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DEPARTMENT OF INFRASTRUCTURE AND TECHNOLOGY MANAGEMENT

LEVERAGING INTELLIGENT DIGITAL SOLUTIONS TO MITIGATE CHALLENGES IN ROAD INFRASTRUCTURE ASSET MANAGEMENT: LESSONS FROM ADDIS ABABA CORRIDOR DEVELOPMENT PROJECTS

A Thesis submitted to the Department of Infrastructure and Technology Management for the partial fulfilment of the requirements for the Master of Science in Construction Management

BY

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DECLARATION

Herein, I affirm that the study has been composed entirely by me and has not been used to seek any other academic award in any other educational institution. All sources cited herein adhere completely to the rules set forth by Addis Ababa University.

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CONFIRMATION

The study undertaken by Shimelis Muleta Hora in a study entitled "Leveraging Intelligent Digital Solutions To Mitigate Challenges In Road Infrastructure Asset Management: Lessons From Addis Ababa Corridor Development Projects" was supervised by us and presented for examination as part of the submission of the requirements for the award of the Master of Science in Construction Management.

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CERTIFICATION

This is to certify that the dissertation prepared by Shimelis Muleta titled "Leveraging Intelligent Digital Solutions To Mitigate Challenges In Road Infrastructure Asset Management: Lessons From Addis Ababa Corridor Development Projects " and submitted for the Master of Science degree in Construction Management adheres to the university's regulations and meets the required standards.

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ABSTRACT

In recent times, the Construction industry has graduated from the old industrial age into the current digital age. The integration of an integrated Architecture, Engineering, Construction, and Operations (AECO) system is one way that the Construction industry has transformed into the digital age. However, there have been challenges in integrating the new technologies, especially in Road Infrastructure Asset Management (RIAM). In order to bridge some of these challenges and make Road Infrastructure Asset Management in Addis Ababa City Roads Authority (AACRA) more modernized, a more effective use of digital technology is critical. For this purpose, this study uses an explanatory sequential mixed methods design in two important corridors with the use of questionnaires (n=40), interviews, focus group discussions, field observation, and literature review. The results indicate that RIAM practice in Addis Ababa City Roads Authority (AACRA) and Ethiopian Roads Administration (ERA) is mainly reactive and paper-based in nature; 75% update rarely, 85% depend on manual operation, while 87.5% face difficulties in ensuring data accuracy. While 87.5% are aware of the latest technologies, such as artificial intelligence (AI), internet of things (IoT), digital twins (DT), and building information model (BIM), their practical implementation is minimal, with only basic GIS/GPS use. Major challenges in implementing the latest technologies include a lack of technical knowledge (95%), poor regulatory support (87.5%), and poor interagency collaboration (80%). Although there are many barriers to implementing the Integrated Intelligent Digital Solution for Road Infrastructure Asset Management (IDS-RIAM) framework, interviewed finding remains optimistic about digitalization and its ability to facilitate better decision-making and asset longevity. The combination of digital tools makes the IDS-RIAM an innovative system that allows cloud based asset monitoring and maintenance. Recognizing that the framework is merely theoretical and that technology has certain limitations now, the current research endorses a systematic process for implementation, which should involve policy changes and capacity building. For further research, it is recommended to test the framework through pilot projects and evaluate cost-effectiveness and environmental benefits.

Keywords: Intelligent Digital Solutions, Road Infrastructure Asset Management, Corridor Development, Framework, Digital Technologies.

Table of Contents

Table of List

List of Figures

List of Abbreviations & Acronyms

AACAESA: Addis Ababa City Administration Electric Services Authority

AACDP: Addis Ababa Corridor Development Project

AACRA: Addis Ababa City Roads Authority

AADCWB: Addis Ababa Design and Construction Works Bureau

AECO: Architecture, Engineering, Construction, and Operations

AI: Artificial Intelligence

BIM: Building Information

BMS: Bridge Management System

DGPS: Differential Global Positioning System

DT: Digital Twin

EEC: Ethiopian Engineering Corporation

ERA: Ethiopian Roads Administration

GIS: Geographic Information Systems

GPS: Global Positioning System

ICRAMS: Integrated Central Road Asset Management System

IDS-RIAM: Integrated Intelligent Digital Solution for Road Infrastructure Asset Management

IoT: Internet of Things

ITS: Intelligent Transportation Systems

LASA: Lea Associates South Asia

MAVI: Mobile Applications for Visual Inspection

PMS: Pavement Management System

RAM: Road Asset Management

RIAMS: Road Infrastructure Asset Management System

TIAMS: Transport Infrastructure Asset Management System

TRANSIP: Transport Systems Improvement Project

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Road infrastructure forms the fundamental framework of transportation networks, serving as a backbone for economic vitality, access to essential destinations, and delivery of vital services. Research indicates that Addis Ababa is experiencing significant population growth, which will necessitate additional infrastructure development, and there is a need for efficient infrastructure (JICA 2023; OECD 2000). Proper road infrastructure asset management (RIAM) is crucial to ensuring the long-term efficiency, safety, and sustainability of the road network. It provides an efficient mechanism that can plan, design, operate, maintain, and conserve infrastructure through effective and efficient use of finances and technology (Gerardo and Bryant 2006). However, most developing cities lack RIAM that can cope with the increasing complexities of congested networks.

The country of Ethiopia is undergoing a revolution, which combines economic reforms with institutional improvements and greater attention to technological advancements. The Digital Ethiopia 2030 Strategy is an example of a national strategy that demonstrates how the use of digital methods can help improve productivity, enhance service delivery, and improve urban governance (Abiy 2024; Mugnier & Cliff 2025). In such a context, the importance of intelligent asset management systems has increased as valuable tools that can help improve infrastructure efficiency and inform evidence based decision-making processes (Attencia and Mattos 2022).

The Ethiopian capital of Addis Ababa faces growing urban issues, including congestion, degradation of the environment, deteriorating road and utility networks, and an inability to maintain infrastructure development. The problem is exacerbated by the lack of a component that will allow the implementation of intelligent, technology based road asset management (Jelalu and Taylor, 2024). To address this issue, Addis Ababa introduced the Addis Ababa Corridor Development Projects, which represent an extensive initiative for infrastructure development in accordance with the structure plan and objectives for building a smart city. Although these projects have helped improve mobility and urban operations, their future sustainability is uncertain without proper asset management.

According to recent studies, the approach to road asset management used by the country is highly dependent on manual methods such as HDM-4 and ERAMS, with very little effort made to implement automated solutions or use artificial intelligence techniques (Tadesse 2025). On the city level, the Addis Ababa City Roads Authority encounters numerous difficulties, including incomplete condition analysis, lack of cooperation between relevant organizations, and insufficient technical expertise (Bihon 2017; Girma and Mulatu 2025; Tadesse 2025).

The evolution of digital techniques such as GIS, BIM, IoT, and AI technology presents tangible opportunities for improving the management of road assets. This includes accurate assessment of the state, real time monitoring, prediction of maintenance requirements, and more rational decision-making during all stages of the asset lifecycle (Gheorghe and Soica 2025; Taheri and Sobanjo 2024). Despite their demonstrated success worldwide, however, the implementation of these techniques has not yet become common practice in Ethiopian urban road projects.

Considering this situation, the present research will examine the potential of intelligent digital systems in addressing existing challenges in Road Infrastructure Asset Management, taking the Addis Ababa corridor developments as an example. The goal is to minimize the discrepancy between world standards and their application by proposing a cost-effective, and sustainable digital asset management approach for Ethiopia.

1.2 Statement of the Problem

The significant expansion of transport infrastructure in Addis Ababa is a key enabler for the smart city initiative. To achieve this, the Addis Ababa City Government has made massive investments in transport infrastructure, such as the Addis Ababa Corridor Development Projects, with over ETB 20 billion invested in Phase I to multimodal corridors with new and overlay asphalt roads, colored cycle paths, stamped concrete sidewalks, pedestrian infrastructure, utilities, underpasses, smart lighting, public parks, and EV charging stations as part of its smart city initiative (Girma and Mulatu 2025; Sahle et al. 2025). However, despite the huge investment, the road infrastructure asset management is not exempt from systemic problems arising from fragmented systems, traditional, reactive, and outdated approaches to maintenance, and a lack of adoption of new technology.

The existing literature emphasizes the existence of large gaps in the prevailing Road Infrastructure Asset Management (RIAM) processes. For example, the empirical findings presented by (Bihon 2017) indicate that the AACRA’s asset management process is poor, with condition assessment at only 45.5%, and technologies are still in the planning stage. Addis Ababa City Road Authority (AACRA) faces technical, financial, and technological limitations. However, this research primarily concentrates on asphalt pavement and drainage and does not properly cover the latest smart corridor features like colored cycle lanes, stamped concrete sidewalks, smart street lighting, and EV charging points, nor do they take into account the latest digital technologies in RIAM. This creates an important research gap about how smart digital solutions can be used to systematically solve the complicated, multi-asset corridor developments that are currently being put into place.

Similarly, (Tadesse 2025) also conducted a research study on the Ethiopian Roads Administration (ERA) that still relies on manual data collection and the limited use of ERAMS and HDM-4, which hinders proactive maintenance and evidence-based decision-making that was limited to professional staff, excluding strategic decision makers such as CEOs and Asset Directors, and did not thoroughly examine the role of digitalization in RIAM. As a result, previous research studies, such as (Bihon 2017; Feyisa 2019; Tadesse 2025), show a research gap because they did not conduct research on the role of leveraging and digitalizing RIAM, which requires a thorough examination of these dynamic clusters.

However, it is also observed that the literature on a global scale and on a local scale indicates that the adoption of technologies such as GIS, IoT, AI, BIM, Digital Twins, and cloud based technologies has the potential to make a significant impact in the area of monitoring, predictive maintenance, lifecycle optimization, and data driven governance, but the adoption of these technologies in Addis Ababa is affected by the lack of centralized data systems, the absence of an integrated technology driven Road Infrastructure Asset Management System a lack of skills, budgetary limitations, and a poor regulatory and institutional framework (Girma and Mulatu 2025; Sahle et al. 2025).

According to literature, the current challenges can be addressed by the use of GIS, IoT, and AI, which can enable better monitoring and predictive abilities. Nevertheless, their use is still hindered by substantial challenges, such as technological constraints, cost, and human resources (Tadesse 2025). These are further exacerbated by the absence of data systems and human resources in AACRA (Bihon 2017). Inadequate asset management has already increased expenditures, and inefficient approaches may potentially decrease the life of infrastructure by as much as 40% (Buckner et al. 2016; JICA 2018; World Bank Group 2021). RIAM has moved from manual and response based approaches to proactive and data informed approaches using technologies such as Digital Twins (DT), Artificial Intelligence (AI), Internet of Things (IoT), Building Information Modelling (BIM), and cloud computing worldwide (Aktan, Bartoli, and Karaman 2019; Attencia and Mattos 2022; Caldera et al 2021).

Thus, the core problem that this thesis aims to solve is the lack of an integrated intelligent digital asset management solution that can facilitate the efficient, predictive, and sustainable management of Addis Ababa's corridor developments. The research aims to explore the existing RIAM shortcomings, evaluate the feasibility of intelligent digital technology, and develop a feasible Integrated Intelligent Digital Solution for Road Infrastructure Asset Management (IDS-RIAM) for AACRA, ERA, and other related stakeholders, thus ensuring that the practice in Addis Ababa is in line with the best practice worldwide while taking into consideration the institutional, financial, and technological constraints of Addis Ababa (Bihon 2017; Caldera et al. 2021; Nnaji et al. 2023; Tadesse 2025).

1.3 Research Questions

1. What are the current practices and challenges in road infrastructure asset management practices within Addis Ababa's Corridor Development Project?
2. What digital solutions can be leveraged to mitigate these identified challenges?
3. How can an Integrated Intelligent Digital Solution Framework (IDS-RIAM) be developed and applied to enhance efficiency, accuracy, and sustainability in road infrastructure asset management?

1.4 Research Objectives

1.4.1 General Objective

The general objective of this study is to assess the contribution of intelligent digital solutions (IDS) for road infrastructure asset management (RIAM) and develop a framework based on lessons from the Addis Ababa Corridor Development Project.

1.4.2 Specific Objectives

- ❖ To analyze current practices and challenges in RIAM for the Addis Ababa Corridor Development Project.
- ❖ To assess the contributions of intelligent digital solutions and advanced RIAM technologies that provide solutions to address existing gaps and challenges.
- ❖ To develop a comprehensive, technology-based road infrastructure asset management framework to scope.

1.5 Scope of the Study

1.5.1 Thematic Scope

This research identifies the current state of affairs related to RIAM in AACRA and ERA, including issues relating to the availability of relevant data and its maintenance, the inadequacy of the current infrastructure, problems in managing the data, lack of coordination in these areas, and others. This research analyzes the viability of using intelligent digital technology solutions such as IoT, GIS, BIM, AI, and Digital Twins.

1.5.2 Spatial Scope

This research will address asset management of road infrastructure in Addis Ababa for the development of corridor roads, namely Bole Airport-Megenagna/Diaspora Square and Mexico-Sarbet-Gotera-Wollo Sefer Corridors. The assets include pavements, bicycle paths, sidewalks, drainage systems, curbs, intelligent lighting systems, and utilities. It is conducted under the auspices of AACRA, ERA, and other relevant city administration bodies.

1.5.3 Temporal Scope

This study will employ a sequential mixed method research design to analyze data from questionnaires, interview records, focus group discussions, observations, and documents related to the concerned stakeholders. This study is carried out in order to examine the deficiencies in RIAM, its feasibility in terms of the adoption of digital technologies, and the development of IDS-RIAM under the circumstances of Corridor Development Projects.

1.6 Significance of the Study

1.6.1 To the Construction Industry

This research provides useful recommendations to both AACRA and ERA in relation to road asset management. The research makes a significant contribution towards RIAM in Addis Ababa since it improves efficiency in terms of infrastructure via the adoption of smart digital tools. The research will help the industry move from manual to data-driven systems.

1.6.2 To Road Sector

This research provides data-driven guidance to decision-makers on critical RIAM problems by incorporating digital road infrastructure asset management tools within each stage of the asset management cycle. The proposed IDS-RIAM framework gives AACRA and ERA a customized, actionable roadmap for adopting cloud-based, real-time monitoring technologies across Addis Ababa's Corridor Development Projects. In particular, the proposal of a cloud-based RIAMS that includes artificial intelligence, geographic information systems, Internet of Things, and UAVs helps the agencies involved take necessary action.

1.6.3 To Scientific Community

The study contributes to scientific literature by proposing a framework of technology adoption factors in the asset management process of the road infrastructure of Addis Ababa. The study addresses an empirical gap in Sub-Saharan urban infrastructure studies through a replicable IDS-RIAM model based on mixed methods evidence drawn from real corridor development projects.

1.7 Limitations of the Study

This study focuses on intelligent digital solutions for road asset management in Addis Ababa’s Corridor Development projects, and assesses intelligent digital technologies for road asset management in the Addis Ababa Corridor Development projects. However, certain issues emerge because there is no previous knowledge about using such technologies in Ethiopia, thereby restricting the ability to collect more experience from the implementations. Moreover, there is inadequate time to conduct more research that is extensive.

1.8 Structure of the Document

The study comprises individual chapters, which are as follows:

Chapter One: Introduction. The introductory chapter introduces the research topic by discussing the introduction, background, statement of the problem, objectives, research questions, scope, and significance of the study.

Chapter Two: Literature Review. The chapter analyzes the concepts, theories, and empirical developments made in the domain of intelligent digital technology in relation to road asset management. It also highlights current best practices associated with intelligent digital technology, focusing especially on the Addis Ababa Corridor Development Project.

Chapter Three: Methodology: This chapter describes the research methodology and provides insight into the data sources.

Chapter Four: Results and Discussion: This chapter presents and discusses findings from data analysis on Intelligent Digital Solutions for mitigating challenges in road asset management.

Chapter Five: Conclusion and Recommendation: This chapter outlines key findings, conclusions, recommendations, frameworks, organizational structure, and future research areas.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, a review of current literature on intelligent digital technology in the context of RIAM in the growing city of Addis Ababa is presented. Theoretical and empirical literature will be considered, drawing both internationally and locally, to determine opportunities and challenges in using AI, GIS, GPS, BIM, IoT, and digital twins in the RIAM context of Addis Ababa. This chapter will, therefore, provide the basis upon which a context-specific RIAM framework can be recommended for the Addis Ababa Corridor Development Project.

2.2 Conceptual and Theoretical Review

2.2.1 Definition

The definition of RIAM is well described in the literature as a process aimed at managing the assets of road infrastructure in an efficient and sustainable manner. According to American Association of State Highway and Transportation Officials (AASHTO 2020), as well as (FHWA 2020), RIAM is defined as a strategic management of physical assets using engineering concepts and principles of business. For instance, according to European Union Road Federation, RIAM includes collecting data on roads, conducting condition assessment of roads, and creating plans for maintenance of assets (Rao, Sri P Ravinder 2025). The same way, (OECD 2000). OECD (2000) describes RIAM as a strategic and iterative approach that combines engineering logic with societal expectations. Overall, RIAM can be viewed as an umbrella concept that encompasses all activities required for efficient management of transportation infrastructure assets throughout their entire lifecycle (Collins et al. 2021).

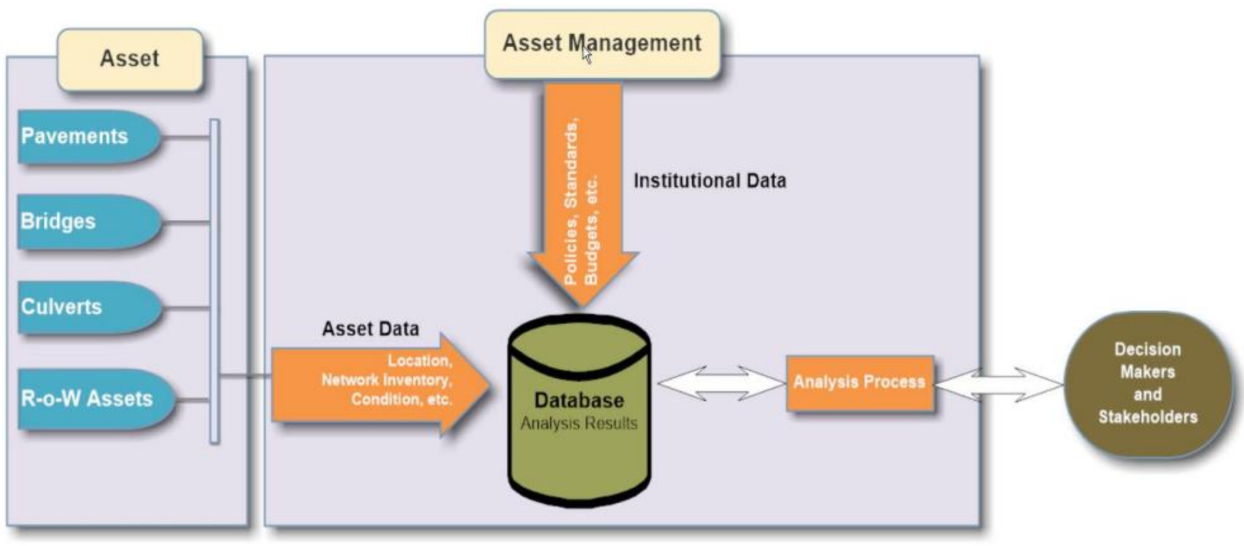


Figure 2-1: Existing Flow of Data in an Asset Management System in AACRA

According to the asset management of social infrastructure, originating in the US in the 1980s to address infrastructure deterioration, it involves systematic and strategic management to maintain and enhance public assets. Road asset management a subset, focuses on roads, bridges, and related structures, aiming to minimize life cycle costs through assessing conditions, predicting degradation, and timing repairs strategically (FHWA 2020; ISO 55000:2024 2024).

The process of road asset management comprises three broad areas:

i. **Reactive maintenance:** The day today monitoring of network condition, ensuring there are no immediate safety hazards on the network

ii. **Planned maintenance:** Measuring network condition over the entire network and planning what areas and repairs to complete

iii. **Managing network inventory**: Assessing and repairing other road assets such as signs, barriers, bollards, and manhole covers

2.2.2 Classification of Road Infrastructure Asset Management

RIAM can be broadly classified into two paradigms: Traditional and Advanced Technological (FHWA 2020; ISO 55000:2024 2024).

1. **Traditional RIAM** relies on manual inspections and reactive repairs, responding to problems only after they emerge. This approach is labor-intensive, error-prone, and costly, resulting in operational inefficiency and accelerated asset degradation (Caldera et al 2021; United Nations 2021). It treats asset management in isolated phases, lacking cross-lifecycle information integration (Huang et al. 2025). Multiple scholars confirm that reactive, manual approaches are increasingly inadequate for modern urban road networks (Feyisa 2019; OECD 2000; Semunigus 2017; Taheri and Sobanjo 2024).

2. **Advanced Technological RIAM**, by contrast, employs computerized systems that integrate data capture, asset inventory, condition inspection, traffic monitoring, and maintenance scheduling. Technologies such as AI, IoT, GIS, BIM, and Digital Twins enable predictive, evidence-based management, substantially improving the efficiency and effectiveness of road asset stewardship (Biswas and Wright 2022; Buckner et al. 2016; Taheri and Sobanjo 2024). Recent scholarship advocates a four-tier framework covering data, governance, integration, and application to ensure full interoperability across digital systems and overcome fragmentation in administrative and maintenance processes (Huang et al. 2025).

2.2.3 Benefits of Intelligent Digital Technologies in Road Asset Management

Intelligent digital technologies including AI, ML, IoT sensors, Digital Twins, GIS, and advanced analytics deliver several compounding benefits for urban road asset management:

➢ Accurate, continuous condition assessment and monitoring (Attencia and Mattos 2022).

➢ Optimized maintenance planning and resource prioritization (Caldera et al. 2021)

➢ Predictive maintenance and early fault detection through AI and analytics (Zhong et al. 2023; Zhou et al. 2024)

➢ Real-time structural and traffic data from embedded sensors

➢ Improved decision-making through GIS-integrated, data-driven analytics (Cepa et al. 2023; Collins et al. 2021).

➢ Dynamic modeling of road networks via Digital Twins and GIS, supporting long-term scenario planning and stakeholder collaboration (Huang et al. 2025).

2.2.4 Road Asset Management Components

The road inventory is critical in any asset management strategy since it provides an all-encompassing database that captures physical assets such as pavements, traffic signs, culverts, guardrails, and road lighting systems for purposes of compliance, budgeting, repairs, improved safety, and tracking of deterioration. The RIAM framework consists of six interlinked layers, namely:

1. **Data Acquisition Layer:** Sensors, LiDAR, UAVs, and mobile images allow health monitoring and highly accurate corridor mapping (FHWA 2022; Journal 2025; Taheri and Sobanjo 2024).

2. **Data Processing and Analysis Layer:** AI and ML software processes raw data and provides insights using computer vision, deterioration predictions, and structure anomalies detection (SaThierbach et al. 2015).

3. **Geospatial Layer:** The GIS system spatially references all assets, integrates the environmental hazards and traffic information, and aids in corridor prioritization and team movement on-site.

4. **Digital Model Layer:** The BIM system creates 3D models of the assets with metadata, while Digital Twin technology simulates the effects of traffic load, resilience to weather, and lifetime costs (Zhong et al. 2023).

5. Decision-Making Layer: Predictive dashboards with analytics provide predictive scheduling and risk assessment based on AI and ML models with applications like iROADS in the UK and IRAMS in India.

6. **Automation and Robotics Layer:** UAVs, robots that perform patching, and surveying vehicles increase safety by reducing the need for labor by 90% during inspections (Kaptur and Karazhanova 2021).

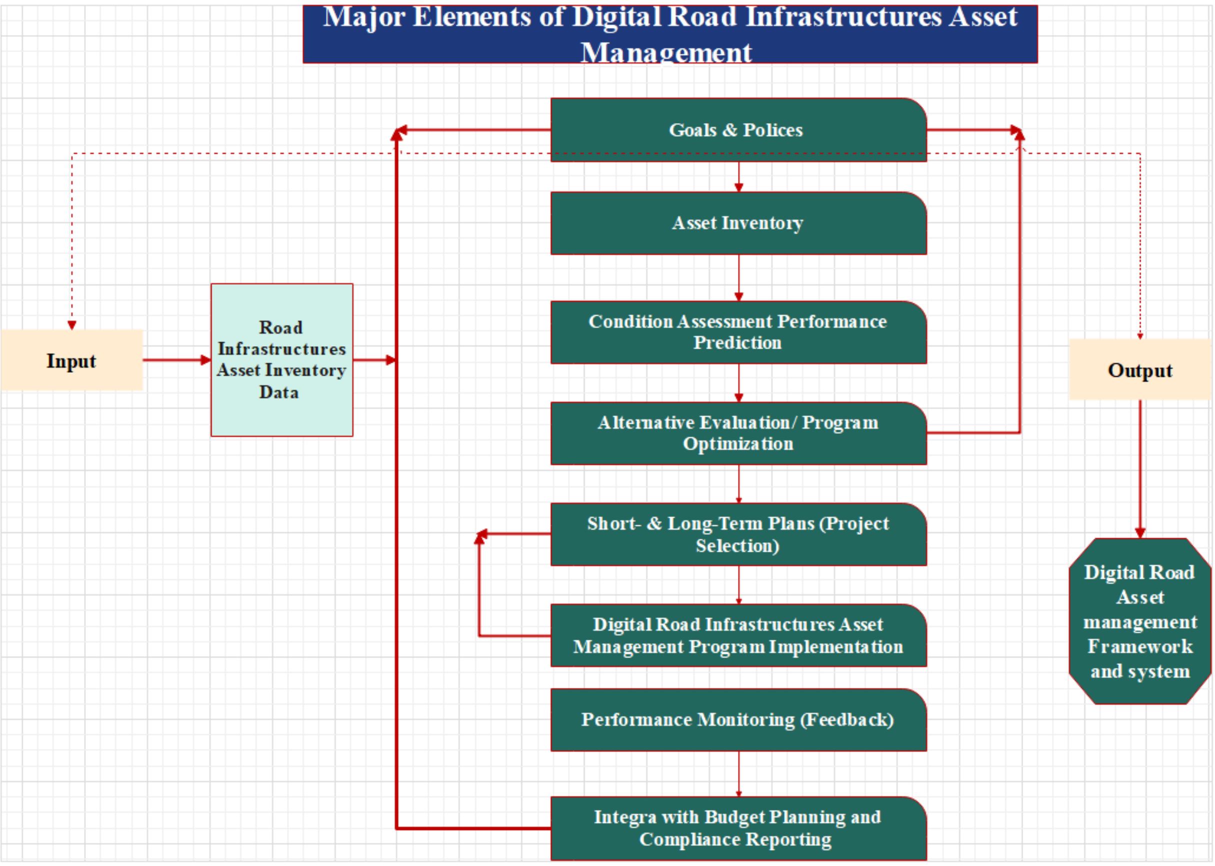


Figure 2-2: Major Elements of Digital Technologies Road Asset Management Components

2.2.5 Overview of Advanced Intelligent Digital Technologies

The increasing pace of urban development requires the use of advanced intelligent digital technologies for managing road infrastructure (Biswas and Wright 2022). In turn, digitalization, automation, and robotics allow for collecting more and different types of data on roads, which enables implementing predictive maintenance and making decisions based on such information (Consilvio et al. 2023). Below, the key technologies necessary for the discussed purposes are considered.

1. **Artificial Intelligence (AI):** AI has become an innovative solution for RIAM. Using algorithms, AI analyses datasets and finds patterns related to the deteriorated state of infrastructure, thus predicting when the infrastructure failure will occur (Huang et al. 2025; Piyush, Rajak, and K E K 2024).
2. **Internet of Things (IoT):** IoT involves the use of sensor-based technology to gather real-time data about the state of infrastructure, traffic, and other environmental aspects related to road condition. The continuous stream of such data plays an important role in the functioning of a digital RIAM model (Attencia and Mattos 2022a; Gheorghe and Soica 2025).
3. **Geographic Information Systems (GIS):** GIS allows for the spatial mapping, monitoring, and condition evaluation of road assets. When GIS is linked with the digital RIAM system, it makes the

job easier for public works workers in understanding the location of road assets, planning their interventions, and discussing maintenance issues (Gheorghe and Soica 2025; Zhang and Ji 2024).

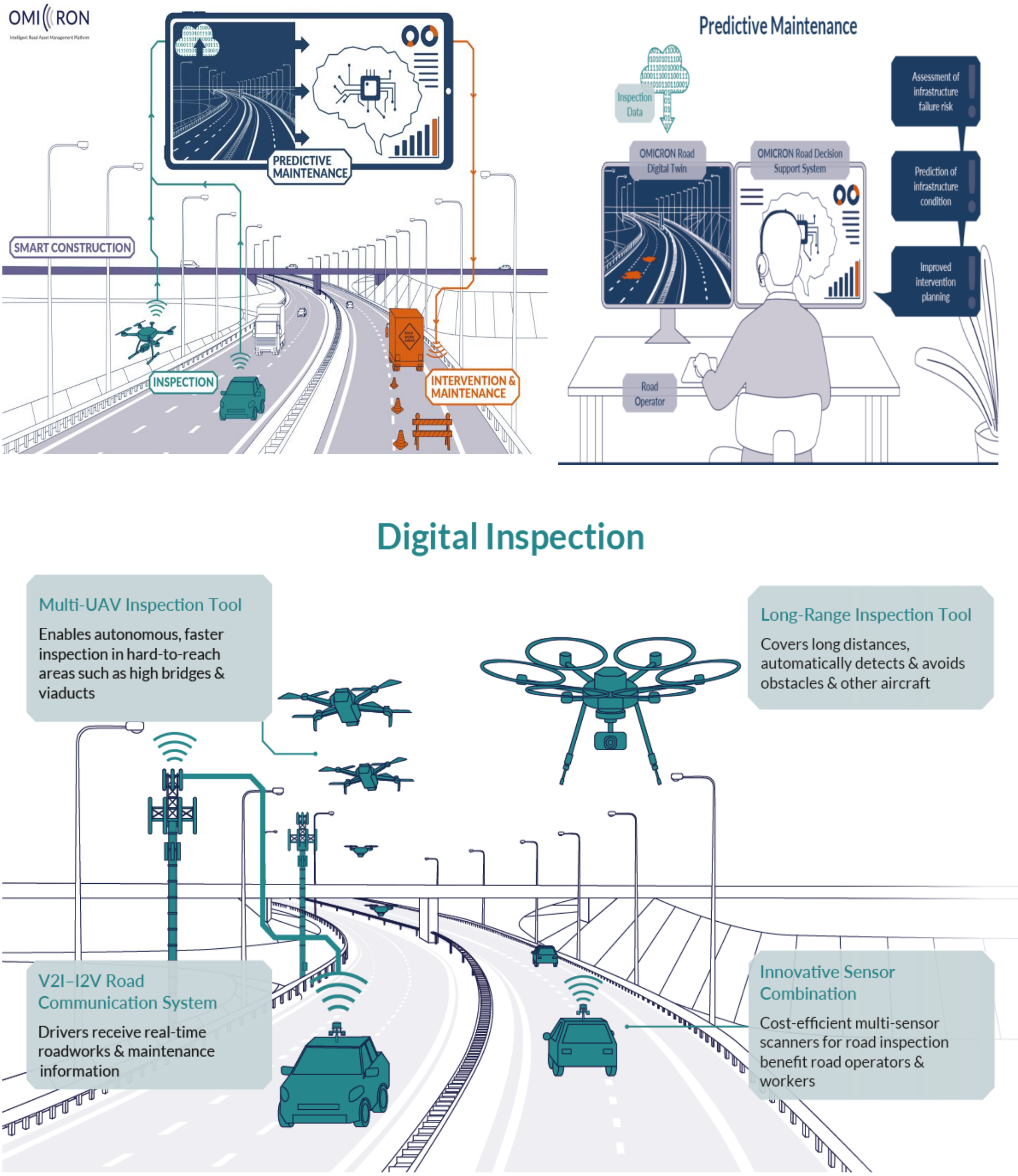


Figure 2.3: RIAM Inspection with Digital Tools for Predictive Maintenance

4. **Digital Twins (DT):** DTs are simulated models of real road assets using real-time data generated via sensors and IoT devices. DTs are constantly being updated and use data that comprises quantified data, geometry, and documents in one system. The concept of DTs is based on three ideas, which are the connection between the physical world and virtually, asset-based information management, and real-time decision making. The technology uses the collaboration of BIM, GIS, IoT, and AI to

provide predictive maintenance, full monitoring of the assets, and life cycle management (Consilvio et al. 2023; Matchett and Wium 2022)

Building Information Modeling (BIM): BIM technology helps manage assets in terms of their planning, design, and maintenance. It enables communication and exchange of information across the asset management process, leading to improved decision-making and efficiency. (Succar 2009) maturity model explains the development of BIM technology since the beginning when it was used to draft plans up to its present state as data ecosystems for life cycle assessment. Contemporary urban infrastructure projects show how effective BIM can be in connecting design and operations (Baldwin and Bordoli 2014; Zhou et al. 2024).

2.3 Empirical Review of the Literature

This study carries out an empirical review that integrates global and local research with the aim of recognizing systemic gaps within globally and locally managed RIAM practice using empirical evidence. It identifies, assesses, and evaluates evidence-based research with regard to the efficacy of intelligent digital solutions and proposes an integrated technological framework for road infrastructure asset management .

2.3.1 Empirical Analysis of the International Context

Globally, the adoption of proactive approaches in the management of road assets has been hastened by Industry 4.0 technologies. For example, in the USA and India, AI coupled with IoT sensors have resulted in up to 30% lower operational expenses(FHWA 2020; Zhong et al. 2023). In China, technologies such as BIM and Digital Twins have been used to achieve optimum lifecycle management within an urban setting, and in India, AI together with GIS has enabled the creation of IRAMS that is capable of cost-efficient pavement management(Nassereddine et al. 2025) . In Pakistan and South Africa, the application of AI to automate pavement inspections was found to be four times faster and less costly than conventional methods (Biswas and Wright 2022). In Singapore, the implementation of IoT technology helped in the reduction of congestion by 22% and in Helsinki, geospatial technology increased lifecycle tracking accuracy by 40% (Buckner et al. 2016).

Nevertheless, empirical findings suggest that there exist difficulties in the use of these technologies on a large scale, namely high capital expenditures, lack of protocols, and inadequate skilled labor forces, especially in developing countries (Biswas and Wright 2022; Buckner et al. 2016; Matchett and Wium 2022).

2.3.2 Empirical Analysis of the Ethiopian Context

Road asset management in Addis Ababa is dominated by reactive strategies, where problems are addressed only once they become visible. There is no effective condition monitoring system, data collection remains largely manual, and information systems are unreliable (Bihon 2017; Feyisa 2019;

Tadesse 2025). The consequences are severe: JICA and World Bank reports indicate that nearly 40% of Ethiopia's road maintenance budget is consumed by emergency interventions attributable to the absence of predictive strategies (JICA 2018; World Bank Group 2021)

An institutional assessment of AACRA reveals critical weaknesses condition assessment scores only 45.5%, and technology integration remains well below operational thresholds (Bihon 2017). Data fragmentation compounds the problem; GIS systems cannot communicate with financial databases, driving cost escalations in the range of 15% (Girma and Mulatu 2025; Yetnayet 2017). Meanwhile, growing urban traffic and environmental pressures further expose the inadequacy of existing systems (Feyisa 2019; Sahle et al. 2025)

Together, these findings reveal a self-reinforcing cycle of deterioration that demands urgent and coordinated action. AI-assisted defect detection combined with IoT-based structural analysis can achieve at least 90% inspection efficiency and dramatically reduce maintenance expenditure (Matchett and Wium 2022) making the adoption of a unified, web-based RIAM framework a strategic imperative for the city.

Table 2.1: Challenges and Impacts in Road Infrastructure Asset Management

Challenge	Evidence from Literature	Impact
Traditional RIAM	(Feyisa 2019) 70% of Addis Ababa's RIAM expenditures are reactive	25% higher lifecycle costs (OECD 2000)
Data Fragmentation	(Girma and Mulatu 2025) Incompatible GIS/BIM systems in A.A	Delayed delivery & cost overruns (Yetnayet 2017)
Skill Gaps	JICA (2018): <10% of RAM staff trained in digital tools	Systemic reliance on manual surveys

As illustrated in Table 2.2, road asset management in Addis Ababa faces three compounding challenges: a predominantly reactive budgeting culture consuming 70% of RAM funds and inflating costs by 25% (Feyisa 2019; OECD 2000), persistent incompatibility between GIS and BIM systems that stalls implementation, and a critically underprepared workforce where fewer than 10% of staff possess the digital skills necessary to drive meaningful technological adoption (JICA 2018) together forming a self-reinforcing cycle that demands urgent, coordinated institutional reform.

The study found that the fast paced expansion and growing environmental challenges are making the existing system unviable. Statistics indicate that following the conventional RAM approach would merely result in escalating expenses without meeting the demands of the city. A combination of AI assisted defect detection and IoT based structural analysis provides the means for scaling the process and ensuring a minimum of 90% inspection efficiency alongside optimal expenditure on maintenance (Matchett and Wium 2022). It is clear that adopting a unified web based RIAM framework is key in breaking the vicious circle of deterioration and ensuring the futureproofing of the city's infrastructure.

2.4 Global Digital Solutions for Road Infrastructure Asset Management Practices

The literature indicates that AI, IoT, GIS, BIM, ML, robotics, and Digital Twins emerge as the key drivers of 21st-century RIAM, tackling the issues of data management, institutional capability, and efficient maintenance at a global level (Taheri and Sobanjo 2024). A number of country-level applications illustrate the revolutionary capabilities of the technology mentioned.

1.United States: In the United States, there is a gradual shift toward AI-based inventories, GIS analysis, and standardized DOT procedures for conducting the required inspections. For instance, companies like RoadVision AI use AI algorithms to conduct large-scale pavement surveys for spotting imperfections on pavement (Introduction 2025). According to the FHWA, the implementation of AI-based pothole detection results in reducing the cost of inspections by 40%, whereas predictive ML increases the service life of assets and reduces maintenance costs by 20-30% (FHWA 2020; Zhong et al. 2023; Zhou et al. 2024).

Figure 2-4: AI-Driven Road Data Collection Advancements in the U.S

2. China: Road infrastructure asset management in China today is highly influenced by technological advancements in areas such as artificial intelligence (AI) and machine learning (ML). The introduction of smart technologies like AI and ML has improved Construction processes as well as road asset management, where predictive maintenance has been greatly enhanced. Through the use of deep learning algorithms on sensors' data, road projects and other processes are now autonomously managed (Zhang and Ji 2024; Zhou et al. 2024) IoT connects the road sensors, traffic systems, and vehicles for data sharing in the V2X system (Zol et al. 2024).

GIS aids in spatial risk assessment and geometry quality validation, particularly in complex landscapes, through the use of high-resolution national datasets that facilitate highways' planning

(Consilvio et al. 2023; Davis, Qian, and Zeng 2025). BIM, when paired with GIS and IoT, increases collaboration among stakeholders and manages asset lifecycles. Robotics leads the automation of Construction activities, such as laying, compacting, and paving operations, and drones conduct corridor inspections autonomously (Guo 2024; Paper 2024). Such technologies merge into CIM and digital twins for simulating the performance of assets and enhancing their maintenance resilience. However, there are issues related to data normalization and rural–urban disparity in implementing these technologies.

Figure 2-5: Autonomous Robots Road Conditions Detection powered by AI

3. India: India's NHAI capitalizes on AI, IoT, BIM, and GIS technologies via the use of tools such as IRAMS that leverage computer vision for pothole and crack detection using satellite images and iROADS for obtaining pavement, bridge, and culvert information in real-time for Kerala's Public Works Department (NHAI 2024; Piyush, Rajak, and K E K 2024). The use of digital twins in projects such as the Mumbai Pune Expressway involves integration of IoT, BIM, and AI technologies to manage tolling and schedule maintenance activities (World Bank Group 2021).

4. Japan: Japan makes use of all leading-edge digital tools in RIAM, such as HDM-4, highway planning, and management software which creates feasibility-based maintenance plans in keeping with engineering and economic criteria. HDM-4 works with asset databases and pavement management systems such as iROADS, and there is assistance available from the Road Asset Management Project (RAMP) of JICA with implementation of the tool (JICA 2018; Taheri and Sobanjo 2024).

5. United Kingdom: The UK is transforming its approach to the management of road assets in alignment with the ISO 55000 standard, adopting an approach of shifting from a reactive to a proactive approach in maintenance. AI and machine learning are employed for predicting wear and tear on infrastructure; IoT is used for monitoring structural and environmental conditions; while GIS plays a role in geographical planning using the National Street Gazetteer. BIM provides 3D digital twin models which have lowered design conflicts by 40%. The example of this can be seen in the Confirm system adopted by Highways England (Campanaro and Masic 2018; Gao 2025).

2.5 Local Digital Solutions for Road Asset Management Practices

The Road Infrastructure Asset Management in Ethiopia is under the responsibility of the Ethiopian Roads Administration (ERA) and the Addis Ababa City Roads Authority (AACRA). Both institutions are critical to the country's by ensuring the connectivity, infrastructure sustainability and socioeconomic development (Bihon 2017; Bitew 2024; Tadesse 2025). The local intelligent digital solution for AACRA and ERA are described in detail in the following section:

2.5.1 Addis Ababa City Roads Authority

AACRA employs a multi-method approach to road asset management across its all districts, combining automated pavement survey vehicles, mobile data collection applications, and conventional manual systems. Supported by JICA since 2015, current digital systems include a Pavement Management System, a Bridge Management System, a Pavement Condition Survey Vehicle (PCSV), mobile inspection applications, and the Transportation Infrastructure Asset Management System (TIAMS) (JICA 2018).

2.5.1.1 Pavement Management System

AACRA's Pavement Management System, established through the JICA technical cooperation project in 2019, processes International Roughness Index (IRI) data and crack metrics collected by the PCSV. However, its utilization remains limited. Key constraints include significant gaps in repair history data entry as maintenance is performed at night by Own Force units, often without adequate record keeping along with hardware failures in GNSS and laser sensors, and critical institutional memory loss following staff turnover (JICA 2018; Yetnayet 2017).

2.5.1.2 Bridge Management System

AACRA's Bridge Management System uses an adaptation of ERA's inventory format, but lacks a fully integrated digital database. Inspection results are stored in Excel files or hardcopy records, and advanced equipment such as bridge inspection vehicles or drones is unavailable. The BMS module within TIAMS aims to document bridge and culvert structures, defects, and condition assessments, and to support risk-based prioritization of repairs; however, it is currently considered insufficient as a standalone engineering tool (JICA 2023; Lea Associates South Asia Pvt. Ltd. 2019).

2.5.1.3 Pavement Condition Survey Vehicle

The Pavement Condition Survey Vehicle (PCSV) is AACRA's primary tool for objective road condition measurement. Procured through JICA, it is equipped with front and side cameras, a a GNSS/IMU (Global Navigation Satellite System/Internal Measurement Unit) positioning system, and a Laser Displacement Sensor (LDS) to measure longitudinal road profiles and generate IRI data. The survey workflow covers planning, calibration, field survey, data processing, and database update stages, targeting the top three road classification tiers: Regional, Primary Arterial, and Secondary Arterial Streets covering approximately 800 km of asphalt roads(JICA 2018). . The external and internal components of the Pavement Condition Survey Vehicle (PCSV) are described by below figures.

Figure 2-6: External and internal parts of the Pavement Condition Survey Vehicle

The work flow of the pavement condition survey comprises activities such as; survey plan, calibration, field survey, Data processing, DB update.

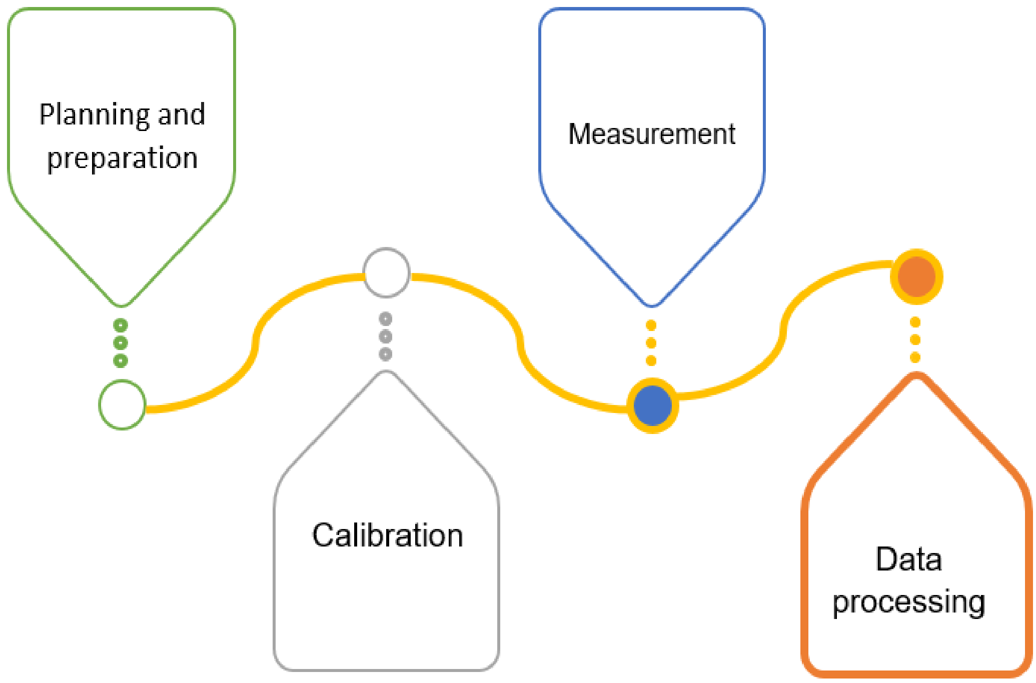


Figure 2-7: Pavement Condition Survey Vehicle Data collection process start to end

A. Planning and Preparation Process

The asphalt road of the highest three routes' hierarchy i.e. RR, PAS, SAS, was surveyed for PCSV. The plan for the survey was the higher-class asphalt road that was 800 km in length. It is worth stating that the total road lengths surveyed above were the ordinary asphalt road length in the traffic way direction. There were routes that are excluded in the survey as it is blocked for Construction and utility repair, as all the Addis Ababa road asset directorate is working according to the schedule.

B. Calibration Process

The PCSV calibration of measurement accuracy is an important reoperation required by the Pavement Condition Survey Vehicle (PCSV) so as to accurately determine all measurement values through careful device calibration. The critical initial stage of this was identified as the camera calibration (horizontal grid), wherein the ratio of captured image length measurements and actual length is altered. This particular calibration requires a no traffic zone with a flat and even surface of 15m X 10m. This particular stage begins with focusing through turning the screw and proceeding until an image is taken on the screen through the use of FV1 & FV2.

Figure 2-8: Pavement Condition Survey Vehicle PCSV Calibration process


Figure 2-9: Pavement condition survey vehicle in AACRA

C. Measurement Process

Distance Calibration /Measurement/ during measurement process Install and connect all used instrument to measure the selected length

D. Data processing steps

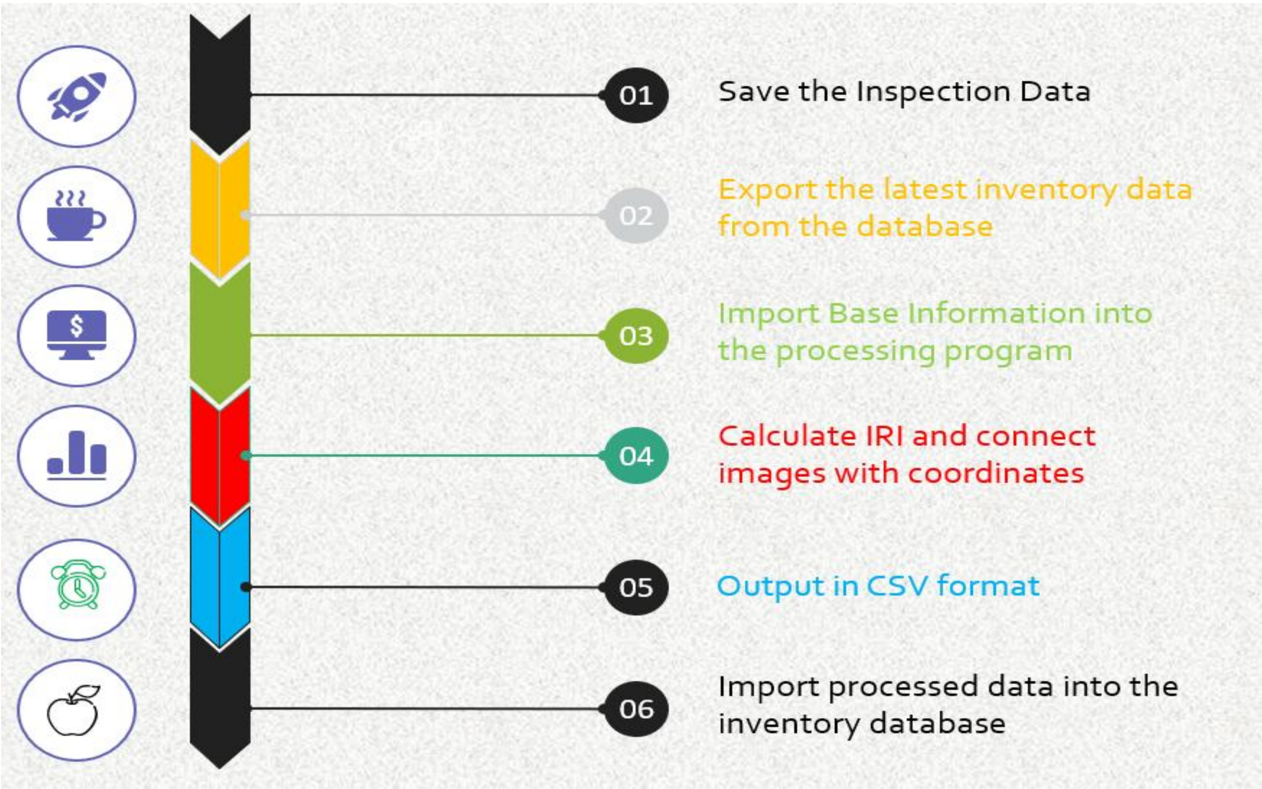


Figure 2-10: Pavement Condition Survey Vehicle Data processing steps

2.5.1.4 Mobile Applications for Visual Inspection

Road visual inspections are conducted using the Visual Inspection Support System (VISS), introduced during JICA collaboration between 2015 and 2019. The app enables field staff at all five regional offices to conduct manual inspections and record road defects visually. Despite its widespread adoption, VISS faces technical sustainability issues caused by Android OS upgrades that disrupt image display, pushing many users toward workarounds such as external camera apps and manual file linking (JICA 2023; Lea Associates South Asia Pvt. Ltd. 2019).

2.5.1.5 SW Maps free source mobile apps

AACRA also uses SW Maps, an open-source GIS mobile application, as a cost-effective field data collection tool. Complementing the Inspection Management System (IMS) module within TIAMS, SW Maps allows field inspectors and maintenance teams to identify, photograph, and geo-tag issues such as potholes and faulty streetlights in real time, with data transmitted directly to TIAMS's central server. This approach underscores AACRA's commitment to improving field-level asset data capture rapidly and economically (Lea Associates South Asia Pvt. Ltd. 2019).

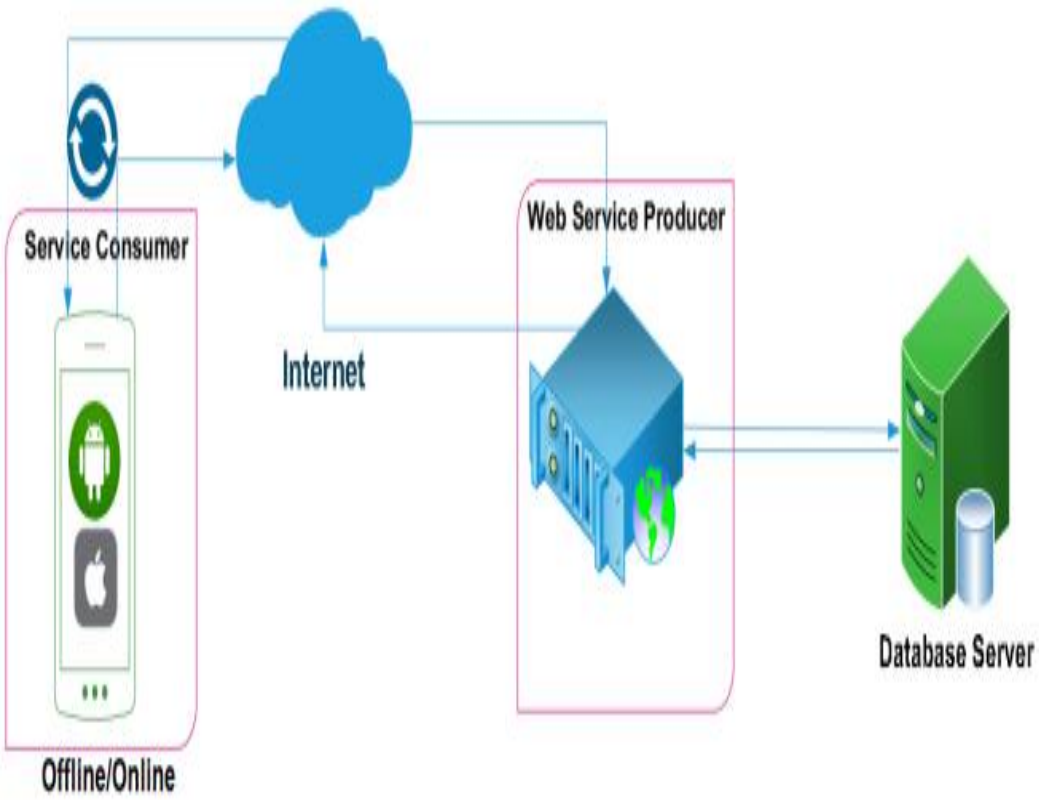


Figure 2-11: Mobile Applications for Road Asset Visual Inspection

2.5.1.6 Transportation Infrastructure Asset Management System

TIAMS represents AACRA's most ambitious digital initiative: a World Bank-supported, web-enabled system designed to unify all urban infrastructure asset modules roads (RAMS), bridges (BMS), drainage, lighting, and utilities within a single geospatial platform (JICA 2023; Lea Associates South Asia Pvt. Ltd. 2019). Developed in partnership with LASA, LEA Consulting, and UNICONE, it is built around a Spatial Database Management System supported by Differential GPS, and is intended to enable stakeholders to plan, program, and allocate funds effectively.

Despite well-defined objectives, TIAMS remains in a trial phase as of the JICA 2023 assessment, stalled by server procurement delays and technical integration failures. Existing PMS data has not been fully migrated into the system, and the BMS module lacks the cost estimation sophistication of more mature systems. These gaps make the case for a more advanced and intelligent RIAM framework even more urgent.

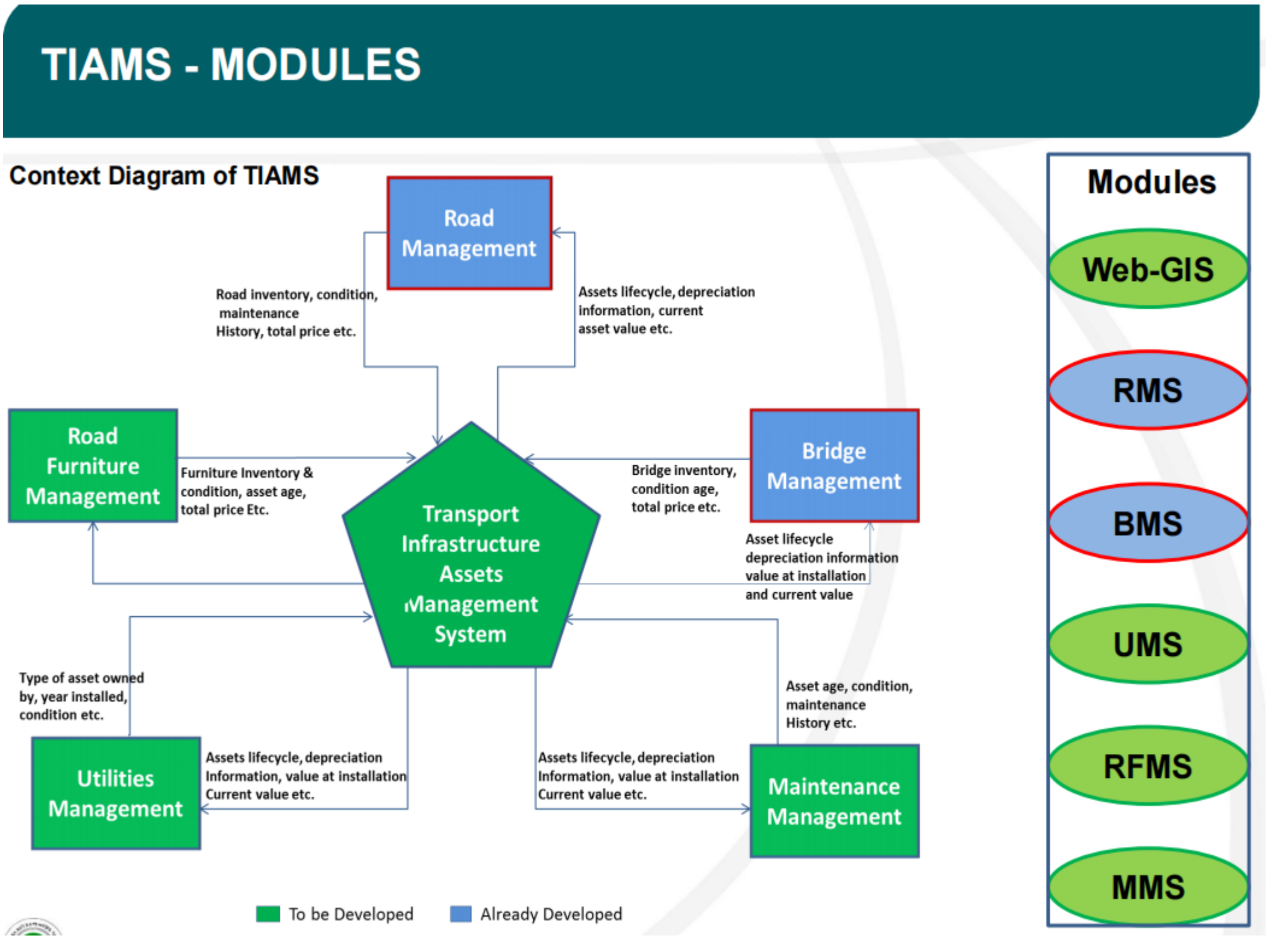


Figure 2-12: Illustration of the Context Diagram of TIAMS

The establishment of a digital central asset management system for Addis Ababa is presently critically stalled, even though there are clearly defined goals spelled out by the Addis Ababa City Roads Authority (AACRA), in association with consultants (LASA, LEA, and UNICONE). The central objective of the initiation study was the establishment and implementation of a web enabled, geospatial Transportation Infrastructure Assets Management System (TIAMS), and a Road Assets Management System (RAMS), for Addis Ababa (Lea Associates South Asia Pvt. Ltd. 2019). However, as of recent work assessment rankings made by JICA in 2023, no fully functional web based road asset management system exists in the city as of yet, as TIAMS remains in a trial phase due to numerous delays in acquiring and installing a server. Besides, the new system faces technical difficulties, as evidenced by its failure in considering the incorporation of existing data in the pavement management system, and further, the Bridge Management System module of TIAMS has been described as naive in terms of its failure to include sophisticated cost estimation and assignment of repair methods, as in more developed systems. All these pointed out an obvious need for the present study work in proposing an effective and intelligent system that can address these shortcomings. Transport Infrastructure Asset Management System (TIAMS). As a solution to such pervasive inadequacies, the concept of TIAMS was introduced, which entails a consolidated and web based system that unifies various asset modules in one database. The system is designed to offer a geographical information system (GIS) approach, whereby each individual asset has a map representation and can be analyzed through comparison with other assets. TIAMS serves as the central platform for interlinking technical and administrative modules such as RAMS, BMS, finance, and HR.

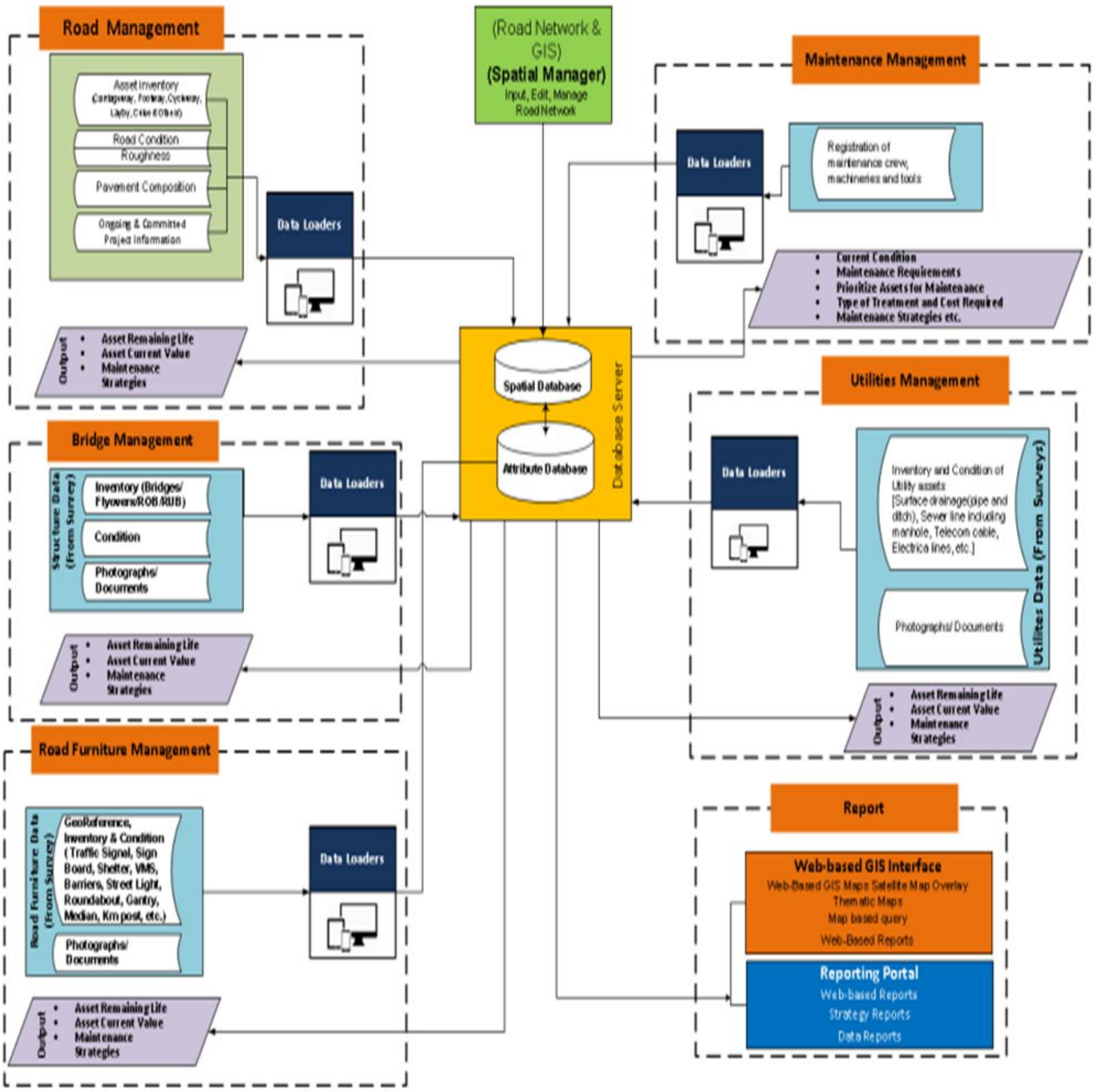


Figure 2-13: Data Flow Diagram in Transport Infrastructure Asset Management System

2.5.1.7 Conventional RIAMS and Operational Practices

Prior to the 2015 JICA project, AACRA operated under a highly fragmented RIAM model, with separate directorates managing maintenance in isolated silos and no comprehensive digital repository. The JICA initiative catalyzed organizational reform, introducing the PCSV, mobile data capture applications, and a Road Maintenance Management System (RMMS). However, severe challenges persisted: equipment failures, high staff turnover causing expertise loss, and underutilization of RMMS often confined to condition assessment without integrating repair history prevented the system from achieving a truly automated and integrated management environment (JICA 2018; Ltd. 2024).

Figure 2 -14: AACRA's Traditional Road Infrastructure Asset Registration

However, severe operational challenges were encountered in the application of these tools; these include frequent malfunctioning of respective equipment, critical loss of technical expertise due to high staff turnovers, and underutilization of the full functionalities of the RMMS often operating within the scope of road condition assessment without integrating much needed repair history, hence failing to achieve a truly automated and integrated management environment. The Road Asset Management Initiative under the AACRA is plagued by ineffective data management, inadequate institutional capacity, and lack of strategic planning (Bihon 2017; Feyisa 2019; JICA 2018)

2.5.2 Ethiopian Roads Administration

ERA employs its Integrated Road Asset Management (IRAM) system to manage national road infrastructure. The framework encompasses asset planning (prioritization by condition and financial need), asset monitoring (performance tracking against user requirements), and maintenance interventions (addressing deterioration to prolong asset life), all aligned with international standards for efficiency and value for money (Bihon 2017; Feyisa 2019).

ERA's digital toolkit includes the Road Functional Classification System (RFCS), IRAMS, the ERA-RAMS strategic tool powered by Deighton's Total Infrastructure Management System (DTIMS), HDM-4 for long-term economic analysis, GIS visualization platforms, a Pavement Management System, and a Bridge Management System. While ERA has introduced automated data collection for road conditions and axle load monitoring, integration into routine operations remains limited (Bihon 2017; Ltd. n.d.; Tadesse 2025).

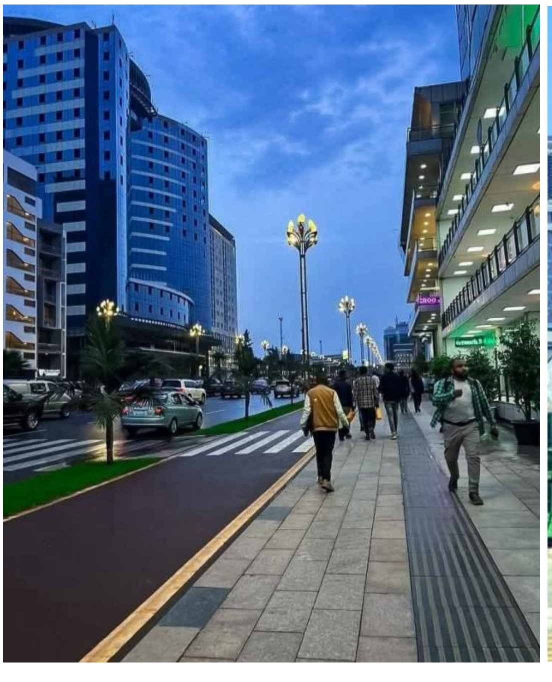
Figure 2-15: Tools and Technologies Currently Used in ERA

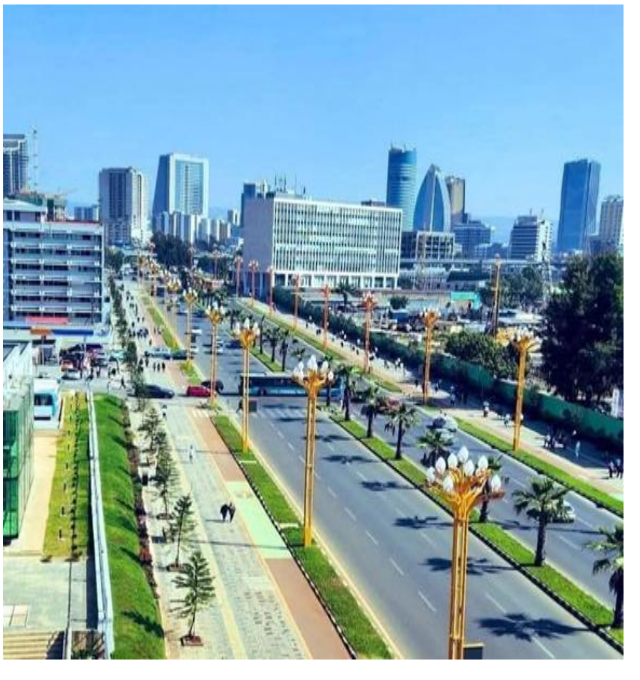
Despite these gaps, ERA and AACRA are receiving technical and financial assistance from the World Bank, AfDB, and JICA to develop digital RIAM capacities, and Ethio Telecom has recently partnered with the Ministry of Transport and Logistics to pilot digital transport sector solutions (AACPPO 2017; JICA 2018; World Bank Group 2021)

2.5.3 Comprehensive Overview of Addis Ababa Corridor Development

The Addis Ababa Corridor Development Project (AACDP) Phase I is a landmark multi-billion Birr initiative to modernize the city's transport infrastructure. With over 20 billion Ethiopian Birr invested across fifteen major projects in six sub-cities, the program encompasses earthworks, subbase and base layers, pavement works, pigmented asphalt bicycle lanes, stamped concrete walkways, underpasses, utilities, parks, and EV charging facilities (Contract Agreements 2025). Most projects have now entered the Defects Liability Period (DLP), shifting focus from construction to long-term operational performance.

Despite the scale and technical ambition of the construction phase, post-commissioning asset management frameworks remain underdeveloped. Stakeholder surveys and interviews conducted for this study reveal a critical absence of systematic data documentation, standardized asset archiving, and lifecycle management mandates issues echoed broadly in the infrastructure management literature as characteristic of the traditional approach (Girma and Mulatu 2025; Sahle et al. 2025). The disconnect between construction and digital management highlights an urgent need for an intelligent, integrated framework. This study therefore proposes the Integrated Intelligent Digital Solution for Road Infrastructure Asset Management (IDS-RIAM) as the appropriate response to AACDP's governance and operational realities (Sahle et al. 2025)(Okonge and Nyaronga 2025).





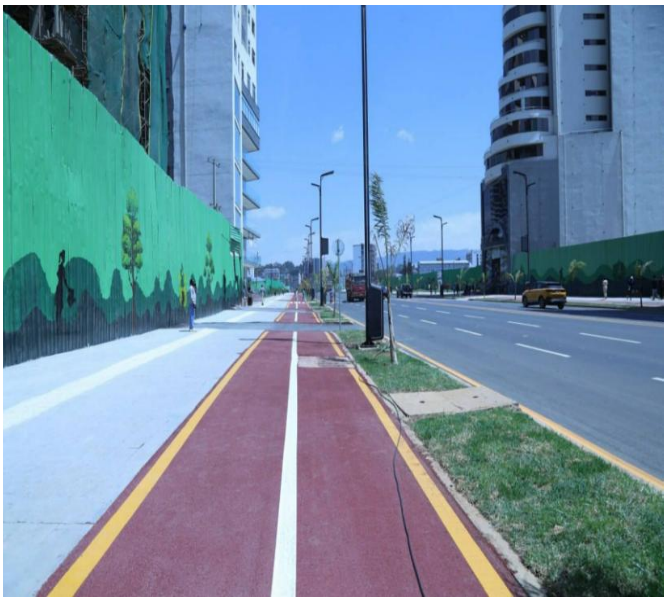


Figure 2-16: Addis Ababa Corridor Development Road Infrastructure Components

In the context of Addis Ababa Corridor development, traditional road asset management faces challenges such as a lack of integrated systems and professional capacity. Adopting intelligent digital solutions can address these gaps. Digitization enables more effective monitoring and maintenance, improves the quality of asset condition data, and supports strategic infrastructure development critical for economic growth (Bihon 2017; Tadesse 2025).

Furthermore, the Addis Ababa Corridor Development Project (AACDP) introduces modern infrastructure but lacks integrated digital solutions, such as AI, IoT, GIS, and BIM, for road asset management. This results in cost overruns and faster deterioration (Girma and Mulatu 2025; Sahle et al. 2025). To address these gaps, this study proposes an Integrated Central Road Asset Management System at a conceptual level. It integrates the capabilities of predictive analytics through artificial intelligence, real time monitoring with IoT technology, and spatial analysis using GIS technology into one comprehensive system. The system makes the transition from a reactive approach to asset management to a proactive one, thus reducing costs and improving safety.

2.6 Research Gap

While the use of AI, IoT, GIS, BIM, and DT is already mainstream in developed countries, there is little information on the use of such advanced technologies in the less resourceful environments of developing cities. While existing literature on Ethiopia highlights the limitations of RAM, including its highly manual and reactive nature, data fragmentation, and lack of comprehensive asset coverage (Bihon 2017; Girma and Mulatu 2025) no study has yet suggested and validated the need for an intelligent and holistic approach to RIAM in Addis Ababa that could address issues of data compatibility, PMS/BMS/TIAMS, and other aspects of RIAM in light of the corridor infrastructure's unique needs. Such infrastructure includes, among others, bicycle lanes, stamped pavements, and intelligent lights.

This study addresses three specific gaps: (1) mapping current RAM practices and challenges along Addis Ababa's corridors; (2) assessing the feasibility of intelligent digital solutions in the local context; and (3) proposing the IDS-RIAM framework for application in the Ethiopian city.

2.7 Summary of Literature Review

Road infrastructure asset management is essential to infrastructure safety, durability, and urban sustainability. Traditional approaches are labor-intensive, imprecise, and costly; by contrast, IoT, AI, BIM, and GIS enable real-time monitoring, preventive maintenance, and improved resource allocation addressing traffic, safety, and deterioration challenges simultaneously (Hussein and Wafik 2024; Zhang and Ji 2024).

In Ethiopia, and particularly in Addis Ababa, these technologies hold the potential to significantly reduce costs, extend asset life, and improve urban mobility. However, their adoption is constrained by limited funding, insufficient technical capacity, data incompatibility, institutional fragmentation, and policy gaps (Bihon 2017; Tadesse 2025). Poor coordination and overdependence on conventional systems amplify these barriers (Girma and Mulatu 2025; Sahle et al. 2025)

The literature converges on the need for a customized, context-sensitive framework that addresses economic, technical, and institutional barriers simultaneously especially in a city like Addis Ababa where governance fragmentation intensifies inefficiencies (Caldera et al 2021). As the review confirms, traditional RIAM is unsustainable; integrating digital tools with proven RIAM techniques is essential to empower all stakeholders and secure better outcomes for the city's rapidly expanding corridor infrastructure.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The chapter reviewed how the research focused on investigating the impact of IDS on the management of RIAM issues within the corridor developments of Addis Ababa. Mixed methodology was applied to get an overview of the research in line with the set objectives of the research. In particular, the research utilized case study methodology whereby different corridor development projects within Addis Ababa were examined.

In line with empirical studies and theories related to road infrastructure management and digitalization, the methodology helped in coming up with practical and relevant recommendations. The use of mixed methodology together with case study analysis ensured that comprehensive, valid and useful information on IDS application for addressing RIAM issues was generated. Lastly, the overall research methodology was systematic and adhered to the ethics of research hence helping in generating conclusive results for answering research questions.

3.2 Study Area

In particular, this study highlights two large road infrastructure development projects of the corridors of major significance in Addis Ababa, Ethiopia. These corridors are Bole Airport Round about Megenagna (Diaspora Square) Corridor and Mexico-Sarbet-Gotera-Wollo Sefer Corridor, each of which is approximately 5 km and 7km in length respectively.

The selection of these corridors was done based on technical and physical properties, significance of functioning, distinctness of designing, and representation of varied surroundings of the city.

Both corridors hold new Road infrastructure components such as dedicated bike lane, underpass bridges, intelligent streetlights, wide stamped concrete/granite sidewalks, and electric car charging stations. The fact that these corridors are situated in the central business district and high traffic area of the city further increases their relevance with respect to assessing contemporary approaches to road infrastructure management. This study is set within the Road Asset Management districts defined within the Addis Ababa City Roads Authority (AACRA) geography, where the AACRA oversees the urban roads through six network districts.

These identified road corridors give a fair representation of urban road infrastructure developed in Addis Ababa and are ideal for evaluating the effectiveness of current asset management and the feasibility of applying intelligent digital technology. The geographical location of the case study area in Ethiopia is shown in the figure 3.1.

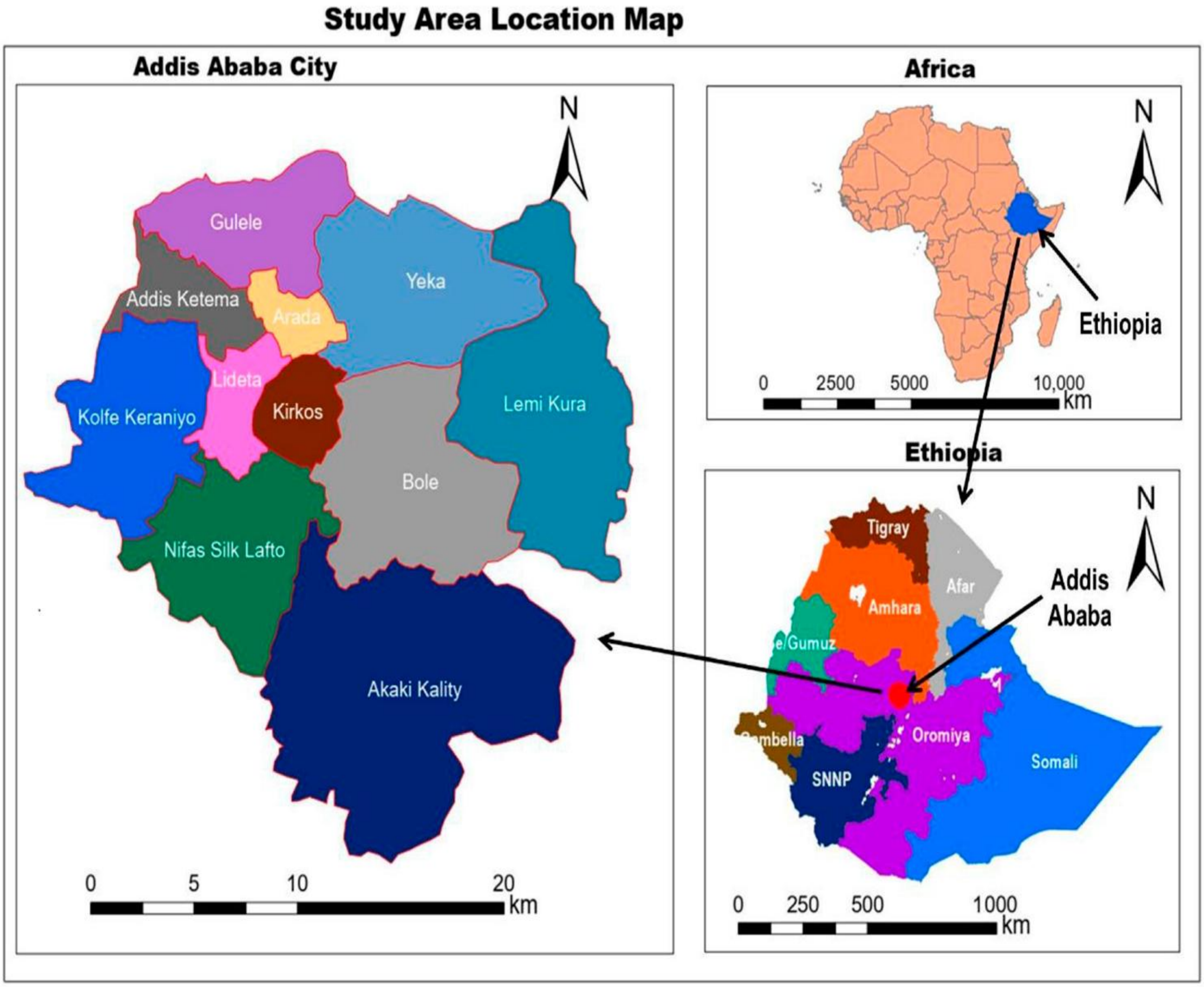


Figure 3-1:Study Area Location Map (Sources: Google Earth, Airbus 2026).

1) Bole Airport to Megenagna Diaspora Square Area Corridor Development Project

One of the most remarkable projects identified in this study is the Bole Airport Roundabout to Megenagna Diaspora Square corridor. This is due to the fact that it is a vital route that connects Bole International Airport to the business districts of Addis Ababa. This project comes under the Addis Ababa City Administration Mega Projects Construction Office. Design and supervision of this project have been done by the Ethiopian Engineering Corporation (Transport Sector), while actual Construction has been performed by China First Highway Engineering Co. Ltd. The total length of this project stretches about 5 kilometers, and it has been an asphalt concrete road. It started from June 2024 and is worth over ETB 2.72 billion.

Its transition to actual operation, through the temporary acceptance and defects liability period, is the best window to examine the challenges related to digital assets, lifecycle data management, and implementation of intelligent digital solutions within urban road asset management.

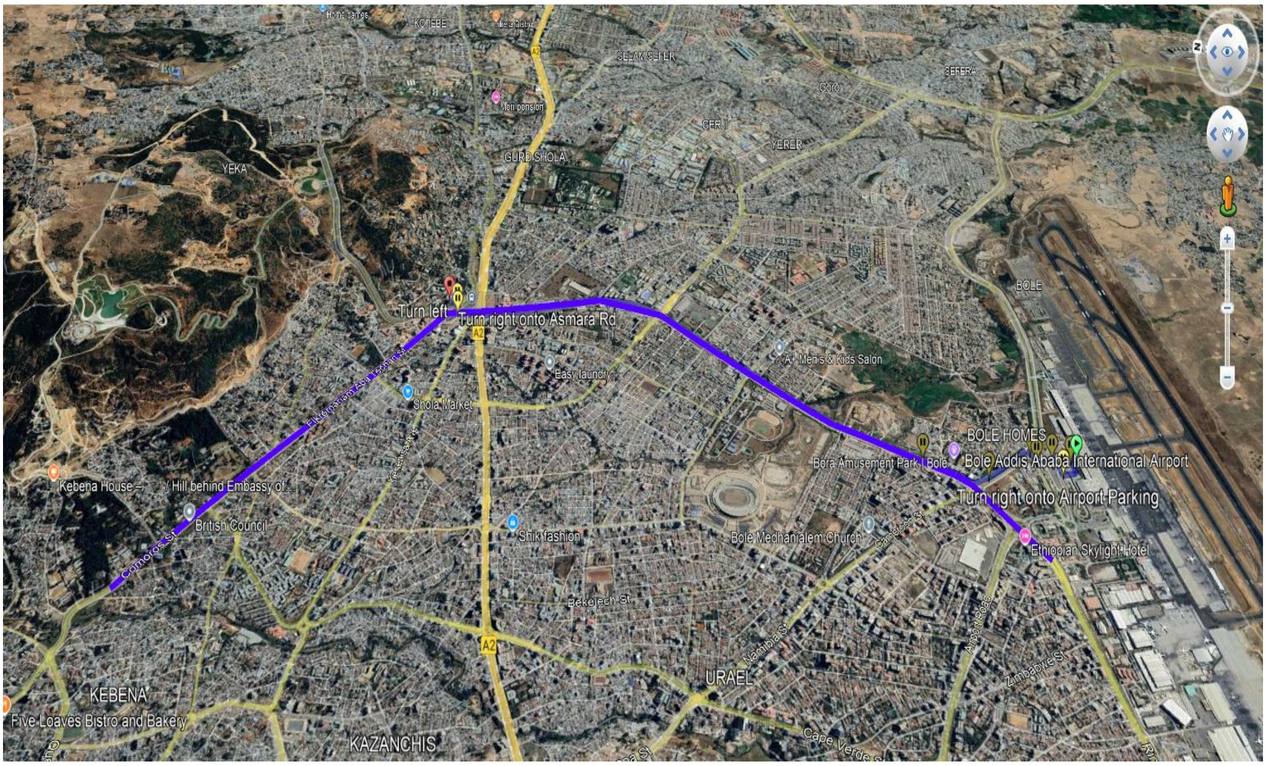


Figure 3-2: Location Map of Bole Airport to Megenagna Diaspora Square Area Corridor Development Project 5 km (Source: Google Earth, Airbus 2026).

2) Mexico-Sarbet-Gotera-Wollo Sefer Corridor Development Project

The 7km kilometers long, stretch will be controlled by Addis Ababa City Road Authority (AACRA) through their Road Asset Management Unit acting as the consultant while working together with MSEs. The Construction firm responsible for the implementation of the project was Yirgalem Construction PLC. Considering the total cost of 886.66 million ETB, it is a fairly largescale project albeit smaller compared to that of Bole Megenagna due to budget constraints.

As indicated, the aim is to undertake rehabilitation and upgrading of the road. Resurfacing of the already laid asphalt concrete pavement as well as full depth reconstruction wherever necessary following earthwork and sub base will be done. Similar to the previously discussed one, it entails a complete streets program that consists of 7km long pigmented asphalt lanes and stamped concrete sidewalks on each side as well as providing bicycle racks. In addition, drainage and utility systems will be put in place together with the conventional manholes. Other amenities include surface parking facilities for public transport services together with creation of recreational areas. The significant variation is that there is no grade separation facility, such as a culvert or an overpass bridge, in this project's scope. It is mentioned in Provisional Acceptance and DLP, but no clear dates are mentioned for the project's start or completion.

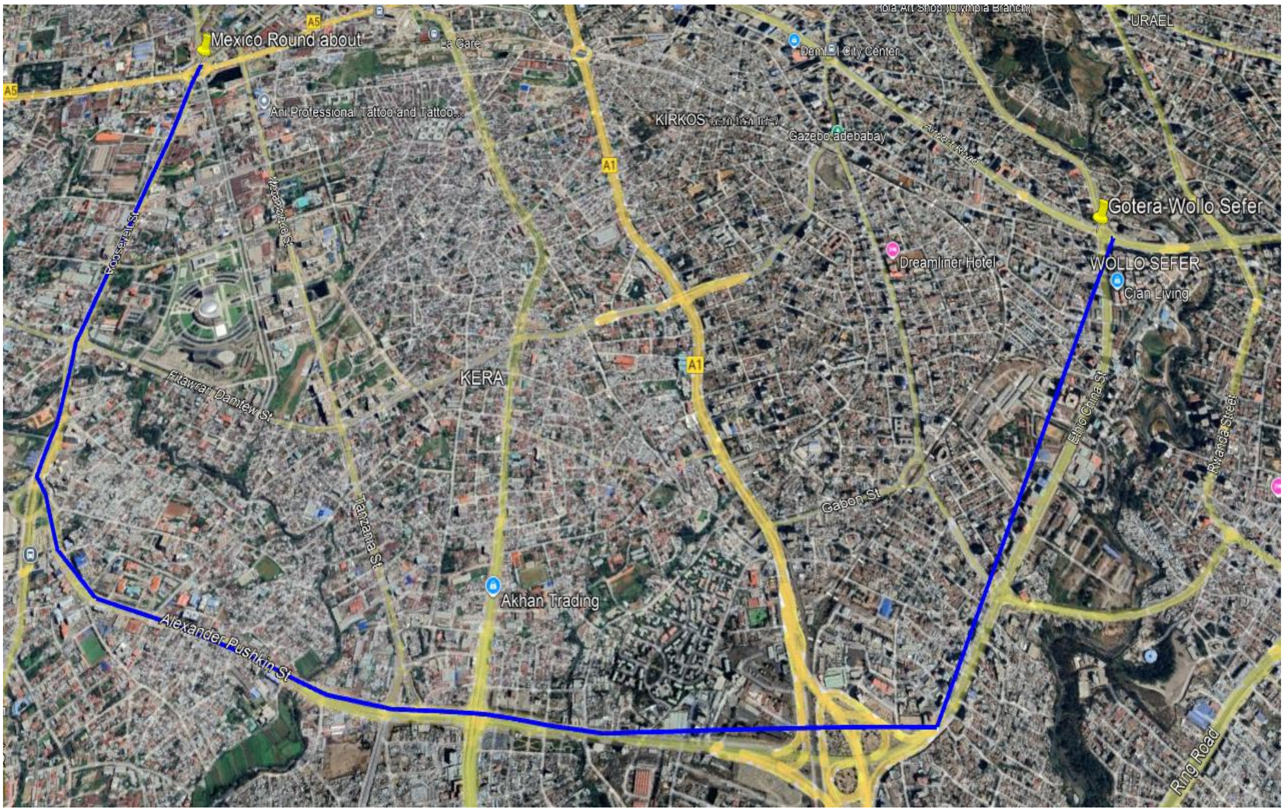


Figure 3-3: Location Map of Mexico–Sarbet–Gotera–Wollo Sefer corridor 7Km (Source: Google Earth, Airbus 2026).

3.3 Site Selection & Criteria

The choice of these two corridor development initiatives is informed by the traditional research design paradigm guidelines of focusing on the principles of representativeness, comparability, feasibility, and the fulfillment of the needs for digital RIAM. The chosen corridors form a very important research component. They provide a basis for the in-depth study of systemic issues within RIAM and the applicability of digital RIAM initiatives within the current Addis Ababa city infrastructure framework. Adhering strictly to the guidelines provided for conducting a case study, as cited within the research work of (Yin 2018), among other methods of research design choice guidelines, the choice of the Bole Airport to Megenagna Diaspora Square Area and Mexico-Sarbet-Gotera-Wollo Sefer is initially explained by the fulfillment of the following guidelines:

1. Technical and Physical Asset Considerations (Huang et al. 2025; Yin 2018).
2. Operational and Functional Significance (Huang et al. 2025).
3. Contextual Significance and Complexity:
4. Institutional and Managerial Context
5. Relevance to Intelligent Digital Solutions (Davis, Qian, and Zeng 2025; Huang et al. 2025; Sajadieh and Noh 2025)

Table 3.3 : Criteria and Rationale for Selecting Case Study

No	Selection Criteria	Bole Megenagna Diaspora Corridor	Mexico-Sarbet-Gotera-Wollo Sefer Corridor	Justification for Comparative Analysis
1	Strategic Importance	Very High VIP Road (Airport, Diplomacy, Commerce)	Very High Commercial Road (Government, Historic Core, Density)	Ensures both are high priority assets worthy of advanced RAM study.
2	Asset Complexity	(Likely grade separation, multimodal lanes, Smart pole, Cycle lane)	High (Likely includes junctions, multimodal lanes)	Controls for physical management complexity.
3	Stakeholder Complexity	Multiple (AACRA, ERA, airports, businesses)	Multiple (AACRA, sub cities, utilities)	A key challenge for digital integration.
4	Data Challenge Potential	High (Multiple project phases, many interface points)	High (Dense urban context, utility conflicts)	Provides a fertile ground to investigate data silos and handover issues.
5	Research Accessibility	[Your assessment based on contacts]	[Your assessment based on contacts]	Ensures practical feasibility of data collection.

3.4 Research Design

In this research, a combination of explanatory & descriptive sequential methodology approach is employed. This includes using convenience sampling in descriptive case studies. The study combines both the quantitative data from surveys as well as qualitative feedback from the interviews and focus groups to identify the loopholes in the system. This is done using Microsoft Excel.

3.5 Research Approach

This study primarily followed a constructive research approach to develop and trial digital solutions to improve road asset management performance in Addis Ababa's urban road corridor developments. It entails repeated cycles of solution development, problem definition, implementation, and evaluation, with exploratory and descriptive components to review issues and innovative mitigations (David 2015).

A mixed methods approach blends quantitative and qualitative techniques to respond to research inquiries and objectives connected to smart digital solutions for RIAM. The study applies a mixed methods approach:

Quantitative Method: Studied the present condition of the roads and examine the effectiveness of the new technologies that have been brought into use in the Addis Ababa road corridors. Gain more insights by conducting further surveys and through the analysis of secondary sources such as asset registers, maintenance records, and usage statistics of digital devices to assess the influence of the smart digital devices on the RIAM process.

Qualitative Method: Interview the participants to find out the deficiencies in the technology and policies related to RIAM. Conduct semi structured interviews with the project manager, engineer, decision maker, and IT specialist regarding their experience in implementing the technology. digital RIAM.

3.6 Sources of Data

Data was gathered from various sources to ensure triangulation. Additionally, for the sake of this research, the data was gathered from a combination of desk review, questionnaire survey, key informant interviews (KII), semi structured interviews, survey techniques, and focus group discussions (FGDs), and document analysis. The study gathered the primary data using the survey technique, key interviews (KI), and focus group discussion (FGDs) techniques. purposive sampling was used to recruit members from stakeholders who have previously been involved in the Addis Ababa corridor projects. This was done for the sake of conducting an in-depth analysis of the research topic within a specific context. And the study obtained the secondary data from research findings, books, review articles, published and unpublished research papers, and observations.

3.6.1 Primary Data Collection

Primary data collection utilized a multimethod strategy to enhance robustness. Qualitative insights were gathered through semi structured interviews with key institutional stakeholders Addis Ababa City Roads Authority (AACRA), the Ethiopian Roads Administration (ERA), the Addis Ababa City Administration Electric Services Authority (AACAESA), the Addis Ababa Design and Construction Works Bureau (AADCWB), Ethiopian Engineering Corporation (EEC), EEU, Ethio Telecom, and City Administration), while structured questionnaires assessed technical personnel's views on digital adoption.

3.6.2 Secondary Data Collection

Secondary data were sourced from project documentation, policy documents, and digital RIAM databases. The data was gathered from the road inventory, as well as industry standards provided by entities such as AACRA and EEC. Documentary data formed the basis of the analysis of local practice and international benchmarks for digital Construction. Literature on road asset management and digital Construction technology, locally and internationally, was reviewed to inform the analysis.

3.7 Sampling Design

3.7.1 Sampling Population

The study shall be limited in scope to exploring digital solutions for road asset management within the corridor development programs of Addis Ababa, with a focus on the Mexico–Sarbet and Bole road corridors. The target population comprises road agency entities (AACRA, ERA), utility sector entities (EEU, AACAESA, Ethio-telecom), and technical sector entities (AADCWB, EEC). In conducting this study, a form of convenience sampling was used to collect data experts for this include AACRA, ERA, EEC, AADCWB, AACAESA, EEU, Ethio-telecom based on relevance to planning, design, Construction, and budgeting processes for Phase I of Addis Ababa Corridors to generate sufficient information on intelligent digital solutions for RIAM in the study corridors.

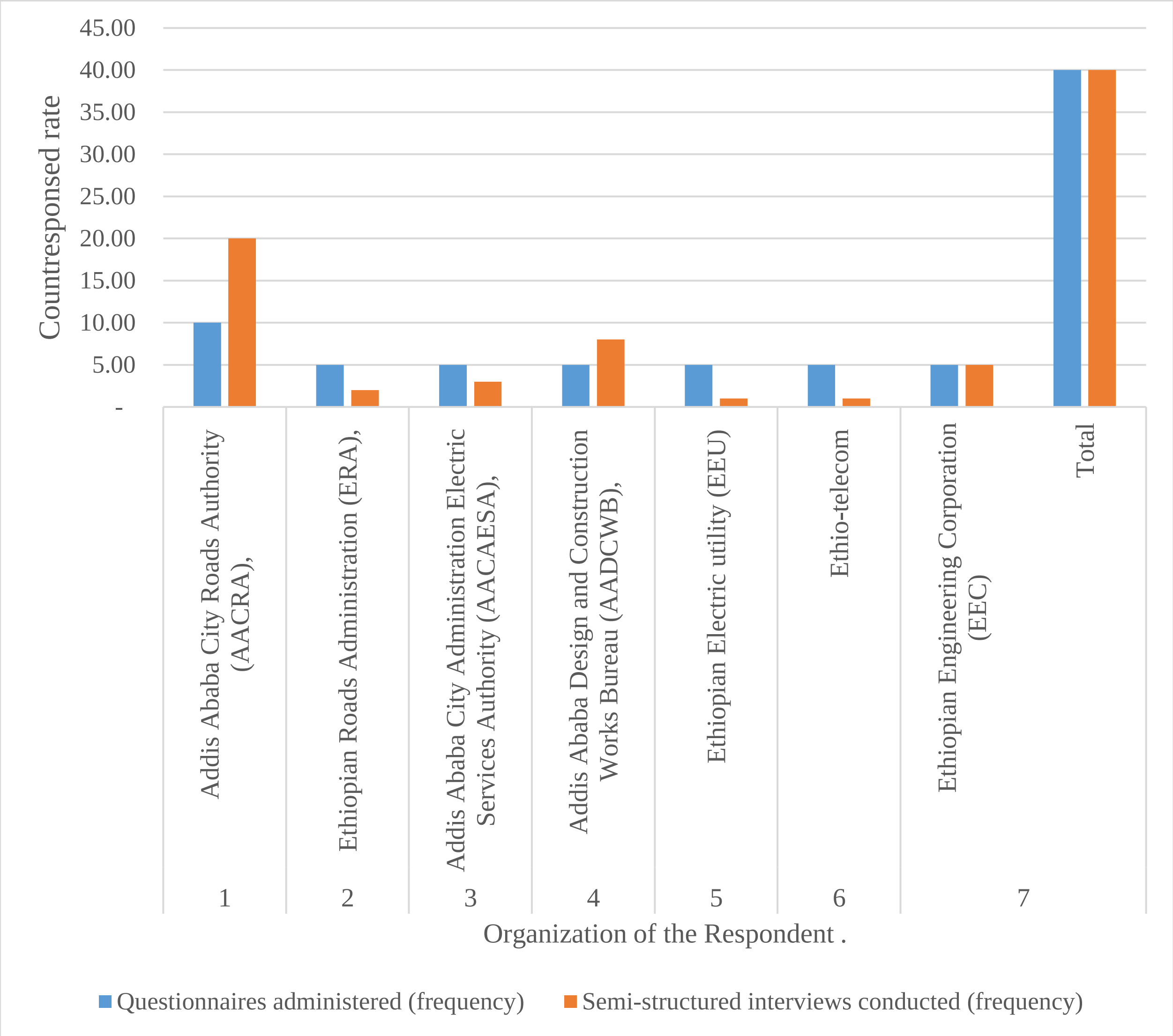


Figure 3-4: Respondents' participation in Addis Ababa corridor development projects (planning, design, Construction Phase)

3.7.2 Sampling techniques and determining sample size

For this study, a Case, based analysis in road asset management uses purposive sampling to select road corridors or sections that represent different conditions or digital solution use cases. Purposive sampling method is highly recommended, as it allows you to select participants with specific expertise or involvement in the projects. These purposive sampling techniques were enables deep qualitative and quantitative analysis of real-life scenarios in asset management practices to select representative participants. However, to enhance representativeness and reduce bias, you can combine purposive sampling with stratified sampling or snowball sampling, depending on the stakeholder group. For this study Stratified Sampling: Description this probability sampling method divides the population into strata based on specific characteristics (e.g., stakeholder type) and then randomly selects participants from each stratum.

The population of this study is employees (Professional Staff (Engineers)) of the AACRA, ERA staff, technology providers, and community stakeholders. who are directly or indirectly involved/ participated in the Road Asset Management process. The method that adopted to select the study area and research participants was purposive sampling technique and for equal representation, select samples randomly from all divisions. The number of samples for each division may be calculated using the formula for proportional allocation, which is:

$nh = \frac{N_h}{1+N*e2}$ x n---Equation 1

$n=50/(1+50*(0.05)^2)=44$

The sample size of the population was determined using the following formula, Yemane (1967).

Where: n= Sample size N= Total population (Only Professional Staff (Engineers) in Road Asset Management) e= Occurrence of error, e=100%-95%=5% (assuming the confidence interval is 95%).

3.8 Method of data collection

The research process was conducted in a sequential manner, divided into six phases. Such an approach ensured that all numerical scaling and qualitative analysis were conducted in accordance with the primary research objectives related to infrastructure management during its entire life cycle.

3.8.1 Desk study

The literature review laid down the foundation by looking at the contracts, the maintenance practices, and the policy frameworks for both 5-km corridors. The review focused on existing road asset management data storage systems and condition assessment techniques that highlight areas for improvement in terms of digital road asset management.

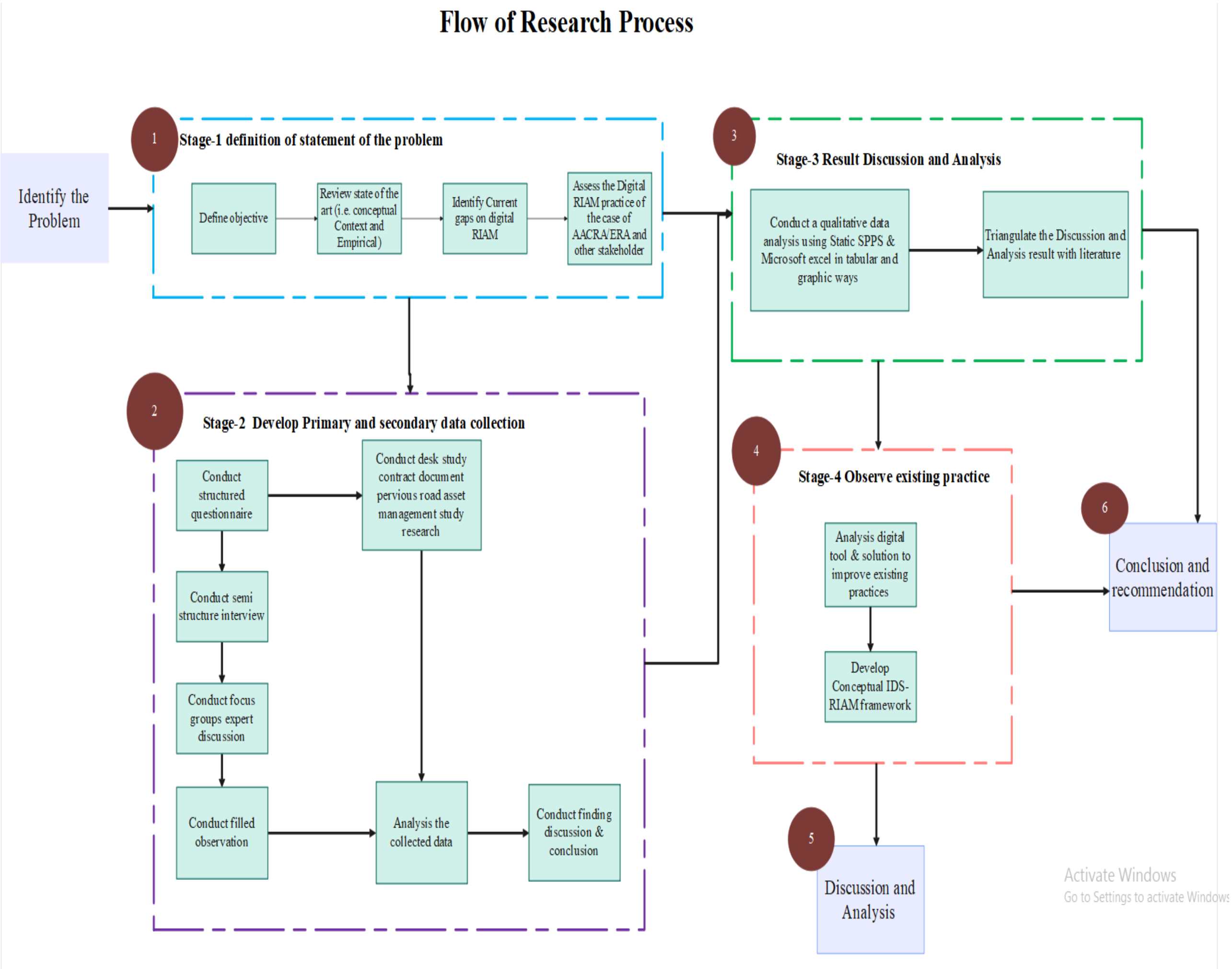


Figure 3-5: Structural Categorization of the Flow of Research Process

3.8.2 Questionnaire

A structured questionnaire, featuring Likert scale and open-ended questions, was distributed to purposively selected respondents. It addressed five core areas: job roles, agency procedures, digital solution impact, adoption drivers, and framework development. This tool facilitated efficient coding while allowing for the expression of professional attitudes and nuances. This allows the researcher to reach better the Respondents' actual feelings across an issue under study and to get additional information from the Respondents. The entire questionnaire is provided in Appendix B.

3.8.3 Interviews

Interviews allow for in-depth exploration of the perspectives, experiences, and insights of key stakeholders involved in road infrastructure asset management. Information on research questions and objectives was requested from key informants in order to deepen the findings of the desk study and questionnaire. The purpose of the interview was to assess the practices and perceptions of key informants on road infrastructure asset management practices. Through interviews, more efforts were made to identify additional problems that were not identified through the questionnaires and the desk studies, and to increase the accuracy and reliability of the challenges obtained through questionnaire. The interview schedule is depicted in Appendix B.

3.9 Methods of Data Analysis

The data was then edited, coded, categorized, and analyzed using Microsoft Excel. Qualitative information gathered from documentation and interviews was transcribed into written form, categorized based on the concept of ideas, and analyzed using thematic techniques in order to determine recurring themes, patterns of digital solution adoption, as well as associated meanings, patterns, or lessons pertaining to Road Asset Management (RAM). The survey information was analyzed using descriptive statistics to establish usage levels, while comparative techniques were utilized to link study information about RAM with conceptual frameworks.

A Multi Criteria Decision Analysis (MCDA) was done to compare digital solutions for cost considerations, feasibility, interoperability, and then scalability to determine how they can be applied to Addis Ababa's corridor projects. The data collected through desk study analysis was compared against assumptions. Then, data obtained from interviews and questionnaires were analyzed using statistics to find out variables that influence RIAM. The findings were scaled between 5 (very high) and 1 (very low).

3.10 Validity and Reliability

To increase the validity of the research findings, the research uses methodological triangulation through interviews, observation, and documentation. The processes of using each methodology are described in detail alongside interview guide lines and data coding processes. The reliability and validity of the data collected is checked using the Cronbach's alpha coefficients. Therefore, from the data collected using questionnaires and analysis of the data using excel spreadsheet, the Cronbach's alpha coefficient of the data is found to be 0.851. The high values of Cronbach's alpha coefficient ($\alpha = 0.851$) show that there is high reliability of the data collected from the instrument used in collecting the data. According to George and Mallery, (2003) if the Cronbach's alpha coefficient ($\alpha > 0.80$), then it is good because it shows that the questions in the questionnaires measure the construct in a reliable way. Additionally, according to Hundleby and Nunnally (1968), the reliability coefficient should be above 0.70.

3.10.1 Study Variables

This paper analyzes the effectiveness of RIAM in Addis Ababa with respect to key determinants of performance. Independent variables include:

i) Technology adoption – Building Information Modeling, digital twin technology, AI analytics, drone technology, Internet of Things (IoT);

ii) Decision making process – evidence based decisions with predictive analysis support.

iii) Organizational culture: readiness for innovation and digital transformation.

iv) Objectives, policies, and strategies: clarity of RIAM objectives, sustainability policies, and regulatory frameworks.

v) Financial resources: RIAM money allocation and management.

vi) Stakeholder engagement: collaboration among agencies, contractors, and other stakeholders.

Dependent variable is how effective RIAM is, which is measured in terms of asset condition indexes (e.g., PCI), technology adoption, and achievement of service levels, cost-effectiveness, asset life, and network sustainability. Performance is quantified in terms of condition inspections, deterioration projection, safety and traffic risk evaluation, lifecycle costing, and optimization modeling.

3.11 Ethical Considerations

The research complied with ethical principles. Dignity, safety, and human rights were maintained for all stakeholders in the project—employers, consultants, contractors, and other parties concerned about corridor development. Interviews and surveys included obtaining informed consent from participants. Confidentiality during data collection and analysis ware guaranteed to maintain the confidentiality of the information provided by the subjects. This study complied with Addis Ababa University's guidelines and Ethiopian legislation on ethical research practice. When developing intelligent digital technologies for managing road assets, the initiative considered ethical aspects of such an endeavor. Data processing used security features that prevented any unauthorized access to information. Responsible decision-making was encouraged to maintain transparency and accountability for any actions taken. The responsibility for managing the outcomes generated using AI-based software were defined, and all relevant parties' consent was gained prior to the implementation of the solution and its operation. Algorithmic bias was addressed to promote fair decision-making and ensure compliance with legal requirements in Ethiopia.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the summarized results of an empirical analysis of the obtained data. The findings are analyzed from the perspective of the major research goals; they are discussed against the background of the extant literature, as well as the problems of implementing them in practice.

4.2 Response rate and Demographic Profile of Respondents

4.2.1 Response rate and Demographic Profile

A structured questionnaire survey was carried out to determine the potential of intelligent digital solutions in meeting road asset management challenges in the corridor development projects of Addis Ababa. The survey was carried out on two major projects, and the target population was professionals in major institutions such as the Addis Ababa City Roads Authority (AACRA), Ethiopian Roads Administration (ERA), Addis Ababa City Administration Electric Services Authority (AACAESA), Addis Ababa Design and Construction Works Bureau (AADCWB), Ethiopian Engineering Corporation (EEC), and other relevant stakeholders. A total of 42 questionnaires and 13 semi-structured interviews was designed and carried out of the 42 questionnaires distributed to 40-targeted respondents, valid responses were collected from experts in employer organizations and road asset management specialists. This improves the validity and representativeness of the results. The detailed breakdown of respondents by organization, job, and response rate is shown in Figure 4.1 and 4.2, while the questionnaire and interview schedules are shown in Appendices A and B, respectively.

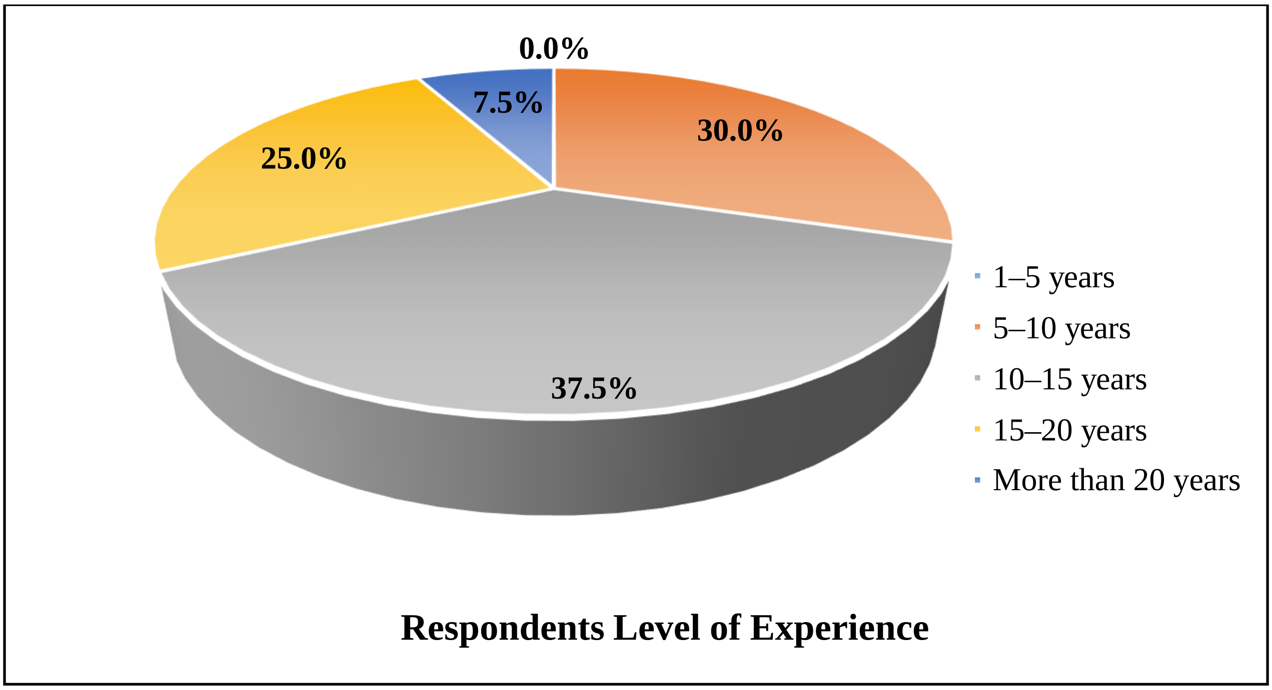


Figure 4-1: Respondents' Level of Experience

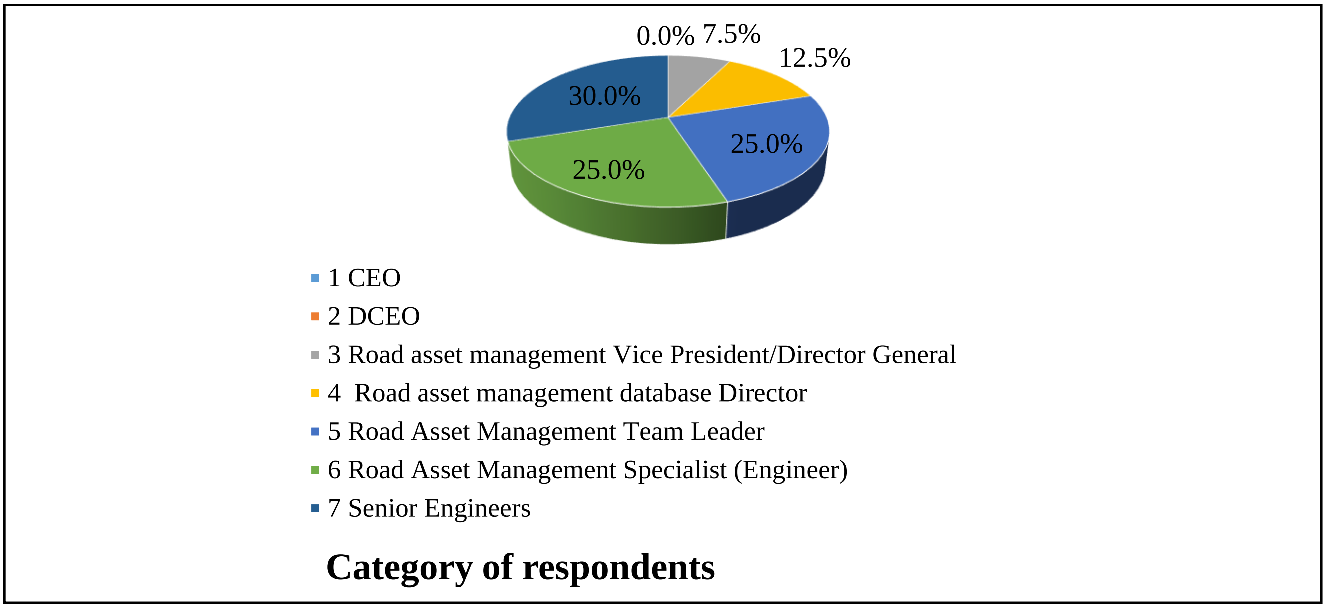


Figure 4-2: Respondents' Category

Figure 4.2 above shows the distribution of respondents' professional experience. From the figure above, Category of respondents indicates that 12 participants (30%) have 510 years of experience, 15 participants (37.5%) have 1015 years of experience, 10 participants (25%) have 1520 years of experience, and 3 participants (7.5%) have over 20 years of experience. This shows that the sample population comprises early and midcareer professionals, supplemented by a moderate number of senior professionals. Consistently, figure 4.1 further shows that the majority of respondents occupy senior roles: Road Asset Management Vice President/Director General (30.0%), Road Asset Management Database Director (25.0%), Road Asset Management Team Leader (25.0%), CEO (7.5%), and DCEO (12.5%), demonstrating that the data reflect views from both strategic leaders and technical specialists.

Table 4.1: Educational Background of the Respondents

Education background	Number of respondents	Percentage (%)
B.Sc.	**12**	**30%**
M.Sc.	**25**	**63%**
PhD	**3**	**8%**
Total	**40**	**100%**

As shown in Table 4.1, the study has found a considerable level of professionalism among the respondents, classified according to their academic background. In particular, 63% (n = 25 people) of the respondents have an M.Sc. degree, while 56% (n = 12 people) and 4% (n = 3 people) have B.Sc. and Ph.D. degrees, respectively. The sample largely consists of senior professionals in the Ethiopian Construction industry, particularly in road infrastructure and asset management.

The participation of such senior professionals in the study increases the validity of the data and ensures that the results are in line with the prevailing realities of the industry.

4.3 Current Practices of Road Infrastructures Asset Management

The study ask in your organization, is road infrastructures condition data consistently collected using conventional methods, and is it insufficient and inaccurate for informed decision-making

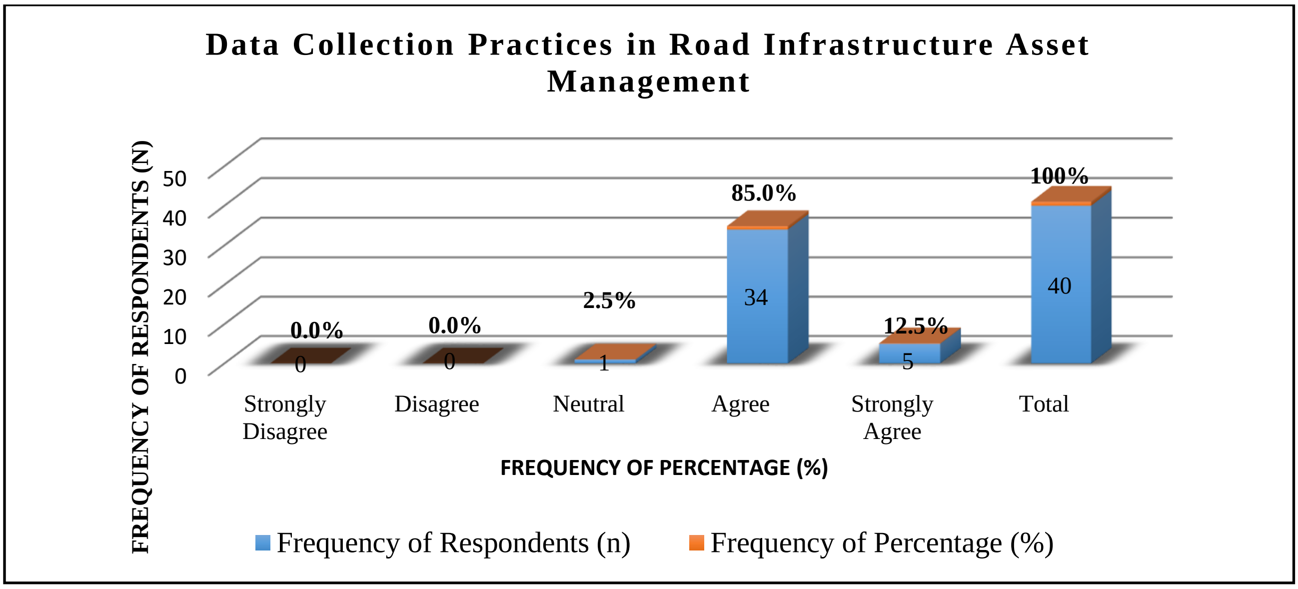


Figure 4-3: Respondents response about conventional methods data collection, and is it insufficient accurate for informed decision-making

The study asks AACRA, ERA, and other stakeholders to know the RIAM current practice and challenges. The information presented in figure 4.3 explained that the vast majority of the respondents (85%) agreed that the data on road infrastructure conditions within organizations, in particular, the Addis Ababa City Roads Authority (AACRA), is constantly collected through conventional approaches that are still largely manual and only occasionally supported by basic GPS and mobile apps like SW Maps. As such, the respondents considered the data inadequate and unreliable for evidence based decision-making. The findings of this study are also in line with the previous literature, which has time and again highlighted the limitations of conventional data collection methods Previous studies on this topic by (Bihon 2017; Girma and Mulatu 2025; JICA 2018; Sahle et al. 2025; Tadesse 2025) have contended that the application of conventional methods has been ineffective in attaining the desired level of accuracy, which can be helpful for evidence based decision-making processes. Moreover, (Feyisa 2019; Worku and Adugna 2025) have also asserted that inaccuracies in the data contribute to the complexities of collaborative governance processes.

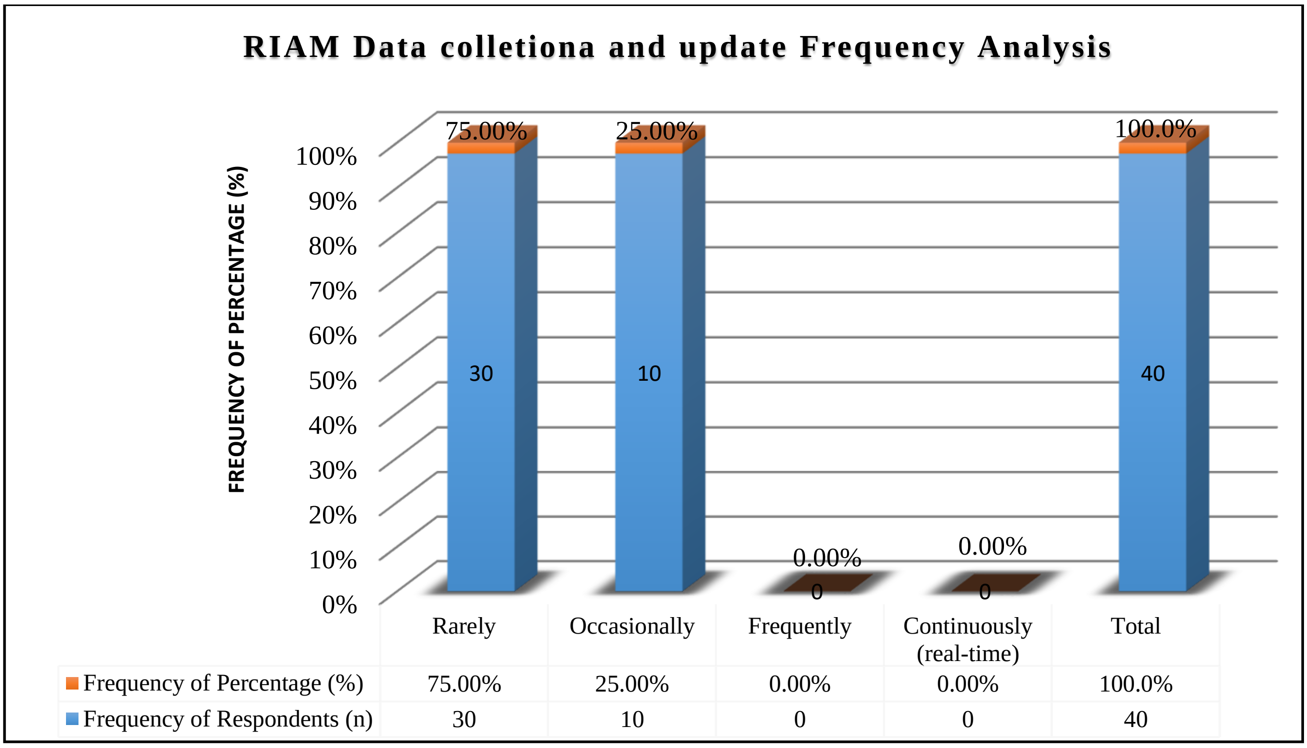


Figure 4-4: Respondents' responses on frequency of Road Asset data collection, updates and analysis in their organizations

Based on the information presented in Figure 4.4 regarding the frequency of data updates and analysis of data for Road Infrastructure Asset Management conditions, the results show that there exists a vast gap in the existing approaches to road asset management in AACRA, ERA, and other stakeholders. Respondents' responses on frequency described the data update process as being a **rare (75%, n = 30)** and **occasional (25%, n = 10)** phenomenon, and none of the subjects (responses) indicated frequent and continuous that is real time processes. Studies like those by (Bihon 2017; Feyisa 2019; Tadesse 2025) have shown that the frequency of road asset condition data updated and analyzed in their organizations is rare and occasional. Such types of gaps highly affect the RIAM.

Table 4.2: Respondents' view of the adequacy of existing road asset management systems

Category of Questionnaire	Response Level	Frequency of Respondents (n)	Frequency of Percentage (%)
How adequate do you consider the existing road asset management system in addressing maintenance and monitoring needs?	Not Adequate	0	0.0%
	Neutral	5	12.5%
	Neither Adequate nor Inadequate	5	12.5%
	Very low adequate	20	50.0%
	Very Inadequate	10	25.0%
	Total	40	100%

Table 4.2: Respondent ratings of current RAM systems. This series of questions yields a telling display of general dissatisfaction with the status quo. In responding to questions about the current state of road asset management systems, fully 50% (n = 20) of 40 participants rate it as very inadequate, 25% (n = 10) rate it as very low adequate, and 12.5% rate it as neutral. No single respondent rated it adequate. Most Respondents rated the existing system as neutral to inadequate, particularly regarding continuous monitoring, integration, and predictive maintenance capacity. This aligns with previously published findings reporting **45.5%** implementation of asset management systems due to organizational and technical limitations (Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025).

4.4 Challenges in Road Infrastructures Asset Management

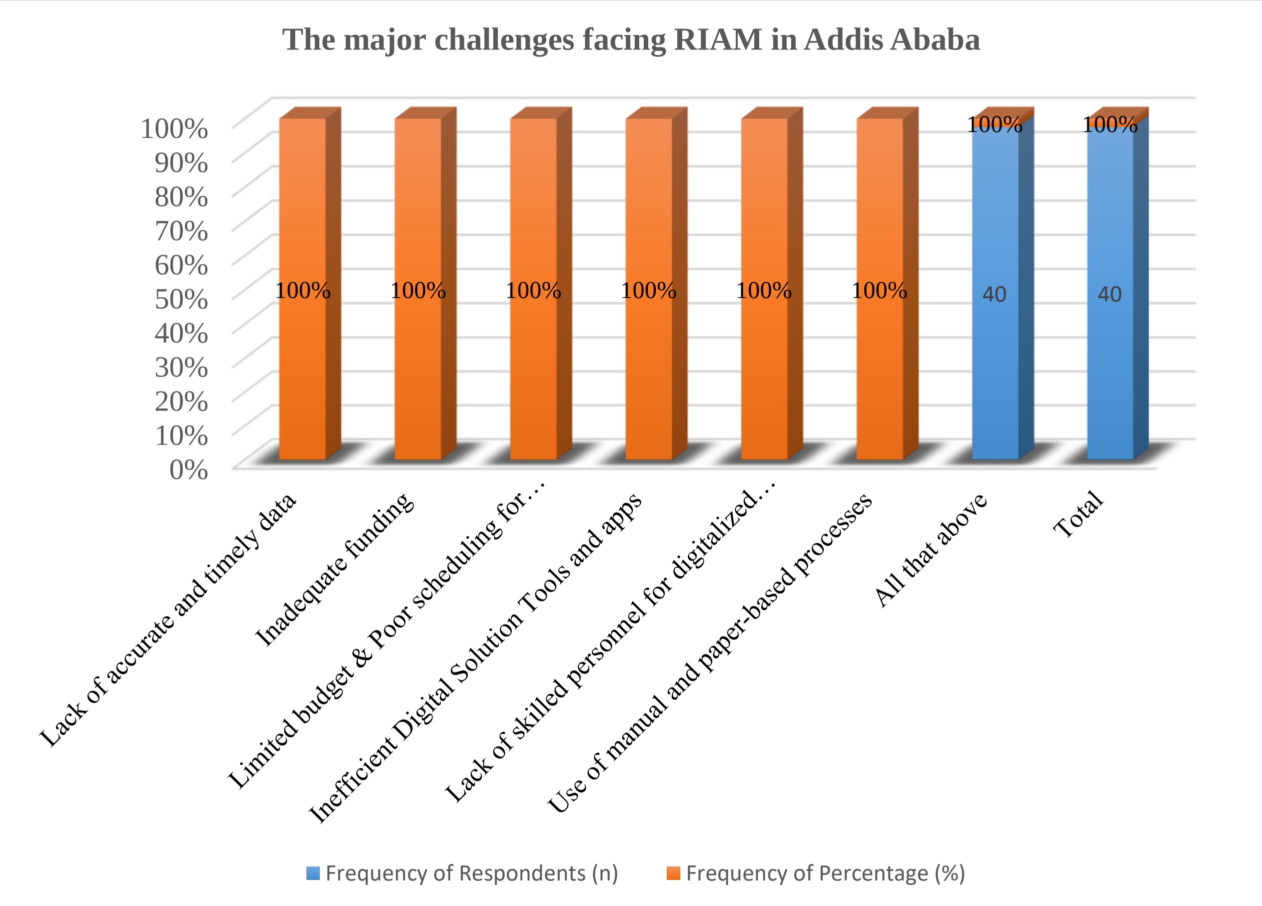


Figure 4-5: Key challenges in managing road assets along Addis Ababa

In order to answer the primary research question concerning the anticipated challenges in road asset management in the Addis Ababa, the study were asked to identify systemic challenges. As illustrated in Figure 4.5, there was unanimous consensus (100%, n = 40) concerning the gravity of the issues in the current infrastructure management practices. Some of the challenges identified include: Inaccurate and non-real time data; Insufficient funding for basic maintenance; Low utilization of digital tools and applications; Inadequate human capacity to manage digitalized infrastructure. The convergence of views from key stakeholders, including the Road Infrastructure Asset Management

Director Generals, Database Directors, and Senior Engineers, indicates a critical dependency on inefficient manual practices, thus emphasizing the complex multifaceted crisis in the sector. There is a clear mandate to change to digitalized infrastructure management to address the technical and financial inefficiencies currently being witnessed by sector specialists. Study like aslo aligns the study results the major challenges facing RIAM in Addis Ababa. The findings of this study are verified by contemporary research (Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025), which similarly identifies these systemic barriers as the primary challenges facing Road Infrastructure Asset Management (RIAM) in Addis Ababa.

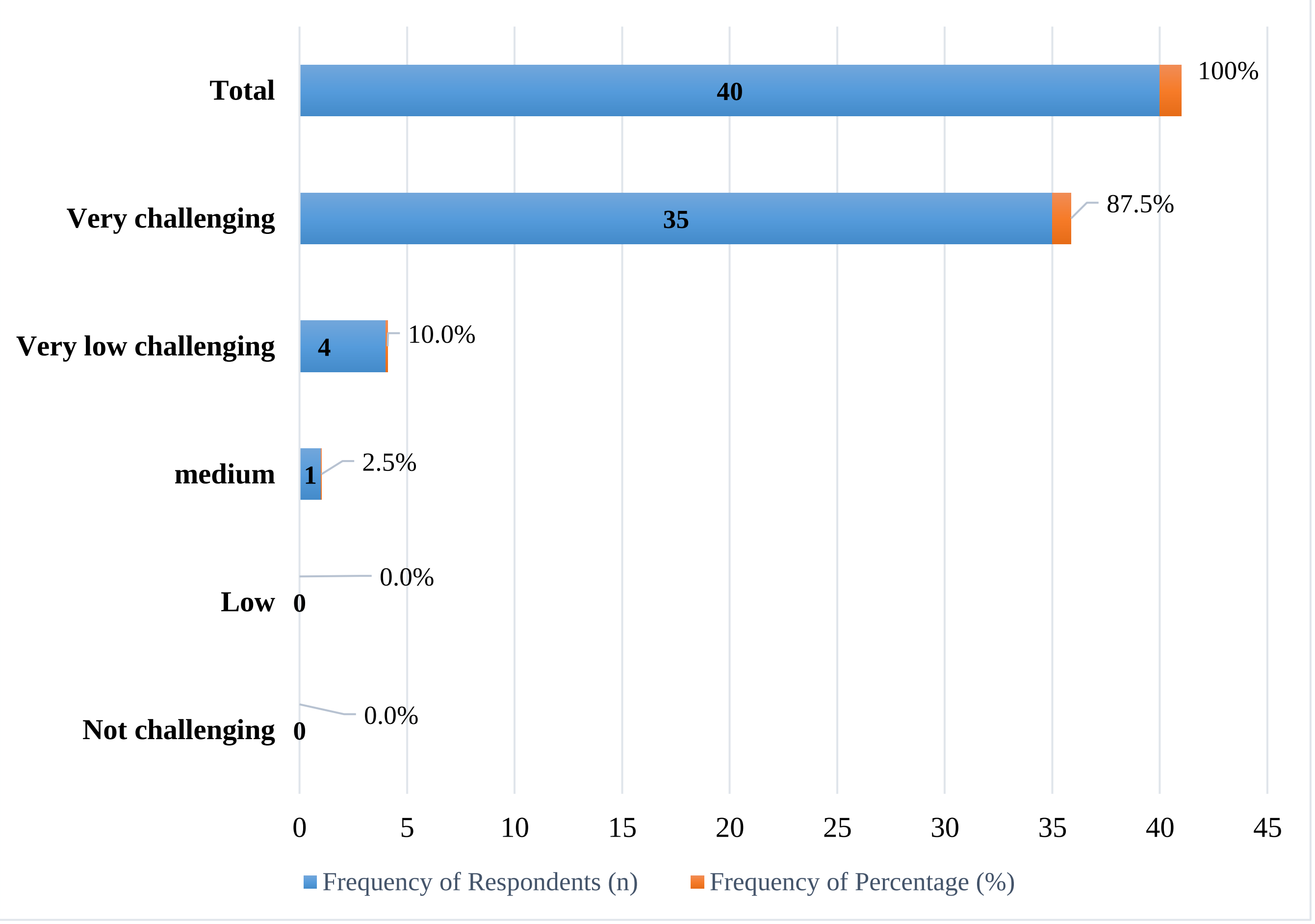
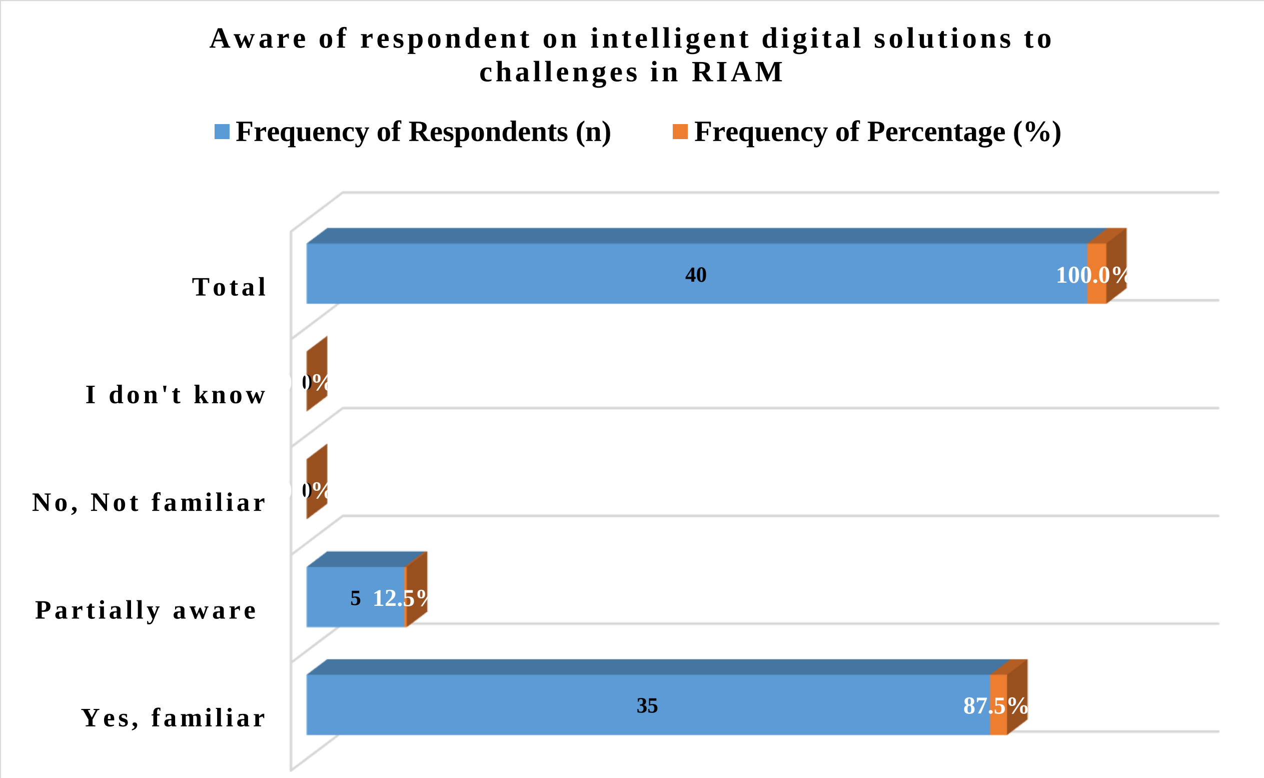


Figure 4-6: Respondents reflect the challenge of accessing timely and reliable road asset data within their organization

The question being addressed is how challenging it is to access timely and reliable road asset data within the organization. Based on Figure 4.6, lack of data availability for current and readily accessible road assets is considered a very challenging factor in effectively managing road assets, since this factor has been rated **very challenging by 87.5% (n = 35)** of the participants. Only 10% (n = 4) rated this factor **very low challenging**, while a meager 2.5% (n = 1) rated this factor **moderately challenging**. Not a single participant rated this factor as **not challenging or low challenging**. This is a clear indication that data latency, transparency, and associated operational challenges existent in the current road asset management framework are in direct opposition to the first basic necessity, which is to ensure that data is accurate, up-to-date, and properly organized.



	Yes, familiar	Partially aware	No, Not familiar	I don't know	Total
Frequency of Respondents (n)	35	5	0	0	40
Frequency of Percentage (%)	87.5%	12.5%	0.0%	0.0%	100.0%

Figure 4-7: Respondents level of Awareness Intelligent Digital Solutions to Overcome Challenges in Road Asset Management

In order to gauge the readiness level for technological adoption in RIAM sector, this study assessed participants' familiarity with Intelligent Digital Solutions that aim to address issues in Road Infrastructure Asset Management (RIAM). As illustrated in Figure 4.7, notice that there is high level of technological awareness among the Respondents. A significant majority (87.5%, n = 35) showed clear familiarity with intelligent digital solutions, with 12.5% (n = 5) being partially aware. However, no participant showed any form of lack of awareness or confusion. This means that this awareness level is 100%. However, this high level of awareness among key Respondents in this sector is paradoxical, especially considering the various issues in this sector that this paper has addressed. While this key group is aware of intelligent digital solutions, the current management style is largely manual. In addition, the current digital solutions in use in this sector are inefficient, and this is due to a lack of technical skills among people in this sector. This discrepancy strongly suggests that the primary barrier to modernizing Addis Ababa’s road sector is not a deficit of knowledge, but rather a critical gap in implementation and capacity execution.

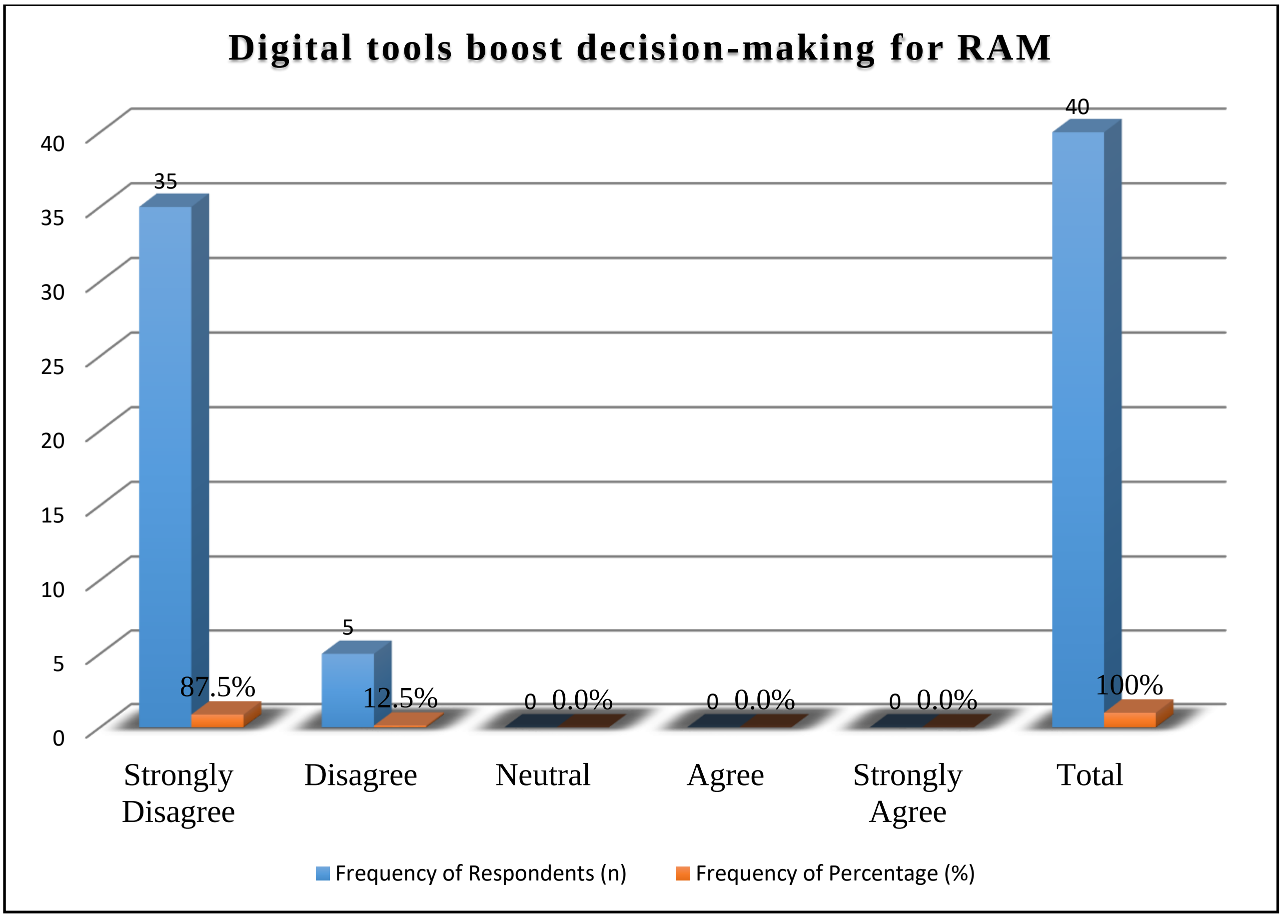


Figure 4-8: Respondents level of Awareness Current digital solutions enhance road asset decisions in Addis Ababa corridors

Senior officials (Director Generals, Database Directors, and senior engineers) were surveyed on whether Addis Ababa's current road asset management digital tools effectively support data-driven decision-making. The study finding figure 4.8 indicates that the level of awareness current digital solutions enhance road asset decisions in Addis Ababa road infrastructure 35 respondents 87.5% strongly disagreed and 5 respondents 12.5% disagreed that the existing tools are not operative for effective road asset decisions. No respondents were neutral or agreed that current digital systems fail to support evidence based decision-making. These findings confirm earlier literatures that the digital tools are poorly effective, data remain largely inaccessible, and an implementation gap persists between the awareness of Intelligent Digital Solutions to Mitigate Challenges in Road Infrastructure Asset Management and the current RIAM practical effectiveness in Addis Ababa very weak. This aligns with previously published findings reporting 45.5% implementation of asset management systems due to organizational and technical limitations (Bihon 2017; Girma and Mulatu 2025; Tadesse 2025).

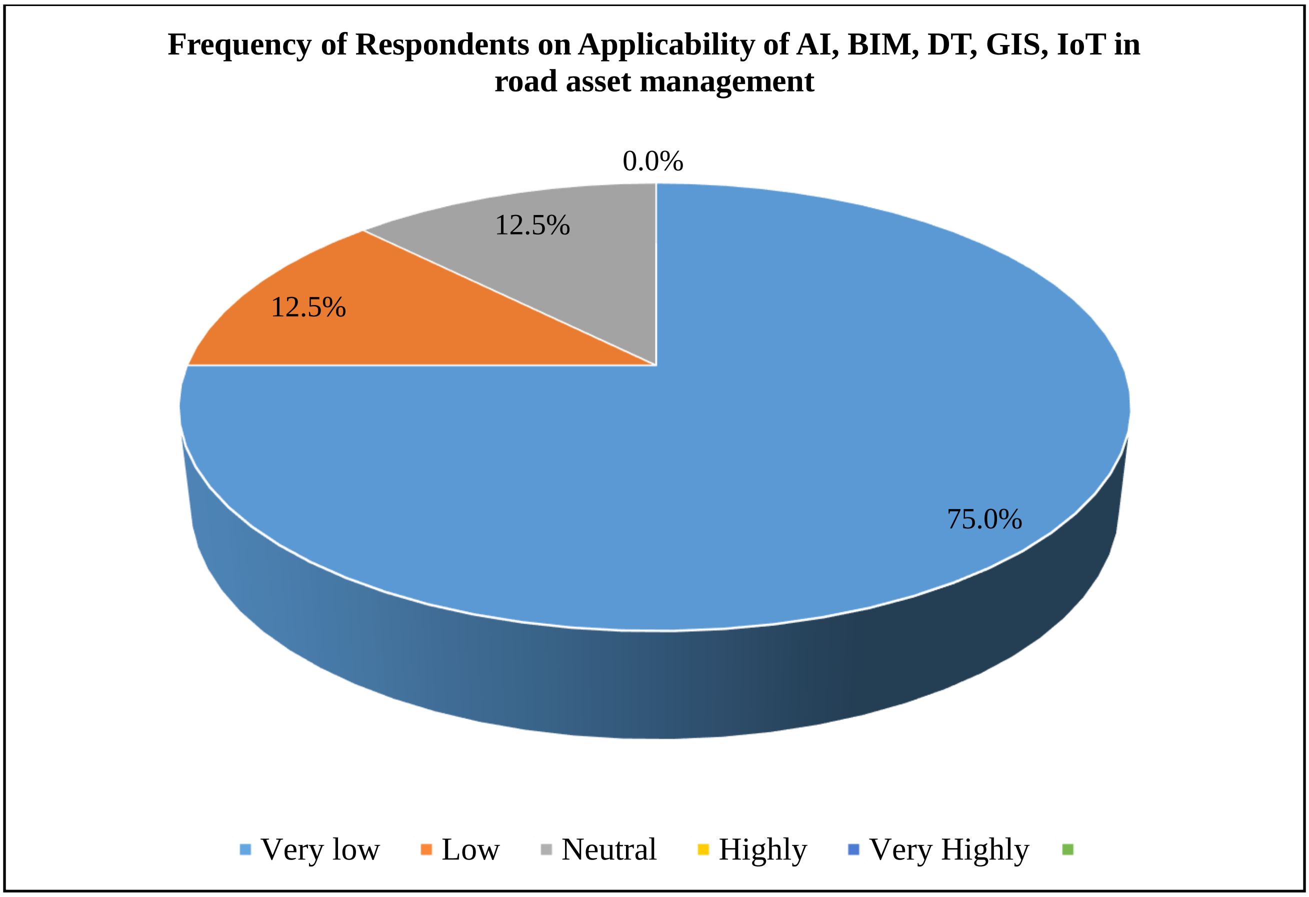


Figure 4-9: Respondents level of adequately applicable or integrated into your organization's

The study aims to determine the level of integration of intelligent digital solutions such as artificial intelligence, building information modeling, digital twin technology, GPS/GIS, and IoT sensors into the road asset management practices in Addis Ababa. The figure below indicates that 75% (n=30) of the respondents rated the implementation as very low and 12.5% (n=5) as low only. The remaining 12.5% (n=5) were unsure about the implementation, as they rated it as ‘not sure. No respondent rated the implementation as adequate or very adequate. The tendency towards negative ratings is very high, indicating a major gap in the practical application of intelligent digital solutions. This aligns with previously published findings reporting implementation of asset management systems due to organizational and technical limitations(Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025).

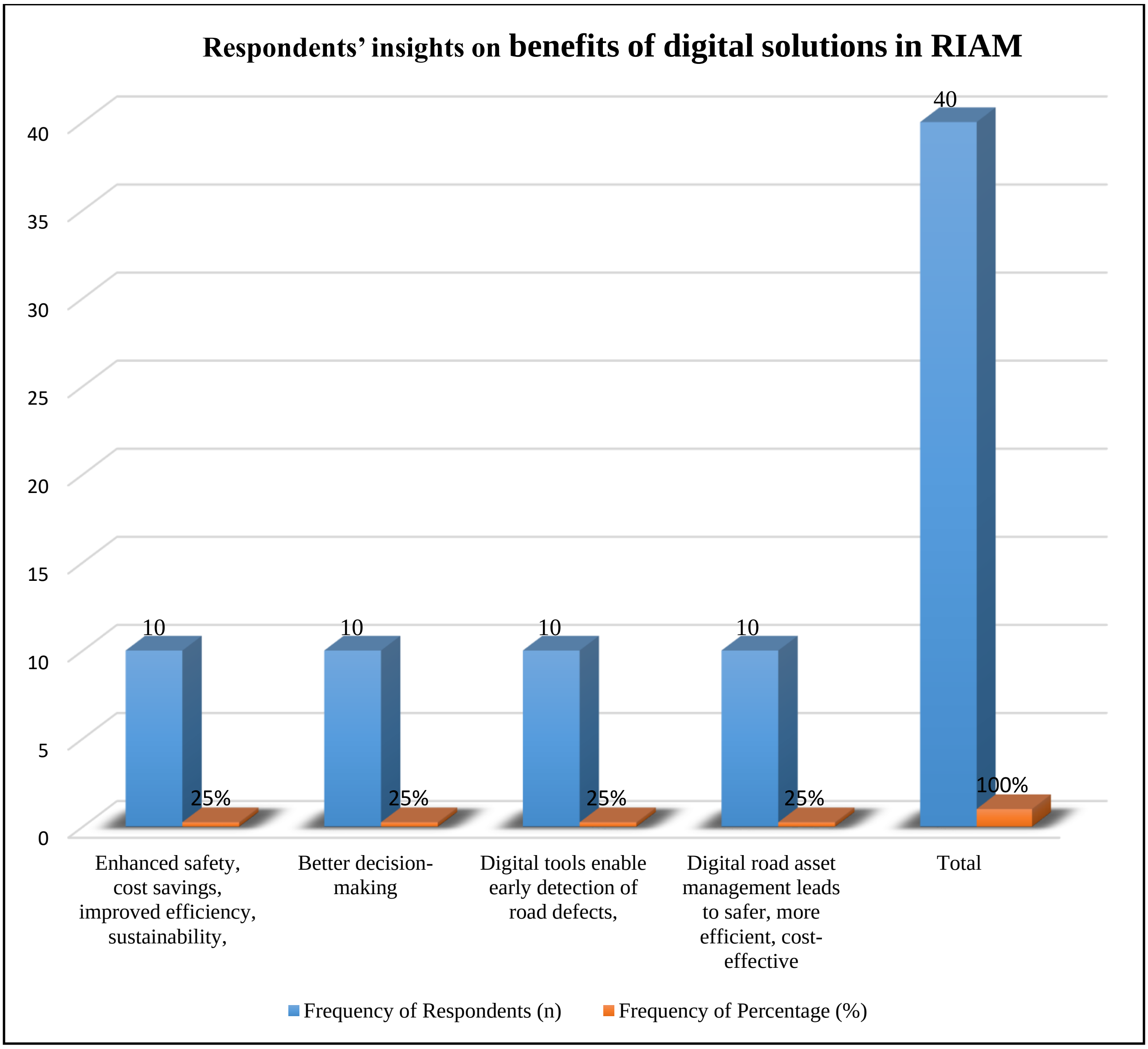


Figure 4-10: Respondents' views on benefits of digital solutions in road asset management

Figure 4.10 indicates that there was a clear consensus among the 40 participants on the various benefits associated with digital road asset management. This is because the responses were evenly distributed across the four major themes, with each theme receiving 25% of the responses. This indicates a wide understanding of the technology and its impacts. At the operational level, digital technology assists in reducing costs and improving efficiency, especially in the surveying and maintenance of the infrastructure. At the strategic level, it assists in decision-making, especially in the integration of various data sets, such as traffic patterns and climate patterns, in a single platform or digital twin this allows predictive exploration and clear prioritization. This, in essence, aligns with the various goals in infrastructure management, especially in the development of smart, sustainable, and resilient roads. This aligns with previously published findings reporting the benefits of digital tools to advanced convectional RIAM into a digital solution RIAM (Consilvio et al. 2023; Zhou et al. 2024).

4.5 Contribution of intelligent Digital for Road infrastructures Asset management

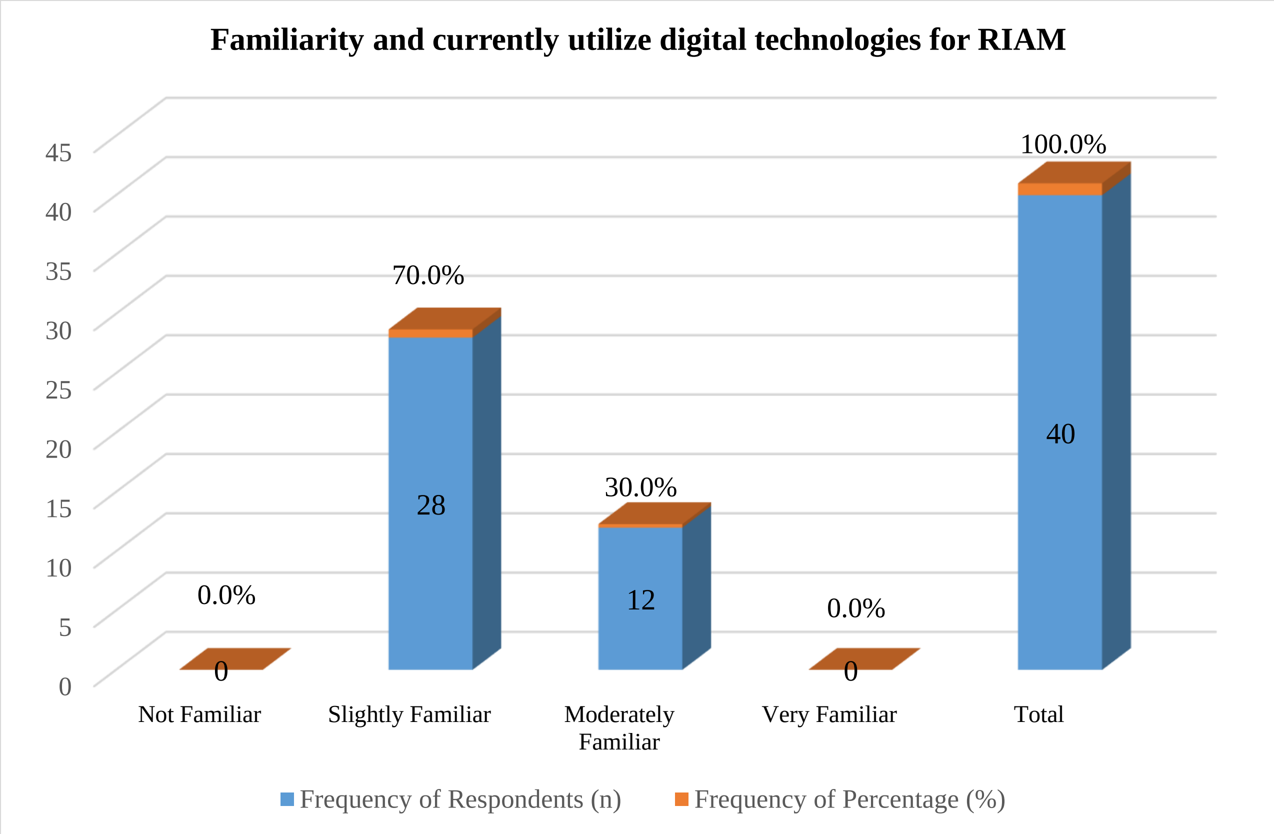


Figure 4-11: Respondents Familiarization with the knowledge of the application of advanced Digital Technology in organization.

The study requires the respondent to know respondents' familiarity with the knowledge of the application of Digital Technology GPS, GIS, BIM, IoT, Drones, AI & ML in organization as it figure 4.11 seeks to assess the organizational awareness of advanced digital technologies such as GIS, BIM, IoT, Drones, and AI/ML within road asset management. The level of familiarity that the respondents have with the use of such technologies as AI, GPS, GIS, BIM, or sensors for IoT in the management of road assets is mainly distributed across the categories of Slightly Familiar and Moderately Familiar. Specifically, it is clear that, according to the 40 respondents to this study, A significant 70% (28 respondents) of the total respondents to this study are only Slightly Familiar with these tools. The other 30% (12 respondents) of the total respondents to this study reported being Moderately Familiar with these tools. The notable point is that 0% of the total respondents to this study felt Very Familiar or Not Familiar at all.

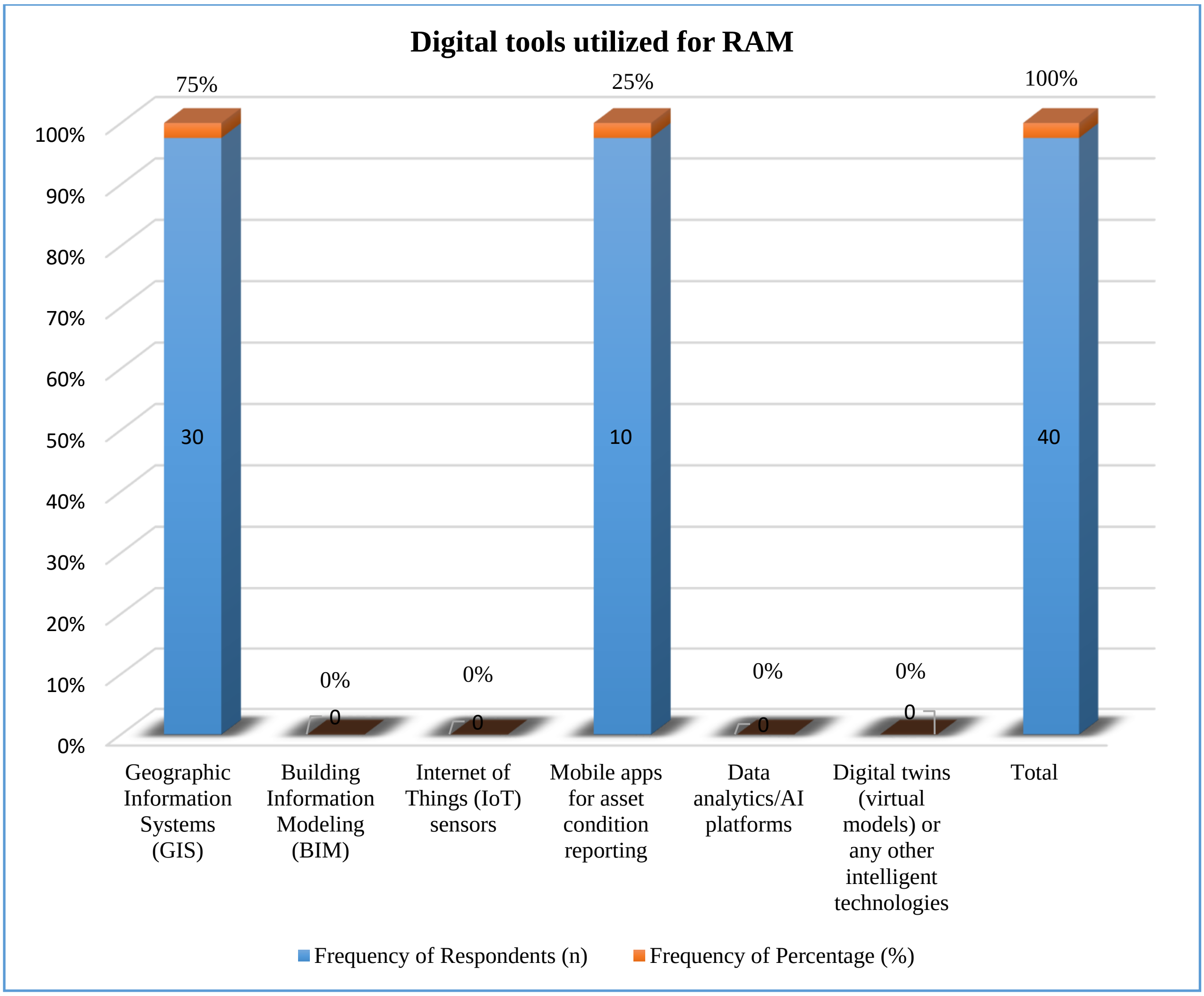


Figure 4-12: Respondents' Views on organizational Use of Specific Intelligent Technologies in Road Asset Management

Figure 4.12 shows that there is limited adoption of digital tools in road asset management. The figure shows that 75%, or 30 respondents, identified GIS and GPS as the main digital tools used in road asset management. The other 25%, or 10 respondents, identified the use of mobile applications such as SW Maps. On the other hand, the use of high-level digital tools such as BIM tools, IoT tools, AI tools, and digital twins is 0%. The results show that the organization has adopted digital tools in basic spatial management and reporting systems but has yet to adopt high-level intelligent systems. Thus, there is a great technological gap that can be exploited in the future. The results show that the organization has yet to adopt high-level intelligent systems such as BIM tools, IoT tools, AI tools, and digital twins in road asset management. On the other hand, supplemental survey results show that the Ethiopian Roads Administration (ERA) mainly uses conventional integrated software systems such as HDM-4, Pavement Management System (PMS), and Bridge Management System (BMS). the finding of this aligned (Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025).

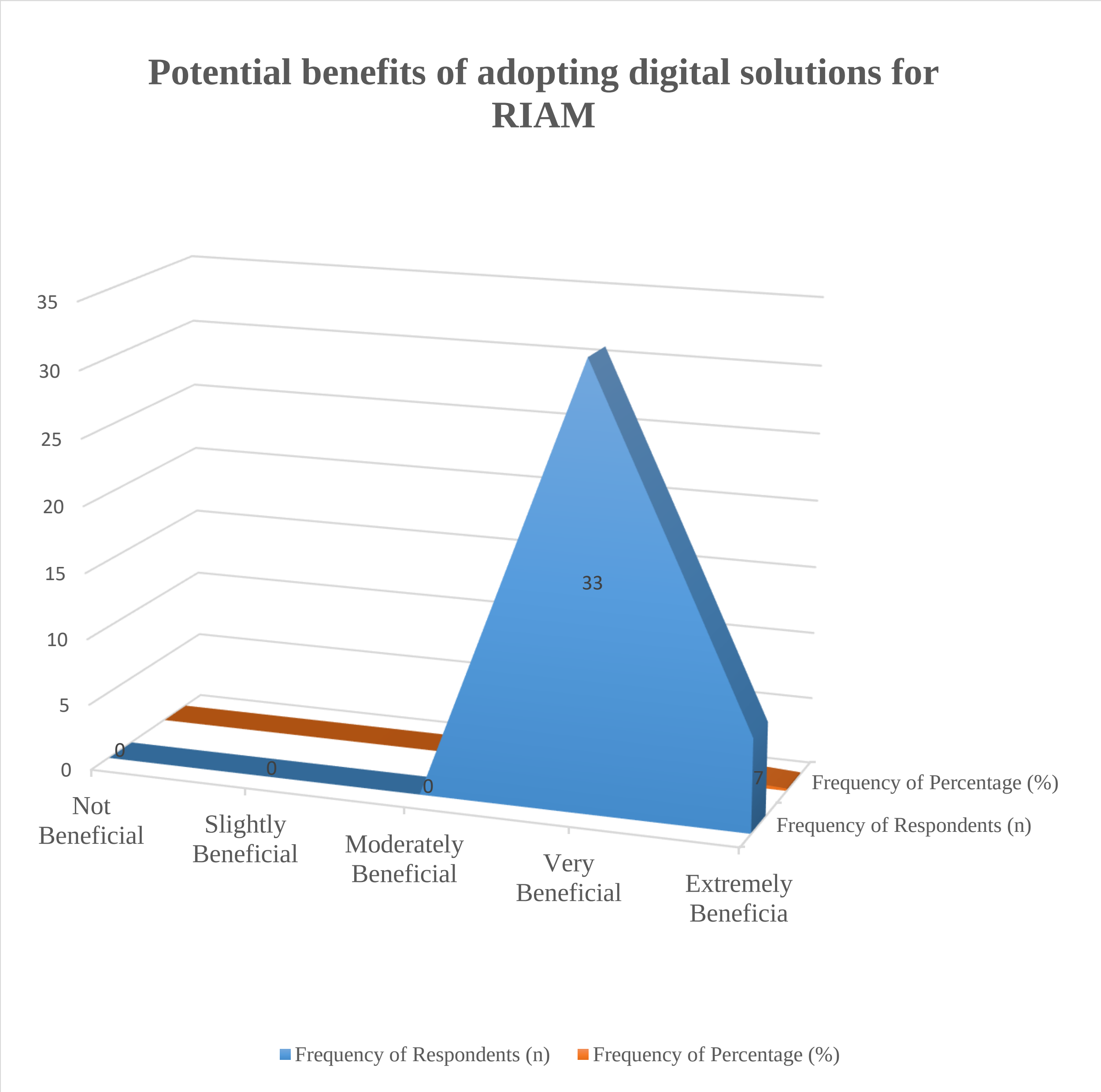


Figure 4-13: Respondents view Benefit of Adopting Digital Solutions for Road Asset Management (RIAM) Challenges

As depicted in Figure 4.13, there is an overwhelming consensus among respondents regarding the advantages of digital integration in Road Asset Management (RAM). In this regard, a significant number of respondents, that is, 82.5% (n=33 respondents), see the adoption of digital technologies as Very Beneficial, while the remaining respondents, that is, 17.5% (n=7 respondents), see it as Extremely Beneficial. What is more, no respondents see digital technologies as having moderate, small, or no benefits whatsoever, thus showing a high level of professional readiness and mandate for technological shift, as they see digital technologies as being instrumental in addressing the current infrastructure challenges in Addis Ababa's corridors.

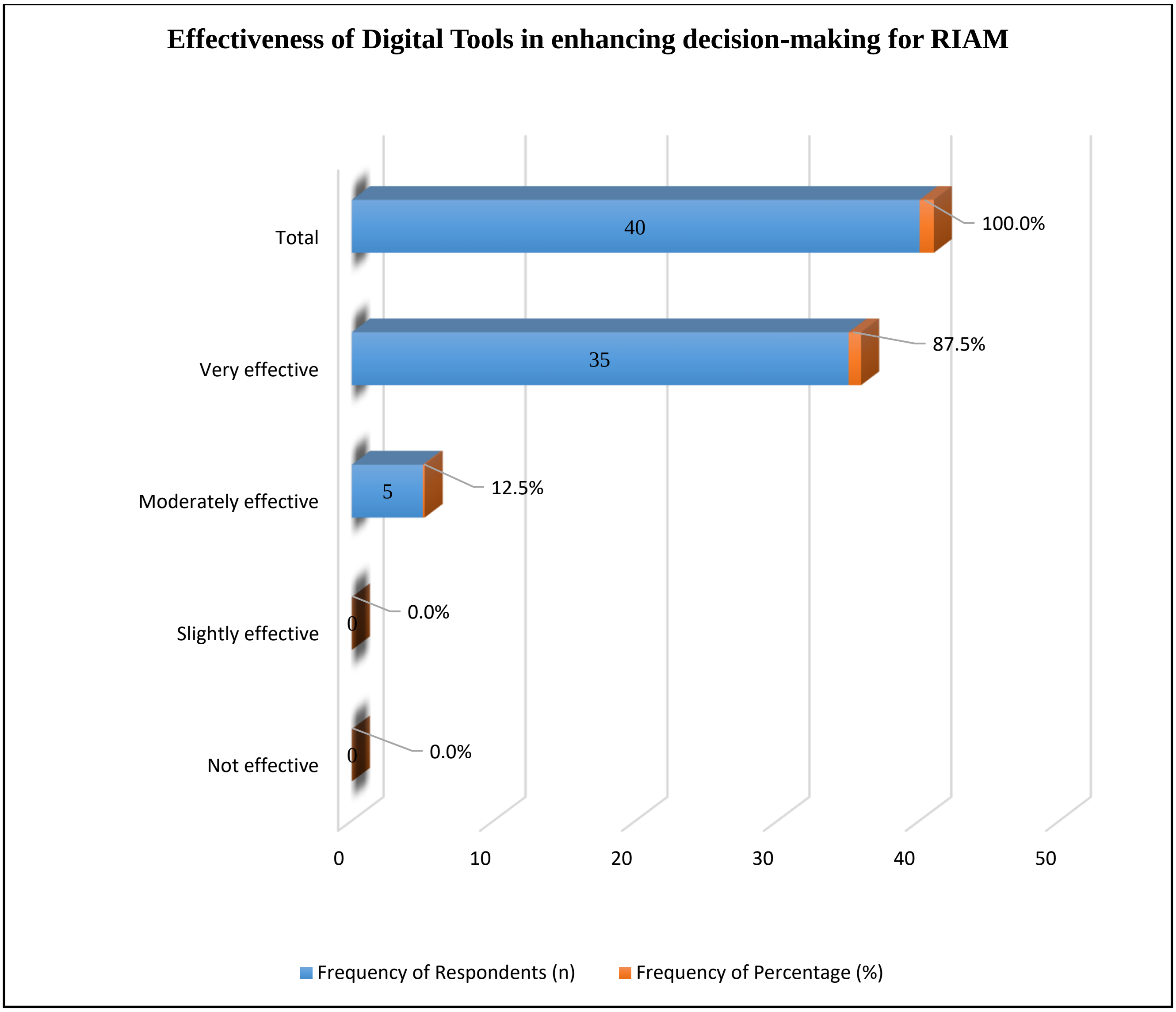


Figure 4-14. Effectiveness of digital tools in enhancing decision-making for road asset Management

The aim of the study is to know the effective of digital tools in improving decision-making for road asset maintenance. The results obtained as of Figure 4.13 show that there is a strong professional conviction as to the impact of digital tools on the decision-making process for road asset maintenance. A vast majority of the respondents, 87.5%, which is 35 individuals, classify digital tools as Very Effective, while 12.5%, or 5 individuals, classify digital tools as Moderately Effective. The most important point is that no individuals classify digital tools as Slightly Effective or Not Effective. The results show that individuals in the sector recognize digital tools as tools that can help in the maintenance of road assets and not as tools that can help in administrative activities. The high efficacy of digital tools implies that if more investment is made in intelligent tools, human errors can be drastically reduced.

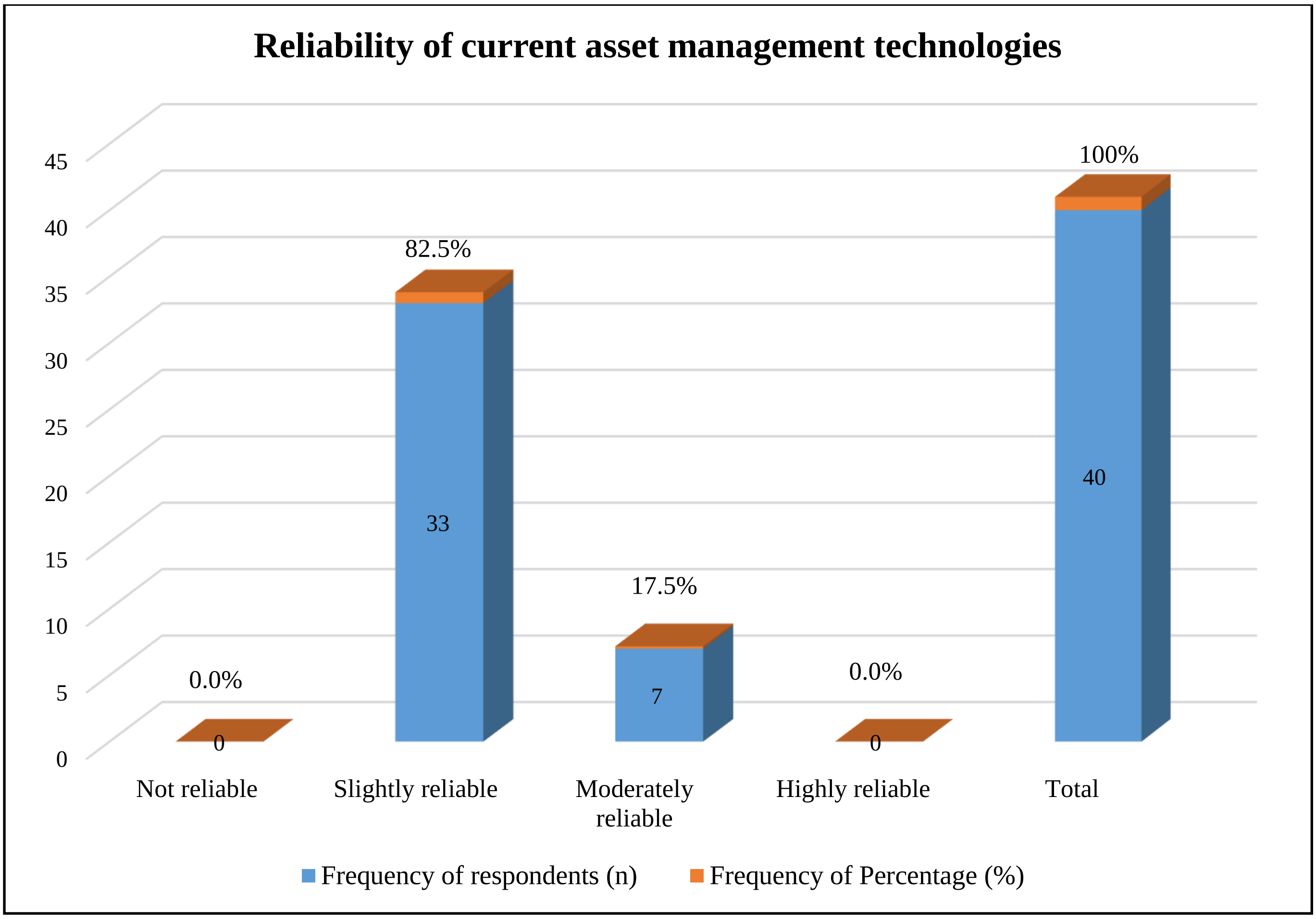


Figure 4-15: Reliability of current asset management technologies in detecting early signs of road deterioration

The bar chart above shows the level of reliability of available asset management technologies as perceived by the respondents (n=40), which indicates one of the major problems of technological reliability. It is evidenced that most of the respondents were uncertain about the reliability of the system, with the highest number of threats voters recording Slightly reliable 82.5% (n=33 respondents). A very small number of respondents voted Moderately reliable 17.5% (n=7 respondents). Notably, the two extreme points of reliability Not reliable & Highly reliable registered zero votes (n=0). The observed concentration of data points at the bottom to middle portion of the reliability scale seems to indicate that, although these technologies do work, possibly in a erratic manner, which is very likely to create much uncertainty during important decision-making moments, thereby confirming the need for a thorough assessment & upgrade of the technological infrastructure of supporting systems of road asset management.

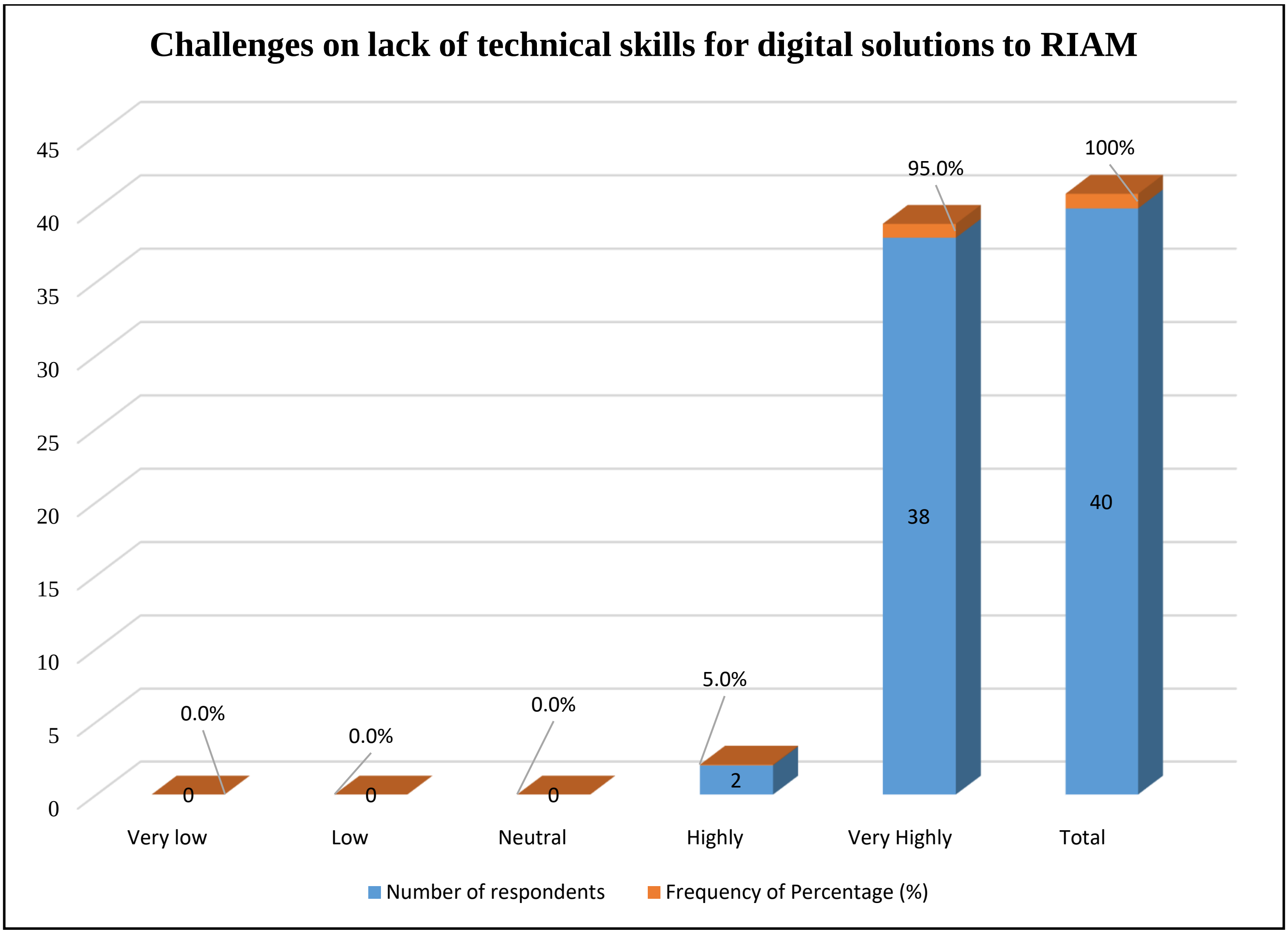


Figure 4-16: Organizational challenges due to limited technical capacity in leveraging intelligent digital solutions

The study inquires to know the challenges associated with the lack of technical skills to fully leverage intelligent digital solutions in the Organization. The responses available in Figure 4.16 have clearly demonstrated the serious, almost universal problem associated with the availability of the required skills that must be employed for the optimal usage of intelligent digital solutions. The overwhelming consensus has been achieved among the respondents, where 95% (n=38 Participants) have responded to the problem associated with the scarcity of the specified skills as Very Highly, while the remaining 5% (n=2 participants) have responded as Highly. The absence of responses in Neutral, Low, or Very Low has effectively demonstrated the gravity and universality of this human resource constraint. These findings are consistent with previous established literature in the field (Bihon 2017; Girma and Mulatu 2025; JICA 2018; Sahle et al. 2025; Tadesse 2025).

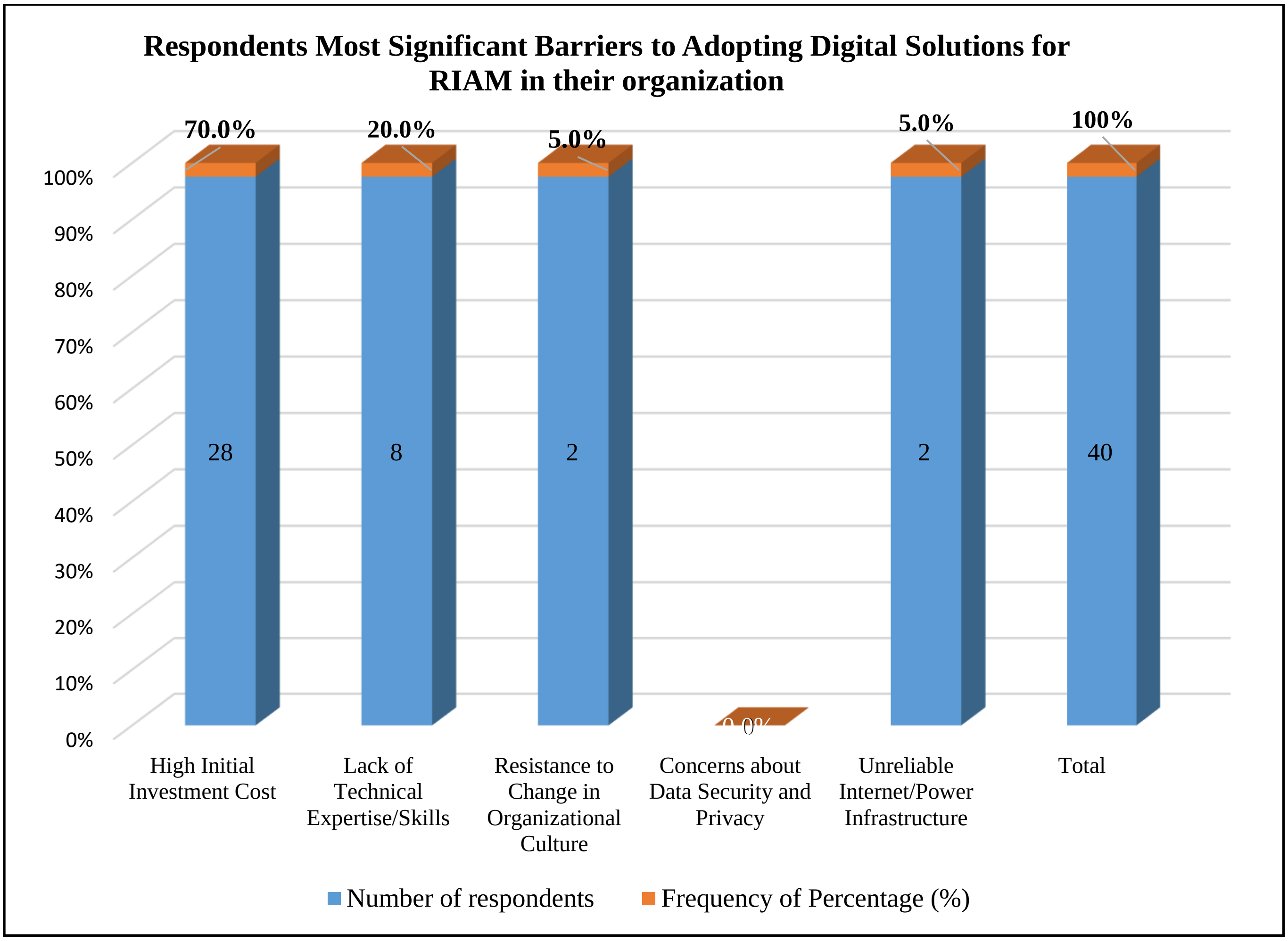


Figure 4-17: Key barriers to adopting digital solutions for road asset management within organizations

The Above figure 4.17 represents the results obtained from the survey in terms of the essential factors hindering the use of digital solutions for road asset management for the participating organizations (n=40) clearly show that financial and technological constraints are the most important factors with the highest criticality. The initial investment costs are the most important factors hindering the application of digital solutions for road asset management for the participants represented by 70.0% (n=28), whereas the absence of technical knowledge or training comes second with the critical importance represented by 20.0% (n=8). The other less important factors include the resistance to change with the critical importance represented by 5.0% (n=2) and the non-reliable data/technology with the same critical importance represented by 5.0% (n=2). However, for the critically important factors related to the issues of data or information security, none were reported by the participants represented by 0.0%.

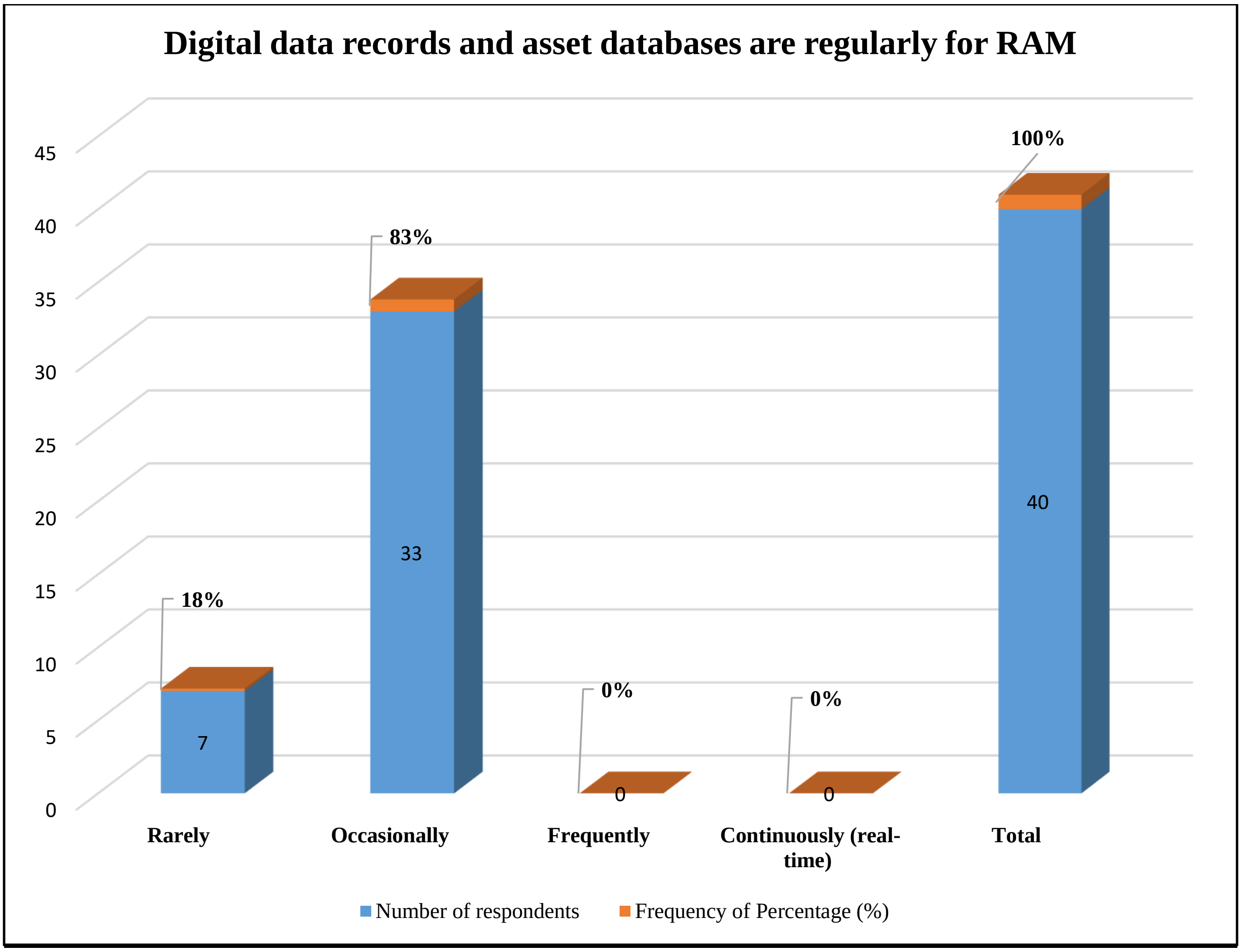


Figure 4-18 : Regular updating and effective use of digital records and asset databases for long-term road asset management

The Above figure 4.18 illustrates the prevalence of data records on a regular basis and asset database updates for RAM among the surveyed organizations (N = 40), indicating blatant data latency. The analysis of the frequency with which digital records and asset databases are updated and effectively used for long-term road asset management strategy reveals a significant limitation in systematic practice. The majority of respondents, comprising **82.5%** (n=33), indicated that this utilization occurs only **occasionally.** In this study there are seven respondents, which is roughly equivalent to 17.5%, who answered “rarely.” It is important to mention that there is no answer to represent continuous utilization, meaning real time utilization, which implies that the organization does not have an effective process to make use of digital data in its strategic planning process.

4.6 Road infrastructures Asset management Framework

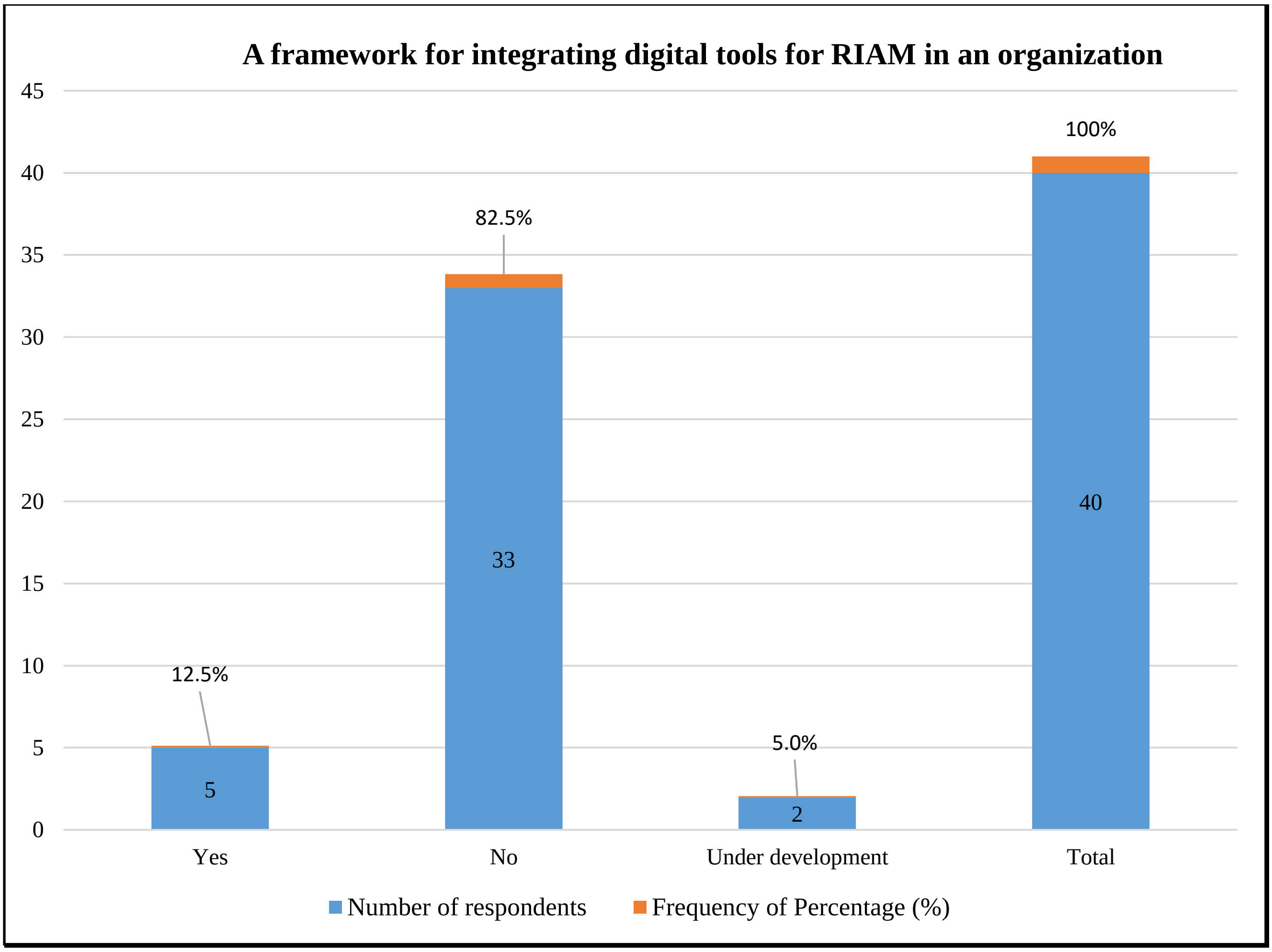


Figure 4-19: Respondents view on the status of a formal framework for integrating digital tools in their organization with the existing road asset management system

An integration framework for digital tools for RIAM, as explained by the figure 4.19, an organizational basis, 2 respondents, 5.0% of the respondents clearly indicated that currently there is no framework in place to integrate digital tools at their respective organizations. In addition, it is noted that there were an estimated 33 respondents, 82.5% who claimed that there was a framework, but it may not be present. Only 5 respondents, 12.5%, were in agreement that there is indeed a framework for integration of digital tools. On the other hand, only 2 respondents, 5.0%, reported that the framework was still under development. Regardless of this finding, it is evident that the respondents had a well-grounded concept of what is needed from an effective framework for integration. These findings are consistent with previous established literature in the field (Bihon 2017; J.Tadesse 2025).

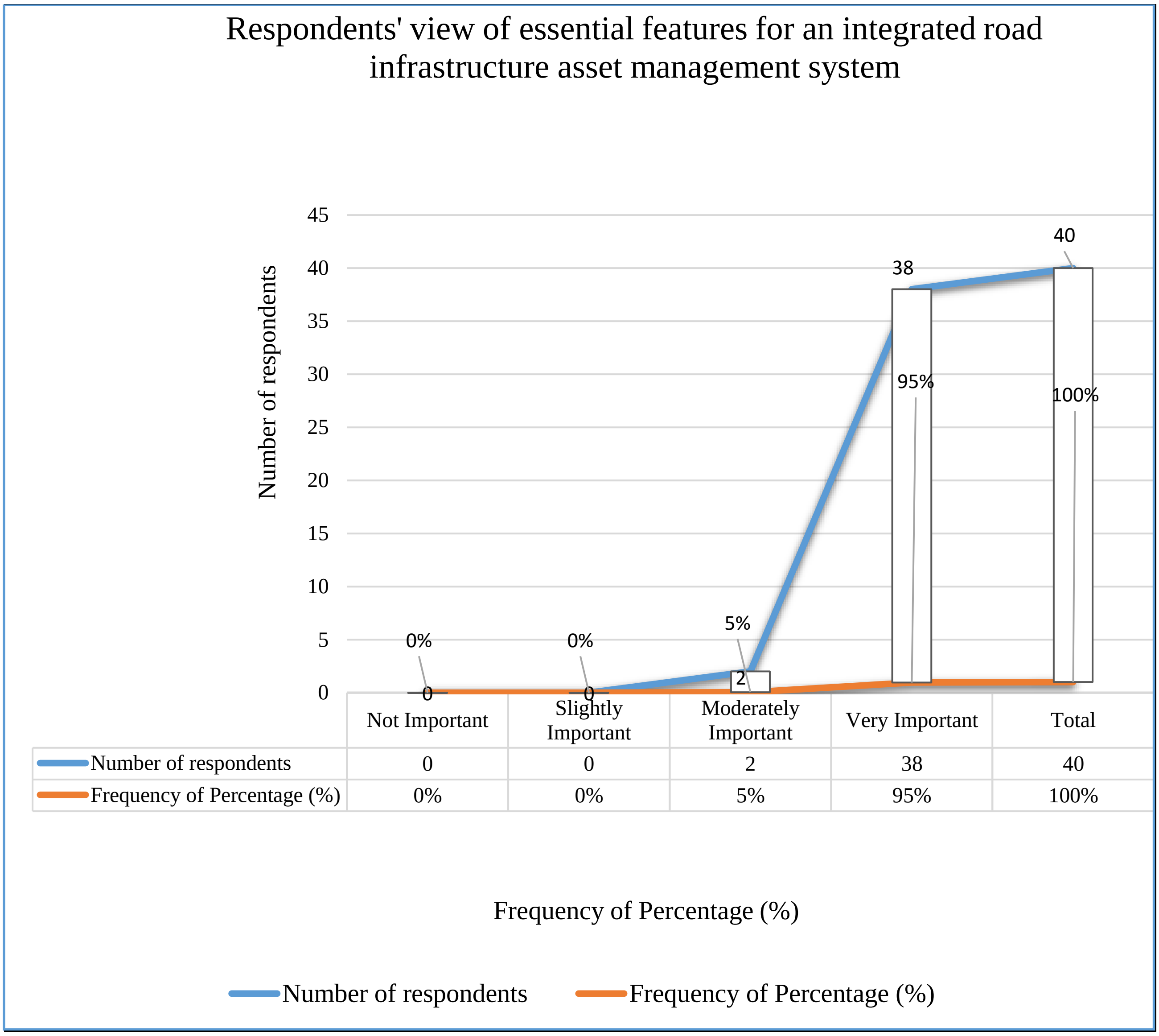


Figure 4-20: Respondents' assessment view of essential features for an integrated road infrastructure asset management system.

The findings highlighted by figure 4.20 show that the evaluation of the significance of the core features for a future integrated asset management system shows a nearly unanimous emphasis on the issue. The following features were identified as highly important: Real time Monitoring, Interoperability, Mobile Access, Automated Reporting, and Life-cycle Cost Analysis. Out of 40 participants, 38 of them, 95%, viewed the above features as being Very Important, whereas just two participants, 5%, believed that these features were Moderately Important. The lack of answers in the other categories indicates that there is a well-defined and cohesive strategy regarding future technological upgrades. In particular, the integration of the advanced functionalities mentioned above is crucial for improving efficiency and implementing an evidence based approach to decision-making and lifecycle cost control.

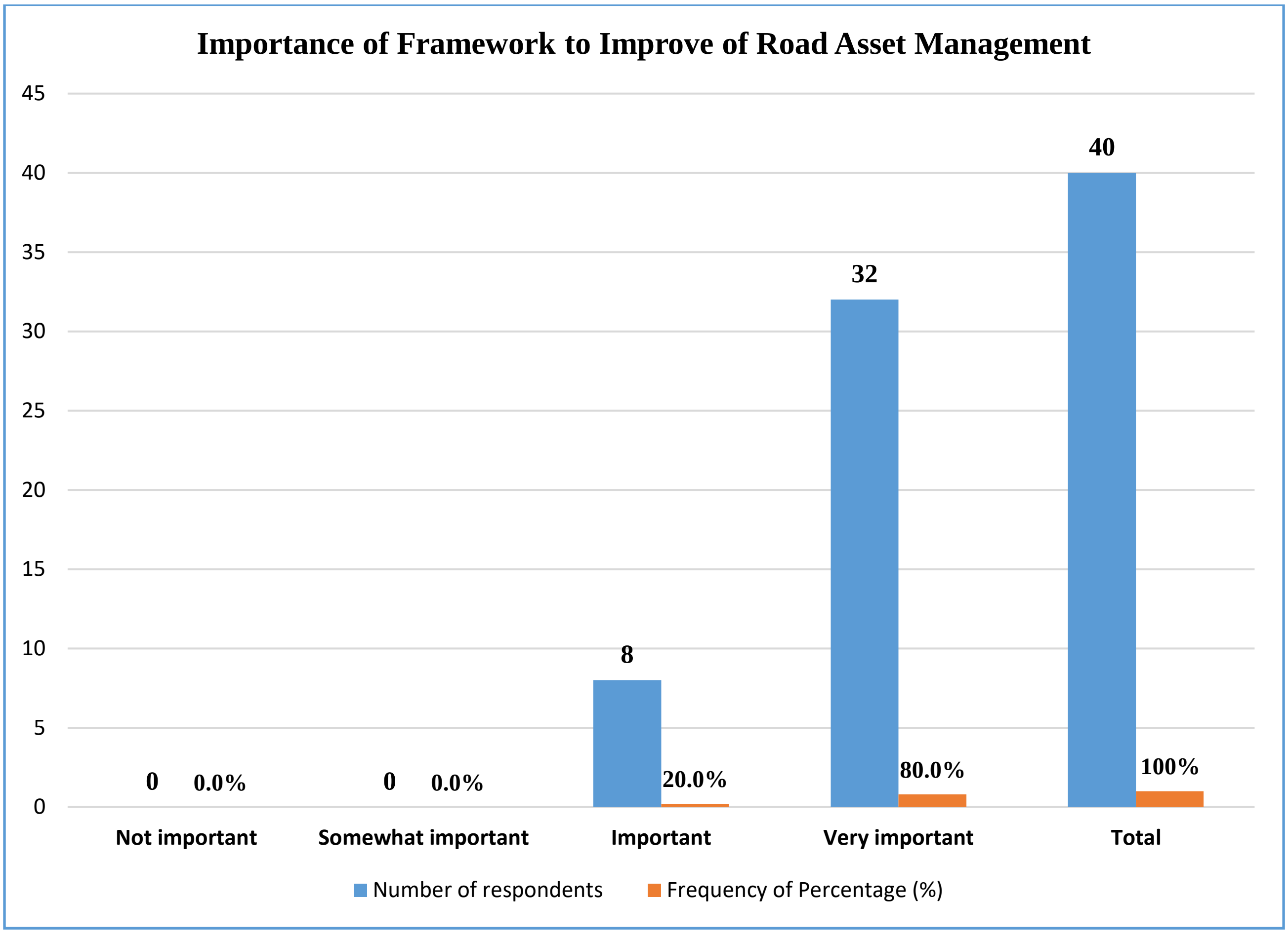


Figure 4-21: The importance of an integrated, technology driven asset management framework in enhancing road management outcomes

The data as a whole represents a significant lack of strategic fit, indicating a significant organizational gap within formalized structures concerning the integration of digital tools, despite the universal recognition of their significance within asset management. The bar chart labeled as Framework to Integrating Digital Tools for RIAM in Organization represents a lack within formalized structures in terms of RIAM, as represented by 45.0% (n =18) who selected that there is no framework in place and a further 37.5% (n=15) suggesting 'maybe,' thus indicating an organizational gap in deriving a formalized strategy, as a total of 82.5% (n=18 and n=15) represent a lack of formalized strategy, as opposed to a significant universal recognition of their importance, as represented in the graph labeled Stakeholder Rated Importance of Key Features for an Integrated Asset Management System, indicating a significant recognition, as a total of 95% (n=38) selected 'very important', and as represented in another graph labeled as Perceived Importance of an Integrated, Technology Driven Asset Management Framework, as a total of 80.0% (n=32), selected 'very important,' thus acknowledging a significant organizational gap between strategic need and organizational structure. This was further confirmed a finding strongly supported by the literature (Bihon 2017; J.Tadesse 2025; Sahle et al. 2025)

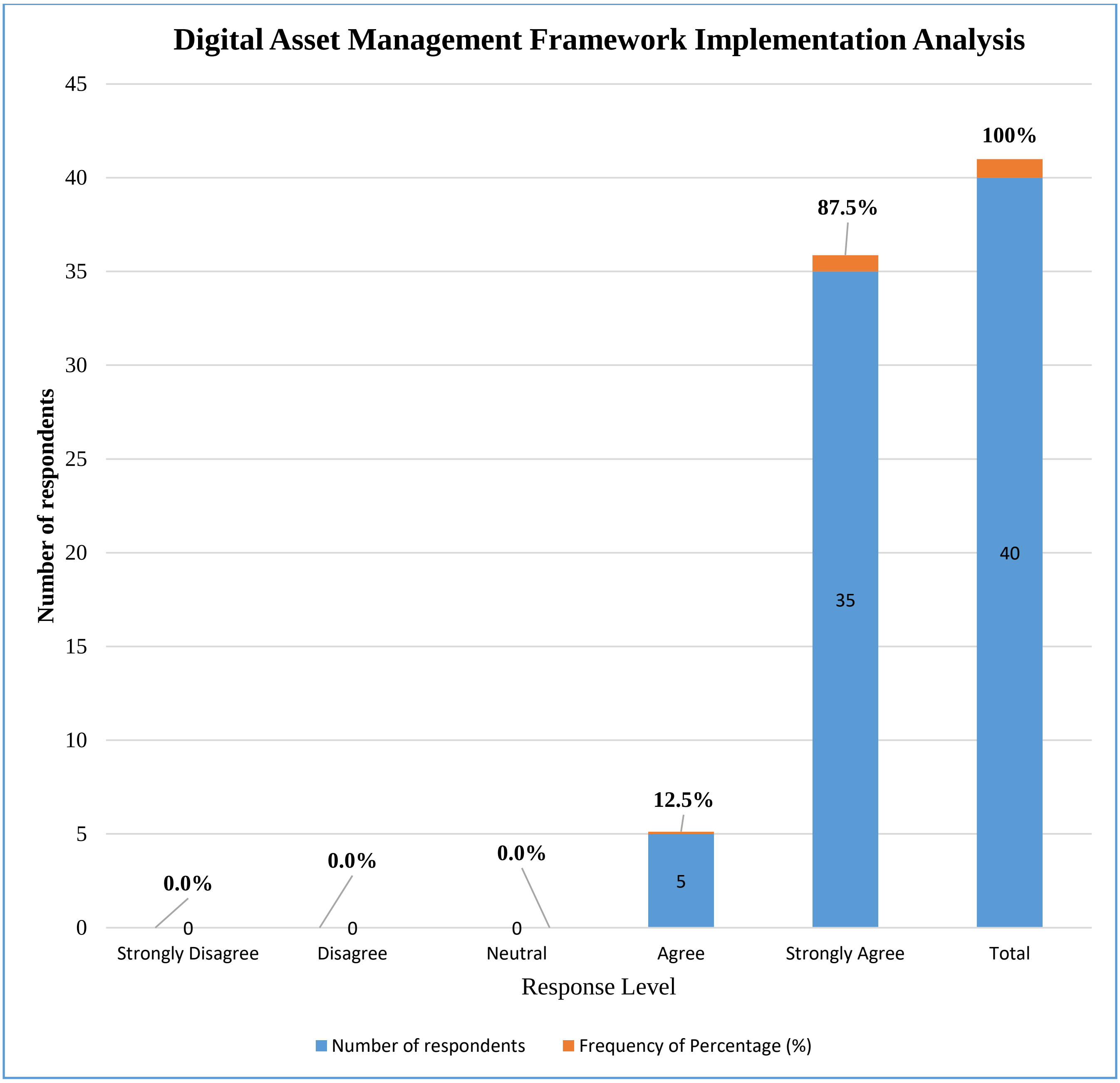


Figure 4-22: Respondents view on status of actual investment in staff training and capacity development for effective implementation of Digital RIAM frameworks.

The study finding figure 4.22 explained that the essential of human capital investment for a digital asset management framework implementation 35 respondent 87.5% strongly agreed to implementation of the Digital asset IDS RIAM and 5 respondent 12.5% response agreed to implementation of the digital frameworks by allocating significant resources, professional capacity building by staff training and skill development. No respondent response Neutral, disagree. The cooperative perspective underscores that while technological tools are essential, the transition to a digital RIAM frameworks in Addis Ababa’s. This was further confirmed a finding strongly supported by the literature(Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025).

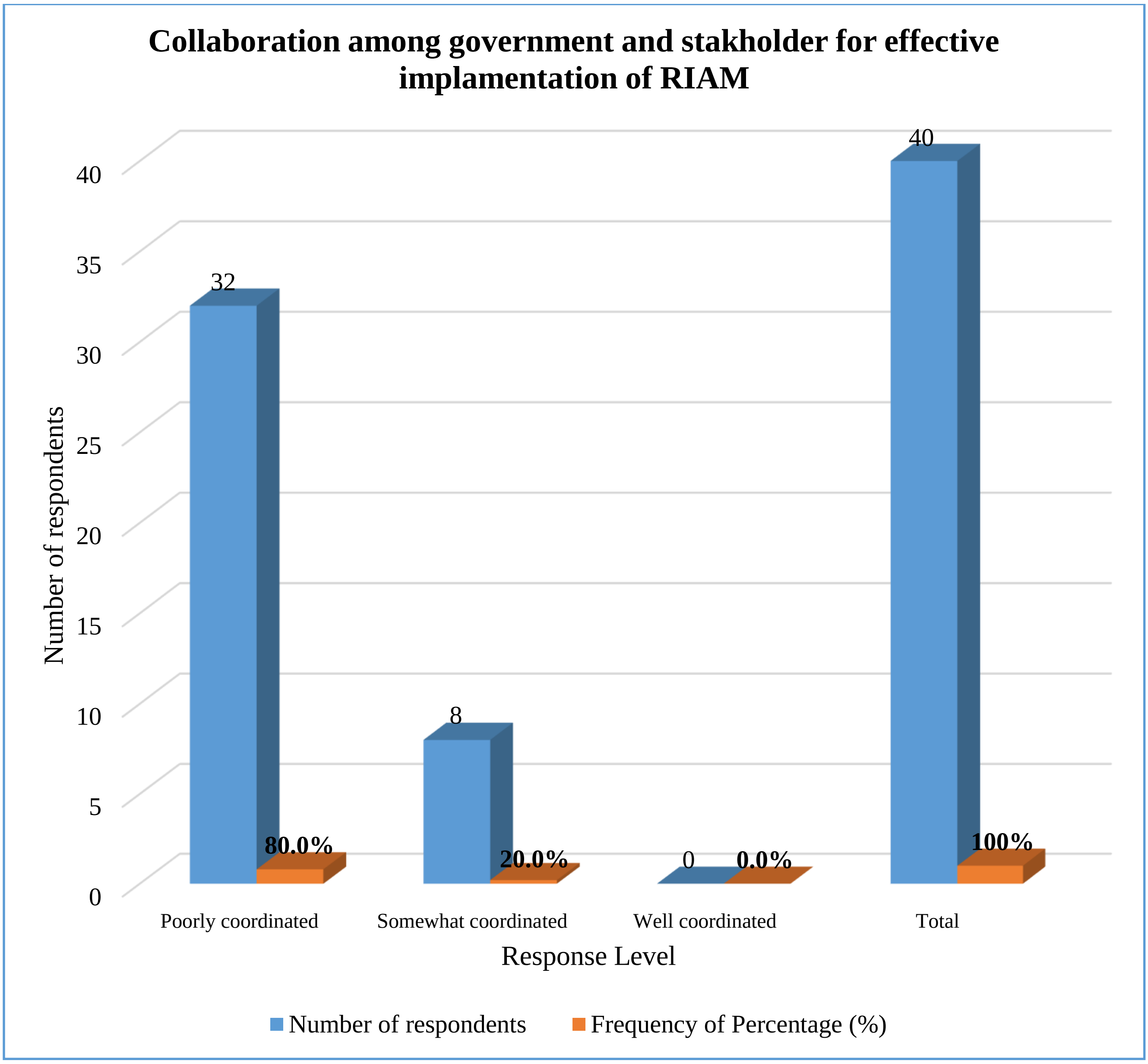


Figure 4-23: Coordination of collaboration among government agencies, consultants, and contractors in digital asset management systems.

Figure 4.23 above illustrate how well key stakeholders are cooperating with one another to implement the digital asset management Framework in Addis Ababa. The results from 40 respondents have shown that cooperation is encountering serious setbacks. A considerable number of respondents, (80.0%, n = 32) revealed that the coordination is Poorly coordinated. Only a meager number of respondents, 8 persons or (20.0%, n = 8), replied that it is Somewhat coordinated. This is alarming because no one from among the respondents chose Well coordinated at all (0%). Such a marked attitude clearly reveals a great deficiency of cooperation at an organizational/agency level. One may wager that this would be a seriously serious impediment for a smooth implementation of a digital asset management framework.

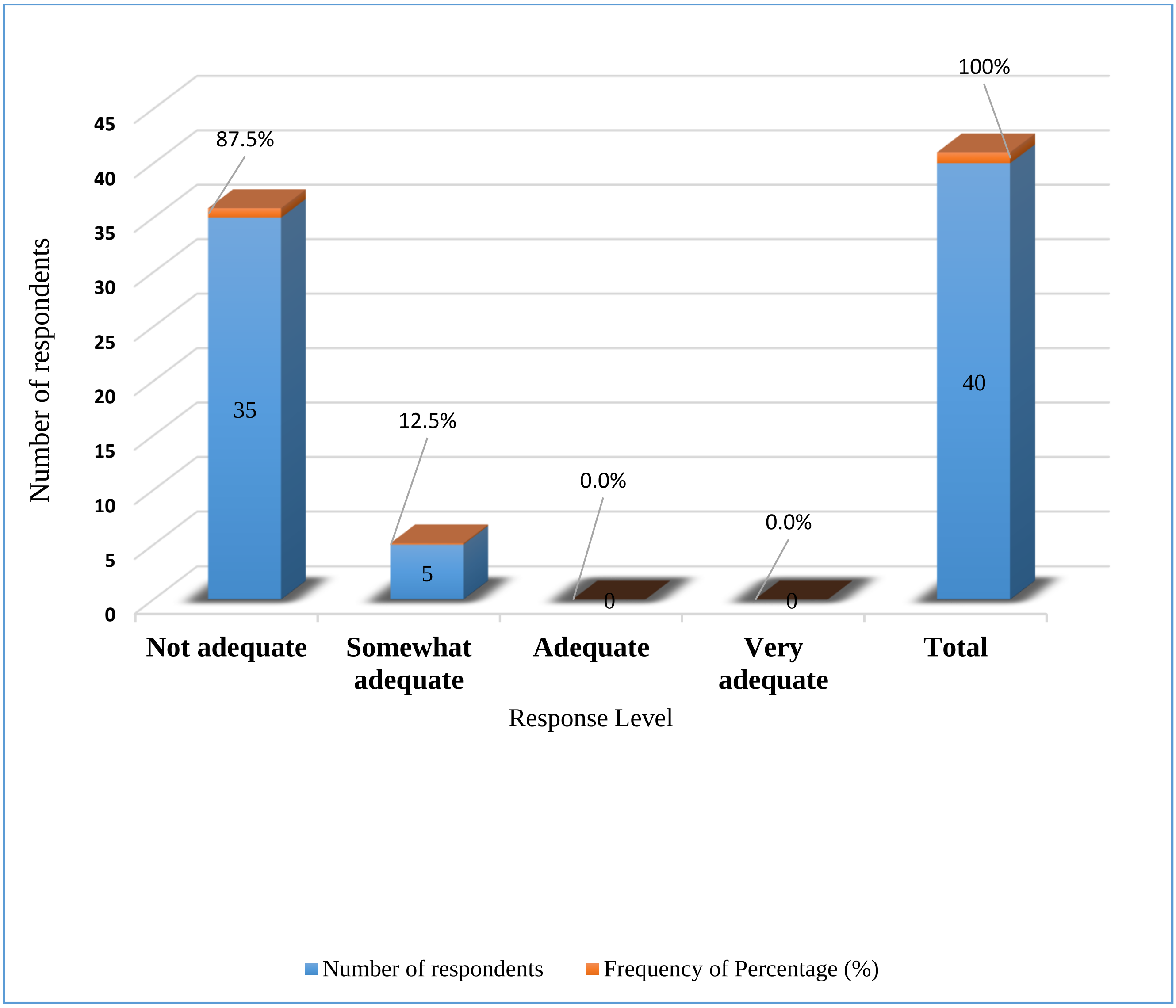


Figure 4-24: Adequacy of policy and regulatory frameworks in facilitating the adoption of digital solutions for road asset management.

The findings in figure 4.24 suggest that almost all the respondents feel that the current policy and regulatory environment is not adequate to facilitate the adoption of digital solutions in the area of road asset management in their respective organizations. Only 12.5% or 5 out of 40 believed that the environment is somewhat adequate, whereas 87.5% or 35 believed that it is not adequate. It may be observed that no survey participant felt that the environment is adequate or very adequate. These observations imply that there is a significant gap in the policy and regulatory environment that could act as an obstacle to the adoption of digital approaches in the area of road asset management.

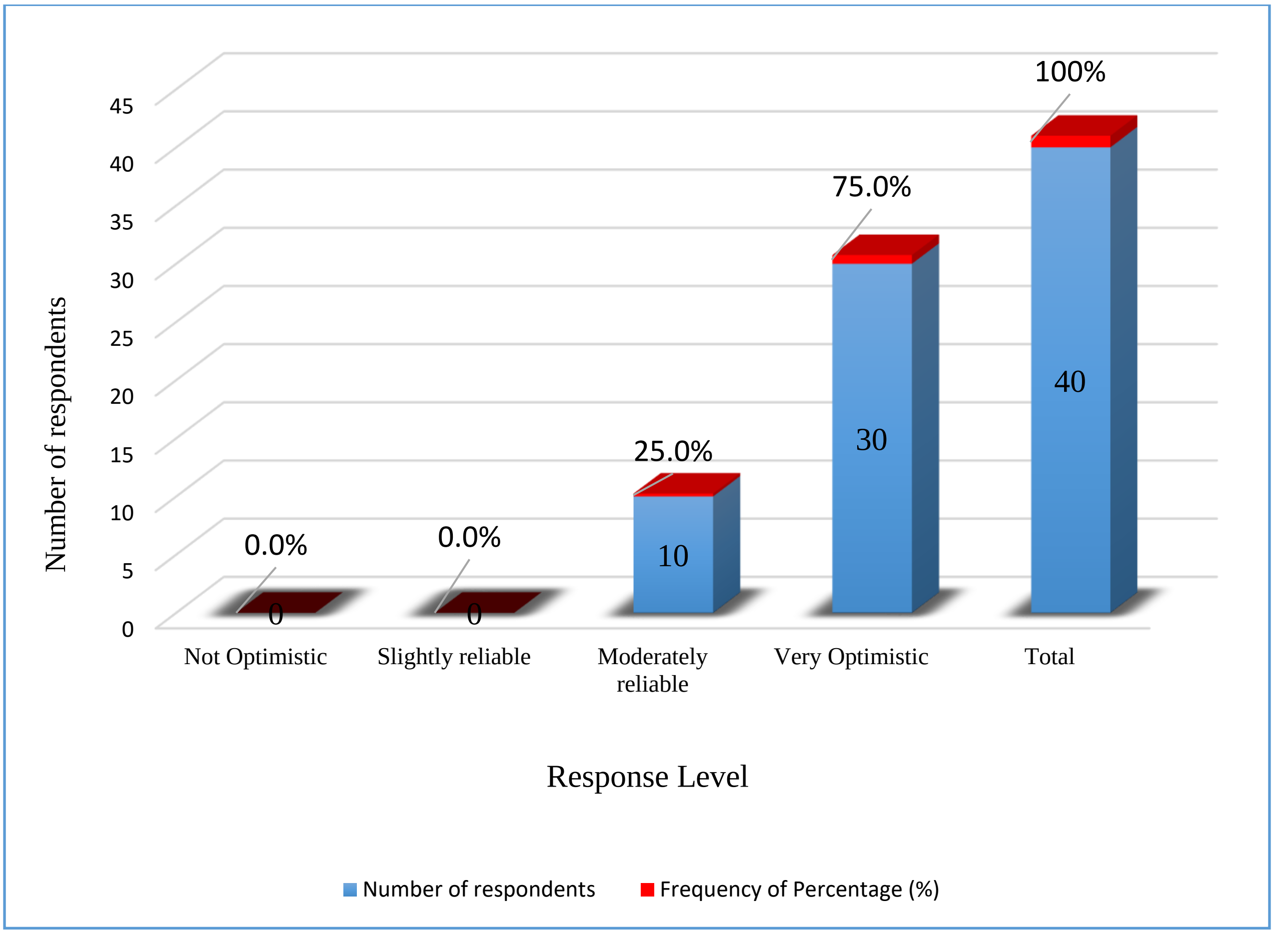


Figure 4-25: Perceptions of optimism regarding the potential of intelligent digital solutions to enhance road asset management in Addis Ababa

Future optimism for smart digital solutions in managing road assets is quite revealing. Figure 4.25 presents how respondents feel about the potential impact of smart digital solutions on improving road asset management in Addis Ababa over the next five years. From the data collected from 40 respondents, there is an overlying feeling of confidence in these solutions. A total of 30 respondents, that is 75% of the respondents, were Very Optimistic, while 10 respondents selected Moderately reliable, which accounts for 25%. Nobody chose Slightly reliable and Not Optimistic, so it means that 100% believe in the positive potential impact of intelligent digital solutions. This overwhelming positivity indicates that stakeholders see the real value and transformative power of technology, thus opening ways for future investments in and the use of advanced digital tools for the effective management of the city's road infrastructure. *This finding aligns with various literature* (Bihon 2017; Girma and Mulatu 2025; Sahle et al. 2025; Tadesse 2025)

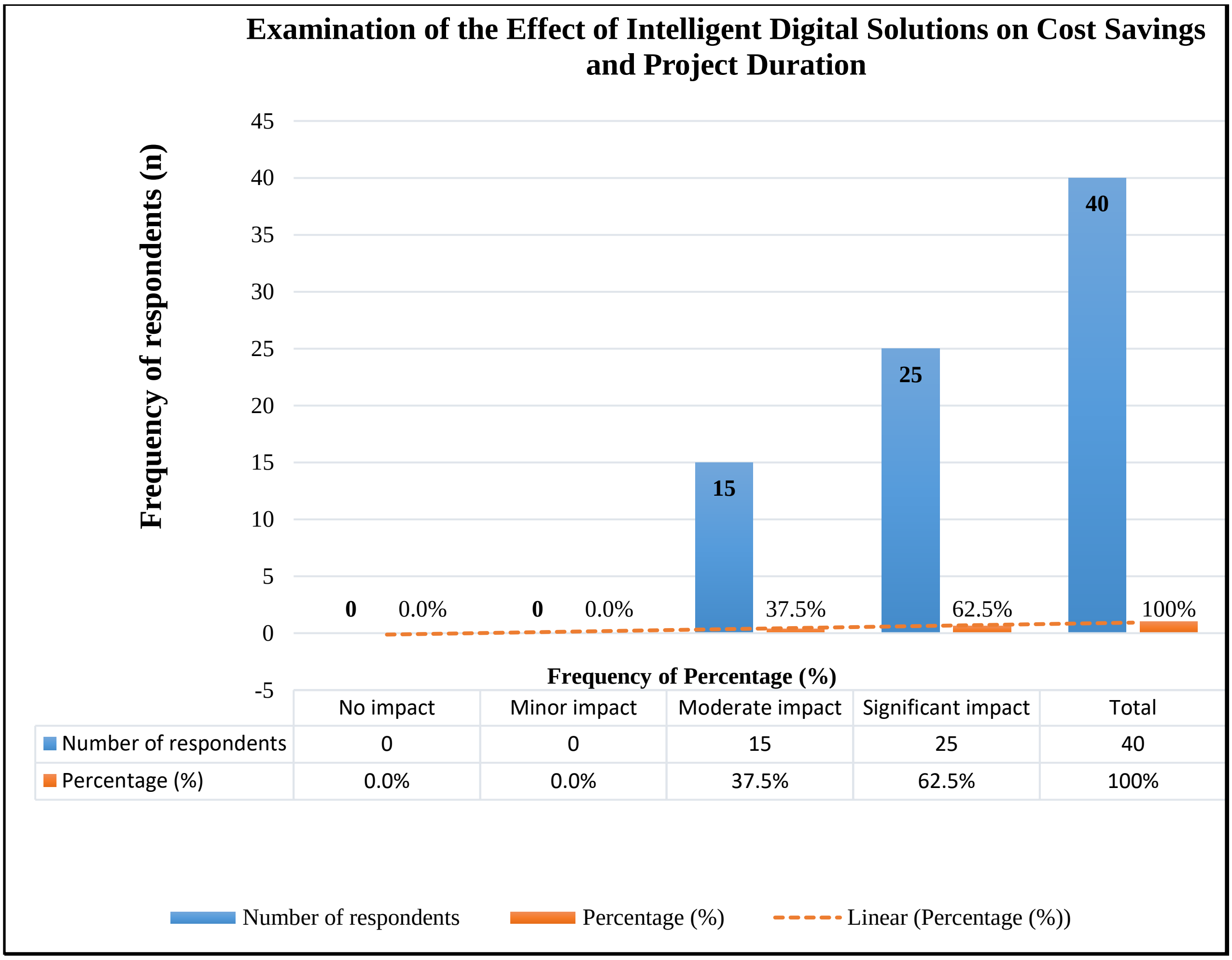


Figure 4-26: Impact of Intelligent Digital Solutions on Cost Savings and Project Lifespan in their organization

The above figure 4.26 illustrates the perceptions of the study participants in relation to the effect of intelligent digital solutions on cost saving and the lifespan of projects in general, and specifically in the realm of road asset management in their organizational setting. As postulated in the study's hypotheses and with a total of 40 study participants, the results are unequivocal in that such digital solutions are viewed as positively impacting in nature. Indeed, a vast majority of 25 study participants (62.5%) were of the significant impact type, while the other 15 respondent (37.5%) were of the Moderate impact persuasion. Importantly, a unified consensus in relation to the impact being of Minor impact and No impact in nature was shared by no study participant (0.0%), as it ideally matters little for the study' analysis. This finding aligns with various literature(Attencia and Mattos 2022, 2022; Biswas and Wright 2022; Caldera et al 2021; Girma and Mulatu 2025)

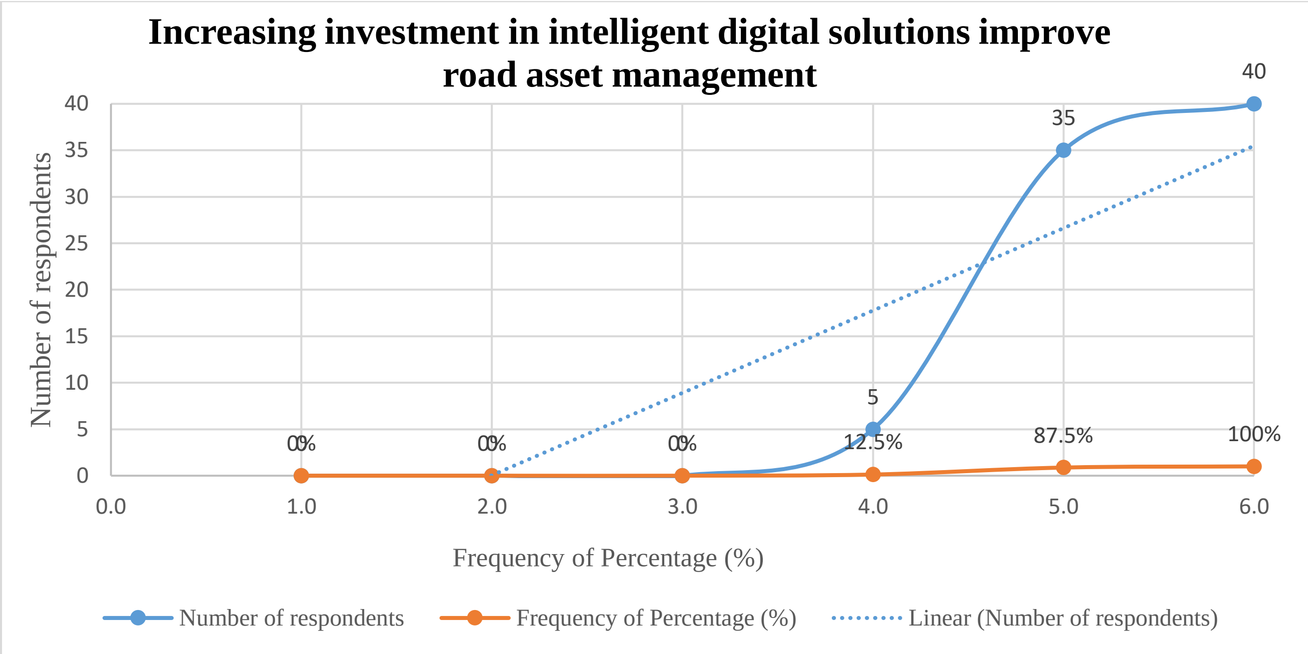


Figure 4-27: Respondents view of digital solutions for road asset management

The above figure 4.27, shows an extremely positive impression held by the respondents towards the impact of increased investment in intelligent digital solutions on road asset management in Addis Ababa. Not one out of a total of 40 respondents agreed to strongly disagree, disagree, or neutral in this perception, with 5 respondents 12.5% agreeing and an overwhelming number of 35 respondents 87.5% strongly agree that increased investment in these technologies would result in the improved management of road assets in their organization. The consensus among the respondents, not to mention the fact that almost nine out of every ten agreed to the strengthened perception, clearly portrays the belief in, as well as the organizational preparedness to justify the additional investment in, these technologies.. This finding aligns with various literature (JICA 2018; Tadesse 2025; Yetnayet 2017)

Table 4.3 :Respondents' Digital tech evaluation for road asset communication coordination

Category of Questionnaire	**Response Level**	**Frequency of respondents (n)**	**Frequency of Percentage (%)**
Digital technologies have improved the communication and coordination between contractors, consultants, and authorities for effective RAM.	Strongly Disagree	**0**	**0%**
	Disagree	**0**	**0%**
	Neutral	**0**	**0%**
	Agree	**5**	**12.5%**
	Strongly Agree	**35**	**87.5%**
	Total	**40**	**100%**

Table 4.3 brings out a strongly positive perception about the use of digital technologies that have improved communication and coordination between contractors, consultants, and government agencies in the respondents' organizations. Not a single respondent from a total of 40 dislikes or has no perception about the use of digital technologies that have improved interaction between these main stakeholders identified in a road asset management project. In other words, all respondents have strongly agreed that digital technologies have improved interaction between these main stakeholders, as supported by the data that no respondents selected the strongly disagree, disagree, and neutral options, while a total of 5 (12.5%) selected 'agree,' and a total of 35 respondents (87.5%) selected 'strongly agree. This finding aligns with various literature (Biswas and Wright 2022; Guo 2024; Nassereddine et al. 2025; Sajadieh and Noh 2025; Zhang and Ji 2024).

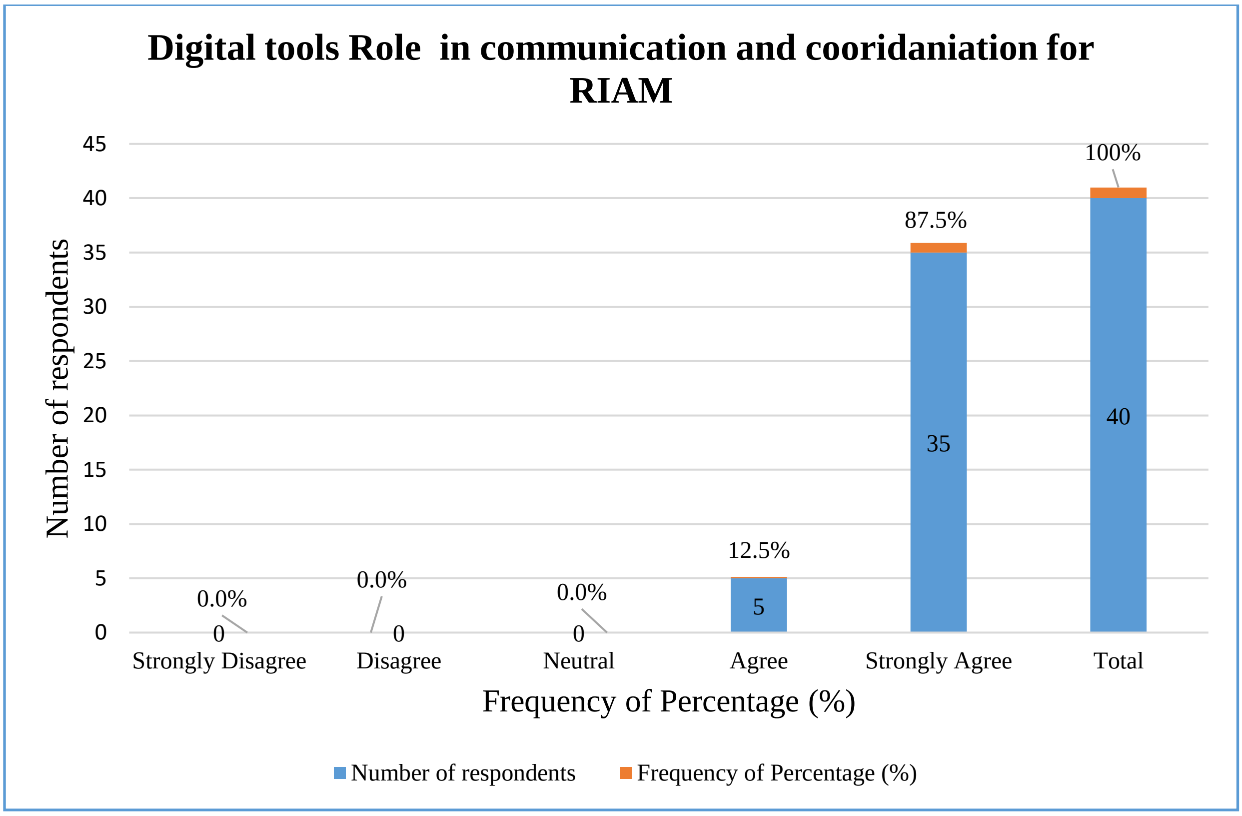


Figure 4-28: Digital tech boosts communication coordination for effective RIAM.

Figure 4.28 Explaining digital technologies have enhanced the communication and coordination among contractors, consultants, and authorities towards effective RAM. The results from 40 participants reflect strong agreement on confirming that digital technologies have been playing a very positive role for collaboration. Here, 35 participants (87.5%) strongly agreed with this preform answer, while others (5 participants = 12.5%) showed agreement. It is notable that 100% agreement has been realized, meaning that none of the participants selected either Neutral, Disagree, or Strongly Disagree (0.0%). Generally, it is evident from Fig above: all participants recognize positive roles of digital technologies towards communication and coordination efforts by contractors, consultants, and authorities. This finding aligns with various literature (Caldera et al 2021; Huang et al. 2025; Hussein and Wafik n.d.; Sajadieh and Noh 2025; Taheri and Sobanjo 2024)

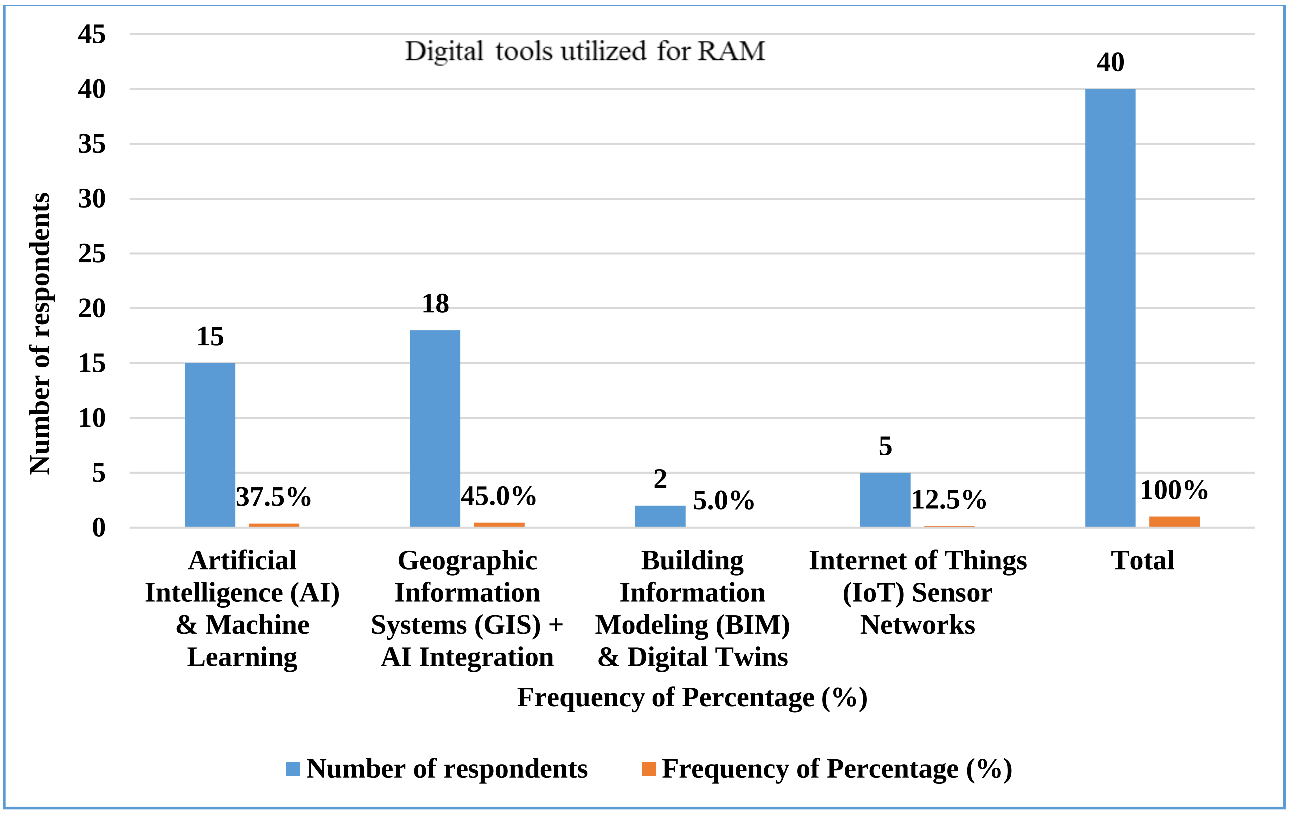


Figure 4-29: Digital Technologies Analysis of Impactful Digital Solutions for Road Asset Management

Figure 4.29 identifies a clear preference for intelligent, analytics oriented tools to enhance coordination in road asset management. The 45% of the 40 respondents selected GIS/GPS and Mobil application with AI integration and however 15 respondent (37.5%) select Al with other (ML) Machin learning tools , emphasizing a demand for predictive, map based diagnostic capabilities. Conversely, (5 participants = 12.5%) prioritize internet of things IoT sensors and BIM/Digital Twins (5%) gained lower rankings. The Study results prioritizing GIS/GPS and Mobil application with AI integration however, AI-driven RIAM is lower select due to current cost complexities or a lack of standardized and Weak real time sensor networks and integrated system. This hierarchy aligns with global research emphasizing the integration of GIS and optimization methods to improve infrastructure fund allocation and decision-making (Caldera et al 2021; Desbalo et al. 2024; Huang et al. 2025; Taheri and Sobanjo 2024)

4.7 Proposed IDS-RIAM Framework:

Proposed Integrated Digital and Smart Road Infrastructure Asset Management framework will remove limitations or challenges that exist in information systems that are not integrated or in activities that are manual intensive in Addis Ababa. In essence, its primary purpose is to provide an integrated digital infrastructure for managing roads that aligns with the proposed movements in digitalization of approaches for managing infrastructure for highways and roads. The IDS RIAM framework allows the structured and integrated management of the road assets in their is framework through the use of intelligent digital solutions. Conceptually speaking, the framework is designed to take the form of a continuous cyclical process that encompasses the application of all the latest forms of digital technology throughout the entire life cycle, according to the latest concept of the digital twin. Intelligent Digital Solutions for Road Infrastructure Asset Management. At its essence, the framework has been designed to be supported by an overall cloud-based data management platform that promotes real time data acquisition, processing, and visualization. The proposed data management platform combines diverse data sets from Artificial Intelligence analytics, Geographic Information Systems, Global Positioning Systems, Building Information Models, Internet of Things sensors, and Digital Twins to facilitate real time Digital Twins of the Addis Ababa road infrastructure. The proposed IDS-RIAM framework seeks to facilitate real time Digital Twins of the road infrastructure in Addis Ababa. This framework is tailored to the Addis Ababa City Roads Authority (AACRA) context, moving from manual/reactive methods to an Integrated Intelligent Digital Solution (IDS).The conceptual framework developed identified key processes, information sources and flows and their integration into Digital Tools RIAM. It also raises awareness regarding the importance of utilizing technological developments to solve challenges in asset management and paves the way to data driven decision-making process.

Figure 4.30 below illustrates the operational flow of the proposed IDS-RIAM framework. The process begins with Data Acquisition (The Senses), where IoT, GPS, and scanning technologies capture the physical state of Addis Ababa's corridors. This raw data is processed by 'The Brain', utilizing AI for defect detection and GPS for Geo referencing. These streams converge in the GIS Master Database, which powers the Digital Twin (The Mind). The Digital Twin executes predictive simulations to produce optimized road asset maintenance plans, which are executed by the asset management crews.

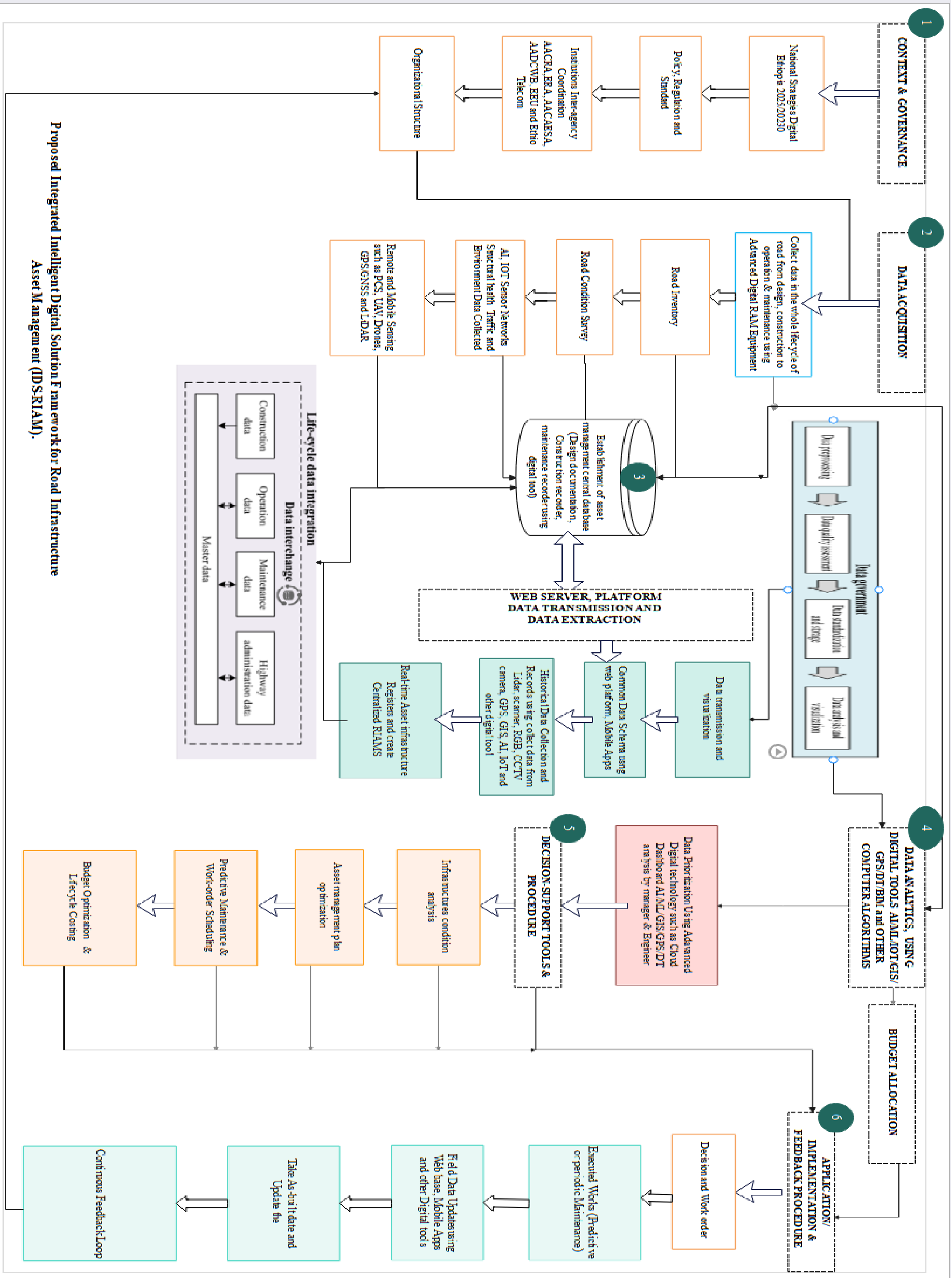


Figure 4-30 Proposed Integrated Intelligent Digital Solution Framework for Road Infrastructure Asset Management

4.8 Summary of Findings and Discussions

The study found that Addis Ababa's key road infrastructure is still managed using traditional, reactive methods. Maintenance relies heavily on manual visual inspections and sporadic data, rather than proactive systems. The traditional sight-based data collection method is practiced by 85% of the respondents, but 85% of them also find the data collected to be poor for making informed decisions, with only 75% reporting that the information is rarely updated and only 25% experiencing occasional changes. There are also severe limitations to accessing available information, with 87.5% of the respondents reporting that data is very difficult to access. The operational problems are also reflected in the governance structure, with 50% of the respondents rating the current management system as very low in terms of adequacy and 25% as very inadequate, with none of them finding it adequate. Difficulties are widespread, with 100% of the respondents agreeing that the absence of data, budget constraints, inefficient use of technology, lack of expertise, and continued use of paper- based systems affect the effective management of RIAM, while 87.5% report severe difficulties in accessing credible and current asset information.

The current level of digital transformation is very rudimentary despite high awareness of the benefits of digital transformation. Awareness of the existence of advanced tools like AI, BIM, IoT, GIS, and Digital Twins is indicated by 87.5% of respondents, and 100% agree that digital solutions would be very or extremely helpful in dealing with RAM issues in the corridors. But 75% state that these technologies are used only to a very low extent, 87.5% strongly disagree that current digital tools significantly improve decision-making, and there is no use of BIM, IoT sensors, AI, or Digital Twins for asset management purposes.

Modernization is further hampered by high capital investment requirements (70%) and lack of technical expertise (20%), with 95% admitting to a large skills gap and 87.5% demanding extensive staff training. Policy and coordination are also weak, with 80% assessing interagency coordination on digital platforms as poor, 87.5% deeming the policy environment as inadequate, and only 12.5% having any formal structure in place for the integration of digital tools, although 8095% assess an integrated, technology driven RIAM system as very important. The stakeholders thus find value in intelligent solutions like the integration of GIS and AI (45%) and Machine Learning (37.5%) for inventories and predictive maintenance, rate real time monitoring and interoperability as very important (95%), do not consider staff and maintenance costs as important or relevant (65% and 70%, respectively), and support the proposed Cloud Road Infrastructure Asset Management System (RIAMS) that integrates IoT and UAV data, with 80% regarding such technology as essential and demanding detailed implementation strategies with policy reform and capacity building.

The study recommends the gradual adoption of a cloud-based RIAMS system that integrates GIS, AI, machine learning, IoT, and UAV data.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The finding indicated that a systemic gap exists between the current state of Road Asset Management in Addis Ababa city Roads Authority (AACRA), and what is necessary for a sustainable form of urban infrastructure. It is found that a reactive operating style exists currently, in which 85% of respondents depend on a conventional visual assessment, while 75% of respondents state that they have access to information about the conditions rarely or not at all. While a degree of awareness of advanced tools such as Artificial Intelligence, IoT and UAV, GPS, GIS and Digital Twin systems is increasing, implementation remains minimal, with more than 75% rating the adoption of intelligent digital technologies as very low and practices largely confined to basic GIS applications.

Critical constraints that affect Road Infrastructures Asset Management are resource intensity, knowing doing gaps, and institution fragmentation. In addition to this lack of technical expertise has been identified as the top constraint by 95% of respondents, while policy frameworks by 87.5%, and lack of interagency cooperation by 80% respectively. It is noted that these challenges can be addressed by adopting a new strategic route that shifts from fragmented and paper based approaches to an integrated and Intelligent Digital Solutions data driven Road Infrastructures Asset Management system.

The existence of a considerable implementation gap between the recognition and application of intelligent technologies among the stakeholders is revealed by the findings. Although 87.5% of respondents perceive the effectiveness of the use of Artificial Intelligence, Internet of Things, and Building Information Modeling technologies for predictive maintenance as well as real time monitoring, the application is still elementary or very poor. It is mainly restricted to elementary GIS/GPS and mobile mapping technology, whereas more advanced technologies, such as HDM-4 and BMS, within the Ethiopian Roads Administration, are mainly utilized for planning purposes rather than real-time monitoring of Road Infrastructure. The current research also emphasizes the preference of 82.5% of stakeholders for the implementation of integrated GIS and AI technologies in proactive approaches for the maintenance of digital infrastructure. Nevertheless, the current accuracy of detection systems for degradation in the existing infrastructure has been evaluated as slightly low, primarily impeded by the lack of technical knowledge of about 95% and the initial investment cost of about 70%. As a result, despite the preference of stakeholders for digital innovation, the current institutional barriers impede the advancement from the current state of asset tracking to a fully integrated digital framework of intelligent infrastructure.

The study concludes that, rather than a lack of interest, the hindrance to adoption of digital solutions is that there is no formal, more encompassing structured approach. Going forward from manual, reactive, piecemeal, departmental handling, towards a holistic Road Infrastructure Asset

Management System (RIAMS), a compulsory adoption of a digital convergence policy is needed. Among these, major hurdles are a lack of interagency coordination (80%), high capital costs of adoption (62.5%), as well as technical expertise deficiencies (27.5%).The major stakeholders recommend (95%) a cloud solutions setup for real-time monitoring, interoperability, and lifecycle costing to facilitate proactive control. But, 45% of the organizations today operate or function without a structured setup, indicating a severe necessity for a systemic shift. For a successful setup, a technology driven holistic setup of GIS, BIM, and internet of things, together with a complete commitment to capacity development by stakeholders, is a must, as it is 100% endorsed by the stakeholders.

In finally conclusion, this study argues that various challenges best the infrastructure asset management in Addis Ababa and are systemic, ranging from manual process systems that are obsolete to fragmented data systems, as well as weak coordination at the institutional level. Whereas these same advanced technologies of AI, IoT, GIS, GPS, IoT sensors, UAVs, and BIM have been recognized as viable solutions, their practical applications remain minimal due to high initial costs and a critical shortage of technical expertise.

5.2 Recommendation

Based on the critical gaps identified in current practices, the following five strategic recommendations are proposed for the Addis Ababa City Roads Authority (AACRA), Ethiopian Roads Administration (ERA), and collaborating governmental stakeholders:

1. AACRA and ERA should establish a unified Digital RIAM Framework and implement a centralized, cloud based platform integrating AI, GPS, GIS, BIM, Mobile apps, and IoT to eliminate data collection, prioritize data, and enable real time road asset recording.
2. Aligning with the Digital Ethiopia 2030 strategy, AACRA, ERA, and other governmental authorities should modernize regulatory frameworks to require digital data submission and automated performance audits for all Road infrastructure assets.
3. AACRA, ERA, and the city administration should execute intensive capacity building training to bridge the know-do gap in digital RIAM.
4. AACRA, ERA, and the city administration should replace manual visual inspection data collection methods with high precision, objective condition data and invest in automated vehicle mounted sensors, UAVs, and advanced robotics technology.
5. Addis Ababa city administration should create a multi-stakeholder steering committee including AACRA, ERA, AAWSA, EEU, and Ethio-telecom to harmonize Road infrastructure assets data standards and ensure digital utility mapping and Road infrastructure assets coordination.

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APPENDIXES

Annex-A: Research Questionnaire

Dear Sir,

The purpose of this MSc thesis in Construction Management is to explore ways through which digital technologies have be utilized to address issues in the management of road assets in the development of corridors in Addis Ababa. The purpose of the Questionnaire: This research uses the questionnaire to support academic research and ensures the confidentiality of the information provided by respondents. It aims to obtain opinions from experts regarding the practice of road asset management and innovative digital solutions.

Sections in the Questionnaire: five sections

Section 1: Respondent Profile
Section 2: Present Practice and Challenges
Section 3: Evaluation of Digital Solutions
Section 4: Proposal of Framework for Digital RIAM Solution
Section 5: Opinions and Recommendation for Digital RIAM Solution

Instructions: Kindly select only one answer for each question using either the checkbox or Likert scale method. Your detailed feedback will be very important for drawing conclusions in this study.

Part One: Personal Information

This portion includes information about the individual and the project he/she is working on.

1. Gender: Male ☐ or Female ☐

2. Age of Respondent: ☐1825 ☐2635 ☐3645 ☐4650 ☐Above

3. Education: ☐Higher diploma ☐BSc/BA ☐MSc/MA ☐PhD

3. How long is your experience in the road Construction and asset management field? ☐15 year's ☐510 years ☐1015 years ☐1520 years ☐More than 20 years

4. Who is your main organization? ☐Employer ☐Consultant ☐Contractor

5. Your Position? ☐CEO ☐DECO ☐Executive Officer ☐RAM Team Leader ☐RAM Engineer ☐Senior Management / Director ☐ Other position

Part Two: Questionnaire Concerning Current Practices and Problems in Road Asset Management

This questionnaire seeks to assess current digital solutions for addressing problems related to road asset management. Kindly indicate the extent of your agreement with each of the statements below according to current practices and problems in the Addis Ababa Corridor Development Project.

1. Has road condition data in your organization been regularly collected through traditional methods and is it reliable enough to make sound decisions based on it? ☐Strongly Disagree ☐Disagree ☐Neutral ☐Agree ☐Strongly Agree

2. How well would you say that the current road asset management meets the requirements of maintenance and monitoring? ☐Neutral / Not Adequate or Inadequate ☐Very Inadequate

3. What do you think are the potential obstacles in the implementation of road asset management in Addis Ababa corridors? (Choose all that applies) ☐ Insufficient availability of reliable and up-to-date information ☐ Insufficient financial resources ☐ Limited budget & inefficient schedule for maintenance tasks ☐ Inefficient monitoring processes ☐ Lack of qualified staff for effective asset management tasks ☐ Use of manual and paper based methods ☐ All of the above

4. How difficult would you say it is to obtain up-to-date and accurate road asset information in your company? ☐ Not difficult at all ☐ Difficult

5. As an employee in this company, are you aware of how Intelligent Digital Solutions can help overcome challenges in road asset management implemented by your company? ☐ Yes, I am ☐ No, I am not ☐ Partially aware ☐ I do not know

6. Do you think that the existing digital technologies in road asset management currently improve decision-making in the development of the corridor of Addis Ababa? ☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

7. Intelligent Digital Solutions such as AI, BIM, DT, GPS GIS, IoT sensors, etc., are appropriately utilized or integrated into the practice of road management in your organization ☐ Very low ☐ low ☐ Neutral ☐ Highly☐ Very Highly

a. Artificial Intelligence and Machine Learning for predictive analytics

b. Building Information Modeling (BIM) for Infrastructure

c. Geographic Information Systems (GIS)

d. IoT Internet of Things. "It refers to a network of physical objects embedded with sensors"

e. Drones (UAVs) for aerial surveying and inspection

f. Digital Transformation (DT) Digital twin

8. What, according to your experience, are the main advantages of applying digital technology for road assets management? ☐ Safety, economy, efficiency, sustainability, ☐ Effective decisions the application of digital technologies helps detect road defects earlier on, ☐ The application of digital road asset management is safe, efficient, economical

9. The application of digital asset management systems enhances the precision of road condition monitoring within corridor projects ☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

10. What is the frequency of updating and analyzing road asset conditions in your company? ☐ Strongly disagree ☐ Rarely ☐ Occasionally ☐ Frequently ☐ Continuously (real-time)

Part Three: Adoption and Use of Digital Tools and Technologies

In this section, please provide details on the adoption and utilization of digital tools and technologies aimed at addressing and eliminating road asset management challenges in Addis Ababa.

1. How familiar are you with the following digital technologies in road asset management? ☐ Not Familiar ☐ Slightly Familiar ☐ Moderately Familiar ☐ Very Familiar ☐ Expert

a. Geographic Information System (GIS)

b. Building Information Modeling (BIM) for infrastructure

c. IoT Sensors (traffic sensors, strain sensors, moisture sensors)

d. UAVs

e. Artificial Intelligence (AI) & Machine Learning

2. Does your organization employ any digital tools or intelligent system (e.g., GIS, BIM, IoT sensors) in road asset management? ☐ Yes ☐ No

3. If Yes, what digital tool(s) are you using? Check all that applies.

☐ GIS

☐ BIM

☐ IoT sensors

☐ Mobile application for asset condition reporting

☐ Data Analytics/AI platforms

☐ Virtual models/digital twins of the corridors for simulation and planning

4. The availability of intelligent technology like (AI, IOT, BIM, DT, GPS, GIS, and Automated Monitoring, Drones) is available in your organization and do you think this digital technology has enhanced the road asset management process? ☐ Yes ☐ No ☐ Maybe

5. In your opinion, what level of benefit would the adoption of these digital technologies bring to solving issues in the corridor of Addis Ababa? ☐ Not Beneficial ☐ Slightly Beneficial ☐ Moderately Beneficial ☐ Very Beneficial ☐ Extremely Beneficial

6. In your opinion, how useful will it be to use these digital technologies to solve problems in Addis Ababa's corridors? ☐ Not useful ☐ Somewhat useful ☐ Moderately useful ☐ Very useful ☐ Extremely useful

7. How useful do you think these digital technologies will be in helping improve decision making on road assets management? ☐ Not useful ☐ Somewhat useful ☐ Moderately useful ☐ Very useful

8. To what extent are digital data and analytics incorporated in your road asset management process? ☐ Not incorporated ☐ Incorporated to some extent ☐ Incorporated moderately ☐ Highly incorporated ☐ Fully incorporated

9. How effective are existing digital asset management tools in identifying early indicators of road asset deterioration? ☐ Not effective ☐ Somewhat effective ☐ Effective to some extent ☐ Very effective

10. Does your organization have issues due to the absence of technological skills needed to maximize intelligent digital solutions? ☐ Strongly disagree ☐ Disagree ☐ Neither agree nor disagree ☐ Agree ☐ Strongly agree

11. What is the biggest impediment to implementing these intelligent digital solutions? (Choose up to two options)

☐ High Cost of Initial Investment

☐ Insufficient Technical Expertise/Skills

☐ Organizational Culture Resistance to Change

☐ Fear of Privacy and Data Security

☐ Unstable Internet and Power Infrastructure

☐ Other (Specify)

12. Digital documentation and asset databases are consistently maintained and utilized efficiently for strategic road asset management planning ☐ Strongly disagree ☐ Disagree ☐ Neither agree nor disagree ☐ Agree

Part Four: Framework for an Integrated System

1. Is there a formal framework or system in place at your organization for integrating digital tools into a comprehensive road asset management Framework? ☐ Yes ☐ No ☐ Maybe ☐ Under development
2. How essential are the following characteristics for a future integrated asset management system? ☐ Not essential ☐ Somewhat essential ☐ Moderately essential ☐ Very essential ☐ Essential
3. How crucial do you think an integrated, technology driven asset management framework is for enhancing road management performance? ☐ Not essential ☐ Somewhat essential ☐ Moderately essential ☐ Very essential ☐ Very essential
4. What challenges do you face in implementing advanced digital technologies in your road asset management processes? (Tick all that apply)

☐ High cost of entry

☐ Lack of technical knowhow

☐ Insufficient infrastructure

☐ Change resistance

☐ Data security issues

☐ Other (please specify)

5. The successful deployment of a digital asset management framework would demand a substantial financial commitment to employee training and skill development ☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree
6. How effectively coordinated is the cooperation between government departments, consultants, and contractors in digital asset management systems? ☐ Poorly coordinated ☐ Moderately coordinated ☐ Well coordinated
7. Is the present policy and regulatory framework conducive to promoting digitalization in road asset management? ☐ No ☐ Somewhat ☐ Yes ☐ Very much so
8. Rate your optimism regarding the prospects of applying intelligent digital technology for optimizing road asset management in Addis Ababa over the next five years on a scale from 1 to 5. ☐ 1=Not at all optimistic ☐ 5=Very optimistic

Part Five: Kindly give your recommendation for digital solution for RIAM.

1. How do you think intelligent digital solutions could affect cost savings and life span of road asset management projects? ☐ No effect ☐ Minimal effect ☐ Average effect ☐ Major effect

2. You think that more investments on intelligent digital solutions will make significant improvements on road asset management in Addis Ababa. ☐ Strongly disagree ☐ Disagree ☐ Neither disagree or agree ☐ Agree ☐ Strongly agree

3. Communication and coordination of contractors, consultants and government officials in the corridor road development projects has improved by digital solutions. ☐ Strongly disagree ☐ Disagree ☐ Neither disagree or agree ☐ Agree ☐ Strongly agree

4. Which digital solution or technology do you think needs priority improvement in road infrastructure asset management?

5. Could you share other comments or suggestions regarding intelligent digital solutions in the road asset management of Addis Ababa's corridors?

Annex-B: Research Interview Questions

Below are 13 interview questions designed to generate qualitative information regarding the utilization of intelligent digital technology for managing road assets, in line with your MSc thesis case study on Addis Ababa corridor development?

1. Could you describe the current process for collecting data on the condition of road assets (like pavement quality, signage, and drainage) in the Addis Ababa corridors? What technologies or methods are primarily used?

2. In your view, what are the most significant gaps or bottlenecks in the current practice how road asset data is managed and used for decision-making?

3. Does your organization currently utilize intelligent digital platforms or automated tools for road infrastructure asset management?

4. Can you describe the current intelligent digital tools and technologies used by your organization for road asset management in Addis Ababa's road infrastructures?

5. In your experience, what are the primary benefits of using digital solutions in managing road assets?

6. What are the primary obstacles or difficulties your organization encounters when trying to adopt digital technologies for managing road assets?

7. In your professional opinion, do you know much about digital approaches for infrastructure related to GIS, drones, IoT, or Digital Twins? If so, which one, in your experience, has the greatest possible use for transforming infrastructure management for roads in Addis Ababa?

8. How do these digital solutions improve collaboration and communication among different stakeholders such as authorities, contractors, and consultants?

9. Can you describe any past or ongoing initiatives within your organization to implement a new digital tool for asset management?

10. Would you talk about the usual or traditional ways your company collects road asset data? And how did you put the collected data in order of importance for road maintenance?

11. Based on your experience, how does the Digital Ethiopia 2030 Strategy, policy framework, government regulations, budget concerns, and organizational structure influence the road asset management system?

12. What kinds of digital technology would you suggest being used in the future?

13. From your perspective, based on years of experience, what is the likelihood that a breakthrough in digital technology will affect Addis Ababa's road asset management practices within the next five years?

Annex-C: Publishable Manuscript