

PROJECT ID: .....

**“FRAMEWORK FOR THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) TO  
TRAFFIC MANAGEMENT IN RWANDA”**

**A DISSERTATION**

*Submitted by*

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## **DECLARATION**

I, **NKUNDABERA Faustin**, declare that this dissertation is the result of my own work and has never been submitted for any other degree at the University of Rwanda or any other institution.

Students Names: **NKUNDABERA Faustin**

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This research project has been submitted with approval from the University supervisor.

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## **DEDICATION**

This project is dedicated to God and my loving, caring and hardworking family, whose efforts and sacrifices have made my goals of obtaining this degree come true. Words cannot fully express my gratitude to all. I pray that you will live long enough to see the results of my works.

## **AKNOWLEDGEMENT**

God has done tremendous things, I appreciate your excellent provision, protection and assistance throughout that journey.

My gratitude also goes to my family for their encouragement and ideas as I develop in life.

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## **ABSTRACT**

This study presents a comprehensive framework for the application of Artificial Intelligence (AI) technologies in traffic management in Rwanda. The research was driven by growing interest in leveraging AI to address persistent traffic-related challenges such as congestion, inefficient signal control and limited real-time decision-making. Data was collected through structured questionnaires and semi-structured interviews to assess the level of awareness, current adoption, perceived challenges and potential strategies related to AI integration in the Rwandan transport sector. The findings revealed a generally low level of awareness and adoption of AI technologies, across various tools such as machine learning, computer vision and natural language processing. Interviews with key stakeholders highlighted infrastructural limitations, lack of technical capacity and absence of a clear policy framework as significant barriers to implementation. Based on these findings, a context-specific framework was developed, focusing on four strategic pillars: awareness and education, capacity building, policy and regulatory support and infrastructure development. The proposed framework aims to guide policymakers, transport authorities and technology stakeholders in a systematically integrating AI into traffic management in a scalable, inclusive and sustainable manner. This study contributes to the growing body of knowledge on AI in smart mobility and offers actionable insights for enhancing urban transport systems in Rwanda.

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## **CHAPTER ONE INTRODUCTION**

### **1.1 Background of Study**

The transportation sector is important to the economic development of countries worldwide, due to its impact on the well-being of the citizens and the investment involved (Davila et al., 2019). For example, considering the 28 members of EU, the transportation sector has contributed 561 billion Euro in Gross Value Added (around 5% of the total), and employed around 11.2 million persons (Pereirinha et al., 2018). The transportation has also contributed up to 5% of economic growth in New Zealand (Awa et al., 2024) and 3.9 % in USA (Gallen & Winston, 2021). However, the efficiency of transportation systems has been hindered by a variety of challenges, and these challenges include congestion, routing and scheduling inefficiencies, insufficient infrastructure capacity, environmental impact and safety concerns among others (Rathod, 2024). For instance, the INRIX Global Traffic Scorecard (2022) reported that the average U.S drivers lost 11 hours annually due to congestion, costing the economy over 81 billion dollars in wasted time and fuel (Shukla et al., 2025).

In response to those challenges, there has been growing interests among transportation researchers and professionals in investigating the potential of applying artificial intelligence (AI) to tackle some of the previously mentioned challenges, with the aim of enhancing the efficiency, safety and environmental sustainability of transportation systems (Wolff et al., 2019).

These interests are well-founded, as AI offers more than just automation, it provides intelligent, data-driven solutions capable of adapting to dynamic urban conditions, unlike traditional traffic management methods that rely on static rules and limited human oversight, AI systems can process vast volumes of real-time data from sensors, cameras and GPS devices to make instant, optimal decisions (Pillai, 2024).

The artificial intelligence (AI) technology emerged, to give companies a competitive advantage by lowering costs and improving efficiency (Davila et al., 2019). In the world of computer science, Artificial intelligence (AI) focuses on creating computer programs that can handle jobs normally needing human intelligence, such as vision perception, speech recognition, decision making, and language translation (Hamet & Tremblay, 2017). AI has become, a game changer across nearly every imaginable industry including finance, education, entertainment and health care, by making a significant impact, which boosts productivity and efficiency in the fields of e-commerce,

agriculture, gaming, robotics, remote sensing, and industrial processes (Kumain et al., 2020) AI technologies can transform projects, offering companies a significant edge (Abbasi-Asl et al., 2019). For example, in Australia because of fast growth of population Artificial Intelligence (AI) is used for the management of congestion and reduction of the CO2 emission during peak times (Abduljabbar et al., 2019). In Nigeria, due to the rapid urbanization population growth in the cities, Artificial Intelligence (AI) is used to optimize signal timings, predict traffic volumes, manage congestion, predict mobility patterns, facilitating better urban planning and infrastructure development, improve road safety and reduce traffic accidents (Aliu, 2024).

However, the traffic management sector in Rwanda seems to less benefit from the advantages of AI adoption such as AI-based traffic prediction, AI-based parking management, AI-based route optimization and predictive maintenance, as it is still experiencing challenges like lack of adequate road traffic management, public transport characterized by delays, inaccessibility and unpredictability, lack of integrated public transport, occurrence of accidents and incidents in the transport sector, over-dependence on road transport and high transport cost (Mugisha & Venuste, 2024).

In response to those challenges, Rwanda introduced a national AI policy, which has the vision and the mission of leveraging AI to power economic growth, improve quality of life and position Rwanda as a global innovator for responsible and inclusive AI and become a global center for AI research and innovation (Musoni, 2024). After the government of Rwanda established the policy, some domain like banking, commerce and education, integrated the artificial intelligence and are now taking advantage of its use (Uwonkunda & Beco, 2025). In 2019, Rwanda National Police introduced human-like artificial intelligence robotic cameras to fine people for violating traffic rules and enhance road safety (Banerjee et al., 2009), but as earlier stated the problem still remains in other economic sectors such as the traffic management, especially in the domain of traffic prediction, parking management, route optimization, safety and predictive maintenance.

Although it is not clear, the reason why the traffic management sector has not been benefiting from the Artificial Intelligence (AI) technologies. The Rwanda's Guidelines on The Ethical Development and Implementation of Artificial Intelligence, developed by RURA (2022), indicated that the use of Artificial Intelligence (AI) requires significant investment in technology and infrastructure. Also, if AI is not well adopted, it may lead to job losses, especially for low-skilled

workers, but it can create new job opportunities in the latest technological value chain. Since the adoption of AI brings both positive and negative impacts, it is important to develop a structured framework for effective AI integration and provision of guidance on how AI can be applied in traffic management. Therefore, this study aims to develop a framework for the application and integration of AI in traffic management.

## **1.2 Problem Statement**

Traffic management makes the transportation sector to be crucial for a nation's economy, acting as foundation for trades and commerce, recognizing this importance, Rwanda's vision 2050 plan incorporates the development of the transportation as a key pillar for achieving a prosperous and competitive national with a high quality of life by 2050 (Perez-Guzman et al., 2023). Despite these importance, the traffic management still struggles with different challenges, such as safety issues, congestion, emission of Co2 and traffic control (Baynazarov & Xasanboy, 2024). To address these challenges, several research papers have demonstrated how Artificial intelligence (AI) can assist in the traffic management.

The research conducted by Tan et al, (2019) showed that Artificial Intelligence (AI) can help in traffic management by predicting traffic patterns and congestion using AI algorithms to optimize traffic signal timings, reroute vehicles dynamically, controls traffic lights and make them adapt to real-time traffic conditions to minimize congestion. Despite the valuable insights presented, the author did not show a concrete roadmap or set of guidelines for practitioners seeking to successfully implement AI solutions within the complex domain of traffic management.

Further, the study of Jevinger et al, (2024) showed that AI algorithms can enhance public transportation by adjusting schedules and frequency according to demand patterns, minimizing delays and boosting overall efficiency. It showed also that AI-powered systems can optimize public transport routes in real-time, adjusting them based on current demand to improve efficiency and service. However, the research failed to address the crucial aspect of public and industry awareness regarding the availability and potential impact of artificial intelligence technologies, specifically designed for improving traffic management systems. Also, AlKhattabi and AlZahrani, (2022) demonstrated that AI technologies can help in smart parking by implementing AI systems to guide drivers to available parking spaces, thus reducing congestion caused by drivers searching

for parking. A significant shortcoming of the author's work is the absence of a well-defined structure that could serve as a blueprint for the successful integration of artificial intelligence technologies into the evolving landscape of traffic management systems.

Furthermore, Tselentis et al, (2023) showed that AI technologies can help in enhancing safety, by predicting potential failures in transportation infrastructure, allowing for proactive maintenance and reducing the risk of accidents. While the author effectively explored the potential of artificial intelligence in traffic management, there is a shortfall in the provision of a clear and actionable framework that could guide decision-makers and engineers in the practical application of these technologies.

From the reviewed literature, the focus on the application of artificial intelligence in traffic management is clear. However, the provision of a clear framework or guide to effectively integrate AI technologies into the traffic management sector is unclear and scarce in literature. Existing studies lack detailed strategies or structured approaches that could facilitate the successful adoption and implementation of AI technologies in traffic management. Therefore, this study fills the gaps of the lack of a framework for the application of artificial intelligence (AI) to traffic management. It also establishes the strategies to ensure that the benefits of AI integration are maximized while any adverse effects are minimized.

Filling the gap in existing literature by providing a clear framework for the effective integration of Artificial Intelligence (AI) into traffic management offers numerous benefits and has a broad range of beneficiaries. Firstly, a structured framework helps city planners, traffic authorities and policymakers make informed decisions by offering step-by-step guidelines for adopting AI technologies, thus reducing trial-and-error approaches and increasing implementation efficiency. This minimizes resources wastage and accelerates the transition from traditional to smart traffic systems. Secondly, it supports the development of scalable, adaptable and secure AI systems that are responsive to the specific needs of different urban and regional contexts. The primary beneficiaries include government transportation agencies, such as Rwanda Transport Development Agency (RTDA), who can enhance operational performance, urban residents and technology developers who can tailor their solutions to match strategic goals.

## **1.3 Study objectives**

### ***1.3.1 General Objectives***

The general objective of this study is to develop a framework for the application of artificial intelligence (AI) in traffic management in Rwanda with a view to improving the performance of transportation in Rwanda.

### ***1.3.1 Specific Objectives***

To achieve the general objective, the following specific objectives were set:

1. To determine the level of awareness of AI technology for traffic management.
2. To evaluate the level of adoption of AI technology to traffic management.
3. To investigate the specific application areas of AI technology to traffic management.
4. To assess the challenges of AI technology adoption to traffic management.
5. To develop a framework for the application of AI technology to traffic management.

## **1.4 Research questions**

1. How effectively are the public aware of AI technology for traffic management?
2. To which extent could the AI technology be effectively adopted in traffic management?
3. In which specific areas are the AI technology applied in traffic management?
4. Are there challenges hindering the successful adoption of AI technology to traffic management?
5. Is there a framework for the application of AI technology to traffic management?

## **1.5 Scope of study**

This study focuses on developing the framework for the application of Artificial Intelligence (AI) in traffic management in Rwanda, hence the study is limited in terms of time, space and scientific domain.

**Time scope:** This study will take into account data from academic papers and relevant publications that were published since the year of 2015 up to now, ensuring up-to-date and comprehensive information sources.

**Geographical scope:** This paper aims to establish the framework for application of AI in traffic

management, and it was conducted in Rwanda Transport Development Agency (RTDA) and in Rwanda Information Society Authority (RISA). The choice of those agencies is based on the fact that the first agency is in charge of development of transportation and the later one is in charge of ICT where it includes the development of Artificial Intelligence

**Content scope:** While this study will touch on AI applications in traffic management, it will not explore them in depth. Instead, its primary focus is on developing a structured framework to effectively guide the successful integration of AI technologies into traffic management systems.

### **1.6. Significance of the study**

The main reason for conducting this research is the need to integrate the artificial intelligence (AI) technologies into traffic management for significantly improves the operational efficiency, Therefore, the research is innovative as it intends to determine how well stakeholders, government of Rwanda and transportation professionals are informed about the potential benefits and application of artificial intelligence (AI) in traffic management development. By assessing the level of awareness of AI, this study can identify gaps in knowledge and provide insights into the readiness of the industry to adopt AI solutions for enhancing road safety, optimize traffic flow and improving maintenance processes. The findings can guide targeted educational efforts, inform policy recommendation and encourage investment in AI technologies.

By evaluating the level of adoption of AI tools in traffic management, the research is significant as it addresses the growing role of artificial intelligence in improving the efficiency, safety and sustainability of transportation, by assessing the extent to which AI technologies are integrated into traffic management system, this research can provide insights into current industry practices, identify barriers to adoption and highlight the potential benefits and challenges associated with AI technologies, understanding the level of adoption can help policymakers, industry professionals and researchers make informed decisions regarding the development and implementation of AI solutions in traffic management.

The research is significant as it investigates the specific application areas of AI technologies in traffic management by identifying the various ways AI technologies can be integrated into traffic management system, such as predictive maintenance, route optimization, parking management and autonomous vehicle technologies, this research can provide valuable insights into how AI can

streamline project execution, reduce costs and improve overall system performance. Additionally, understanding these application areas can aid policymakers, transportation professionals and developers in adopting AI-driven solutions that contribute to smarter, more resilient transportation systems, ultimately benefiting communities through safer and more efficient road networks.

By assessing the challenges of AI adoption in traffic management, the study will provide valuable insights into the barriers and obstacles that hinder the effective implementation of artificial intelligence (AI), within the road transportation sector. As AI technologies have the potential to revolutionize areas such as vehicle automation and infrastructure development, understanding the challenges associated with their adoption is crucial for policymakers, urban planners and industry stakeholders. By identifying these challenges whether technical, financial, regulatory or social can inform strategies for overcoming them, ensuring that AI integration in traffic management is efficient, sustainable and beneficial. This research can ultimately contribute to the smoother and more effective deployment of AI-driven solutions, enhancing road safety, reducing congestion and improving overall transportation infrastructure.

By also developing a framework for the application of AI in traffic management, this research holds a significant value in addressing the opportunities in the transportation sector. With rapid advancements in artificial intelligence (AI), the framework aims to integrate AI technologies into traffic management systems, enhancing operational efficiency, safety and sustainability. By developing a structured approach, it can optimize traffic management, reduce accidents, improve predictive maintenance of infrastructure and support the transition to smart, autonomous transportation systems. Furthermore, such a framework can drive innovations in urban planning and policy-making, enabling governments and organizations to harness AI's full potential for smarter, more efficient transportation networks that meet the needs of an increasingly interconnected world.

### **1.7 Definition of terms**

**Artificial Intelligence (AI):** It a branch of computer science focused on creating machines or software that can perform tasks that typically require human intelligence.

**Congestion:** Refers to a situation where the demand for road transportation exceeds the available capacity leading to slower travel speeds, increased travel times and overcrowding.

**Robotics:** Refers to the integration of intelligent systems with physical robots to enable them to

perform tasks autonomously or semi-autonomously. Robotics combines hardware and software to create machines that can sense, reason and act in the physical world.

Machine learning (ML) is a subfield of AI, that focuses on developing systems that can learn from data and improve their performance over time without being explicitly programmed for specific tasks.

Computer vision: A field of AI that focuses on enabling computers to interpret, analyze and make decisions based on visual information from the world, this includes images, videos and other visual inputs.

Knowledge-Based System (KBS) is an AI system that relies on a structured knowledge base and inference mechanisms to solve problems, make decisions or perform tasks.

Artificial Neural Networks (ANNs) are a class of machine learning algorithms inspired by the structure and function of the human brain. They are designed to recognize patterns and relationships in data through a system of interconnected nodes.

Genetic Algorithms (GA) is a type of optimization algorithm inspired by the process of natural selection and genetics. GAs are used to find approximate solutions to optimization and search problems by mimicking the process of natural evolution.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

This chapter provides a synthesis of theoretical views from different works of literature, which is vital to understand the awareness of Artificial Intelligence in traffic management, to determine the adoption of Artificial Intelligence in traffic management, to investigate the specific application areas of Artificial Intelligence in traffic management and to assess the challenges of Artificial Intelligence adoption in traffic management.

#### **2.2 ARTIFICIAL INTELLIGENCE**

##### **2.2.1 History and description of Artificial Intelligence**

According to Larsson and Heintz, (2020) Artificial Intelligence (AI) is defined as the intelligence demonstrated by artificial entities, typically computers or machines, to solve complex problems, it integrates computer science with cognitive processes. Simply put, AI involves the computational aspects of achieving goals in the real world, intelligence encompasses abilities such as thinking, imagining, creating, memorizing, understanding, recognizing patterns, making decisions, adapting to changes and learning from experiences. AI aims to make computers behave in more human-like manner, often accomplishing tasks more quickly than humans (Valavanidis, 2023).

AI was initially introduced in 1956 by John McCarthy, but it failed to meet its goals due to insufficient technological advancements, which made it seem less promising at the time (Banadeshwar & Anand, 2025). Between 1960 and 1970, researchers investigated AI through Knowledge-Based System (KBS) and Artificial Neural Networks (ANNs). KBS are computer systems that offer guidance based on pre-set rules derived from human-provided knowledge. In contrast, ANNs are networks of interconnected neurons arranged in layers, modeled after the human brain, these systems have been applied in fields such as medicine, biology language translation, engineering, law and manufacturing (Trujillo, 2023).

Today, the availability of data has led to the development of Machine Learning as a subset of AI, Machine Learning involves programming computers to function like the human brain rather than explicit teaching them every detail, it allows computers to access large datasets and extract key

features from them to address complex problems (Aggarwal, 2023).

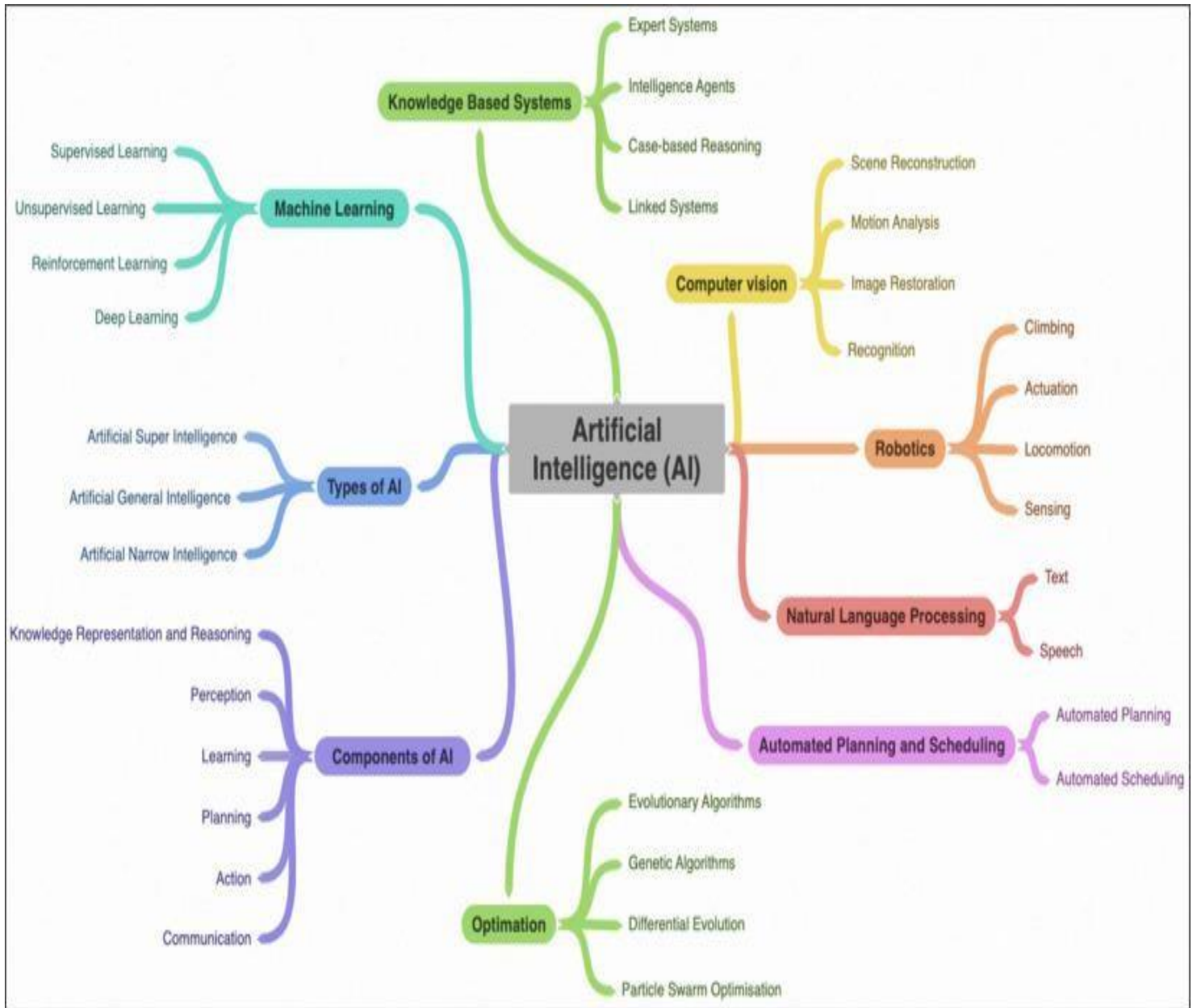


Figure 1: Components, types and subfields of AI

### 2.2.2 Subfield of Artificial Intelligence

According to Bagloee et al, (2017) generally, the advances of AI application in industry has birthed various well known subfields of AI including: Machine learning, computer vision, natural language processing, knowledge-based systems, optimization, robotics and automated planning and scheduling.

Machine learning focuses on developing computer programs that learn from experience or

historical data to model, control or predict outcomes using statistical methods without explicit programming (Alam, 2023). The main types of Machine Learning include: Supervised Machine Learning, which examines how machines make decisions based on what they have learned from labeled datasets, involving input-output pairings, and is divided into classification and regression, Unsupervised Machine Learning, which enables machines to identify important structures within unlabeled datasets, categorized into clustering and dimensionality reduction techniques (Naeem et al., 2023). Reinforcement Learning (RL), defined as the process of learning a mapping from situations to actions to maximize a scalar reward or reinforcement signal, relying on learning from interactions with the environment, and Deep Learning (DL), the cutting-edge area of machine learning known for delivering more accurate predictions than traditional techniques (Schmidhuber, 2015).

Computer vision: Computer vision is the study of how computers can understand and interpret images. It aims to create machines that can see and think like humans. To do this, it involves taking pictures with special devices, using advanced computer programs to process them and analyzing the images to make decisions (Wu et al., 2019). Automated planning and scheduling: Planning and scheduling are AI techniques used to help systems achieve goals by carefully choosing and organizing actions. Planning focuses on selecting the best actions, while scheduling assigns time and resources to those actions (Fukunaga et al., 1997). These techniques are becoming more common in complex applications because they can better solve problems and meet user needs. Although planning can be complex, time consuming and expensive, it's worth it when the benefits outweigh the costs. Common methods for planning and scheduling include search, optimization and genetic algorithms (Cortellessa et al., 2014).

Kober et al, (2018) Stated that Robotics are advanced machines that can perform physical tasks in the real world. Robotics is the field of engineering focused on designing, building and using robots to imitate human actions, robots are often designed for specific jobs and may not look like humans, they use sensors to understand their surroundings and motors to interact with the world, many of the challenges in robotics involve teaching robots through trial and error, similar to how humans learn. According to Luger, (2009). Knowledge-based system (KBS) are a subset of AI focused on machine decision-making using existing knowledge, it typically includes a knowledge base is built from domain expert knowledge, historical cases or other relevant sources, its primary benefit is enhancing productivity and efficiency by providing easy access to extensive domain knowledge

(Ehizojie et al., 2024). KBS can make inferences and draw conclusions that are heuristic, adaptable and transparent, explaining the reasoning behind their advice when needed and KBS are categorized into: Expert Systems, which use task-specific knowledge from domain experts to replicate human decision-making for solving specific problems, Case-Based Reasoning (CBR) System, which rely on past experiences or cases to analyze and understand new situations, often requiring expert knowledge to identify relevant past cases (Atchade-Adelomou et al., 2022). Intelligent Tutoring Systems, which utilize AI techniques to tailor tutoring methods based on the subjects, learners and teaching approaches, and Database Management Systems (DBMS) with Intelligent User Interfaces, which are database systems enhanced by AI-driven interfaces. Linked or Hypertext Manipulation Systems (HMS) facilitate easy navigation through complex information networks, enabling writers to connect passages and references seamlessly (Kabir, 2016). Natural language processing: (Wysocki & Lawrynczuk, 2015) NPL focuses on creating computer programs that can understand and use language like human do, these programs have been used for things like translating languages, summarizing text, creating user-friendly interfaces, searching for information in different languages, understanding spoken language and building expert systems. NPL tasks include identifying parts of speech, grouping words together, recognizing specific names or things and labeling the roles of words in a sentence (Collobert, 2011).

Optimisation involves selecting the best option from a range of possibilities, considering specific limitations. As Martins, (2024) point out, optimization problems focus on making the most beneficial choices, this concept has been a lifelong pursuit, originally studied in mathematics as a way to find the best solutions to problems, with the rise of AI in the 1950s, a new group of algorithms called evolutionary algorithms (EAs) emerged. Some popular EAs include evolutionary strategies, evolutionary programming, genetic algorithms, differential evolution and particle swarm optimization (Kiranyaz et al., 2014).

### **2.2.3 AI technologies for traffic management**

AI traffic management tools are the types of technologies that use artificial intelligence to improve the traffic management, they use machine learning, data analysis and automation to make traffic faster, more accurate, safer and better overall (Bankar & Lihitkar, 2023). There are many AI traffic management technologies, but here are the top AI technologies that are transforming traffic

management sector, from initial planning to final completion, these innovative solutions streamline traffic management and improve efficiency.

**Machine Learning** (ML) plays a pivotal role in modern traffic management by enabling systems to learn from historical and real-time data to optimize decision-making and enhance efficiency, ML algorithms are widely used to predict traffic flow, congestion levels and travel times by analyzing patterns from large datasets collected through GPS, sensors and traffic cameras (Lv et al., 2014).

**Deep Learning** (DL) has emerged as a powerful tool in traffic management by enabling the automatic extraction of complex features from vast and diverse data sources such as video footage, sensor streams and satellite imagery. The model allows for more accurate and adaptive control of traffic signals and dynamic traffic rerouting based on real-time conditions. Furthermore, DL facilitates smart surveillance systems that can autonomously detect anomalies such as accidents or road blockages, improving incident response times and public safety (Ahmad & Tsuji, 2021).

**Computer Vision** plays a crucial role in traffic management by enabling systems to interpret visual data from cameras and sensors in real time, thus improving safety and enforcement. Through advanced image processing and deep learning techniques, computer vision systems can accurately detect and classify vehicles, pedestrians and bicycles, as well as recognize traffic signs and signals (Manguri & Mohammed, 2023). One of its most impactful applications is in automated license plate recognition (ALPR), which aids in monitoring traffic violation, toll collection and law enforcement (Silva & Jung, 2018).

The integration of **Internet of Things** (IoT) with Artificial Intelligence (AI) has revolutionized traffic management by enabling real-time data collection, analysis and responsive action across transportation networks. IoT devices such as cameras, GPS units and road-embedded sensors continuously gather vast amounts of data on traffic flow, vehicle speed and environmental conditions which AI algorithms then process to generate actionable insights (Zanella et al., 2014). This synergy supports applications such as smart traffic lights that adapt in real time to changing traffic volumes, intelligent parking systems that guide drivers to available spots and vehicle-to-infrastructure (V2I) communication that enhances safety and coordination (Awan et al., 2021).

**Natural Language Processing** (NLP) is increasingly being utilized in traffic management to

analyze and extract meaningful insights from unstructured textual and spoken data, thereby enhancing situational awareness and decision making. NLP techniques are applied to process information from social media platforms, traffic reports and emergency dispatch communications to detect traffic incidents, congestion or road closures in real-time (Sakaki et al., 2010).by analyzing tweets or public posts, NLP can identify traffic related events faster than traditional sensors, enabling quicker responses to evolving conditions (Imran et al., 2018).

**Graph Neural Networks** (GNNs) have emerged as a powerful tool in traffic management by enabling the modeling of complex spatial and temporal relationships within road networks. Unlike tradition AI models, GNNs are designed to operate on graph-structured data, making them ideal for representing transportation systems where intersections and roads from nodes and edges, respectively (Wu et al., 2019). GNNs can predict traffic flow, travel time and congestion by capturing both the topological structure of road networks and the dynamic interactions among them (Li et al., 2018).

**Swam Intelligence**, inspired by collective behavior of decentralized systems in nature such as ant colonies or bird flocks, is increasingly applied in traffic management to enhance real-time coordination and decision-making across transportation networks. In this context, swam-based algorithms, are employed to optimize traffic signal timing, vehicle routing and congestion mitigation by simulating how autonomous agents can interact locally to achieve global objectives (Dorigo et al., 2006). The vehicles can collaborate in real-time to reroute themselves based on congestion levels, while intersections can communicate to coordinate signal phases and reduce waiting times.

**Fuzzy Logic** is widely applied in traffic management to handle the inherent uncertainty and imprecision of real world traffic scenarios, enabling intelligent systems to make human-like decisions based on vague or incomplete data. Fuzzy Logic allows variables to take on range of values, making it particularly effective for traffic signal control, congestion estimation and incident detection where conditions are not always clear-cut (Abdou et al., 2022).

**NoTraffic** (Munir et al., 2022), is an AI technology specialized in developing AI-powered traffic management systems aimed at modernizing urban intersections, their platform transforms traditional traffic signals into smart infrastructure capable of understanding and responding to a real-time traffic condition, by integrating machine vision, radar and connected vehicle technologies (Saxena, 2024). **NoTraffic** optimizes traffic flows, reduces congestion and enhances

road safety, the system can retrofit existing intersections, making them cloud-connected and fully autonomous within hours and it operates as a managed service with continuous monitoring and support. **NoTraffic**'s platform is designed to address the challenges of increasing vehicle numbers and traffic congestion. It offers a scalable solution that can be implemented globally, ensuring intersections operate efficiently and safely (Wided et al., 2023).

**Minus Zero** (Katiyar et al., 2024) is specialized in developing autonomous vehicle technology powered by artificial intelligence, their focus is on creating self-driving cars that can navigate complex environments with high precision and safety, **Minus Zero**'s algorithms enable their vehicles to make real-time decisions, adapt to varying conditions and ensure a smooth and safe driving experience.

**NuPort Robotics** (Truong et al., 2019), develops AI-driven autonomous vehicle systems focused on enhancing the efficiency and safety of transport operations, their technology includes real-time navigation, advanced sensor integration and AI algorithms that enable vehicles to operate autonomously in various environments, **NuPort Robotics** aims to optimize logistics and transportation networks through innovative autonomous solutions.

**NuPort Robotics**' approach integrates advanced AI and machine learning to provide precise navigation, route planning and real-time management. **NuPort Robotics**' solutions are designed to support a wide range of applications, including freight transportation, last-mile delivery and public transit systems.

**Optibus** (Pinzolits, 2023) develops a sophisticated AI-enabled SaaS platform designed for the planning and operation of mass transportation systems, their technology is focused on enhancing the efficiency and effectiveness of public transport networks, **Optibus**' AI-driven platform provides comprehensive tools for route optimization, scheduling and resource management, allowing transit agencies to improve service delivery and operational performance.

**Optibus**' AI solutions are tailored to meet the unique demands of public transportation, enabling agencies to manage fleets, schedules and personnel more effectively. **Optibus** employs advanced algorithms and machine learning techniques to analyze vast amounts of data, ensuring that transportation systems are optimized for both cost and performance (Sanders & Tewkesbury, 2015).

**Citymapper** (Aery & Ram, 2017), leverages AI to provide real-time public transportation routes, schedule predictions and intelligent trip planning for users, the app uses historical data and real-

time information from buses, subways and trains to offer the most efficient route options, avoiding delays and disruptions, **Citymapper**'s AI-powered platform adapts to changing conditions, offering travelers the quickest or cheapest routes at any given time.

**Trainline** (Zhang et al., 2020) uses AI to optimize ticket pricing, suggesting the cheapest and most efficient train routes, its AI system learns from travel patterns to offer personalized travel recommendations and discounts, this helps passengers make smarter choices while allowing transportation companies to improve revenue generation through dynamic pricing.

#### **2.2.4 Awareness of AI technologies in traffic management**

The spectrum of public awareness and acceptance of AI in traffic management ranges from high exposure in advanced economies to minimal knowledge in some parts of East Africa. (Kennedy et al., 2023) stated that awareness of common uses of Artificial intelligence is a first step toward broader public engagement with debates about the appropriate role and boundaries for AI, expert have raised a host of moral, ethical and legal questions about the expanding capabilities of AI, and the ethical and responsible use of AI is a growing focus of research within the field (Dergunova et al., 2022). Government agencies must be aware that they are subject to public accountability and must abide by strict regulations on when and how data is collected, analyzed and stored. Public awareness and scrutiny around AI make it even more important that transportation professionals understand how AI works, mitigate or eliminate risks and communicate effectively the benefits of this technology (Arakpogun et al., 2021a).

Many developed nations have successfully integrated AI into traffic systems and have initiated broad public engagement campaigns to raise awareness. Countries like the United States, Germany, Japan and South Korea have implemented AI-powered traffic signal systems and autonomous vehicle testing in urban environments (Yampolskiy, 2021). These efforts have increased public interaction with AI technologies, improving overall awareness. For example, intelligent traffic systems in Los Angeles automatically adjust signal timing based on real-time traffic data and citizens are often informed through public awareness campaigns, smart city portals and local government apps (Davenport et al., 2020). However, understanding the underlying mechanisms of these AI systems is often limited to technical experts and the broader public may not fully comprehend how these systems work or their long-time implications (Manser & O'Brien,

2024).

A new survey conducted in America, find that many Americans are aware of common ways they might encounter Artificial Intelligence (AI) in daily life, such as customer service chatbots and product recommendations based on previous purchases. At the same time, only three in ten US adults are able to correctly identify all uses of AI asked about in the survey, underscoring the developing nature of public understanding (Brian et al., 2023).

Amid these ongoing discussions, the public strikes a cautious tone toward the overall impact of AI in society today, on balance, a greater share of Americans say they are more concerned than excited about the increased use of Artificial Intelligence in daily life (38%) than say they are more excited than concerned (15%). Many express ambivalent views: 46% say they are equally concerned and excited (Kennedy et al., 2023).

In Europe, public awareness campaigns have been more proactive in ensuring that citizens are informed about how AI is used in traffic management. The European Union has funded numerous projects promoting digital literacy, smart mobility and ethical AI implementation leading to increased citizen engagement (Abbott & Rothman, 2018). These include AI-driven parking guidance systems, adaptive traffic control and emergency vehicle prioritization systems. Public consultations and surveys indicate that while people are generally supportive of AI in traffic management due to its efficiency benefits, concerns remain about data privacy, job displacement and cyber risks (Blackwood, 2025). High profile incidents involving autonomous vehicles have also contributed to cautious optimism, suggesting that while people are aware, full trust in AI has not yet been achieved (Michael et al., 2017).

In Asia, particularly in countries like China and India, public awareness is relatively high, especially in metropolitan areas where such technologies are part of daily life. However, this awareness is often associated more with enforcement than with traffic efficiency, raising concerns over surveillance and state control (Stahl, 2021). In contrast, in India, AI-powered traffic management remains at a developmental stage in many regions and public awareness is fragmented-limited mostly to urban population and professionals in tech sector (Chatterjee & Bhattacharjee, 2020).

Moving to developing regions such as Latin America and Southeast Asia, awareness levels vary

widely. In Brazil and Indonesia, for example, AI is being piloted in smart city initiatives, yet public awareness remains limited to specific urban enclaves where projects are deployed. Outreach programs are often inadequate and technological jargon can alienate the general public. This disconnect illustrates a global digital divide, where access to technology does not automatically equate to meaningful awareness or understanding (Crompton & Burke, 2023).

In Africa, the awareness of AI in traffic management is generally low, though rising slowly as technology adoption grows. South Africa leads the continent in terms of integrating AI into traffic systems, particularly in cities like Cape town and Johannesburg, public engagement and awareness in these cities are higher compared to other African nations due to media coverage, academic involvement and private sector initiatives (An et al., 2023a).

However, even in these advanced cases, many people still confuse AI with basic automation or GPS-based systems, highlighting the need for more comprehensive public education. In East Africa, awareness of AI technologies in traffic management remains limited but is gaining momentum. However, most of the population remains unaware of these developments due to limited media coverage, lack of public sensitization and digital literacy gaps. A survey conducted by the Kenya Urban Roads Authority (KURA) in 2022 found that only 28% of Nairobi residents had heard of AI being used in local traffic systems and only 12% could explain what it does or how it works (Ndibalema, 2025). In Uganda, public awareness is minimal, with many road users that any form of AI or automation is in use. Similarly, in Tanzania, AI-related traffic management is still in proposal stage, with limited public discourse or policy backing to inform or involve citizens (Fenwick & Molnar, 2022). Most awareness initiatives come from universities or non-governmental organizations focused on tech literacy, but these often have limited reach beyond academic or urban communities.

Initiatives, such as hackathons, startup incubators and university research programs are gradually raising awareness of AI's role in transportation. For example, Kenya's iHub and Uganda's Innovation Village have both hosted workshops on smart mobility, introducing young professionals and students to AI traffic management solutions, these forums help demystify AI and build a new generation of technologists who are both aware and capable of building locally relevant solutions (Makridakis, 2017).

In Rwanda, citizen awareness programs specifically focusing on AI are not yet in place in the

country, but community awareness on digital literacy is covered under the Rwanda Digital Ambassador Program (Rwanda DAP), (Dinika, 2023). Started in 2017, the DAP initiative aims to transform the lives of five million citizens by bringing them online through training held in their respective communities. This initiative drives digital awareness and help bridge the ICT skills gap exposed to digital devices, citizens are educated on opportunities, rights and security online, (Rwirahira, 2013).

Globally, awareness of AI is increasing, especially regarding its ethical, legal and social implications, experts emphasize that understanding AI's uses is crucial for public engagement and policy development. Continentally, awareness of AI is emerging but uneven, there is a growing recognition of the risks, especially regarding digital divides, infrastructure gaps and data inequality. The African Union is actively promoting AI governance through various strategies, but challenges around access, education and infrastructure still limit widespread understanding.

Regionally, research indicates a positive public perception of AI's potential to boost productivity and affect labor markets, the awareness here seems more economically driven tied to employment dynamics and productivity, showing a more practical engagement with AI's benefits and challenges. Nationally, direct AI awareness efforts are minimal. However, digital literacy is being tackled through initiatives, this shows that while AI-specific education is limited, foundational digital awareness is improving.

### **2.2.5 Adoption of AI in traffic management**

Adoption of AI into traffic management sector can greatly influence the industry's economic landscape, as a major contributor to the national economy, the transportation sector can benefit from AI through enhanced productivity, improved efficiency and reduced costs (Kober et al., 2018).

However, adopting AI in the traffic management sector necessitates substantial investments in technology and infrastructure (Rauch et al., 2019). The transportation relies heavily on labor, and the adoption of AI may result in job displacement for workers. Furthermore, the implementation of AI in the traffic management sector may result in job losses, particularly affecting low-skilled workers. However, AI can create new job opportunities in the latest technological value chain (Parschau & Hauge, 2020). Consequently, the effect of adoption in the transportation's economy hinges on the balance between job losses and job creation, given that the transportation sector is

currently under-digitized, adopting AI has potential to enhance productivity, efficiency and cost savings (Newman et al., 2021).

AI is a versatile technology that allows individuals to reconsider how we gather information, analyze data and leverage insights to enhance decision-making (West & Allen, 2018). Over the past 18 months, the adoption of AI of surged, driven by digital innovation during the Covid-19 pandemic, which has placed AI and analytics at the core of business operations. However, as AI becomes more prevalent in society, it evokes both concerns and excitement among people (Kuziemski & Misuraca, 2020).

The United States stands as a global powerhouse in Artificial Intelligence, boasting a rich ecosystem of leading technological companies, top-tier research institutions and a vibrant startup culture. Silicon Valley, located in California is synonymous with innovation and serves as the epicenter for AI breakthroughs, the adoption of AI in United States has been accelerated by major tech giants such as Google, Apple, Facebook and Microsoft that are headquartered in the United States, driving cutting-edge AI research and development, (Oikonomitsiou, 2018).

They have also adopted AI technologies to apply them in transportation, covering areas such as autonomous vehicles, traffic prediction and route optimization, they are applying AI algorithms, particularly machine learning and their integration into traffic management systems, as well as their potential to improve road safety and transportation (Catherine et al., 2024).

China has emerged as a formidable player in the field of Artificial Intelligence, undergoing a rapid transportation that has positioned it as a key competitor on the global stage, leading the charge are the tech giants like Alibaba, Tencent, Baidu and Huawei, which have become synonymous with innovation and technological prowess, (Roberts et al., 2021).

China's specialized adoption of AI in transportation, with a particular emphasis on its massive investments in autonomous driving, AI-powered smart cities and logistics optimization, China established "Made in China 2025" policy, which seeks to dominate the AI field, and how that has influenced transportation infrastructure, including AI-based traffic management, predictive logistics and EV deployment, (Silva & Jung, 2018).

The adoption of AI in German government has been triggered by the strategic importance of AI for the country's economy and has taken steps to support its development. Initiatives such as the

“AI Made in Germany” strategy aim to strengthen Germany’s position in AI innovation globally. The government has allocated funding for research projects, technology transfer and the establishment of AI research centers (Agrawal et al., 2018). Germany’s approach to integrating AI in its transportation sector, focusing on the country’s industry-driven advancements in AI for automotive technologies and smart mobility, the Germany’s strong automotive industry such as Volkswagen and BMW has leveraged AI for autonomous vehicles and how the country is incorporating AI into its smart city and industry 4.0 efforts, (R. Müller et al., 2023).

In Nigeria, they have adopted AI technologies in solving the problems caused by traffic congestion, enhancing the planning and operation of public transport systems, optimizing route planning and bus schedules, reducing wait times and improving service reliability, impacting economic productivity and quality of life, (Aliu, 2024). Nigeria is making use of AI technologies such as ANN and GA have been applied to traffic management systems to optimize signal timings, predict traffic volumes and manage congestion. AI-driven self-driving cars and buses have the potential to improve road safety and reduce traffic accidents, although trials and implementations are still in early stages globally, AI research and development in Nigeria have benefited from exploring partnerships and pilot projects involving autonomous vehicles, (Michael et al., 2017).

In Algeria, the AI technologies are leading to better vehicle control and monitoring which reduce road accidents, by applying artificial intelligence systems, efficiency can be achieved in reducing resource use and costs associated with road accidents and traffic congestion, these systems also are helping them to enable the improvement of traffic flow, reducing travel time and fuel consumption, which positively impacts economic productivity, economic performance, energy efficiency and time saving, (Boulmelh, 2024).

AI adoption in traffic management sector is accelerating worldwide, driven by its potential to boost efficiency, productivity and cost savings. Globally, AI is transforming how transportation system are managed, particularly through automation, predictive analytics and smart infrastructure. The COVID-19 pandemic further spurred digital transformation, placing AI at the forefront of innovation. Despite momentum, uneven adoption exists across continents and regions due to variations in infrastructure, investment and technological capabilities. Developed countries, especially in North America, Europe and Asia, are leading the way, while many developing nations are still at early stages but showing strong interest and potential.

## 2.2.6 The specific application areas of AI technologies in traffic management

The research conducted by (Samaei, 2024) highlighted different areas in traffic management sector, where Artificial Intelligence can play a crucial role. Here are some:

Huang et al, (2021) Stated that AI-based **traffic prediction** uses artificial intelligence techniques, such as machine learning and deep learning, to analyze historical and real-time traffic data to forecast traffic conditions, by processing data from sensors, cameras and GPS, AI models predict congestion, travel times and traffic flow, these prediction help optimize traffic management, improve route planning, reduce congestion and enhance overall transportation efficiency in urban environments.

Li et al, (2018) showed that AI-controlled lights use artificial intelligence for optimization of traffic signals timings based on real-time traffic flow data, by analyzing vehicle counts, speed and congestion, AI adjusts signal phases to reduce wait times, improve traffic efficiency and minimize congestion, enhancing overall urban mobility and safety.

Shukla et al, (2025) showed that in **Route Optimization** AI algorithms analyze historical and real-time data to predict demand patterns for public transportation, by adjusting routes, schedules and vehicle frequency dynamically, AI optimizes service efficiency, minimizes delays and ensures better resource allocation, ultimately enhancing the overall passenger experience and reducing operational costs.

Nampalli, (2024) showed that in Demand-Responsive Transit, AI-driven systems monitor **real-time passenger demand** and adjust public transport routes accordingly, by dynamically rerouting buses or trains based on current demand, these systems optimize service coverage, reduce overcrowding and improve efficiency, ensuring timely and responsive transport options.

(Karnati & Mehta, 2022) showed that by integrating **Autonomous Vehicles** (Self-Driving Cars) into traffic systems can enhance flow by communicating with infrastructure and other vehicles, AVs reduce human error, minimize accidents and optimize road capacity by adjusting speeds, routes and braking patterns for smoother, safer traffic management.

(Pritam Roy, 2025) showed that in AI for **Fleet Management**, AI optimizes routes and schedules for autonomous vehicle fleets by analyzing real-time traffic, demand and vehicle availability, this improves efficiency in ridesharing and delivery services, reducing wait times, fuel consumption and operational costs while enhancing service reliability and customer satisfaction.

(Singh et al., 2024) showed that in **AI-Powered Parking Management**, AI systems guide drivers to available parking space by analyzing real-time data from sensors and cameras, this reduces congestion caused by drivers circling for parking, improving traffic flow, reducing emissions and enhancing overall urban mobility efficiency.

Ucar et al, (2024) showed that in **Predictive Maintenance**, AI analyzes sensor data and historical patterns to predict potential failures in transportation infrastructure, such as bridges or roads, this enables proactive maintenance, addressing issues before they cause disruptions or accidents, enhancing safety and reducing repair costs.

(Nagvekar, 2025) showed that in **Driver Assistance Systems**, AI-powered driver assistance technologies, such as collision detection, lane-keeping and adaptive cruise control, enhance road safety by providing real-time alerts and automatic interventions, these systems reduce human error, prevent accidents and support safer driving behavior for all road users.

(Campeau & Dubois, 2019) showed that in **Real-Time Monitoring**, AI-based systems use sensors, cameras and data analytics to monitor traffic, public transport and infrastructure in real time, these systems detect congestion, delays and maintenance needs, enabling immediate responses to optimize flow, enhance service and prevent issues.

(Thomas, 2025) showed that in **Adaptive Routing**, AI algorithms analyze live traffic data to dynamically adjust navigation routes, avoiding congestion, accidents and delays, by providing real-time route recommendations, these systems optimize travel time, improve efficiency and enhance the overall driving experience for users.

Pujar and Kulkarni, (2023) Showed that AI technologies such as **Automatic Number Plate Recognition** (ANPR) and facial recognition are used for electronic toll collection and detecting traffic violations like speeding or re-light running. These systems enable efficient law enforcement and reduce corruption by minimizing manual intervention.

### **2.2.7 The challenges of AI adoption in traffic management**

But despite that contribution in country economy, the application of AI in traffic management sector is facing the many challenges that have hindered its development in the domain (Wolniak & Stecuła, 2024). Adoption AI in transportation requires a **fundamental shift from traditional**

**methods to innovative**, data-driven approaches, AI enables smarter, more efficient systems, from autonomous vehicles to predictive traffic management, optimizing safety and reducing congestion, this **transformation challenges old paradigms**, calling for new infrastructure, policies and skill sets, embracing AI not only redefines how we travel but also reshapes the future of urban mobility and sustainability, (Ferraz & Al-Khazraji, 2025).

AI technology requires **constant maintenance** to function properly and remain efficient. This involves regular updates to software, hardware and databases, ensuring accuracy, security and optimal performance. The upkeep process can be **time-consuming and costly**, placing a strain on an organization's resources. AI systems also face the challenge of becoming **outdated quickly**, as rapid technological advancements can render older systems obsolete (Arakpogun et al., 2021b).

To keep AI operations running smoothly, **continuous monitoring and repair** are essential, this means organizations must allocate resources for ongoing support, which includes troubleshooting issues, upgrading components and adapting to new technologies. In some cases, even minor disruptions can lead to **significant performance degradation**, as a result, AI systems require dedicated teams to perform round-the-clock maintenance to ensure they operate at peak capacity. Without proper care, the benefits of AI technology can be diminished, affecting productivity and overall business performance (Khanfar et al., 2024).

Another disadvantage of AI in transport is that it often requires **extensive staff training**, due to its novelty, AI experts may not readily be available, finding professionals with the job expertise and capacity to deal with AI will be a challenge (Faustine & Rachmawati, 2024). Another obstacle is teaching others how to use this technology, regardless of the amount of artificial intelligence training tools, this takes time and some people may find it difficult to adjust, training workers on how to use the system, the legislation controlling its usage and any related safety protocols can require a **substantial amount of time and resources**. Additionally, regular retraining may be necessary as technology and regulation evolve (Parappat, 2025).

AI-powered systems, while offering immense potential to streamline operations and reduce costs in sectors like transport, also introduce significant risks, one of the primary concerns is their **vulnerability to cyberattacks**, which can severely disrupt operations and compromise safety,

Hackers can exploit weaknesses in AI systems, gaining unauthorized access to critical data, including personal client information (Das & Sandhane, 2021). This exposure could lead to **identify theft, financial fraud and significant reputational damage**, to mitigate these risks, it's crucial to implement robust cybersecurity measures, regular software and hardware updates, along with constant monitoring for vulnerabilities, are essential to safeguard against attacks (Aldhamer, 2024). Furthermore, organizations must ensure that AI systems are equipped with **advanced encryption and multi-layered security**, businesses can protect both their systems and their customers' sensitive information, ensuring that AI technologies remain a reliable and secure asset in modern transport operations (Dokur, 2023).

Another commonly discussed disadvantages of AI-enabled systems in transport is the potential for **human job loss**, truck drivers will be the first to be disadvantaged when self-driving cars become more mainstream, their job opportunities will be more scarce, similarly, automation systems may render some roles obsolete, replacing them with robots or computers, businesses must recognize this impact on the workforce and have detailed planning to manage it. Before implementing an AI transportation system, they should pay close attention to their long-term employees and the impact on their needs (Du, 2024).

While AI technology can be incredibly accurate and efficient, it is still prone to **make mistakes** as it relies on data and algorithms, these mistakes might be little ones like misunderstanding the data, or they can be more catastrophic, **like malfunctioning autonomous vehicles and automobile accidents**-possible incorrect projections made by predictive analytics systems (McDonald et al., 2025).

While AI-driven systems are created to respond to particular circumstances and situations, they are sometimes **unable to adapt or react when something unexpected happens**, or an operator makes a mistakes, it can cause delays or accidents that a human driver would have been able to prevent (Anderson et al., 2024). Furthermore, dealing with unexpected may be beyond AI's capabilities. AI-based machines tend to be **too rigid or inflexible, lacking improvisation**, this inability will cause problems, due to these scenarios, AI transportation systems need to ensure enough flexibility is built into their AI solutions protocol for them to be able to handle any potential situations that may be out of the ordinary (An et al., 2023b).

**Collecting accurate data for predictions** is one of the most challenging aspects of utilizing AI in transport, weather, traffic patterns and **machine breakdowns** are just a few of the named aspects that impact the data's quality (Baek et al., 2025). Additionally, collecting enough data to make reliable predictions may require **extensive tracking and monitoring over time**. Naturally, it is an **expensive procedure** that consumes time, this process makes it a challenge to gather accurate data. Furthermore, any inaccuracies or gaps in collected data can lead to fault predictions, with potentially disastrous consequences for transport operations (Brady et al., 2025).

Another potential roadblock that could prevent the successful implementation of an AI system is **human resistance**, this resistance is not limited to employees fearing their jobs and being replaced by machines, but also regulators and members of the public worrying about safety and privacy issues. To guarantee a smooth transition, business must take these worries seriously and address them immediately. For instance, they should concentrate on involving the workforce early in the process to raise awareness of the advantages of AI and ease its application (Ansarinejad et al., 2025).

Another crucial instruments for global transportation systems is quickly emerging with AI technology, but access to these advanced technologies is unequal among the would be users, AI-enabled systems require more **financing and infrastructure**, besides other factors, than some can afford, there's bound to be a gap in the accessibility of AI-driven transport solutions between wealthier and poorer countries, there will be a **gap between urban and rural areas** even within the same borders (Mihalj et al., 2022). For example, many rural areas may **lack the necessary infrastructure or resources** to implement AI solutions on a large scale, and developing countries may have trouble setting up these advanced technologies due to the cost. Thus, they may take longer to join the technological revolution and benefit from its advantages. AI should be accessible to everyone so that no one is left behind in enjoying these advanced transportation solutions. However, accessibility to advanced technology will remain a problem because not every nation grows at the same pace (Luan et al., 2020).

**AI's impact on the environment** can go both ways. Yes, artificial intelligence technology may significantly reduce the environmental impact of transportation, but autonomous vehicles requiring more energy than traditional vehicles are the exact opposite, their reliance on sensors

and advanced computing power may **consume more energy than normal**. Developing AI technology and components for transport applications also demands large amounts of resources, which could have a detrimental environmental impact (Khajeh & Nouhi, 2023).

### **2.2.8 Solutions to challenges of AI adoption in traffic management**

To ease the transition, governments and transportation bodies should **promote phased integration of AI through pilot programs and public-private partnerships** that allow gradual testing and trust-building (Ozbay et al., 2018). Investment in change management and inclusive innovation strategies will help align legacy systems with AI-based technologies (Cohen & Cavoli, 2019). **Adopting modular and scalable AI architectures** enables easier updates and reduces full-system overhauls, **utilizing cloud-based AI services** also minimizes on-site maintenance and facilitates quick upgrades, open-sources AI frameworks can also drive down costs while enabling customization (Zhang et al., 2020).

**Instituting continuous education programs and collaborating with universities** to develop transportation-specific AI curricula will create a pipeline of talent, additionally, **leveraging no-code AI platforms** allows non-experts to interact with and benefit from AI systems without needing deep technical expertise (Huang et al., 2021). **Implementing AI-specific cyber-security protocols** such as AI anomaly detection, blockchain-based data integrity systems and routine penetration testing can safeguard systems, organizations should also establish dedicated cyber-security teams and align with global standards like ISO/IEC 27001 (Zhou & Schofield, 2024).

Governments and industry leaders should **adopt workforce transition plans** that include retraining and redeployment, focus can be placed on creating new AI-related roles like system monitors, ethics auditors and AI trainers (Frey & Osborne, 2017). AI should be used to augment rather than replace workers wherever possible, hybrid systems that blend human oversight with AI control can improve safety in unpredictable condition, **continuous learning algorithms and reinforcement learning techniques** can also help AI systems become more adaptable over time. **Implementing robust fallback protocols** ensures human intervention during system failures (Nasrudin et al., 2018).

**Investing in IoT infrastructure like smart sensors and V2X** (Vehicle to everything)

communication enables real-time, high-quality data collection, data cleaning tools and anomaly detection can reduce the influence of corrupt inputs, establishing data governance frameworks ensures consistency and accuracy .**Transparent communication, public awareness campaigns and stakeholder engagement programs** are crucial, regulatory sandboxes can also allow for safe experimentation with AI while building public trust, ensuring algorithmic transparency and providing opt-in mechanisms for data sharing builds user confidence (Batty, 2018).

**Equity-focused AI deployment frameworks** should be adopted, ensuring rural and low-income region receive tailored solutions, international cooperation and development funds can support infrastructure investments in underserved areas, developing open-source AI tools can also bridge accessibility gaps. **Optimizing algorithms for energy efficiency, promoting the use of renewable-powered data centers** and adopting lightweight AI models can mitigate environmental impacts, incorporating AI into route optimization and energy-efficiency transport modes can offset its own carbon footprint overtime (Sadowski, 2020).

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.1 Introduction**

This chapter explains how the research data was collected and analyzed. Based on the information gathered from the literature review, a specific research methodology was adopted for improved awareness and understand, and setting guidance for developing an appropriate framework for application of AI technologies in traffic management, including the data collection procedures, survey instruments development and data analysis techniques.

#### **3.2 Research design**

Research design serves as a blueprint for conducting a study, outlining the procedures and methods employed to answer research questions or test hypotheses, it ensures the logical flow of the research process, from problem identification to data interpretation, providing a framework that guides the selection of participants, data collection techniques and analysis strategies (Creswell & Creswell, 2018). Broadly classified into qualitative, quantitative and mixed-methods approaches, research design is tailored to the study's objectives and the nature of the phenomenon under investigation, for instance, a qualitative design emphasizes exploring complex, contextualized experiences whereas a quantitative design focuses on measuring variables and establishing relationships through statistical analysis.

According to Torres-Carrion et al, (2018a) in a mixed research method a researcher put together the elements of qualitative and quantitative research approaches for the targets of breath and depth of understanding and corroboration (Escudero-Mancebo et al., 2023). suggests that combining different research methods enhances the study's design, the complementary nature of these methods allows for a more comprehensive and compelling understanding of the issue than can be achieved through single-method research (Torres-Carrion et al., 2018b). A practical advantage of mixed method research is its ability to bring together experts from various disciplines and incorporate different research perspectives. This research adopts a mixed approach, the choice of this method is based on the fact that it is deemed the most suitable method for collecting data to effectively address the research objectives and ensure a comprehensive understanding of the subject under investigation. The combination of both approach enhances the depth, validity and

practical relevance of the research findings, supporting the development of a robust and applicable framework.

### **3.3 Sources of data**

Sources of data are essential for conducting empirical research, as they provide the raw information necessary to address research questions and test hypotheses (Ajayi, 2023). Data sources are broadly categorized into primary data and secondary data, each serving distinct purposes in the research process.

#### ***3.3.1 Primary data***

Primary data are original information collected firsthand for a specific research objective through techniques such as surveys, interviews, focus groups, direct observation, experiments and sensor-generated logs (Paullada et al., 2021). Primary data offer a close fit to the research questions, ensure contemporaneity and permit control over data quality variable such as validity and reliability. Common advantages include contextual richness and the ability to probe for clarification, however, primary collection is often time-consuming, costly and susceptible to non-response or interviewer bias (Saunders et al., 2023).

#### ***3.3.2 Secondary data***

Secondary data are previously collected records, published or unpublished, reused to address new questions or to complement primary findings (Creswell & Creswell, 2018). Sources range from government statistics, academic articles, corporate reports and historical archives to digital traces such as mobile-phone call detail records, social-media feeds and open data portal (Johnson, 2014). Because they already exist, secondary data economize on time and cost, enable longitudinal or cross-national comparisons that a single researcher could not feasibly gather and provide larger sample sizes that improve statistical power (Cheong et al., 2023). Limitations include lack of control over how the data were originally collected, potential mismatch with current variables of interest and uncertainty about reliability or measurement error, researchers must therefore engage in rigorous source evaluation, data cleaning and triangulation procedures (Bryman, 2012).

Combining both primary and secondary data sources can enhance the depth and breadth of a study allowing researchers to corroborate findings and address complex research questions. The data for this research was collected through the use of surveys targeting the agency in charge of

transportation (RTDA) and the agency in charge of ICT (RISA). A literature review that incorporates critical thinking on published, materials regarding the application of AI in the traffic management laid the groundwork for the researcher's study.

### **3.4 Study area**

The study area refers to the specific geographical, social or institutional context within which a research project is conducted, clearly defining the study area is essential, as it provides the boundaries and framework for data collection, analysis and interpretation, the selection of a study area is typically guided by research objectives, the nature of the phenomenon under investigation and logistical considerations such as accessibility and resource availability (Creswell & Poth, 2018). The study area also influences the generalizability of findings as socio-cultural, environmental and economic characteristics of the location shape the context of the research.

This paper aims to establish the framework for application of AI to traffic management in Rwanda and it was conducted in Rwanda Transport Development Agency (RTDA) and in Rwanda Information Society Authority (RISA). The choice of those agencies is based on the fact that the first agency is in charge of development of transportation and the later one is in charge of ICT where it includes the development of Artificial Intelligence.

### **3.5 Population of the study**

The population of the study refers to the complete group of individuals, objects or phenomena that a researcher aims to investigate and draw conclusions about, this population serves as the broader context within which the research findings are generalized, making its careful definition critical to the validity of a study (Denzin & Lincoln, 2018). A well-defined population is characterized by shared attributes relevant to the research objectives, such as demographic, geographic or behavioral criteria, clearly defining the population ensures that the research remain focused and feasible while providing a foundation for making meaningful inferences about the group being studied.

The study population included selected staff from RTDA and RISA, chosen simultaneously. However, not all employees were considered, only personnel directly involved in transportation management were included, this comprised civil engineers, IT engineers, project managers and all individuals whose roles specifically relate to the planning, coordination or oversight of transportation systems and activities within their respective institutions. Staff without

responsibilities in transportation were excluded from the scope of the research.

### 3.6 Population size

Population size refers to the total number of individuals or units within a defined group from which researcher aim to draw conclusion or make generalizations. In research, the population represents the entire set of entities relevant to the study, such as individuals, organizations or events, depending on the research objectives (Baek et al., 2025). The size of the population significantly influences the sampling process, as larger populations often require more resources and robust sampling techniques to ensure representativeness and accuracy. In contrast, smaller populations may allow for comprehensive data collection without sampling. Accurate identification and definition of the population ensure that the research findings are both applicable and credible (B. Müller et al., 2020).

#### Population from RTDA

No	INSTITUTIONS	POPULATION SIZE
1	Civil Engineers	40
2	Project Engineer	6
3	Division Manager	2
4	Program Manager	2
<b>TOTAL</b>		<b>50</b>

Table 1: Population size from RTDA (Source: [www.rtda.gov.rw](http://www.rtda.gov.rw))

#### Population from RISA

No	INSTITUTIONS	POPULATION SIZE
1	IT Engineers	37

2	Project Engineer	2
3	Division Manager	1
4	Program Manager	2
<b>TOTAL</b>		<b>42</b>

Table 2: Population size from RISA (Source: [www.risa.gov.rw](http://www.risa.gov.rw))

Hence, according to the data gathered, the population size is equal to 92, including 40 civil engineers, 37 IT engineers, 8 project engineers, 3 division managers, and 4 program managers. Out of these 92, 77 individuals were selected to respond to the questionnaire. Additionally, 15 participants (8 projects engineers, 3 division managers, 4 projects engineers) from both institutions were targeted for interviews.

### 3.7 Sampling size

Sampling size plays a pivotal role in the validity and reliability of research findings, as it determines the extent to which a study can generalize its results to the broader population (Campelo & Takahashi, 2019). Factors influencing sample size include the study’s objectives, the population’s variability, the desired level of confidence and the acceptable margin of error. For instance, larger sample sizes are typically needed for populations with high variability to achieve accurate estimates. Researchers often use formulas or software to calculate the optimal sample size, ensuring a balance between precision and feasibility.

Staff from both RTDA and RISA were simultaneously selected as the study population and sample size due to the limited number of individuals relevant to the research in the study area. Since the population was small and easily accessible, it was practical to include everyone to gather valuable information. As a result, the entire population of 92 participants was used as the sample for the study, ensuring comprehensive data correction.

### 3.8 Research instruments

Research instruments are the tools or mechanisms used by researchers to gather data systematically and accurately in a study. These instruments can take various forms, such as surveys, questionnaires, interview guides, observation checklists and standardized tests, depending on the research objectives and methodology (Dhlakama & Murairwa, 2024). The selection of the

appropriate research instrument is crucial as it directly impacts the reliability and validity of the collected data. For instance, a well-designed questionnaire with clear and unbiased questions can provide valuable quantitative insights, while an in-depth interview guide can capture rich qualitative data. To ensure the effectiveness of research instruments, they must undergo rigorous development and testing processes (Chen & Song, 2019). Piloting or pre-testing the instrument helps identify ambiguities, errors and potential biases, enabling researchers to make necessary adjustments before full-scale data collection. Ethical considerations, including obtaining informed consent and ensuring participant anonymity, must also be embedded in the design and administration of the instrument (Stocker et al., 2020). By carefully selecting, designing and validating research instruments, researchers can enhance the accuracy and integrity of their findings, thereby contributing to the overall quality of the study.

### ***3.8.1 Questionnaire design***

Questionnaire survey was designed in such a way to gather information from respondents to meet research objectives. In this research, the structured questionnaire survey was conducted for data collection. Same questions with same wording were asked to all respondents. The purpose of using the structured questionnaire survey is to avoid any kind of bias in gathering information.

Questionnaire is subdivided into two main sections:

**Section 1:** Is concerned with personal or demographic information for respondents;

**Section 2:** Is concerned with research questions, which have been designed with the purposes of having an idea on awareness of AI technologies, adoption of Artificial Intelligence in traffic management, challenges hindering the successful adoption of AI technologies into traffic management.

The questionnaire used in this study incorporated the Likert five point scales to facilitate an evaluation of responses between the minor to major ranges. The Likert Scale is an ordered, one-dimensional scale from which respondents choose one option that best aligns with their view. There are typically between four and seven options, five is very common. A five-point Likert Scale, which had a common use in the previous literature, ranged from 1 (low performance) to 5 (high performance) was adopted in this thesis. Based on the aim and objectives of the study to be conducted, all variables to be investigated using questionnaire survey have equal strength in terms

of importance because they are complementary in ensuring effectiveness of AI in traffic management.

### ***3.8.2 Structured interview***

Structured interview is used to complement survey questionnaire to seek detailed information about research participants' perception on application of AI in traffic management. In order to provide enhanced understanding of the concept of AI in traffic management, and get the detailed information from the relevant people (Elhami, 2022) the interview technique has also been thought as the most appropriate methods for this study. The interview was conducted with top management personnel (Project managers) from key institutions involved in transportation and digital infrastructure, specifically the Rwanda Transportation Development Agency (RTDA) and Rwanda Information Society Authority (RISA), to gain expert insights into the step-by-step process necessary for the effective application of Artificial Intelligence (AI) in traffic management. The interview sought insights into potential strategies that could be employed to facilitate and enhance the integration of AI solutions in the country's traffic systems.

### ***3.8.3 Reliability and validity of research instrument***

To understand the degree to which the questionnaire survey scale yields consistent results to the same sample over a period of time, a reliability analysis using the internal consistency was conducted. Internal consistency refers to how well a questionnaire survey measures what it is intended to be measured. The higher the internal consistency, the more confident that survey is reliable.

In this study, a statistic Cronbach's Alpha was calculated to test the internal consistency of our survey. The value for Cronbach's Alpha normally range between 0 and 1, with higher values indicating that the survey is more reliable, whereas lower value indicates that the survey is less reliable.

The Cronbach's Alpha value is calculated as follows:

$$\alpha = \frac{N}{N-1}$$

$$\left( \begin{array}{cc} \sum_{i=1}^N x_i^2 & \sum_{i=1}^N x_i y_i \\ \sum_{i=1}^N x_i y_i & \sum_{i=1}^N y_i^2 \end{array} \right) \quad \begin{array}{c} S_x - S_y \\ S_y^2 \end{array}$$

Where N is the number of Items or questions,  $S_i^2$  is the variance of each item and  $S_y^2$  is the variance of the total score (Sum of all items per respondent).

### 3.9 Methods of data collection

According to (Kabir, 2016), data collection is a fundamental aspect of any research study, as it directly impacts the quality and accuracy of the findings. Researchers utilize various methods of data collection, which can be broadly categorized into quantitative and qualitative techniques. Quantitative methods, such as surveys, experiments and structured observations focus on numerical data and statistical analysis. Surveys, for example, are commonly used to gather large amounts of data from a sample population through questionnaires, often employing Likert scales or multiple-choice questions to facilitate analysis (Rubeena & Maseeh, 2023). Experiments, on other hand, allow researchers to manipulate variables in controlled settings to observe cause and effect relationships. These methods are particularly effective when aiming for generalizability and testing hypotheses across larger populations, however, while quantitative methods offer precision and replicability, they may not fully capture the complexity of human experience or contextual factors.

To facilitate data collection for this study, a mixed-method approach was employed, questionnaires were distributed to respondents using Google Forms, allowing for efficient, wide reaching and contactless participation. This digital method enabled the collection of standardized responses from a diverse group of participants, including engineers, urban planners and the specialists in charge of transportation and ICT. In addition to the online survey, face-to-face interviews with project managers were conducted to gain deeper and qualitative insights. These in-person interviews allowed for follow-up questions, clarification of complex issues and the exploration of nuanced opinions regarding the application of AI in traffic management.

### 3.10 Methods of data analysis and presentation

According to (Mwange et al., 2023) data analysis and presentation are critical stages in the research process, as they transform raw data into meaningful findings that can answer research questions and support conclusions. The method of analysis depends on the type of data (qualitative or

quantitative) and the research design. For quantitative data, statistical techniques such as descriptive statistics, inferential statistics, regression analysis and hypothesis testing are commonly employed. These methods allow researchers to identify patterns, relationships and trends as well as to make generalizations about a population based on sample data (Osmanović & Maksimović, 2021). Qualitative data, on the other hand, is often analyzed through thematic analysis, constant analysis or narrative analysis, where researchers interpret the underlying theme, patterns and meaning embedded in the data (Braun & Clarke, 2013). Once data is analyzed, presenting the findings in a clear, concise and visually appealing manner is key to communicating the research outcomes effectively. Common methods of presentation for quantitative data include tables, graphs, charts and infographics which provide a visual representation of the numerical results and trends (Alem, 2020). For qualitative research, results are often presented through thematic summaries, quotes and conceptual diagrams that highlight the themes and patterns that emerged from the data. Regardless of the methods, clarity and coherence are paramount to ensure that the audience can interpret the findings accurately.

The Statistical Package for Social Scientists (SPSS) was used to analyze the quantitative data collected for the study, where the first section of questionnaire, which focused on demographic information, was analyzed using descriptive statistics, specifically frequencies and percentages, the second section, which explored key aspects such as the level of awareness, extent of adoption, specific areas of application and challenges related to the use of AI technologies in traffic management, was examined using a combination of mean scores and inferential statistics. Independent samples t-test were employed to determine whether there were significant differences in responses between groups and the results were interpreted using p-values to assess the statistical significance of those differences.

The qualitative analysis of fifteen interviews conducted with fifteen top leaders from RTDA and RISA, both institutions involved in transportation and ICT. The analysis followed a reflexive thematic approach, extracting themes, using both inductive coding. The final codebook summarizes the key themes, their descriptions, keywords and frequencies across the interviews

Table 3: Research matrix

Specific objectives	Research design	Method of data analysis

To determine the level of awareness of AI technology for traffic management.	-Questionnaire	-Descriptive statistics -Inferential statistics
To evaluate the level of adoption of AI technology to traffic management.	-Questionnaire	-Descriptive statistics -Inferential statistics
To investigate the specific application areas of AI technology to traffic management.	-Questionnaire	-Descriptive statistics -Inferential statistics
To assess the challenges of AI technology adoption to traffic management.	-Questionnaire -Interview	-Descriptive statistics -Inferential statistics

## **CHAPTER FOUR**

### **DATA PRESENTATION, ANALYSIS AND INTERPRETATION**

#### **4.1 Introduction**

This chapter presents a comprehensive account of the research findings based on the collected data. The first section of questionnaire, which focused on demographic information, was analyzed using descriptive statistics, specifically frequencies and percentages, the second section, which explored key aspects such as the level of awareness, extent of adoption, specific areas of application and challenges related to the use of AI technologies in traffic management, was examined using a combination of mean scores and inferential statistics. Independent samples t-test were employed to determine whether there were significant differences in responses between groups and the results were interpreted using p-values to assess the statistical significance of those differences.

The qualitative analysis of 15 interviews conducted with 15 top leaders from RTDA and RISA, both institutions involved in transportation and ICT. The analysis followed a reflexive thematic approach, extracting themes, using both inductive coding. The final codebook summarizes the key themes, their descriptions, keywords and frequencies across the interviews

#### **4.2 Rate of response**

The research aimed to collect data from two government institutions (RTDA and RISA), targeting a population and sample size of 92 personnel. Out of these, 77 individuals were selected to respond to the questionnaire, including 40 participants from RTDA and 37 participants from RISA. Additionally, 15 (8 project engineers, 4 Program managers and 3 division managers) from both institutions were targeted for interviews.

#### **4.3 Questionnaire results presentation and analysis**

Table 4, indicates the general information of the respondents of the study, among the respondents, 80.6% were male, 18.1% were female and 1.4 % preferred not to say their gender. Among the respondents also none of participants were between 18 and 25 years old, 30.6% of participants were between 26 and 35 years old, 56.9% of participants were between 36 and 45 years old. The figure indicates also that none of participants were between 46 and 55 years old and no participants

were from 56 years old upward. Also 77.8 % of respondents hold a Bachelor’s degree, 22.2 % of respondents have attained a Master’s degree and none of respondent hold a Ph. D. Further, 34 respondents, which is equal to 47 % were IT engineers, 38 respondents which is equal to 53 % were civil engineers. Again, 2 respondents equivalent to 2.8 % had less than 1 year of experience, 12 respondents (16.7 %) had between 1 to 3 years of experience, 32 respondents (44.4 %) had between 4-6 years of experience, 22 respondents (30.6 %) had between 7 to 10 years of experience and 4 respondents (5.6 %) had above 10 years of experience.

28 respondents (39 %) have been involved in project planning and design, 21 respondents (29 %) have been involved in supervision and quality control, 21 respondents (29 %) have been involved in construction execution, 2 respondents (3 %) has been involved in other fields. 31 respondents (43 %) were registered with Institute of Engineers Rwanda (IER), 1 respondent (1.4 %) were registered with Rwanda Institute of Architects (RIA), 1 respondent (1.4 %) were registered with other professional body, 39 respondents (54.2 %) had no professional body registered with. 71 respondents which is equal to 98.6 % were working in Government agency, whereas 1 respondent which is equal to 1.4 % were working in other institutions. 18 respondents (25.4 %) worked on the project of new road construction, 25 respondents (35.2 %) worked on the project of road upgrading and rehabilitation, 12 respondents (17%) worked on the project of network expansion, 13 respondents (18.3 %) worked on the project of ICT, 4 respondents (5 %) worked on other projects.

**Table 4: Results presentation of demographic information**

Statements	Options	Frequency	Percent	Percentage
Gender	Female	13	18.1	18%
	Male	58	80.6	81%
	Prefer not to say	1	1.4	1%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Age group	26 – 35	22	30.6	31%
	36 – 45	41	56.9	57%
	46 – 55	9	12.5	13%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Highest Academic	Bachelor (BSc) Degree	56	77.8	78%

Qualification	Master's Degree	16	22.2	22%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Areas of specialization	Civil Engineer	38	52.8	53%
	IT Engineer	34	47.2	47%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Working experience	1- 3 years	12	16.7	17%
	10 years and above	4	5.6	6%
	4 – 6 years	32	44.4	44%
	7 – 10 years	22	30.6	31%
	Less than 1 year	2	2.8	3%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
The nature of your involvement in transportation and ICT project	Project Planning and Design	28	38.9	39%
	Supervision and Quality Control	21	29.2	29%
	Construction Execution	21	29.2	29%
	Other	2	2.8	3%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Professional body	RIA	1	1.4	1%
	IER	31	43.1	43%
	Other	1	1.4	1%
	None	39	54.2	54%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Type of Organization	Government Agency	71	98.6	99%
	Other	1	1.4	1%
	<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>
Type of projects have you mostly worked on	New Road Construction	18	25.0	25%

Road Upgrading/Rehabilitation	25	34.7	35%
Network expansion project	12	16.7	17%
ICT project	13	18.1	18%
Other	4	5.2	5%
<b>Total</b>	<b>72</b>	<b>100.0</b>	<b>100%</b>

Table 5, presents the level of awareness of AI technologies in Rwanda, based on the areas of specialization of respondents. The most known AI technologies by Civil engineers were Google Maps AI (1.53), Reinforcement Learning (1.34), Machine Learning (1.32) and Robotics (1.26). the least known AI technologies by Civil engineers were Minus Zero (1.16) and Genetic Algorithms (1.18). The most known AI technologies by IT engineers were Google Maps AI (1.50), Machine Learning (1.26) followed by Genetic Algorithms and Artificial Neural Networks with 1.24 each. The least known AI technologies by IT engineers were Citymapper, Optibus, NoTraffic and Fuzzy Logics with 1.03 each. Collectively, the most known AI technologies among Civil engineers and IT engineers were Google Maps AI, Machine Learning, Reinforcement Learning, Swam Intelligence and Robotics. In contrast, the least known were Minus Zero, NoTraffic, Fuzzy Logics and NuPort Robotics.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of awareness between the Civil engineers and the IT engineers. The study found that there was no significant difference ( $p > 0.05$ ) in the level of awareness of Civil engineers and IT engineers, except for the awareness of Fuzzy Logics and Citymapper ( $0.02 < p < 0.05$ ).

**Table 5: Results presentation on level of awareness of AI technologies according to areas of specialization**

AI Technologies	Civil Engineer mean and rank	IT Engineer mean and rank	Overall Mean and rank	Dec.	Sign. (2-tailed)	Sign.
Machine Learning	1.32 (3)	1.26 (2)	1.29 (2)	NA	0.717	NS
Computer Vision	1.24 (5)	1.15 (6)	1.19 (7)	NA	0.469	NS
Knowledge- Based System	1.24 (5)	1.21 (4)	1.22 (5)	NA	0.799	NS

Artificial Neural Networks	1.21 (6)	1.24 (3)	1.22 (5)	NA	0.829	NS
Genetic Algorithms	1.18 (7)	1.24 (3)	1.21 (6)	NA	0.7	NS
Robotics	1.26 (4)	1.21 (4)	1.24 (4)	NA	0.623	NS
Reinforcement Learning	1.34 (2)	1.18 (5)	1.26 (3)	NA	0.267	NS
Deep Learning	1.24 (5)	1.15 (6)	1.19 (7)	NA	0.416	NS
Natural Language processing	1.26 (4)	1.12 (7)	1.19 (7)	NA	0.263	NS
Swam Intelligence	1.24 (5)	1.24 (3)	1.24 (4)	NA	0.991	NS
Fuzzy Logics	1.24 (5)	1.03 (9)	1.14 (10)	NA	0.036	S
NoTraffic	1.21 (6)	1.03 (9)	1.13 (11)	NA	0.105	NS
Minus Zero	1.16 (8)	1.06 (8)	1.11 (12)	NA	0.23	NS
NuPort Robotics	1.21 (6)	1.12 (7)	1.17 (8)	NA	0.438	NS
Optibus	1.18 (7)	1.03 (9)	1.11 (12)	NA	0.098	NS
Citymapper	1.26 (4)	1.03 (9)	1.15 (9)	NA	0.032	S
Trainline	1.26 (4)	1.18 (5)	1.22 (5)	NA	0.498	NS
Google Maps AI	1.53 (1)	1.5 (1)	1.51 (1)	LA	0.889	NS

Note: NA=Not Aware= $\leq 1.50$ ; LA=Low Aware= 1.50-2.49; NS=No Significant difference ( $p>0.05$ ); Dec.=Decision; Sign. =Significance).

Table 6, presents the level of awareness of AI technologies in Rwanda, based on the nature of involvement of respondents in transportation and ICT projects. The most known AI technologies according to those who were in supervision and quality control were Google Maps AI (1.39), Trainline (1.29), Nuport Robotics (1.25) Natural language processing, Machine Learning, Reinforcement Learning all with (1.21). the least known AI technologies by those supervision and quality control were Citymapper, Optibus, Knowledge-Based System all with (1.11). The most known AI technologies by those who were involved in Project Planning and Design were Google

Maps AI (1.48), Knowledge-Based System (1.24) followed by Machine Learning, Artificial Neural Networks and Deep Learning all with (1.19) each. The least known AI technologies those who were involved in Project Planning and Design were Trainline, NuPort Robotics, Minus Zero and Genetic Algorithms with (1.10) each.

Collectively, the most known AI technologies between those who were involved in Project Planning and Design and those who were involved in transportation and ICT projects were Google Maps AI, Reinforcement Learning, Machine Learning, Swam Intelligence. In contrast, the least known were Minus Zero, Genetic Algorithms, Optibus, Citymapper.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of awareness between the respondents who were involved in Project Planning and Design and the respondents who were involved in transportation and ICT projects. The study found that there was no significant difference ( $p > 0.05$ ) in the level of awareness.

**Table 6: Results presentation on level of awareness of AI technologies according to nature of involvement**

AI Technologies	Supervision & Quality Control and rank	Project Planning & Design and rank	Overall Mean and rank	Dec.	Two-Sided p	Sign.
Machine Learning	1.21 (4)	1.19 (3)	1.2 (3)	NA	0.888	NS
Computer Vision	1.14 (6)	1.14 (4)	1.14 (8)	NA	1	NS
Knowledge- Based System	1.11 (7)	1.24 (2)	1.17 (6)	NA	0.383	NS
Artificial Neural Networks	1.11 (7)	1.19 (3)	1.15 (7)	NA	0.533	NS
Genetic Algorithms	1.14 (6)	1.1 (5)	1.12 (10)	NA	0.757	NS
Robotics	1.14 (6)	1.14 (4)	1.14 (8)	NA	1	NS
Reinforcement Learning	1.21 (4)	1.24 (2)	1.23 (2)	NA	0.96	NS
Deep Learning	1.14 (6)	1.19 (3)	1.17 (6)	NA	0.731	NS

Natural language processing	1.21 (4)	1.14 (4)	1.18 (5)	NA	0.666	NS
Swam Intelligence	1.14 (6)	1.24 (2)	1.19 (4)	NA	0.537	NS
Fuzzy Logics	1.14 (6)	1.14 (4)	1.14 (8)	NA	1	NS
NoTraffi	1.14 (6)	1.14 (4)	1.14 (8)	NA	1	NS
Minus Zero	1.15 (5)	1.1 (5)	1.12(10)	NA	0.648	NS
NuPort Robotics	1.25 (3)	1.1 (5)	1.17 (6)	NA	0.348	NS
Optibus	1.11 (7)	1.14 (4)	1.13 (9)	NA	0.782	NS
Citymapper	1.11 (7)	1.14 (4)	1.13 (9)	NA	0.782	NS
Trainline	1.29 (2)	1.1 (5)	1.19 (4)	NA	0.257	NS
Google Maps AI	1.39 (1)	1.57 (1)	1.48 (1)	NA	0.441	NS

Note: NA=Not Aware=<1.50; LA=Low Aware= 1.50-2.49; NS=No Significant difference (p>0.05); Dec. =Decision; Sign. =Significance).

Table 7, presents the level of awareness of AI technologies in Rwanda, based on the nature of involvement of respondents in transportation and ICT projects. The most known AI technologies according to those who were in Construction Execution were Google Maps AI (1.52), Machine Learning (1.48), Artificial Neural Networks and Genetic Algorithms all with (1.43). the least known AI technologies by those who were in Construction Execution were Minus Zero, NoTraffic, Fuzzy Logics, Minus Zero all with (1.10). The most known AI technologies by those who were involved in others were Google Maps AI (1.48) and Trainline (2.00). The least known AI technologies those who were involved in others were Trainline, NuPort Robotics, Minus Zero and Genetic Algorithms, Deep Learning, all with (1.00) each.

Collectively, the most known AI technologies between those who were involved in Construction Execution and those who were involved in others were Google Maps AI, Robotics, Knowledge-Based System and Trainline. In contrast, the least known were Minus Zero, Optibus, Citymapper.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of awareness between the respondents who were involved in Construction

Execution and the respondents who were involved in others. The study found that there was no significant difference ( $p>0.05$ ) in the level of awareness. except for the awareness of Trainline ( $0.02<p<0.05$ ).

**Table 7:Results presentation on level of awareness of AI technologies according to nature of involvement**

<b>AI Technologies</b>	<b>Construction Execution and rank</b>	<b>Other (Please specify) and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Machine Learning	1.48 (2)	1.5 (3)	1.49 (5)	NA	0.958	NS
Computer Vision	1.29 (6)	1.5 (3)	1.39 (7)	NA	0.551	NS
Knowledge-Based System	1.29 (6)	2 (2)	1.64 (3)	NA	0.045	S
Artificial Neural Networks	1.43 (3)	1 (4)	1.21 (9)	NA	0.255	NS
Genetic Algorithms	1.43 (3)	1 (4)	1.21 (9)	NA	0.332	NS
Robotics	1.38 (4)	2 (2)	1.69 (2)	NA	0.1	NS
Reinforcement Learning	1.33 (5)	1.5 (3)	1.42 (6)	NA	0.654	NS
Deep Learning	1.29 (6)	1 (4)	1.14 (10)	NA	0.42	NS
Natural language processing	1.24 (7)	1 (4)	1.12 (11)	NA	0.547	NS
Swam Intelligence	1.33 (5)	1.5 (3)	1.42 (6)	NA	0.737	NS
Fuzzy Logics	1.1 (10)	1.5 (3)	1.3 (8)	NA	0.114	NS
NoTraffic	1.1 (10)	1 (4)	1.05 (13)	NA	0.666	NS
Minus Zero	1.1 (10)	1 (4)	1.05 (13)	NA	0.666	NS
NuPort Robotics	1.14 (9)	1 (4)	1.07 (12)	NA	0.587	NS
Optibus	1.1 (10)	1 (4)	1.05 (13)	NA	0.666	NS

Citymapper	1.24 (7)	1 (4)	1.12 (11)	NA	0.547	NS
Trainline	1.19 (8)	2 (2)	1.6 (4)	NA	0.011	S
Google Maps AI	1.52 (1)	2.5 (1)	2.01 (1)	NA	0.092	NS

Note: NA=Not Aware= $\leq 1.50$ ; LA=Low Aware= 1.50-2.49; NS=No Significant difference ( $p>0.05$ ); Dec.=Decision; Sign. =Significance).

Table 8, presents the level of adoption of AI technologies between Civil engineers and IT engineers. The most adopted AI technologies among Civil engineers were Google Maps AI (1.82), Robotics (1.61), Natural Language Processing (1.47), Knowledge-based Systems (1.32) and Deep Learning (1.24). The most adopted AI technologies among IT engineers were Google Maps AI (1.71), Robotics (1.53), Natural Language Processing (1.35), Artificial Neural Networks (1.24) and Swam Intelligence (1.18). The least adopted AI technologies among Civil engineers were Computer Vision (1.18), Citymapper and Trainline both with 1.13, followed by Fuzzy Logics (1.16). The least adopted AI technologies among IT engineers were Citymapper (1.06), followed by NuPort Robotics, NoTraffic and Deep Learning, each with 1.09. Collectively, the most adopted AI technologies among Civil engineers and IT engineers were Google Maps AI, Robotics, Natural Language Processing, Knowledge-Based System, Artificial Neural Networks, Swam Intelligence. In contrast, the least adopted were Citymapper, Trainline, NoTraffic and Fuzzy Logics.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of adoption of AI technologies between the Civil engineers and the IT engineers. The study found that there was no significant difference ( $p>0.05$ ) in the level of adoption of AI technologies between Civil engineers and IT engineers. Therefore, methods of AI technologies adoption should be applied to both categories of respondents.

**Table 8: Results presentation on level of adoption of AI technologies according to areas of specialization**

AI Technologies	Civil Engineer mean and rank	IT Engineer mean and rank	Overall Mean and rank	Dec.	Sign. (2-tailed)	Sign.
Machine Learning	1.16 (8)	1.18 (5)	1.17 (8)	NA	0.877	NS
Computer Vision	1.18 (12)	1.12 (7)	1.15 (9)	NA	0.572	NS

Knowledge- Based System	1.32 (4)	1.12 (7)	1.22 (4)	NA	0.118	NS
Artificial Neural Networks	1.18 (7)	1.24 (4)	1.21 (5)	NA	0.65	NS
Genetic Algorithms	1.18 (7)	1.12 (7)	1.15 (9)	NA	0.514	NS
Robotics	1.61 (2)	1.53 (2)	1.57 (2)	SA	0.622	NS
Reinforcement Learning	1.21 (6)	1.15 (6)	1.18 (7)	NA	0.651	NS
Deep Learning	1.24 (5)	1.09 (8)	1.17 (8)	NA	0.187	NS
Natural Language processing	1.47 (3)	1.35 (3)	1.42 (3)	NA	0.378	NS
Swam Intelligence	1.21 (6)	1.18 (5)	1.19 (6)	NA	0.758	NS
Fuzzy Logics	1.16 (8)	1.12 (7)	1.14 (10)	NA	0.689	NS
NoTraffic	1.18 (7)	1.09 (8)	1.14 (10)	NA	0.404	NS
Minus Zero	1.21 (6)	1.12 (7)	1.17 (8)	NA	0.438	NS
NuPort Robotics	1.18 (7)	1.09 (8)	1.14 (10)	NA	0.404	NS
Optibus	1.21 (6)	1.12 (3)	1.17 (8)	NA	0.519	NS
Citymapper	1.13 (9)	1.06 (9)	1.1 (11)	NA	0.496	NS
Trainline	1.13 (9)	1.15 (6)	1.14 (10)	NA	0.893	NS
Google Maps AI	1.82 (1)	1.71 (1)	1.76 (1)	SA	0.594	NS

Note: NA=Not Adopted= $\leq 1.50$ ; SA=Slightly Adopted= 1.50-2.49; A=Adopted=3.50-4.49; NS=No Significant difference ( $p > 0.05$ ); Dec. =Decision; Sign. =Significance).

Table 9, presents the level of adoption of AI technologies based on the nature of involvement of respondents in transportation and ICT projects. The most adopted AI technologies among those who were in Project Planning and Design were Robotics (1.64) Google Maps AI (1.54), Natural Language Processing (1.39), Knowledge-Based System (1.25). The most adopted AI technologies

among those who were involved in supervision and quality control were Google Maps AI (2.10), Robotics (1.43), Natural Language Processing (1.35). The least adopted AI technologies among those who were involved in Project Planning and Design were Citymapper (1.11) Trainline, NoTraffic and Genetic Algorithms, all with 1.14. The least adopted AI technologies among those who were involved in supervision and quality control were Citymapper (1.06), Trainline, Optibus and Deep Learning each with 1.00. Collectively, the most adopted AI technologies among those who were involved in supervision and quality control and those who were in Project Planning and Design were Google Maps AI, Robotics, Natural Language Processing, Knowledge-Based System, Artificial Neural Networks, Swam Intelligence. In contrast, the least adopted were Citymapper, Trainline, NoTraffic and Minus Zero.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of adoption of AI technologies between the respondents who were in Project Planning and Design and the respondents who were involved in supervision and quality control. The study found that there was no significant difference ( $p > 0.05$ ) in the level of adoption of AI technologies. Therefore, methods of AI technologies adoption should be applied to both categories of respondents.

**Table 9: Results presentation on level of adoption of AI technologies according to nature of involvement**

AI Technologies	Supervision & Quality Control and rank	Project Planning & Design and rank	Overall Mean and rank	Dec.	Two-Sided p	Sign.
Machine Learning	1.21 (5)	1.05 (5)	1.13 (7)	NA	0.433	NS
Computer Vision	1.21 (5)	1.05 (5)	1.13 (7)	NA	0.612	NS
Knowledge- Based System	1.25 (4)	1.14 (4)	1.2 (4)	NA	0.488	NS
Artificial Neural Networks	1.21 (5)	1.05 (5)	1.13 (7)	NA	0.74	NS
Genetic Algorithms	1.14 (7)	1.05 (5)	1.1 (6)	NA	0.553	NS
Robotics	1.64 (1)	1.43 (2)	1.54 (2)	SA	0.813	NS

Reinforcement Learning	1.18 (6)	1.05 (5)	1.11 (8)	NA	0.616	NS
Deep Learning	1.21 (5)	1 (6)	1.11 (8)	NA	0.488	NS
Natural language processing	1.39 (3)	1.24 (3)	1.32 (3)	NA	0.813	NS
Swam Intelligence	1.25 (4)	1.1 (3)	1.17 (5)	NA	0.547	NS
Fuzzy Logics	1.21 (5)	1.05 (5)	1.13 (7)	NA	0.683	NS
NoTraffi	1.14 (7)	1.05 (5)	1.1 (6)	NA	0.433	NS
Minus Zero	1.18 (6)	1.14(4)	1.16 (4)	NA	0.612	NS
NuPort Robotics	1.18 (6)	1.1 (3)	1.14 (3)	NA	0.683	NS
Optibus	1.25 (4)	1 (6)	1.13 (7)	NA	0.63	NS
Citymapper	1.11 (8)	1 (6)	1.05 (6)	NA	0.612	NS
Trainline	1.14 (7)	1 (6)	1.07 (6)	NA	0.525	NS
Google Maps AI	1.54 (2)	2.1 (1)	1.82 (1)	SA	0.587	NS

Note: NA=Not Adopted= $\leq 1.50$ ; SA=Slightly Adopted= 1.50-2.49; A=Adopted=3.50-4.49; NS=No Significant difference ( $p > 0.05$ ); Dec. =Decision; Sign. =Significance).

Table 10, presents the level of adoption of AI technologies based on the nature of involvement of respondents in transportation and ICT projects. The most adopted AI technologies among those who were in Construction execution were Google Maps AI (1.71), Robotics (1.62), Natural Language Processing (1.62), Artificial Neural Networks (1.33). The most adopted AI technologies among those who were involved in others were Google Maps AI (2.00), Machine Learning, Artificial Neural Networks, Genetic Algorithms all with (1.50). The least adopted AI technologies among those who were involved in Construction execution were NuPort Robotics and Fuzzy Logics (1.14). The least adopted AI technologies among those who were involved in others were Citymapper (1.06), NuPort Robotics, Optibus and Deep Learning each with 1.00. Collectively, the most adopted AI technologies among those who were involved in Construction execution and those who were in others were Google Maps AI, Robotics, Natural Language Processing. In contrast, the least adopted were Nuport Robotics, Fuzzy Logics, NoTraffic and Minus Zero.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in the level of adoption of AI technologies between the respondents who were in Construction execution and the respondents who were involved in others. The study found that there was no significant difference ( $p>0.05$ ) in the level of adoption of AI technologies. Therefore, methods of AI technologies adoption should be applied to both categories of respondents.

**Table 10: Results presentation on level of adoption of AI technologies according to nature of involvement**

<b>AI Technologies</b>	<b>Construction Execution and rank</b>	<b>Other (Please specify) and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Machine Learning	1.19 (7)	1.5 (2)	1.35 (7)	NA	0.63	NS
Computer Vision	1.19 (7)	1 (3)	1.1 (9)	NA	0.218	NS
Knowledge-Based System	1.29 (4)	1 (3)	1.14 (8)	NA	0.63	NS
Artificial Neural Networks	1.33 (3)	1.5 (2)	1.42 (3)	NA	0.218	NS
Genetic Algorithms	1.25 (5)	1.5 (2)	1.38 (4)	NA	0.645	NS
Robotics	1.62 (2)	1.5 (2)	1.56 (2)	SA	0.359	NS
Reinforcement Learning	1.29 (4)	1.5 (2)	1.39 (4)	NA	0.499	NS
Deep Learning	1.29 (4)	1 (3)	1.14 (8)	NA	0.218	NS
Natural language processing	1.62 (2)	1.5 (2)	1.56 (2)	SA	0.356	NS
Swam Intelligence	1.24 (6)	1 (3)	1.12 (9)	NA	0.218	NS
Fuzzy Logics	1.14 (8)	1 (3)	1.07 (11)	NA	0.731	NS
NoTraffic	1.19 (7)	1.5 (2)	1.35 (7)	NA	0.57	NS
Minus Zero	1.19 (7)	1 (3)	1.1 (10)	NA	0.772	NS

NuPort Robotics	1.14 (8)	1 (3)	1.07 (11)	NA	0.218	NS
Optibus	1.24 (6)	1 (3)	1.12 (9)	NA	0.568	NS
Citymapper	1.19 (7)	1 (3)	1.1 (10)	NA	0.567	NS
Trainline	1.24 (6)	1.5 (2)	1.37 (6)	NA	0.436	NS
Google Maps AI	1.71 (1)	2 (1)	1.86 (1)	SA	0.518	NS

Note: NA=Not Adopted= $\leq 1.50$ ; SA=Slightly Adopted= 1.50-2.49; A=Adopted=3.50-4.49; NS=No Significant difference ( $p > 0.05$ ); Dec. =Decision; Sign. =Significance).

Table 11, presents the application of AI technologies in some specific areas of traffic management, according to Civil engineers and IT engineers. The areas which mostly utilize AI technologies among Civil engineers were Smart parking management (1.71), Traffic violation and enforcement automation (1.66) and Number plate recognition (1.58). The areas which mostly utilize AI technologies among IT engineers were Number plate recognition (1.79), Smart parking management (1.71), Traffic violation and enforcement automation (1.68). The areas which rarely utilize AI technologies among Civil engineers were Incident detection and management (1.13), Autonomous and connected vehicle integration (1.11), Adaptive traffic signal control and Traffic flow prediction each with 1.16. The areas which rarely utilize AI technologies among IT engineers were Autonomous and connected vehicle (1.06) followed by Traffic flow prediction, Public transportation optimization and Road condition and maintenance monitoring, each with (1.09).

Collectively, the areas which mostly utilize AI technologies among Civil engineers and IT engineers were Smart parking management, Number plate recognition, Traffic violation and enforcement automation. In contrast, the areas which rarely utilize AI technologies among Civil engineers and IT engineers were Autonomous and connected vehicle integration, Road condition and maintenance monitoring and Traffic flow prediction.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in application of AI technologies in some specific areas between the Civil engineers and the IT engineers. The study found that there was no significant difference ( $p > 0.05$ ) between Civil engineers and IT engineers.

**Table 11: Results presentation on specific application areas of AI technologies according to areas of specialization**

<b>Application areas</b>	<b>Civil Engineer mean and rank</b>	<b>IT Engineer mean and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Sign. (2-tailed)</b>	<b>Sign.</b>
Adaptive traffic signal control	1.16 (6)	1.18 (4)	1.17 (4)	NA	0.852	NS
Traffic flow prediction	1.16 (6)	1.09 (6)	1.13 (7)	NA	0.558	NS
Congestion management	1.18 (5)	1.12 (5)	1.15 (5)	NA	0.598	NS
Incident detection and management	1.13 (8)	1.21 (4)	1.17 (4)	NA	0.674	NS
Smart parking management	1.71 (1)	1.76 (2)	1.74 (1)	A	0.953	NS
Public transportation optimization	1.24 (4)	1.09 (6)	1.17 (4)	NA	0.229	NS
Autonomous and connected vehicle integration	1.11 (7)	1.06 (7)	1.08 (8)	NA	0.672	NS
Road condition and maintenance monitoring	1.16 (6)	1.09 (6)	1.13 (7)	NA	0.558	NS
Emission and environment al impact monitoring	1.18 (4)	1.09 (6)	1.14 (6)	NA	0.425	NS
Demand- Responsive traffic planning	1.24 (4)	1.09 (6)	1.17 (4)	NA	0.254	NS
Traffic violation and enforcement automation	1.66 (2)	1.68 (3)	1.67 (3)	A	0.917	NS
Number plate recognition	1.58 (3)	1.79 (1)	1.68 (2)	A	0.466	NS

Note: NA=Not Applied=<1.50; A=Applied=>1.50; NS=No Significant difference (p>0.05); Dec. =Decision; Sign. =Significance).

Table 12, presents the application of AI technologies in some specific areas of traffic management, according to the nature of involvement of respondents in transportation and ICT projects. The areas which mostly utilize AI technologies according those who were involved in supervision and quality control were Traffic violation and enforcement automation (2.05) and Number plate recognition and Smart parking management (2.00). The areas which mostly utilize AI technologies according those who were in Project Planning and Design were Number plate recognition and Smart parking management (3.00), Traffic violation and enforcement automation (2.00). The areas

which rarely utilize AI technologies according those who were involved in supervision and quality control were Road condition and maintenance monitoring (1.10), Autonomous and connected vehicle integration (1.10), Adaptive traffic signal control and Traffic flow prediction each with (1.14). The areas which rarely utilize AI technologies according those who were in Project Planning and Design were Autonomous and connected vehicle, Traffic flow prediction, Public transportation optimization and Road condition and maintenance monitoring, each with (1.00).

Collectively, the areas which mostly utilize AI technologies according those who were involved in supervision and quality control and according those who were in Project Planning and Design were Smart parking management, Number plate recognition, Traffic violation and enforcement automation. In contrast, the areas which rarely utilize AI technologies were Autonomous and connected vehicle integration, Road condition and maintenance monitoring and Traffic flow prediction.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in application of AI technologies in some specific areas between the respondents who were involved in supervision and quality control and the respondents who were in Project Planning and Design. The study found that there was no significant difference ( $p > 0.05$ ).

**Table 12: Results presentation on specific application areas of AI technologies according to nature of involvement**

<b>Application areas</b>	<b>Supervision &amp; Quality Control and rank</b>	<b>Project Planning &amp; Design and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Adaptive traffic signal control	1.14 (5)	1 (4)	1.07 (7)	NA	0.683	NS
Traffic flow prediction	1.14 (5)	1 (4)	1.07 (7)	NA	0.683	NS
Congestion management	1.24 (3)	1.5 (3)	1.37 (3)	NA	0.525	NS
Incident detection and management	1.24 (3)	1 (4)	1.12 (5)	NA	0.547	NS
Smart parking management	2 (2)	3 (1)	2.5 (1)	A	0.159	NS

Public transportation optimization	1.24 (3)	1.5 (3)	1.37 (3)	NA	0.525	NS
Autonomous and connected vehicle integration	1.1 (6)	1 (4)	1.05 (8)	NA	0.765	NS
Road condition and maintenance monitoring	1.1 (6)	1 (4)	1.05 (8)	NA	0.765	NS
Emission and environmental impact monitoring	1.19 (4)	1 (4)	1.1 (6)	NA	0.612	NS
Demand- Responsive traffic planning	1.14 (5)	1.5 (3)	1.32 (4)	NA	0.337	NS
Traffic violation and enforcement automation	2.05 (1)	2 (2)	2.02 (2)	A	0.944	NS
Number plate recognition	2 (2)	3 (1)	2.5 (1)	A	0.113	NS

Note: NA=Not Applied= $\leq 1.50$ ; A=Applied= $\geq 1.50$ ; NS=No Significant difference ( $p > 0.05$ ); Dec. =Decision; Sign. =Significance).

Table 13, presents the application of AI technologies in some specific areas of traffic management, according to the nature of involvement of respondents in transportation and ICT projects. The areas which mostly utilize AI technologies according those who were involved in construction execution were Traffic violation and enforcement automation (1.46) and Number plate recognition (1.50) Smart parking management (1.54). The areas which mostly utilize AI technologies according those who were involved in others were Smart parking management (1.62), Number plate recognition (1.48) Traffic violation and enforcement automation (1.52). The areas which rarely utilize AI technologies according those who were involved in construction execution were Road condition and maintenance monitoring (1.10), Autonomous and connected vehicle integration and Congestion management (1.10), Adaptive traffic signal control and Traffic flow prediction each with (1.14). The areas which rarely utilize AI technologies according those who were involved in others were Autonomous and connected vehicle, Road condition and maintenance monitoring and

Public transportation optimization, all with (1.05).

Collectively, the areas which mostly utilize AI technologies according those who were involved in construction execution and according those who were involved in others were Smart parking management, Number plate recognition, Traffic violation and enforcement automation. In contrast, the areas which rarely utilize AI technologies were Autonomous and connected vehicle integration, Congestion management, Public transportation optimization.

The current study then adopted the independent samples t-tests statistics to establish if there was a difference in application of AI technologies in some specific areas between the respondents who were involved in construction execution and the respondents who were involved in others. The study found that there was no significant difference ( $p>0.05$ ).

**Table 13: Results presentation on specific application areas of AI technologies according to nature of involvement**

<b>Application areas</b>	<b>Construction Execution and rank</b>	<b>Other (Please specify) and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Adaptive traffic signal control	1.21 (6)	1.14 (4)	1.18 (3)	NA	0.666	NS
Traffic flow prediction	1.14 (8)	1.1 (5)	1.12 (6)	NA	0.737	NS
Congestion management	1.14 (8)	1.05 (6)	1.1 (8)	NA	0.486	NS
Incident detection and management	1.21 (6)	1.05 (6)	1.13 (5)	NA	0.252	NS
Smart parking management	1.54 (1)	1.62 (1)	1.58 (1)	A	0.767	NS
Public transportation optimization	1.18 (7)	1.05 (6)	1.11 (7)	NA	0.354	NS
Autonomous and connected vehicle integration	1.14 (8)	1 (7)	1.07 (9)	NA	0.275	NS

Road condition and maintenance monitoring	1.25 (4)	1 (7)	1.13 (5)	NA	0.083	NS
Emission and environment al impact monitoring	1.18 (7)	1.05 (6)	1.11 (7)	NA	0.354	NS
Demand-Responsive traffic planning	1.22 (5)	1.1 (5)	1.16 (4)	NA	0.441	NS
Traffic violation and enforcement automation	1.46 (3)	1.52 (2)	1.49 (2)	NA	0.84	NS
Number plate recognition	1.5 (2)	1.48 (3)	1.49 (2)	NA	0.923	NS

Note: NA=Not Applied= $\leq 1.50$ ; A=Applied= $\geq 1.50$ ; NS=No Significant difference ( $p > 0.05$ ); Dec. =Decision; Sign. =Significance).

Table 14, showcases the challenges that hinder the adoption of AI technologies in traffic management, based on the responses of Civil engineers and IT engineers. The top significant challenges of Civil engineers were High investment cost (4.89), Limited educational involvement (4.87), Poor infrastructures (4.84) and Infrastructure incompatibility (4.79). The top significant challenges of IT engineers were High investment cost (4.82), Limited educational involvement (4.76), Poor infrastructures (4.74) and Infrastructure incompatibility (4.59). In contrast, the least significant challenges of Civil engineers were Resistance to change (3.63), Limited data availability (3.76) and Data privacy and security concerns (4.24). In contrast, the least significant challenges of IT engineers were Limited data availability (3.68), Fear of job loss (4.09), Cyber-security risks and ethical and equity concerns, each with (4.12).

In general, the most significant challenges for Civil engineers and IT engineers were High investment cost, limited educational involvement, Poor infrastructures and Infrastructure incompatibility, whereas, the least significant challenges for Civil engineers and IT engineers Resistance to change, Limited data availability, Data privacy and security concerns and Poor data quality.

The current study then adopted the independent samples t-tests statistics to establish if there were

differences in the opinions of Civil engineers and IT engineers on the challenges which hindered the adoption of AI technologies in traffic management. The finding established that there were no significant differences ( $p>0.05$ ) in the opinions of Civil engineers and IT engineers on the challenges of adoption of AI technologies in traffic management.

**Table 14: Results presentation on challenges of application of AI technologies according to areas of specialization**

<b>Challenges</b>	<b>Civil Engineer mean and rank</b>	<b>IT Engineer mean and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Sign. (2-tailed)</b>	<b>Sign.</b>
Limited data availability	3.76 (12)	3.68 (15)	3.72 (13)	S	0.769	NS
Poor data quality	4.37 (10)	4.15 (10)	4.26 (11)	S	0.375	NS
Data privacy and security concerns	4.24 (11)	4.24 (9)	4.24 (12)	S	0.995	NS
Infrastructure incompatibility	4.79 (4)	4.59 (4)	4.69 (4)	VS	0.242	NS
Poor infrastructures	4.84 (3)	4.74 (3)	4.79 (3)	VS	0.342	NS
Limited trainings	4.5 (7)	4.29 (8)	4.4 (7)	S	0.388	NS
Limited educational involvement	4.87 (2)	4.76 (2)	4.82 (2)	VS	0.26	NS
Lack of technical expertise	4.53 (4)	4.32 (6)	4.43 (6)	S	0.403	NS
Resistance to change	3.63 (13)	3.76 (7)	3.69 (14)	S	0.647	NS
Regulatory and legal barriers	4.49 (8)	4.15 (10)	4.32 (9)	S	0.171	NS
Ethical and equity concerns	4.54 (6)	4.12 (11)	4.34 (8)	S	0.062	NS
Cyber- security risks	4.5 (7)	4.12 (11)	4.32 (9)	S	0.106	NS
Fear of job loss	4.45 (9)	4.09 (12)	4.28 (10)	S	0.128	NS
High investment cost	4.89 (1)	4.82 (1)	4.86 (1)	VS	0.439	NS

Lack of trust in AI technologies	4.58 (5)	4.47 (5)	4.46 (5)	S	0.642	NS
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Note: S= Significant=3.50-4.49; VS=Very Significant=>4.50; NS=No Significant difference (p>0.05); Dec. =Decision; Sign. =Significance)

Table 15, showcases the challenges that hinder the adoption of AI technologies in traffic management, based on the nature of involvement of respondents in transportation and ICT projects. The top significant challenges according those who were involved in supervision and quality control were High investment cost (4.81), Poor infrastructures (4.71), Infrastructure incompatibility (4.67) Limited educational involvement (4.62). The top significant challenges according those who were in Project Planning and Design were High investment cost (4.82), Cyber-security risks (5.00), Limited educational involvement (5.00). In contrast, the least significant challenges according those who were involved in supervision and quality control were Resistance to change (3.43), Limited data availability (3.86) Fear of job loss (3.45) and the least significant challenges according those who were in Project Planning and Design were Limited data availability (2.50), Resistance to change (3.00).

In general, the most significant challenges according those who were involved in supervision and quality control and according those who were in Project Planning and Design were High investment cost, limited educational involvement, whereas, the least significant challenges for Civil engineers and IT engineers Resistance to change, Limited data availability, Fear of job loss and Data privacy and security concerns.

The current study then adopted the independent samples t-tests statistics to establish if there were differences in the opinions among those who were involved in supervision and quality control and those who were in Project Planning and Design on the challenges which hindered the adoption of AI technologies in traffic management. The finding established that there were no significant differences (p>0.05) in the opinions.

**Table 15: Results presentation on challenges of application of AI technologies according to nature of involvement**

<b>Challenges</b>	<b>Supervision &amp; Quality Control and rank</b>	<b>Project Planning &amp; Design and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Limited data availability	3.86 (13)	2.5 (5)	3.18 (14)	S	0.095	NS
Poor data quality	4.24 (8)	4.5 (2)	4.37 (9)	S	0.649	NS
Data privacy and security concerns	4.29 (7)	4 (3)	4.14 (12)	S	0.619	NS
Infrastructure incompatibility	4.67 (3)	4.5 (2)	4.58 (5)	VS	0.74	NS
Poor infrastructures	4.71 (2)	4.5 (2)	4.61 (4)	VS	0.551	NS
Limited trainings	4.19 (9)	4.5 (2)	4.35 (10)	S	0.582	NS
Limited educational involvement	4.62 (4)	5 (1)	4.81 (2)	VS	0.31	NS
Lack of technical expertise	4.43 (6)	4.5 (2)	4.46 (7)	S	0.96	NS
Resistance to change	3.43 (14)	3 (4)	3.21 (13)	S	0.53	NS
Regulatory and legal barriers	4.29 (7)	4.5 (2)	4.39 (8)	S	0.714	NS
Ethical and equity concerns	4.1 (10)	4.5 (2)	4.3 (11)	S	0.444	NS
Cyber- security risks	4.05 (11)	5 (1)	4.52 (6)	VS	0.062	NS
Fear of job loss	3.95 (12)	4 (3)	3.98 (13)	S	0.93	NS
High investment cost	4.81(1)	5 (1)	4.9 (1)	VS	0.519	NS
Lack of trust in AI technologies	4.57 (5)	5 (1)	4.79 (3)	VS	0.435	NS

Note: S= Significant=3.50-4.49; VS=Very Significant=>4.50; NS=No Significant difference (p>0.05); Dec. =Decision; Sign. =Significance)

Table 16, showcases the challenges that hinder the adoption of AI technologies in traffic

management, based on the nature of involvement of respondents in transportation and ICT projects. The top significant challenges according those who were involved in Construction Execution were Limited educational involvement (4.96), High investment cost (4.89), Poor infrastructures (4.79), Infrastructure incompatibility (4.86). The top significant challenges according those who were involved in others were Poor infrastructures (4.90), High investment cost (4.86), Limited educational involvement (4.86). In contrast, the least significant challenges according those who were involved in Construction Execution were Resistance to change (4.00), Limited data availability (3.86) Data privacy and security concerns (3.86) and the least significant challenges according those who were involved in others were Limited data availability (3.52), Resistance to change (3.62).

In general, the most significant challenges according those who were involved in construction execution and according those who were involved in others were High investment cost, limited educational involvement, whereas, the least significant challenges according those who were involved in construction execution and according those who were involved in others were Resistance to change, Limited data availability.

The current study then adopted the independent samples t-tests statistics to establish if there were differences in the opinions among those who were involved in Construction Execution and those who were involved in others on the challenges which hindered the adoption of AI technologies in traffic management. The finding established that there were no significant differences ( $p > 0.05$ ) in the opinions, except for the challenge of Cyber-security risks and Fear of job loss ( $0.02 < p < 0.05$ ).

**Table 16: Results presentation on challenges of application of AI technologies according to nature of involvement**

<b>Challenges</b>	<b>Construction Execution and rank</b>	<b>Other (Please specify) and rank</b>	<b>Overall Mean and rank</b>	<b>Dec.</b>	<b>Two-Sided p</b>	<b>Sign.</b>
Limited data availability	3.86 (11)	3.52 (11)	3.69 (14)	S	0.383	NS
Poor data quality	4.46 (8)	4 (9)	4.23 (11)	S	0.171	NS

Data privacy and security concerns	4.39 (9)	4 (9)	4.2(12)	S	0.213	NS
Infrastructure incompatibility	4.86 (3)	4.52 (4)	4.69 (4)	Vs	0.146	NS
Poor infrastructures	4.79 (4)	4.9 (1)	4.85 (3)	Vs	0.388	NS
Limited trainings	4.68 (6)	4.24 (5)	4.46 (5)	S	0.168	NS
Limited educational involvement	4.96 (1)	4.81 (3)	4.89 (1)	Vs	0.079	NS
Lack of technical expertise	4.61 (7)	4.19 (7)	4.4 (7)	S	0.2	NS
Resistance to change	4 (10)	3.62 (10)	3.81 (13)	S	0.331	NS
Regulatory and legal barriers	4.56 (8)	4.05 (8)	4.3 (10)	S	0.132	NS
Ethical and equity concerns	4.61 (7)	4.2 (6)	4.4 (7)	S	0.188	NS
Cyber- security risks	4.71 (5)	4 (9)	4.36 (9)	S	0.023	S
Fear of job loss	4.71 (5)	4.05 (8)	4.38 (8)	S	0.031	S
High investment cost	4.89 (2)	4.86 (2)	4.88 (2)	Vs	0.754	NS
Lack of trust in AI technologies	4.71 (5)	4.19 (7)	4.45 (6)	S	0.094	NS

Note: S= Significant=3.50-4.49; VS=Very Significant=>4.50; NS=No Significant difference (p>0.05); Dec. =Decision; Sign. =Significance)

#### **4.4 Interview results presentation and analysis on strategies adopted for integration of AI.**

##### **4.4.1 Introduction**

This is a qualitative analysis of fifteen interviews conducted with 8 project engineers, 4 Program managers and 3 division managers from RTDA and one from RISA, both institutions involved in transportation and ICT. Those top leaders were chosen for interviews because they play a central role in overseeing the planning, implementing and integration of new technologies within

transportation project, including AI systems. Their position gives them a broad perspective on both the technical and administrative aspects of adoption, including budgeting, stakeholder coordination, infrastructure planning and risk management. The purpose of the interviews was to explore participants’ perceptions, awareness, institutional adoption, challenges and strategies related to Artificial Intelligence (AI) technologies in traffic management. The analysis followed a reflexive thematic approach, extracting themes, using both inductive coding. The final codebook summarizes the key themes, their descriptions, keywords and frequencies across the interviews.

#### 4.4.2 Analysis of demographic data

Table 17, indicates the general information of the respondents of the study, among the respondents, 73% were male, 27% were female. Among the respondents also none of participants were between 18 and 25 years old, 20% of participants were between 26 and 35 years old, 80% of participants were between 36 and 45 years old. The figure indicates also that none of participants were between 46 and 55 years old and no participants were from 56 years old upward. Also 33 % of respondents hold a Bachelor’s degree, 67 % of respondents have attained a Master’s degree and none of respondent hold a Ph. D. Further, 4 respondents, which is equal to 27 % were IT engineers, 9 respondents which is equal to 60 % were civil engineers and 4 respondents which is equal to 60 % were in the areas of project management. Again, 10 respondents (67 %) had between 4-6 years of experience, 5 respondents (33 %) had between 7 to 10 years of experience. 3 respondents (20 %) were Division Manager, 3 respondents (20 %) were Division Manager and 9 respondents (60 %) were project engineers.

**Table 17: Demographic information of interviewees**

	<b>Variables</b>	<b>Frequency</b>	<b>Percentage</b>
<b>Gender</b>	Female	4	27
	Male	11	73
	<b>Total</b>	<b>15</b>	<b>100</b>
<b>Age Group</b>	26 – 35	3	20
	36 – 45	12	80
	<b>Total</b>	<b>15</b>	<b>100</b>
<b>Highest Academic</b>	Bachelor (BSc) Degree	5	33
	Master’s Degree	10	67

<b>Qualification</b>	<b>Total</b>	<b>15</b>	<b>100</b>
<b>Areas of specialization</b>	Civil Engineer	9	60
	IT Engineer	4	27
	Project Management	2	13
	<b>Total</b>	<b>15</b>	<b>100</b>
<b>Working Experience</b>	4 – 6 years	10	67
	7 – 10 years	5	33
	<b>Total</b>	<b>15</b>	<b>100</b>
<b>Your position</b>	Division Manager	3	20
	Program Manager	3	20
	Projects Engineer	9	60
	<b>Total</b>	<b>15</b>	<b>100</b>

Table 15, shows the results of the interview conducted on strategies for AI technologies adoption in traffic management. After analysis, 16 strategies were identified and tabulated. The table shows the identified strategies, number of interviewees that chose them and their corresponding percentages. It is pertinent to emphasize that all strategies highlighted by the respondents will serve as foundation pillars in developing a comprehensive and effective framework for the application of AI in traffic management. The order of the strategies as rated by respondents are allocation of funds, creation of regulatory agency, establishment of policy, Digital infrastructures, academic institutions participation, capacity building, public awareness and public-private partnership all with (100%), pilot projects (86.7%), AI Model development and calibration (80%), Scaling and nationwide rollout (80%), Centralized data hub (73.3%), Integration with other smart systems (66.7%), Sustainability and local innovation (60%), Feedback and monitoring (33.3%) and Continuous evaluation (20%).

**Table 18: Codebook showing themes and frequencies**

<b>STRATEGIES FOR AI INTEGRATION</b>	<b>Themes</b>	<b>Descriptions</b>	<b>Frequencies</b>	<b>Percentage</b>	<b>Rank</b>
	Allocation of funds	Government should allocate funds for investment in AI.	15	100%	1
	Regulatory agency	Creation of AI regulatory agency	14	93.3%	2

Policy and regulations	Need for national AI strategies and laws	13	86.6%	3
Public-Private partnership	Engage telecoms and tech startups	13	86.6%	3

Academic institutions participation	Universities and technical institutes should introduce programs in AI	12	80%	4
Capacity buildings	Training engineers and experts in AI	11	73.3%	5
Public awareness	Raising awareness and trust among citizens	11	73.3%	5
Digital Infrastructures	Setting out of real-time data collection devices.	10	66.6%	6
Integration with other smart systems	Link traffic AI with public transport, emergency services and urban planning	10	66.6%	6
AI Model development and calibration	To build and test AI models using Rwanda-specific data	9	60%	7
Scaling and nationwide rollout	To expand AI integration to secondary cities	8	53.3%	8
Centralized data hub	Create a national traffic data hub to aggregate data from sensors	7	46.6%	9
Feedback and	To set up the fine-tune models using real-time data and feedback	5	33.3%	10

	monitoring				
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#### 4.4 Proposed Framework

The framework proposed for integrating AI technologies into traffic management in Rwanda is grounded in qualitative insights of project engineers, program managers and division managers interviewed from RTDA and RISA. These individuals, with hands on experience in infrastructure planning and technology implementation, highlighted the actionable steps needed for AI adoption. Through thematic analysis, the series of interlinks steps and strategic elements that directly reflect the realities and suggestions raised during the interviews.

All participants (100%) agreed that financial investment should form the foundational pillar of the framework. Without sufficient funding the various components required for successful integration of AI, cannot be developed or sustained. Adequate financial resources are essential not only for acquisition of technology but also for the institutional development and policy-making processes that govern AI adoption. It was emphasized by participants that once a reliable funding mechanism is in place, it will pave the way for the establishment of a dedicated regulatory agency, a view supported by 93.3% of the participants. This regulatory agency would be charged with overseeing the entire lifecycle of AI implementation in traffic management, from strategic planning to execution and governance. A key mandate of the agency would be the development and enforcement of a national AI policy for the transport sector, which 86.6% of the participants considered essential. Such a policy would provide formal guidelines, ethical standards and operational procedures to ensure the responsible and effective deployment of AI technologies in traffic systems. The policy would also create a framework for coordination among different stakeholders, thereby minimizing fragmentation and duplication efforts.

In line with this, the regulatory agency, in collaboration with private sector stakeholders, would spearhead the establishment of academic institutions or dedicated programs to teach the technical and operational aspects of AI in transportation. This initiative was supported by 80% of participants. These academic institutions would act as centers of excellence, equipping

professionals with the necessary skills to implement and manage AI-based systems. Importantly, these institutions would work closely with the regulatory agency to ensure that their curricula align with national AI strategies and global best practices. Furthermore, 73.3% of participants noted the need for capacity-building programs and hands-on training workshops aimed at both government staff and select individuals involved in traffic management operations.

Beyond technical training, these institutions would also play a key role in public awareness campaigns, also supported by 73.3% of participants. In terms of infrastructure, 66.6% of participants emphasized the importance of building digital infrastructure as a core requirement for integration. This includes the installation of Internet of things (IoT) sensors, data transmission networks, real-time monitoring platforms and cloud models. Once developed, this digital infrastructure would be integrated with existing transportation systems, including traffic lights, road cameras and public transport coordination systems. The integration would lead to the creation of an AI model tailored to Rwanda's traffic environment, a process suggested by 60% of participants.

This AI model would then undergo calibration and testing, ensuring it reflects real-world conditions such as traffic density, accident hotspots and road conditions. Upon successful calibration the model would be rolled out on a national scale, enabling smart traffic management not only in Kigali but also in secondary cities. However, only 53.3 of participants agreed on the feasibility of immediate nationwide implementation. Finally, following the widespread implementation of AI in traffic management, the next strategic step would be the creation of an AI centralized hub, as supported by 46.6% of participants. This hub would function as the nerve center for data collection, system monitoring, performance evaluation and strategy refinement. It would also serve as a platform for continuous learning and adaptation, receiving feedback from various urban nodes and making real-time adjustments. According to 33.3% of the participants, the centralized hub would be especially valuable for monitoring key performance indicators, user feedback and technical performance, thereby ensuring that the system remains responsive, efficient and aligned with policy objectives.

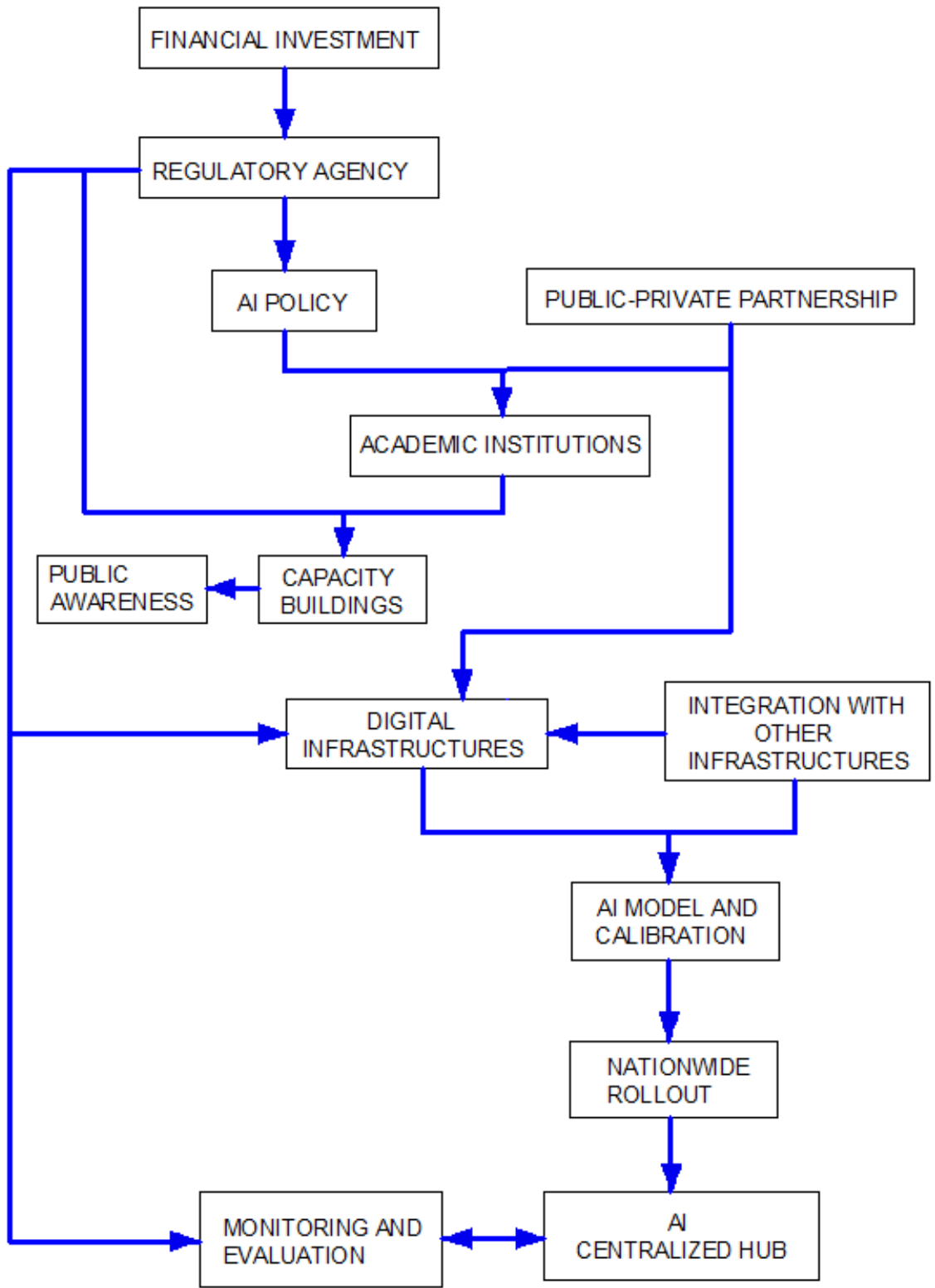


Figure 2: Framework for the application of AI in traffic management

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Introduction

This chapter of the study aims to present the conclusions and recommendations derived from the research. The conclusions are drawn based on the key findings related to the study objectives, while the recommendations are formulated to address the issues identified and suggest practical actions for improvement.

#### 5.2 Conclusion

The study sought to propose the framework for applying Artificial Intelligence (AI) technologies in traffic management in Rwanda by examining levels of awareness, current adoption, existing challenges and potential strategies, particularly focusing on civil and AI engineers from RTDA and RISA. The quantitative findings revealed that the overall awareness and adoption of AI technologies are still at low level, with Google Maps AI being the most recognized and slightly adopted system across both groups. The statistical analysis indicated no significant differences in awareness or adoption between civil and IT engineers for most technologies, suggesting a uniformly low exposure. Similarly, the actual application of AI in traffic management remains limited to basic functions like smart parking, number plate recognition and traffic enforcement, with more advanced applications largely underutilized or unknown.

The qualitative interviews reinforced these findings, highlighting key barriers such as lack of technical expertise, inadequate digital infrastructures, limited strategic planning and concerns over data privacy and high costs. However, the participants also expressed strong openness to AI adoption and proposed a multi-faceted framework for integration. This includes investment in infrastructure, establishment of regulatory frameworks and AI policy, capacity building through academic partnerships, public awareness campaigns and creation of a centralized traffic data hub. The combination of insights from both quantitative and qualitative data emphasizes that while Rwanda has foundational readiness, significant institutional and systemic efforts are needed to achieve meaningful and scalable AI integration in traffic management.

### **5.3 Recommendations**

To facilitate the successful integration of Artificial Intelligence (AI) in Rwanda's traffic management systems, a number of targeted interventions are recommended. First, there is a pressing need to enhance awareness and education across all stakeholder groups. Secondary, the development of a National AI policy for transport is essential, the Government of Rwanda should establish a dedicated AI policy that clearly articulates the legal, ethical and technical guidelines for adopting AI technologies in the transportation sector.

Additionally, it is critical to invest in physical and digital infrastructure capable of supporting AI applications. This includes upgrading existing road networks, installing smart traffic lights, deploying surveillance cameras and integrating GPS and sensor systems that enable real-time data collection and automated decision-making. Without such infrastructure support, AI systems are unlikely to perform effectively or produce reliable outcomes.

To ensure sustainability and innovation, the government should actively foster public-private partnerships (PPPs). Collaborating with local tech startups, international technology firms and academic institutions will help to design, implement and maintain AI solutions tailored to Rwanda's unique transportation challenges. These partnerships can also contribute to resource mobilization and the sharing of technical expertise. Finally, it is vital to promote interdisciplinary research and human capital development. University and research institutions in Rwanda should be supported to develop specialized AI curricula focused on transportation, equipping future professionals with the skills necessary for effective system development and management. In parallel, government and institutional actors should fund applied, interdisciplinary research projects that address real-world mobility issues and inform evidence-based policymaking.

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## APPENDICES



**School of Postgraduate Studies,**  
Department of Civil, Environmental and Geomatics Engineering  
Faculty of Environmental Sciences, School of Engineering.  
College of Science and Technology,  
University of Rwanda,  
Date: ...../...../ 2025

### **Request to Respond to Questionnaire**

Dear Respondent,

I am a postgraduate student at the University of Rwanda, conducting a research study on "**Framework for the application of Artificial Intelligence (AI) in traffic management in Rwanda.**" This study aims to assess the level of awareness on AI, evaluate its adoption challenges and develop a framework of its application in traffic management in Rwanda.

Your participation in this survey is highly valuable. The questionnaire will take approximately 5–10 minutes to complete. All responses will be used solely for academic research and will remain strictly confidential.

Thank you for your time and contribution to this study.

Yours faithfully,

NKUNDABERA Faustin

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**PROJECT “FRAMEWORK FOR THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN TRAFFIC MANAGEMENT IN RWANDA”**

**SECTION A: BIO-DATA**

**Instruction:** Please tick good (√) for your correct option selected among the options provided for each question

**1. What is your gender?**

- a. Male
- b. Female
- c. Prefer not to say

**2. What is your age group?**

- a. 18 – 25
- b. 26 – 35
- c. 36 – 45
- d. 46 – 55
- e. 56 and above

**3. Highest Academic Qualification**

- a. Bachelor (BSc) Degree
- b. Master’s Degree
- c. Ph.D
- Other (Please specify)

**4. What is your areas of specialization? (Tick all that apply)**

- b. IT Engineer
- c. Civil Engineer
- d. Transportation Engineer
- e. Services Engineer
- f. Project manager
- g. Architect
- h. Other (Please specify)

**5. Working Experience**

- a. Less than 1 year
- b. 1- 3 years
- b. 4 – 6 years
- c. 7 – 10 years
- d. 10 years and above

**6. Which professional body are you registered with? (Tick all that apply)**

- a. Institution of Engineers Rwanda (IER)
- b. Rwanda Institute of Architects (RIA)
- c. Project Management Professional (PMP)
- d. Rwanda Institute of Quantity Surveyors (RIQS)
- e. Other (Please specify) .....

f. None

**7. What is the nature of your involvement in transportation and ICT project? (Tick all that apply)**

- a. Project Planning and Design
- b. Supervision and Quality Control
- c. Contract Administration
- d. Construction Execution
- e. Other (Please specify)

**8. What type of organization did you work for?**

- a. Consultancy Firm
- b. Contracting Firm
- c. Government Agency
- d. Other (Please specify)

**9. What type of projects have you mostly worked on? (Tick all that apply)**

- a. New Road Construction
- b. Road Upgrading/Rehabilitation
- c. Network expansion project
- d. Artificial intelligence project
- e. ICT project
- f. Other (Please specify)

**SECTION B: “QUESTION ITEMS ON “FRAMEWORK FOR THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN TRAFFIC MANAGEMENT IN RWANDA””**

**Objective 1: To determine the level of awareness of AI technology for traffic management.**

(Rate your level of awareness of these AI technologies for traffic management: 5 = Very High, 4 = High, 3 = Moderate, 2 = Low, 1 = None)

	1	2	3	4	5
<b>AI technologies for traffic management</b>					
1. Machine Learning					
2. Computer Vision					
3. Knowledge-Based System					
4. Artificial Neural Networks					
5. Genetic Algorithms					
7. Robotics					
8. Reinforcement Learning					
9. Deep Learning					
10. Natural Language processing					
11. Swam Intelligence					
12. Fuzzy Logics					
13. NoTraffic					
14. Minus Zero					
15. NuPort Robotics					
16. Optibus					
17. Citymapper					

18. Trainline					
19. Google Maps AI					
20.					
21.					
22.					
23.					

**Objective2: To evaluate the level of adoption of AI technology to traffic management.**

(Rate the level of adoption of these AI technologies to traffic management: 5 = Highly adopted, 4 = adopted, 3 = Moderately adopted, 2 = Slightly Adopted, 1 = Not Adopted)

	1	2	3	4	5
<b>AI technologies for traffic management</b>					
1. Machine Learning					
2. Computer Vision					
3. Knowledge-Based System					
4. Artificial Neural Networks					
5. Genetic Algorithms					
7. Robotics					
8. Reinforcement Learning					
9. Deep Learning					
10. Natural Language processing					
11. Swam Intelligence					

12. Fuzzy Logics					
13. NoTraffic					
14. Minus Zero					
15. NuPort Robotics					
16. Optibus					
17. Citymapper					
18. Trainline					
19. Google Maps AI					
20.					
21.					
22.					
23.					

**Objective 3: To investigate the specific application areas of AI technology to traffic management.**

(Rate the level of application of AI technologies in these specific areas of traffic management: 5 = Well applied, 4 = Applied, 3 = Moderately applied, 2 = Slightly applied, 1 = Not applied)

<b>Specific application areas of traffic management</b>	1	2	3	4	5
1. Adaptive traffic signal control					
2. Traffic flow prediction					
3. Congestion management					

4. Incident detection					
5. Incident management					
6. Smart parking management					
7. Public transportation optimization					
8. Autonomous and connected vehicle integration.					
9. Road condition monitoring					
10. Road maintenance monitoring					
11. Emission and environmental impact monitoring					
12. Demand-Responsive traffic planning					
13. Traffic violation and enforcement automation					
14. Number plate recognition					
15.					
16.					
17.					
18.					

**Objective 4: To assess the challenges of AI technology adoption to traffic management.**

(Rate the level of significance of the challenges below: 5 = Very significant, 4 = Significant, 3 = Moderately significant, 2 = Slightly significant, 1 = Not significant)

	1	2	3	4	5
<b>The challenges of AI technology adoption to traffic management</b>					
1. Limited data availability					
2. Poor data quality					
3. Data privacy					

4. Security concerns					
5. Infrastructure compatibility					
6. Poor infrastructures					
7. Limited training					
8. Involvement of educational institutions					
9. Lack of technical expertise					
10. Resistance to change					
11. Regulatory barriers					
12. Ethical and equity concerns					
13. Cyber-security risks					
14. Legal barriers					
15. Fear of job loss					
16. High investment cost					
17. Lack of trust in AI technologies					
18.					
19.					
20.					
21.					