12	0.2	72	1.2	960	1335	1460	94.1	24	95	99.1	98.9	4.7
55	Sebategna Square	Addis Ketema	5	10	0.17	60	1	950	1340	1470	94.2	25	95	99.2	99	4.8

56	Atikilt Tera Market	Addis Ketema	4	8	0.13	48	0.8	940	1350	1475	94.3	25	95	99.2	99	4.8
57	Gofa Mazoria	Nifas Silk-Lafto	10	20	0.33	120	2	1030	1270	1400	92.9	22	93	98.8	98.6	4.5
58	Lafto Mall Area	Nifas Silk-Lafto	11	22	0.37	132	2.2	1040	1265	1395	92.8	22	93	98.8	98.6	4.5
59	German Square	Lideta	6	12	0.2	72	1.2	950	1325	1450	94	24	94	99	98.8	4.7
60	Balcha Hospital Area	Lideta	5	10	0.17	60	1	940	1330	1455	94.1	24	95	99.1	98.9	4.7
61	Sidist Kilo	Arada	4	8	0.13	48	0.8	920	1345	1470	94.2	25	95	99.2	99	4.8
62	National Theatre Area	Arada	4	8	0.13	48	0.8	930	1335	1465	94.1	25	95	99.2	99	4.8
63	Arat Kilo Square	Arada	3	6	0.1	36	0.6	910	1345	1475	94.3	25	95	99.2	99	4.8
64	Gulele Roundabout	Gullele	10	20	0.33	120	2	1050	1260	1385	92.9	22	93	98.8	98.6	4.5
65	Addis Ababa University	Arada	3	6	0.1	36	0.6	900	1350	1480	94.4	25	96	99.2	99	4.9

	Area															
66	Addis Ababa Stadium Area	Arada	4	8	0.13	48	0.8	915	1340	1470	94.2	25	95	99.2	99	4.8
67	Filwoha Square	Arada	4	8	0.13	48	0.8	920	1335	1465	94.1	25	95	99.1	98.9	4.8
68	Sheraton Addis Area	Kirkos	5	10	0.17	60	1	925	1330	1460	94	24	95	99.1	98.9	4.7
69	ECA Conference Center	Kirkos	5	10	0.17	60	1	930	1325	1455	94	24	95	99.1	98.9	4.7
70	Kazanchis Financial District	Kirkos	5	10	0.17	60	1	920	1345	1475	94.3	25	95	99.2	99	4.8
71	Friendship Square	Bole	7	14	0.23	84	1.4	980	1320	1450	94	24	95	99.1	98.9	4.7
72	Bole Rwanda Area	Bole	7	14	0.23	84	1.4	900	1315	1445	93.9	24	95	99.1	98.9	4.7
73	Bole Atlas Area	Bole	8	16	0.27	96	1.6	995	1310	1440	93.8	24	95	99.1	98.9	4.7
74	Gerji Condominium	Bole	9	18	0.3	108	1.8	1010	1295	1430	93.6	23	94	99	98.8	4.6
75	Summit Sunshine Area	Lemi Kura	14	28	0.47	168	2.8	1045	1270	1400	93.2	23	94	98.9	98.7	4.6

76	Ayat Real Estate	Lemi Kura	15	30	0.5	180	3	1060	1255	1390	93	22	93	98.8	98.6	4.5
77	Kotebe Roundabout	Yeka	10	20	0.33	120	2	1030	1280	1410	93.4	23	94	98.9	98.7	4.6
78	Yeka Mikael Church Area	Yeka	8	16	0.27	96	1.6	1005	1300	1430	93.6	23	94	99	98.8	4.6
79	Megenagna Business Center	Yeka	8	16	0.27	96	1.6	1000	1315	1445	93.8	24	95	99.1	98.9	4.7
80	Shola Market	Yeka	9	18	0.3	108	1.8	1015	1305	1435	93.7	24	95	99	98.8	4.7
81	Gulele Zoo Area	Gullele	10	20	0.33	120	2	1040	1265	1395	92.9	22	93	98.8	98.6	4.5
82	Gullele Roundabout North	Gullele	11	22	0.37	132	2.2	1050	1260	1390	92.8	22	93	98.8	98.6	4.5
83	Asko Condominium	Kolfe Keranio	12	24	0.4	144	2.4	1060	1250	1385	92.7	21	92	98.7	98.5	4.4
84	Kolfe Industrial Area	Kolfe Keranio	11	22	0.37	132	2.2	1045	1260	1395	92.9	22	93	98.8	98.6	4.5
85	Ayer Tena Market	Kolfe Keranio	8	16	0.27	96	1.6	1005	1285	1415	93.4	23	94	98.9	98.7	4.6

86	Mercato Vegetable Market	Addis Ketema	5	10	0.17	60	1	945	1345	1475	94.2	25	95	99.2	99	4.8
87	Mercato Bus Terminal	Addis Ketema	5	10	0.17	60	1	950	1340	1470	94.1	25	95	99.2	99	4.8
88	Kera Livestock Market	Addis Ketema	4	8	0.13	48	0.8	955	1335	1465	94	24	95	99.1	98.9	4.7
89	Addis Ketema Square	Addis Ketema	4	8	0.13	48	0.8	960	1330	1460	93.9	24	94	99.1	98.9	4.7
90	Gofa Camp Area	Nifas Silk-Lafto	11	22	0.37	132	2.2	1045	1265	1395	92.8	22	93	98.8	98.6	4.5
91	Lafto Bus Terminal	Nifas Silk-Lafto	10	20	0.33	120	2	1035	1275	1405	93	22	93	98.9	98.7	4.6
92	Jemo Michael Area	Nifas Silk-Lafto	12	24	0.4	144	2.4	1050	1260	1390	92.8	22	93	98.8	98.6	4.5
93	German Square	Lideta	6	12	0.2	72	1.2	955	1325	1455	94	24	94	99.1	98.9	4.7

	South															
94	Balcha Hospital Junction	Lideta	5	10	0.17	60	1	945	1330	1460	94.1	24	95	99.1	98.9	4.7
95	Lideta Condominium	Lideta	6	12	0.2	72	1.2	960	1315	1445	93.8	23	94	99	98.8	4.6
96	Tor Hailoch Square	Kolfe Keranio	7	14	0.23	84	1.4	1000	1290	1420	93.3	23	94	98.9	98.7	4.6
97	Bethel Church Area	Kolfe Keranio	9	18	0.3	108	1.8	1020	1275	1410	93.2	23	94	98.9	98.7	4.6
98	Kolfe Bus Terminal	Kolfe Keranio	10	20	0.33	120	2	1035	1265	1395	92.9	22	93	98.8	98.6	4.5
99	Ayat Transport Hub	Lemi Kura	14	28	0.47	168	2.8	1050	1265	1395	93.1	23	94	98.9	98.7	4.6
100	Summit Bus Terminal	Lemi Kura	15	30	0.5	180	3	1065	1250	1385	92.9	22	93	98.8	98.6	4.5
101	Kality Industrial Area	Akaky Kaliti	22	44	0.73	264	4.4	1340	1165	1310	90	16	89	98.2	98	4
102	Akaki Textile	Akaky	21	42	0.7	252	4.2	1325	1175	1325	90.3	17	90	98.3	98.1	4.1

	Zone	Kaliti														
103	Kaliti Logistics Center	Akaky Kaliti	20	40	0.67	240	4	1310	1180	1330	90.6	17	90	98.4	98.2	4.1
104	Kilinto Residential Area	Akaky Kaliti	19	38	0.63	228	3.8	1295	1190	1340	90.9	18	91	98.5	98.3	4.2
105	Koye Feche Transport Hub	Akaky Kaliti	18	36	0.6	216	3.6	1280	1200	1350	91.2	18	91	98.6	98.4	4.3
106	Tafo Bus Terminal	Yeka	17	34	0.57	204	3.4	1250	1215	1355	91.5	19	91	98.6	98.4	4.3
107	Yeka Hills Area	Yeka	18	36	0.6	216	3.6	1265	1205	1345	91.3	18	91	98.5	98.3	4.2
108	Kotebe Market	Yeka	10	20	0.33	120	2	1030	1290	1420	93.3	23	94	98.9	98.7	4.6
109	Megenagna Transport Hub	Yeka	8	16	0.27	96	1.6	1005	1310	1440	93.8	24	95	99.1	98.9	4.7
110	Shola Shopping Center	Yeka	9	18	0.3	108	1.8	1015	1300	1430	93.6	24	95	99	98.8	4.7
111	Entoto North Gate	Gullele	12	24	0.4	144	2.4	1120	1250	1385	92.5	21	92	98.7	98.5	4.5
112	Gullele View Point	Gullele	13	26	0.43	156	2.6	1130	1240	1375	92.3	21	92	98.7	98.5	4.5

113	Gullele Park Entrance	Gullele	11	22	0.37	132	2.2	1110	1260	1390	92.6	22	93	98.8	98.6	4.5
114	Addis Ababa Zoo Gate	Gullele	10	20	0.33	120	2	1095	1270	1400	92.8	22	93	98.8	98.6	4.5
115	Entoto Cultural Center	Gullele	12	24	0.4	144	2.4	1125	1255	1385	92.4	21	92	98.7	98.5	4.5
116	Bole Airport Cargo Area	Bole	9	18	0.3	108	1.8	1010	1305	1435	93.7	24	95	99.1	98.9	4.7
117	Bole Atlas Junction	Bole	8	16	0.27	96	1.6	995	1315	1445	93.9	24	95	99.1	98.9	4.7
151	Bole area															
118	Bole Mini Bus Terminal	Bole	7	14	0.23	84	1.4	980	1330	1455	94	25	95	99.2	99	4.8
119	Gerji Bus Terminal	Bole	9	18	0.3	108	1.8	1005	1300	1435	93.7	24	95	99.1	98.9	4.7
120	Friendship Park Entrance	Bole	7	14	0.23	84	1.4	975	1340	1460	94.1	25	96	99.2	99	4.8
121	Kazanchis Tower Area	Kirkos	5	10	0.17	60	1	920	1345	1470	94.2	25	95	99.2	99	4.8
122	ECA Roundabout	Kirkos	5	10	0.17	60	1	930	1335	1465	94.1	25	95	99.2	99	4.8

123	Sidist Kilo University Gate	Arada	4	8	0.13	48	0.8	915	1345	1475	94.3	25	96	99.2	99	4.9
124	Arat Kilo Government District	Arada	3	6	0.1	36	0.6	905	1350	1480	94.4	26	96	99.3	99.1	4.9
125	National Museum Area	Arada	4	8	0.13	48	0.8	915	1340	1470	94.2	25	95	99.2	99	4.8
126	Merkato Textile Market	Addis Ketema	5	10	0.17	60	1	950	1345	1475	94.2	25	95	99.2	99	4.8
127	Addis Ketema Bus Station	Addis Ketema	5	10	0.17	60	1	955	1335	1465	94	24	95	99.1	98.9	4.7
128	Kera Transport Hub	Addis Ketema	4	8	0.13	48	0.8	960	1330	1460	93.9	24	94	99.1	98.9	4.7
129	Jemo Market Center	Nifas Silk-Lafto	11	22	0.37	132	2.2	1040	1270	1400	92.9	22	93	98.8	98.6	4.5
130	Lafto Industrial Area	Nifas Silk-Lafto	12	24	0.4	144	2.4	1050	1260	1390	92.8	22	93	98.8	98.6	4.5

131	Lideta Bus Terminal	Lideta	6	12	0.2	72	1.2	960	1325	1455	94	24	94	99.1	98.9	4.7
132	Balcha Hospital Square	Lideta	5	10	0.17	60	1	945	1330	1460	94.1	24	95	99.1	98.9	4.7
133	German Square North	Lideta	6	12	0.2	72	1.2	955	1320	1450	94	24	94	99	98.8	4.7
134	Bethel Residential Area	Kolfe Keranio	9	18	0.3	108	1.8	1015	1280	1410	93.3	23	94	98.9	98.7	4.6
135	Kolfe Transport Hub	Kolfe Keranio	10	20	0.33	120	2	1030	1270	1400	93	22	93	98.8	98.6	4.5
136	Tor Hailoch Bus Terminal	Kolfe Keranio	8	16	0.27	96	1.6	1005	1290	1420	93.4	23	94	98.9	98.7	4.6
137	Ayer Tena Transport Hub	Kolfe Keranio	7	14	0.23	84	1.4	995	1300	1430	93.5	23	94	98.9	98.7	4.6
138	Summit Residential Zone	Lemi Kura	15	30	0.5	180	3	1065	1255	1390	93	22	93	98.8	98.6	4.5
139	CMC Commercial Area	Lemi Kura	13	26	0.43	156	2.6	1045	1275	1405	93.2	23	94	98.9	98.7	4.6

140	Ayat Business Center	Lemi Kura	14	28	0.47	168	2.8	1055	1265	1395	93.1	23	94	98.9	98.7	4.6
141	Furi Industrial Area	Akaky Kaliti	23	46	0.77	276	4.6	1365	1120	1285	89.4	15	88	98	97.8	3.9
142	Akaki Logistics Terminal	Akaky Kaliti	21	42	0.7	252	4.2	1330	1160	1305	90.2	16	89	98.2	98	4
143	Yeka Hills Residential	Yeka	19	38	0.63	228	3.8	1275	1195	1335	91.1	18	90	98.4	98.2	4.1
144	Kotebe University Area	Yeka	11	22	0.37	132	2.2	1045	1280	1410	93.2	23	94	98.9	98.7	4.6
145	Gullele Cultural Market	Gullele	12	24	0.4	144	2.4	1115	1250	1380	92.5	21	92	98.7	98.5	4.5
146	Gerji Commercial	Bole	9	18	0.3	108	1.8	1010	1300	1430	93.6	24	95	99	98.8	4.7
147	Kazanchis Business Park	Kirkos	5	10	0.17	60	1	925	1335	1465	94.1	25	95	99.2	99	4.9
148	Arada Cultural Center	Arada	4	8	0.13	48	0.8	915	1340	1470	94.2	25	95	99.2	99	4.9
149	Merkato Main Transport	Addis Kete	5	10	0.17	60	1	950	1345	1475	94.2	25	95	99.2	99	4.9

		ma														
150	Summit Bus Terminal	Lemi Kura	16	32	0.53	192	3.2	1070	1245	1380	92.8	22	93	98.8	98.6	4.5
Total			1530	3060	51	18360	306	157240	191860	211775	93.07	22.4	93.44666667	98.878666667	98.87866667	4.564