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UTILIZATION OF ENGINEERING AND MANAGEMENT STRATEGIES TO MINIMIZE TRAFFIC FATALITIES AND SEVERE INJURIES ON ASPHALT ROADS IN RWANDA: THE CASE OF KIGALI CITY

A dissertation Submitted in partial fulfilment of the requirements for the award of Masters of Science Degree in Internet of Things: HIGHWAY ENGINEERING AND MANAGEMENT

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DECLARATION

I hereby declare that the thesis entitled **"UTILIZATION OF ENGINEERING AND MANAGEMENT STRATEGIES TO MINIMIZE TRAFFIC FATALITIES AND SEVERE INJURIES ON ASPHALT ROADS IN RWANDA: THE CASE OF KIGALI CITY"** submitted for the Degree of Master of Science in Highway Engineering and Management Programme, is my original work and the thesis has not formed the basis for the award of any Degree, Diploma, Associateship, Fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any Degree or Diploma.

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CERTIFICATION

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ABSTRACT

Road traffic injuries continue to pose a major public health and development challenge in Rwanda, particularly in urban centers like Kigali where vulnerable road users (VRUs) frequently interact with mixed traffic under inadequate infrastructure conditions. This study assessed the utilization of engineering and management strategies to minimize traffic fatalities and severe injuries along the CBD Roundabout- KN1–RN1 Giticyinyoni corridor a 6.3 km stretch with high pedestrian and motorcyclist activity and recurrent crash hotspots. Using a mixed-methods approach, data were collected from 384 respondents through structured questionnaires, field observations, and key informant interviews. Descriptive analysis revealed that 59.9% of respondents had witnessed or been involved in a road crash along the corridor, with the highest concentration at Nyabugogo intersection (71.3%) and the Giticyinyoni curve (48.2%). Chi-square analysis showed a statistically significant association between crash experience and occupation ($\chi^2 = 36.28$, $p < 0.001$), with drivers and pedestrians reporting the highest exposure. ANOVA results indicated significant differences in perceived enforcement effectiveness across user groups ($F = 14.40$, $p < 0.001$), with traffic police rating enforcement more favourably than other road users. More than 56% of respondents suggested urgent repairs to traffic signals, and 51.6% recommended the installation of automated enforcement systems such as speed cameras. Open-ended responses emphasized infrastructure needs including pedestrian overpasses (23.2%), protected cycling lanes (19.8%), and redesign of hazardous locations like the Giticyinyoni curve (17.7%). The study concludes that a combination of inadequate infrastructure, insufficient enforcement, and limited public awareness significantly contributes to traffic-related fatalities and injuries in Kigali.

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LIST OF ABBREVIATIONS

Abbreviation	Full Meaning
AfDB	African Development Bank
ANOVA	Analysis of Variance
ASE	Automated Speed Enforcement
CBD	Central Business District
CDC	Centers for Disease Control and Prevention
CCTV	Closed Circuit Television
GWR	Geographically Weighted Regression
ITF	International Transport Forum
JICA	Japan International Cooperation Agency
KN1, RN1	Kigali National Road 1, Rwanda National Road 1
KDE	Kernel Density Estimation
NMT	Non-Motorized Transport
OECD	Organisation for Economic Co-operation and Development
RNP	Rwanda National Police
RTDA	Rwanda Transport Development Agency
RURA	Rwanda Utilities Regulatory Authority
SDG	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
UNESCAP	United Nations Economic and Social Commission for Asia-Pacific
UN-Habitat	United Nations Human Settlements Programme
V2I	Vehicle-to-Infrastructure Communication
VRU	Vulnerable Road Users
WHO	World Health Organization

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background of the study

The World Health Organization (WHO) estimates that 1.35 million major traffic accidents occur year, gravely injuring 20 to 50 million people globally. If the current trend continues, it will likely move up to the seventh-leading cause of death in the world by 2030 (Shakil, Akbar, Sayan, Mafijul, & Saifur, 2023). Road accidents involving injuries, fatalities, and economic losses are a prominent unintended consequence of transportation systems. This lead considerably to traffic congestion, a critical problem that affects society as a whole (Yetay, Esayas, & Dietrich, 2023).

Road transport contributes to the socioeconomic development of Africa through facilitating movement of goods and people, opening up isolated areas, and promoting trade. Intricate movement patterns involve short, medium, and long distances, different modes of transport, and interaction within and between different places in Africa (Alila *et.al;,* 2015).

The number of motor vehicles, volume of road traffic, and utilization of the road by different road users in Africa have grown noticeably. The bicycle is increasingly used for passenger and freight transport in urban and rural areas. These transport characteristics indicate the need to pay adequate attention to safety measures in road transport development, especially safety of urban and rural communities living within the vicinity of roads. Development aid meant for road building takes no account of road safety, and there seems to be neglect of the fact that thousands will die and many more thousands will be injured while using roads in Africa and other parts of the world (Khayesi & Peden, 2015).

Kigali City, Rwanda's capital, has seen significant urban growth in recent years, leading to increased demand for road transport. Most of the city's major roads are asphalt-paved, connecting critical commercial, residential, and institutional hubs. However, many of these roads are not adequately designed or managed to handle the growing traffic volume safely, especially at intersections, pedestrian crossings, and high-speed corridors (Nkurunziza *et al.,* 2021). The lack of sufficient traffic calming measures, poor signalization, inadequate road markings, and limited public awareness contribute to the city's high crash rates.

This study focuses on the application of engineering and management strategies to minimize traffic fatalities and severe injuries on asphalt roads in Kigali City. Specifically, it aims to

analyze crash patterns, assess the effectiveness of existing safety measures, and propose evidence-based interventions to enhance road safety. By focusing on Kigali's urban road network, particularly intersections and high-risk segments, the study intends to contribute actionable recommendations that can inform policymakers, traffic engineers, and urban planners working toward safer and more sustainable urban mobility in Rwanda.

1.2 Problem statement

Despite multiple efforts to improve road safety in Kigali City, including public campaigns, automated enforcement, and intersection upgrades, the city continues to experience a high rate of traffic fatalities and severe injuries on asphalt roads. According to Rwanda National Police (2023), over 3,000 road crashes were recorded in Kigali in 2022 alone, many resulting in fatalities or long-term disabilities, with intersections identified as critical conflict points. Vulnerable road users (VRUs) including pedestrians, cyclists, and motorcyclists account for a disproportionate share of these fatalities, largely due to poor intersection design, inadequate pedestrian infrastructure, and insufficient traffic calming measures (Nkurunziza *et al.,* 2021).

While Rwanda has adopted several strategies, such as the Gerayo Amahoro awareness campaign, Automated Speed Enforcement (ASE) systems, and selective road improvements, many of these interventions operate in isolation, without a coordinated engineering and management framework (JICA, 2023). Furthermore, limited local research has been conducted to systematically assess how a combined set of engineering such as geometric design improvements, signalization, pedestrian facilities and management strategies including enforcement, traffic operations, public education) can effectively minimize crash severity and fatalities in Kigali's urban context.

This knowledge gap restricts the capacity of city authorities and policymakers to design targeted, evidence-based interventions aligned with Rwanda's rapid urbanization and the increasing complexity of its urban traffic systems (World Bank, 2023). Therefore, the central problem this study seeks to address is the lack of an integrated application of engineering and management strategies tailored to minimizing traffic fatalities and severe injuries on Kigali City's asphalt roads, particularly at high-risk intersection

1.3 Research objectives

1.3.1 General objective

The general objective of this study was to analyze the utilization of engineering and

management strategies in minimizing traffic fatalities and severe injuries on asphalt roads in Rwanda, using the case of Kigali city.

1.3.2 Specific objectives

The specific objectives were the following:

1. To identify the primary causes and patterns of traffic fatalities and severe injuries on asphalt roads in Kigali City,
2. To evaluate existing engineering measures implemented on asphalt roads in Kigali City and assess their effectiveness in reducing accidents,
3. To examine the role of traffic management practices, including enforcement, planning, and data use, in mitigating severe road incidents in Kigali, and
4. To propose integrated engineering and management strategies tailored to minimizing traffic-related fatalities and severe injuries on Kigali's asphalt roads.

1.4 Research questions

1. What are the major causes and contributing factors of traffic fatalities and severe injuries on asphalt roads in Kigali City?
2. What engineering interventions have been implemented to enhance road safety on Kigali's asphalt roads?
3. How do current traffic management practices including enforcement, planning, and data collection contribute to road safety in Kigali?
4. What are the integrated engineering and traffic management strategies can be developed to reduce fatalities and severe injuries on asphalt roads in Kigali?

1.5 Scope of the study

1.5.1 Geographical scope

This study is geographically limited to Kigali City, the capital and most urbanized region of Rwanda. Focus will be placed specifically on asphalt-paved roads, with particular attention given to high-traffic corridors and identified accident-prone zones. These areas will be selected based on available traffic data, reported incidents, and input from local transport authorities. The aim is to analyse how engineering and management strategies can be effectively applied in areas of greatest road safety concern.

1.5.2 Timeframe

The temporal scope of the study encompasses a three-year period from 2022 to 2024. This period allows for the analysis of recent and relevant data, providing insights into traffic accident trends, seasonal patterns, and the impact of road safety interventions introduced within that time frame. Where possible, a comparative assessment will be conducted to evaluate road safety before and after the implementation of specific engineering and management strategies.

1.5.3 Domain scope

1.5.3.1 Engineering strategies

This component of the study focused on the technical and infrastructural elements of road safety on asphalt roads. It assessed the influence of various engineering interventions, including but not limited to:

- Road design features such as lane widths, road markings, pedestrian crossings, and intersection layout;
- Traffic calming measures like speed bumps, rumble strips, roundabouts, and chicanes;
- Intelligent traffic control technologies, including adaptive traffic signals, surveillance cameras, and road-embedded sensors;
- Road condition monitoring and maintenance practices, especially those that ensure surface integrity and visibility under diverse weather and traffic conditions.

1.5.3.2 Management Strategies

The study also investigated the management-based approaches undertaken by traffic authorities in Kigali City. These include:

- Traffic law enforcement initiatives such as mobile police patrols, speed detection and enforcement, and alcohol checkpoints;

- Traffic control measures involving signage placement, signal coordination, and physical barriers;
- Public education and road safety awareness programs, including campaigns targeting driver behavior, pedestrian safety, and school zone awareness;
- Traffic monitoring and data systems, with a focus on the application of real-time data collection, GPS-based vehicle tracking, and digital accident reporting platforms.

1.6 Significance of the Study

It aims to provide evidence-based insights for policymakers, urban and regional planners, transportation professionals, and residents of Kigali City. By exploring effective engineering and management strategies, the study contributes to the formulation of interventions that can significantly reduce traffic-related fatalities and severe injuries, particularly on asphalt roads.

Beyond its practical applications, this research contributes to knowledge generation in the field of road safety and traffic management. It offers a data-driven foundation to support informed policymaking and urban planning decisions. The study is expected to strengthen awareness among institutions and the general public regarding the importance of strategic planning in traffic safety.

Furthermore, the findings are anticipated to be of value not only to local agencies such as the Ministry of Infrastructure (MININFRA), the Rwanda Transport Development Agency (RTDA), and the City of Kigali, but also to international stakeholders seeking to improve road safety in urban areas. The insights derived may serve as a reference point for other cities and developing countries facing similar challenges.

Ultimately, the study seeks to promote safer road environments, improve transportation system performance, and protect communities from the socio-economic impacts of road crashes. It supports Rwanda's ongoing efforts toward achieving Sustainable Development Goal (SDG) targets related to road safety and inclusive, sustainable cities.

1.7 Research gap

Despite the growing body of literature on road safety and accident prevention, most studies in Rwanda have focused on general causes of road traffic crashes, pedestrian mobility, and speed regulation in public transport. For instance, Verjus (2014) developed a basic road safety audit procedure, while Nkurunziza and Tafahomi (2020) assessed pedestrian mobility in Kigali. Similarly, Ndagijimana (2021) explored the effect of speed governors on public transport safety. However, these studies have not sufficiently addressed the comprehensive

application of engineering and traffic management strategies to reduce fatalities and severe injuries specifically on asphalt roads, which represent a large share of Rwanda's urban transport infrastructure.

Moreover, there is limited integration of multidisciplinary approaches that combine infrastructure design (engineering) with traffic regulation and behavior control (management strategies) in the context of Kigali City. While international studies have shown the effectiveness of combining geometric design improvements, traffic calming measures, and enforcement strategies (Elvik & Vaa, 2020), such integrated analysis remains largely unexplored in Rwanda's urban road safety research.

Another key gap is the lack of localized data-driven studies that evaluate accident-prone zones in Kigali, particularly at intersections and high-traffic corridors on asphalt roads. The absence of such targeted research limits the ability of policymakers and practitioners to implement context-specific, evidence-based interventions.

Therefore, this study seeks to fill these gaps by focusing specifically on asphalt roads in Kigali City; examining both engineering and management strategies in tandem; using recent accident data (2022–2024) to identify trends and intervention outcomes; and providing actionable recommendations tailored to Rwanda's urban setting.

1.8 Research outline

Chapter one provides a general introduction to the study, including the background of the problem, the context of traffic fatalities and severe injuries on asphalt roads in Kigali City, and the motivation for focusing on engineering and management strategies. This chapter also presents the problem statement, outlines the main and specific research objectives, poses the key research questions, and explains the significance, scope, and expected contributions of the study.

Chapter Two offers a comprehensive review of the relevant literature, focusing on previous studies, theoretical frameworks, and key concepts related to road safety, traffic engineering, and management strategies. It also examines regional and global best practices related to minimizing traffic fatalities and severe injuries, particularly on asphalt roads in urban settings like Kigali.

Chapter Three outlines the proposed research methodology, detailing the research design, description of the study area, Kigali City, data sources, sampling methods,

and data collection procedures. This chapter also explains the data analysis techniques, addresses ethical considerations and study limitations.

Chapter Four presents and interprets the findings of the study based on the results of the study based on the statistical, and qualitative analyses.

Chapter Five provides a summary of the key findings, draws conclusions, offers practical recommendations, and outlines areas for further research related to this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Road safety trends

Road accidents are a major cause of death and injury in the modern world. Each year over 1.3 million people are killed in road accidents, and these are a leading cause of death and injury for all age groups. The US Centre for Disease Control and Prevention estimates that road trauma costs the world economy nearly $US 2 trillion annually. While there are more cars per head of population in developed nations, the death rate from such crashes is far higher in less developed nations due to a variety of factors including poor road infrastructure, substandard vehicles and inadequate driver education (CDCP, 2023).

Over the years vehicles have incorporated more safety features, such as seat belts, roads have been better designed to reduce accidents, and road safety codes, such as the prohibition of drink driving, have been strengthened. In Victoria, Australia, these measures have contributed to the gradual reduction of deaths and injuries in road accidents (AGBITRE, 2021)

In Africa, the number of road traffic injuries and deaths have been increasing over the last three decades. According to the 2015 Global status report on road safety, the WHO African Region had the highest rate of fatalities from road traffic injuries worldwide at 26.6 per 100 000 population for the year 2013. In 2013, over 85% of all deaths and 90% of disability adjusted life years lost from road traffic injuries occurred in low- and middle-income countries, which have only 47% of the world's registered vehicles (Welle *et al.,* 2020).

Given that air and rail transport are either expensive or unavailable in many African countries, the only widely available and affordable means of mobility in the region is road transport. However, the road infrastructure has not improved to the same level to accommodate the increased number of commuters and ensure their safety and as such many people are exposed daily to an unsafe road environment Adeloye *et al*. (2016)

In fact, Rwanda has shown great improvement in Rwanda's road safety data and outcomes estimating a decrease of 15 to 12/100,000 road accidents annually. The report the fifth edition since 2009, released this December 13 showed that Rwanda reported 593 fatalities in 2018 (population of 11.92m) and 655 fatalities in 2021 (with an increased population of 13.46m) while numbers of vehicles also increased in the same period from 180.140 to 270.600.The report shows that more male fatalities were reported in Rwanda (86.2%)

compared to women (13.8%) and Rwanda had an improved Confidence Interval (CI) (WHO, 2023).

Moreover, statistics released by the Rwanda National Police (RNP) has revealed a concerning trend, with over 3,000 road accidents recorded in Rwanda between January and June 2023. These accidents have been predominantly attributed to various factors, including drivers' inattention, failure to maintain a safe following distance, and over speeding, accounting for 31%, 15%, and 13% of the accidents, respectively. Furthermore, incidents involving obstructing vehicles attempting to overtake or violating zebra crossings made up 12% of the accidents, while 9% resulted from a failure to stay within designated lanes. Illegal overtaking contributed to 8% of the accidents, and a significant 7% and 5% were linked to drunk driving and the non-use of wing mirrors, respectively (The New Times, 2023).

Road safety practitioners are constantly seeking the most effective means for preventing injuries and fatalities on the road. To accomplish this, they need to understand the nature of the road safety problems and which behavioral or infrastructure countermeasures are the best at addressing these problems. Understanding the primary causes of traffic fatalities and severe injuries is crucial for implementing effective road safety measures.

2.2 Theoretical frameworks in road safety

To effectively design strategies that minimize traffic fatalities and severe injuries, it is essential to ground such strategies in well-established road safety theories. These theoretical frameworks help guide the understanding of traffic accidents as complex, systemic problems, and inform both engineering and management interventions. Among the most widely used frameworks are the Haddon Matrix, the Safe System Approach, and the Vision Zero philosophy.

2.2.1 Haddon Matrix

One view on traffic safety is conceptualised in the Haddon Matrix. The Haddon Matrix categorises traffic safety measures in two dimensions. One dimension is the time compared to crash when they are deployed: Before crash, in crash, after crash. The other dimension is categorising measures according to their relation to the road users, the vehicle or the road. (Haddon 1980)

According to Ahmed (2013), the matrix developed by Dr. William Haddon identifies three main factors that contribute to road accidents: human factors, environmental factors, and vehicle/equipment factors. Human behavior includes influences such as drug or alcohol use,

excessive speed, poor driving attitudes, mobile phone use, and other distractions. Environmental factors involve weather conditions, road design, wind speed, improper road intersections, and similar elements. Vehicle-related factors include vehicle design, type, traffic volume, and traffic composition on the road. The Haddon Matrix in Table 1 is an analytical tool designed to help identify these contributing factors related to road accidents. Once the factors are identified and analyzed, appropriate countermeasures can be developed to serve as guidelines for both short-term and long-term interventions.

Table 1: Haddon Matrix

		FACTORS		
	Phase	**Human**	**Vehicles & Equipment**	**Environment**
Pre-crash	Crash prevention	- Information - Attitudes - Impairment - Police Enforcement	- Roadworthiness - Lighting - Braking - Handling -Speed management	- Road Design - Road layout - Speed limits - Pedestrian facilities
Crash	Injury prevention during crash	Use of restraint - Impairment	-Occupant restraint -Other safety device -Crash protective design	-Crash-protective roadside objects
Post-crash	Life sustaining	-First aid skill -Access to medics	-Ease of access -Fire risk	-Rescue facilities -Congestion

Source: Ahmed (2013)

2.2.2 Safe system approach

The Safe System Approach builds upon the limitations of traditional road safety models by emphasizing the idea that human errors are inevitable and that the road transport system

must be resilient enough to accommodate these errors without resulting in death or serious injury. It places the responsibility for safety not solely on the individual road user, but also on road designers, vehicle manufacturers, law enforcers, and policy-makers (OECD, 2008). A Safe System approach has the following characteristics:

- Mistakes, errors of judgment and poor decisions are intrinsic to humans. The road system needs to be designed and operated to account for this.
- Humans are fragile. Unprotected, we cannot survive impacts that occur at greater than around 30km/h.
- The 'engineered' elements of the system – vehicles and roads – can be designed to be compatible with the human element, recognising that while crashes might occur, the total system can be designed to minimise harm, particularly by making roads self-explanatory and forgiving of human error.

The Safe System Approach recognizes the interdependence of the safe system components: Safe roads, safe speeds, safe road users and safe vehicles, and the actions that can be taken to achieve continuous improvements across these components. The goal of this approach is to prevent all collisions and to assure that if collisions do occur, road users will not be seriously injured. While road users must always try to interact safely, the Safe System Approach emphasizes that the transportation system must be designed to accommodate human vulnerability and error. Therefore, the Safe System approach places more responsibility on the system designers than on individual road users.

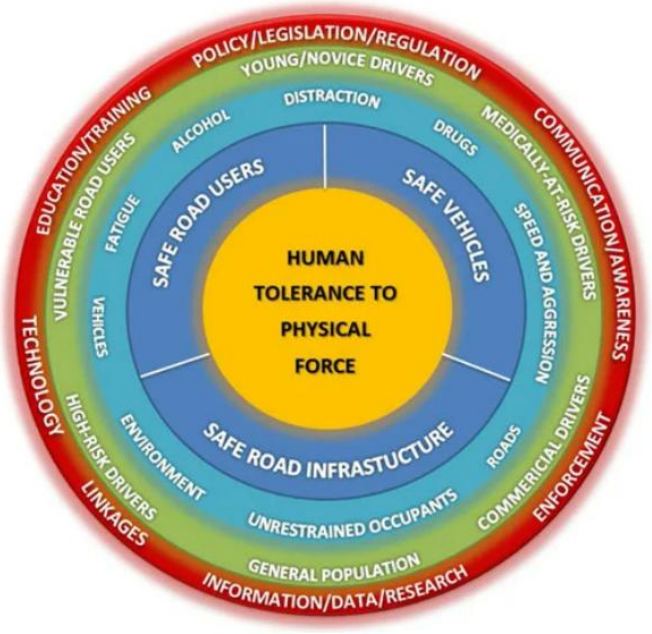


Figure 1: Components of Safe System Approach

The Safe System Approach has been widely adopted in road safety planning in countries like

Sweden, Australia, and New Zealand, and its principles are gaining traction in African countries through development initiatives (World Bank, 2020).

2.2.3 Vision Zero

Vision Zero is a proactive and ethical road safety framework that originated in Sweden in 1997 and has since been adopted globally. Its fundamental premise is that no human life should be lost or seriously injured as a result of road traffic incidents, emphasizing that road safety is a shared responsibility among road designers, vehicle manufacturers, policymakers, and users (WHO, 2023). Unlike traditional safety approaches that accept a certain level of risk, Vision Zero aims to design systems that accommodate human error without resulting in death or serious harm.

This approach includes strategies such as lowering speed limits in areas with high pedestrian activity, implementing self-explaining roads, equipping vehicles with advanced safety technologies, and ensuring that transport and land use planning prioritize vulnerable road users (OECD, 2022). Vision Zero also aligns closely with the Safe System approach, focusing on system resilience and forgiving infrastructure that reduces crash severity.

Countries that have adopted Vision Zero such as Sweden, Norway, and the Netherlands have seen a sustained reduction in road fatalities. In Sweden, road deaths decreased from over 500 per year in the 1990s to below 200 by 2020 (ITF, 2022). Moreover, some African cities like Addis Ababa and Cape Town have recently begun integrating Vision Zero principles in urban planning, although challenges related to infrastructure funding and enforcement remain significant (Welle *et al.,* 2020).

2.3 Engineering strategies for road safety

Engineering strategies play a vital role in the prevention of road traffic fatalities and severe injuries, especially on asphalt roads which dominate many urban areas in developing countries like Rwanda. These strategies focus on improving the physical layout and operational efficiency of roadways. The following sections detail key engineering interventions that have been proven effective globally and hold great potential for local adaptation in Kigali City.

2.3.1 Road design and infrastructure

Road design influences driver behavior, traffic flow, and the severity of crashes. Clear, predictable, and safe road environments are essential for preventing errors that lead to fatalities and serious injuries. One fundamental aspect of safe road design is lane marking.

Clear lane delineation such as centerlines, edge lines, arrows, and pedestrian crossings enhances visibility and guides road users, especially under adverse weather or at night (AASHTO, 2021). Reflective thermoplastic materials and rumble strips have been widely used in the United States and Europe to reduce unintentional lane departure and head-on collisions.

Modern roundabouts are also a proven road safety design. Unlike traditional intersections, roundabouts are designed to reduce vehicle speeds and eliminate conflict points that cause severe crashes. Studies by the European Transport Safety Council (ETSC, 2022) show that well-designed single-lane roundabouts can reduce fatal and serious injury crashes by up to 70%. Multi-lane roundabouts, while slightly more complex, still reduce such crashes by around 45%. These features include central islands, deflection at entries, pedestrian refuge islands, and yield-at-entry rules that calm traffic while ensuring continuous flow. In Kigali, roundabouts at busy junctions can reduce the incidence of T-bone and angle crashes, which are common at uncontrolled intersections.

2.3.2 Traffic calming measures

Traffic calming refers to physical measures designed to slow down or reduce motor vehicle traffic, thereby enhancing safety for pedestrians and other vulnerable users. Raised crosswalks are particularly effective in pedestrian-prone areas such as school zones and markets. These crossings are elevated to the same level as the sidewalk and marked with high-visibility paint and signage. Litman (2022) found that raised crossings can reduce traffic speeds by 20–30% and pedestrian crash rates by over 50%.

Speed humps and cushions are other common measures that have a measurable impact on crash frequency and severity. Zimmerman *et al.* (2023) report that speed humps can reduce neighbourhood vehicle speeds by 25%, while speed cushions designed to accommodate emergency vehicles achieve similar effects with less disruption to service delivery. Chicanes, which involve alternating curb extensions that force drivers to navigate a serpentine path, have been shown to reduce mid-block crash rates by approximately 30% (Zimmerman et al., 2023). In Kigali's residential zones and near schools, these calming devices could effectively deter over speeding and inattentive driving.

Curb extensions or bulb-outs also shorten pedestrian crossing distances and increase their visibility to approaching drivers. These are particularly useful at uncontrolled pedestrian crossings and intersections with high pedestrian volume. Their use, coupled with pedestrian signals and refuge islands, helps reduce conflicts between pedestrians and motor vehicles.

2.3.3 Smart technology and innovations

Technological innovations in traffic engineering are advancing rapidly and offer new methods to monitor, manage, and enhance road safety. Adaptive traffic control systems such as SCOOT (Split Cycle Offset Optimization Technique) and In Sync use sensors to adjust signal timings in real time based on traffic flow. Wu, Zhang, and Li (2023) demonstrated that these systems can increase intersection throughput by up to 25% and reduce red-light running incidents by 40%. In high-traffic corridors like those in Kigali, adaptive systems can reduce congestion-related crashes and improve overall traffic flow.

Closed-circuit television (CCTV) integrated with artificial intelligence is another tool for enhancing road safety. These systems provide real-time traffic monitoring and automated enforcement for offenses like illegal turns, red-light running, and over-speeding. Research by Chen, Tan, and Goh (2021) indicates that CCTV systems with analytic capabilities can reduce such infractions by 20–30%. Kigali's central business district and accident-prone zones would benefit significantly from expanded camera coverage and AI-enabled enforcement.

Another emerging solution is Vehicle-to-Infrastructure (V2I) communication. This technology enables vehicles to exchange information with traffic signals, road signs, and other infrastructure elements. According to Pan *et al.* (2024), V2I systems improve drivers' reaction time and reduce intersection-related violations. While the full deployment of such systems in Rwanda may be constrained by funding, pilot initiatives along key corridors could provide proof of concept.

2.3.4 Pedestrian safety measures

Pedestrian infrastructure is a vital component of safe urban road networks, especially in low- and middle-income countries where a high proportion of road traffic victims are pedestrians. Engineering interventions such as zebra crossings, raised crosswalks, pedestrian refuge islands, and footbridges play a significant role in reducing pedestrian fatalities. A study conducted in Nairobi and Addis Ababa found that raised zebra crossings reduced pedestrian crashes by 45%, particularly in school zones and commercial areas (Mekonnen & Waithaka, 2021).

In Kigali, the introduction of pedestrian refuge islands along major corridors like KN5 Road has improved crossing safety by providing a midway stopping point, especially for children and the elderly. Additionally, proper lighting of pedestrian crossings at night and use of

reflective road markings enhance visibility. The African Development Bank (AfDB, 2022) also encourages the use of audio signals and tactile paving to assist visually impaired road users. While footbridges are effective on multi-lane arterials, their location, gradient, and maintenance are key to ensuring usability. Thus, engineering interventions must be context-specific, data-driven, and user-centric to maximize safety benefits.

2.3.5 Implications for Kigali and Rwandan urban roads

The successful implementation of engineering strategies requires a context-sensitive approach. In Kigali, the combination of poorly disciplined traffic, mixed vehicular flows, and inadequate road infrastructure presents unique challenges. Nonetheless, several strategies stand out as both feasible and impactful. First, the introduction of mini-roundabouts in areas with frequent intersection crashes could mitigate crash severity. Second, traffic calming measures such as raised pedestrian crossings and speed humps should be deployed near schools, markets, and transit terminals. Third, investment in adaptive signal control and CCTV-based enforcement can strengthen the city's traffic management capabilities.

Moreover, the prioritization of engineering interventions must align with the broader goals of Rwanda's road safety action plan and the national vision for sustainable urban transport. Engineering improvements, if executed alongside enforcement and education campaigns, can form the backbone of a Safe System approach that is resilient, inclusive, and life-saving.

2.4 Management strategies for road safety

Effective road safety management goes beyond infrastructure improvements and requires institutional, regulatory, and educational interventions. This section explores the role of management strategies in reducing road traffic fatalities and severe injuries on asphalt roads, with a particular focus on Kigali City, Rwanda.

2.4.1 Law enforcement and speed regulation

Law enforcement plays a crucial role in ensuring compliance with traffic rules and deterring dangerous driving behavior. Speeding, drunk driving, and distracted driving are leading causes of road crashes globally and are particularly prevalent in urban settings with poor regulatory oversight. In Kigali, speed enforcement has been strengthened through the deployment of speed cameras and mobile patrols by the Rwanda National Police (RNP), contributing to a noticeable reduction in overspeeding violations (RNP, 2023).

The introduction of speed governors in public transport vehicles, as mandated by Rwanda Utilities Regulatory Authority (RURA), has also been instrumental in regulating speed and reducing traffic fatalities. Studies have confirmed that countries implementing strict speed management protocols, including automated speed enforcement and roadside checks, tend to have lower crash rates and fatality indices (WHO, 2023).

2.4.2 Road user education campaigns

Educational programs targeting road users particularly drivers, motorcyclists, and pedestrians have been shown to influence behaviour and reduce risky practices. In Rwanda, road safety education is carried out through media outreach, school-based programs, and community mobilization. For instance, the "Gerayo Amahoro" campaign, launched by RNP, educates citizens on safe road behaviour, reaching millions of Rwandans annually.

According to the International Transport Forum (2021), road safety education enhances user responsibility and fosters a culture of compliance. These programs are most effective when combined with enforcement, infrastructure improvements, and community involvement (UNESCAP, 2022).

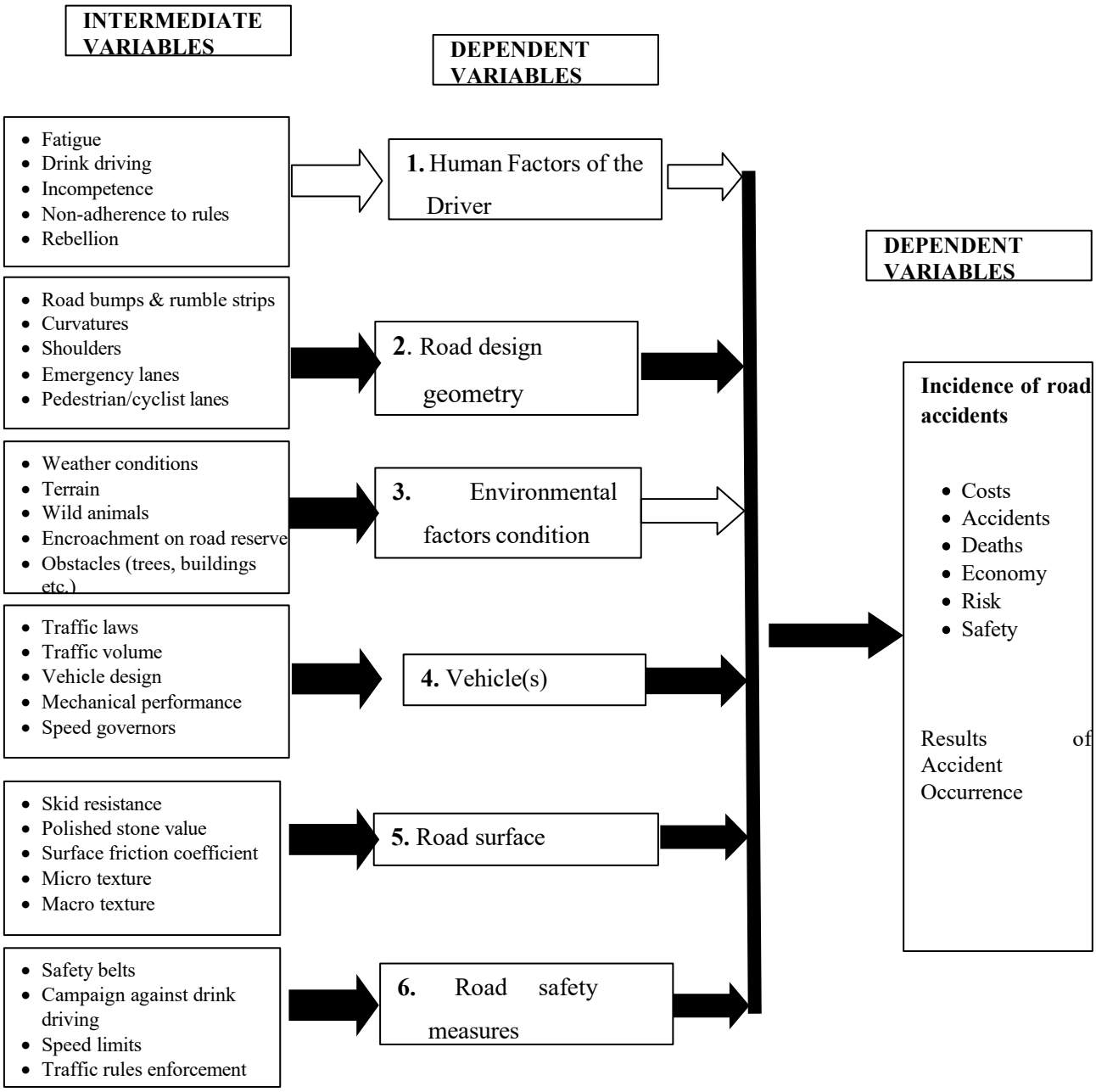
2.4.3 Data-driven traffic policing

Modern road safety management increasingly depends on the use of data analytics to identify high-risk locations and target enforcement. In Rwanda, the RNP uses crash data to pinpoint accident-prone zones, commonly referred to as "black spots". These insights inform the deployment of police patrols, traffic signal adjustments, and public information efforts.

Additionally, traffic violation databases help authorities track repeat offenders and trends in behavior, improving policy interventions. For example, digital ticketing systems and the integration of driver behavior records help ensure accountability and inform policy development. Studies show that countries adopting such data-driven approaches have seen enhanced resource allocation and greater enforcement efficiency (World Bank, 2023).

2.5 Conceptual framework

The study's conceptual framework is predicated on six independent variables indicated in the literature above that cause RTAs. The human, road, environmental and vehicular constructs are predisposing parameters to be operationalized into explanatory variables and related to the accident variables in the research.


INTERMEDIATE VARIABLES
DEPENDENT VARIABLES
Fatigue
Drink driving
Incompetence
Non-adherence to rules
Rebellion
1. Human Factors of the Driver
Road bumps & rumble strips
Curvatures
Shoulders
Emergency lanes
Pedestrian/cyclist lanes
2. Road design geometry
Weather conditions
Terrain
Wild animals
Encroachment on road reserve
Obstacles (trees, buildings etc.)
3. Environmental factors condition
Traffic laws
Traffic volume
Vehicle design
Mechanical performance
Speed governors
4. Vehicle(s)
Skid resistance
Polished stone value
Surface friction coefficient
Micro texture
Macro texture
5. Road surface
Safety belts
Campaign against drink driving
Speed limits
Traffic rules enforcement
6. Road safety measures
DEPENDENT VARIABLES
Incidence of road accidents
Costs
Accidents
Deaths
Economy
Risk
Safety
Results of Accident Occurrence

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodological approach adopted in the study. It presents the research design, description of the study area, population and sample size, data collection methods, data analysis procedures, and ethical considerations. The methodology is designed to ensure the reliability, validity, and comprehensiveness of the findings concerning the utilization of engineering and management strategies to minimize traffic fatalities and severe injuries on asphalt roads in Kigali City.

3.2 Research design

The study employed a mixed-methods research design, integrating both quantitative and qualitative approaches. Quantitative data were obtained through structured questionnaires administered to a representative sample of road users, while qualitative insights were gathered through interviews and field observations. This design enabled triangulation of data, thereby enhancing the depth and validity of the findings. The approach was selected to capture both measurable outcomes and contextual understanding of the engineering and management strategies applied in Kigali City.

3.2 Study area

The research focused on Kigali City, the capital of Rwanda, which has experienced rapid urbanization, increasing traffic volumes, and rising road safety challenges. Specific attention was given to high-traffic asphalt road, major intersections, and areas identified as accident hotspots based on historical crash data provided by the Rwanda National Police and Kigali City authorities.

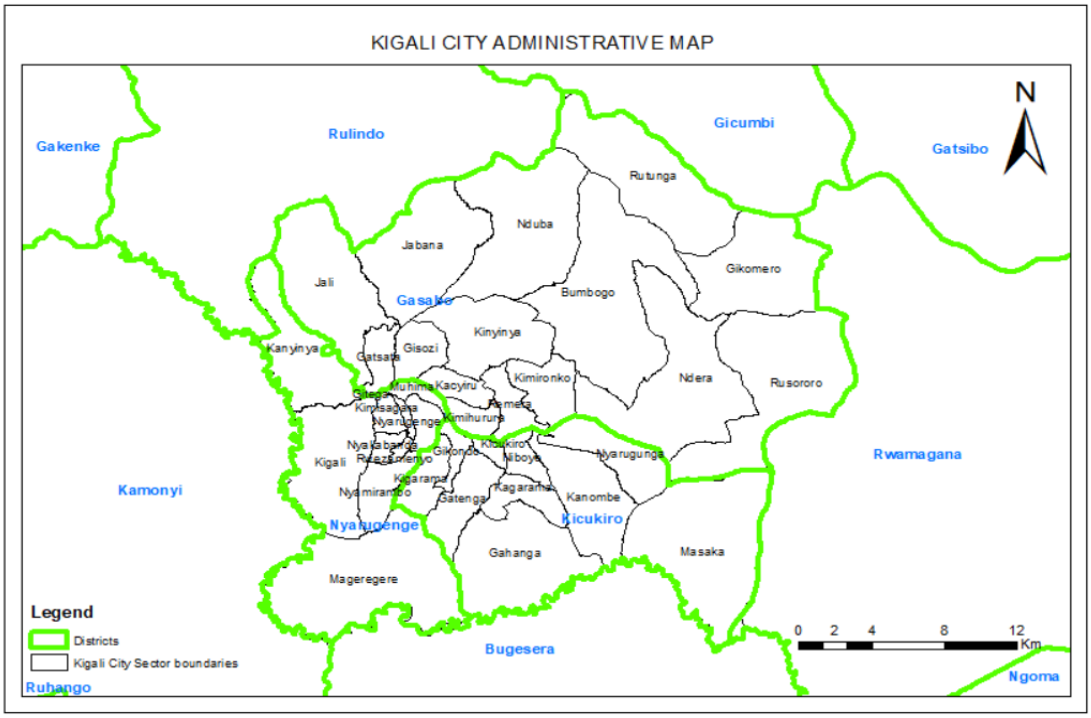


Figure 2: Study area

3.4 Target population

The target population of this study consisted of diverse road users and traffic safety stakeholders within Kigali City, including pedestrians, motorcyclists, drivers, traffic police officers, engineers, and urban planners. These groups were selected because they either experience or influence traffic safety outcomes on asphalt roads. Vulnerable road users such as pedestrians and motorcyclists are especially at risk and provide critical insights into road safety challenges (WHO, 2018). Traffic police and infrastructure planners were also included due to their involvement in enforcing and designing safety interventions. This comprehensive target population supports a holistic understanding of the utilization and effectiveness of engineering and management strategies (Bhalla *et al.,* 2017).

3.5 Sample size determination

The sample size was determined using Slovin's formula with a 95% confidence level and 5% margin of error. Based on the estimated population of road users and stakeholders in Kigali City, a sample of 384 respondents was deemed sufficient. The formula is as follows:

$$n=\frac{\mathbf{N}}{\mathbf{1}+\mathrm{N}(e^2)} \qquad (1)$$

Where:

n = required sample size

N = population size

e = margin of error (0.05)

3.6 Sampling techniques

A combination of purposive and stratified random sampling techniques was adopted in this study to ensure the inclusion of relevant participants and the representativeness of the sample. Purposive sampling was used to identify and engage key informants such as traffic police officers, road safety engineers, and transport policy implementers. These individuals were selected based on their roles and expertise in road safety management and infrastructure planning in Kigali City. Their insights were essential in understanding the practical aspects and challenges of implementing engineering and management strategies.

Stratified random sampling was employed to obtain a balanced and diverse sample of road users. The population was stratified by mode of transport (pedestrians, motorcyclists, and drivers). Within each stratum, random sampling was used to select participants, ensuring proportional representation and reducing sampling bias. This approach helped capture a broad range of perspectives and experiences related to road safety on asphalt roads in Kigali.

3.7 Data collection instruments

The study utilized three main data collection instruments: structured questionnaires, observation checklists, and key informant interviews.

3.7.1 Structured questionnaire

The structured questionnaire was administered to a sample of 384 respondents, capturing data on demographic characteristics, experiences with traffic crashes, perceptions of existing engineering and management strategies, and recommendations for improvement. The questionnaire was designed to collect both closed- and open-ended responses, allowing for quantitative analysis and qualitative insights.

3.7.2 Observation checklist

An observation checklist was used to evaluate the physical condition of selected asphalt roads across Kigali City. The roads selected for observation included KN1, and RN1 leading to Giticyinyoni, which are known to experience high traffic volumes and frequent crash

occurrences. These roads were chosen due to their strategic importance and elevated crash risks, particularly for vulnerable road users such as pedestrians and motorcyclists. The checklist assessed features such as surface condition, signage, lighting, pedestrian infrastructure, and traffic calming measures. Observations were conducted during various times of the day to capture differences in traffic behavior and visibility.

3.7.3 Key informant interviews

Key informant interviews were carried out with selected traffic police officers, urban road engineers, and relevant policy implementers. These interviews provided in-depth insights into the current road safety strategies, challenges in implementation, institutional coordination, and policy gaps. All data collection tools were pre-tested in a pilot study to ensure reliability, validity, and clarity. Necessary adjustments were made before final deployment to enhance the quality of data collected.

3.8 Data analysis techniques

Quantitative Data: Analysed using SPSS and Microsoft Excel. Descriptive statistics (frequencies, percentages, means) summarized key variables. Inferential statistics such as Chi-square tests were used to assess associations between categorical variables, while Analysis of Variance (ANOVA) compared mean perceptions among different groups.

Qualitative Data: Interview responses and observation notes were analysed using thematic analysis, identifying recurring patterns and themes related to road safety infrastructure, management practices, and policy implications.

3.10 Ethical considerations

Ethical compliance was ensured throughout the study. Prior to participation, all respondents were informed of the purpose of the study, the voluntary nature of their participation, and their right to confidentiality. Written or verbal informed consent was obtained from all participants. No personal identifiers were used in data analysis or reporting. Ethical approval was obtained from the relevant university review board and local authorities in Kigali City.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

In order to fully answer the research questions and meet with our objectives , this study combined quantitative and qualitative data using a mixed-methods approach. Excel and SPSS were used to analyse quantitative data, organizing and interpreting numerical data using descriptive and inferential statistics like regression, cross-tabulations, frequencies, and correlations.

To find important trends and insights, thematic analysis was used to examine qualitative data, including field notes and open-ended responses. To guarantee consistency, data were manually coded using distinct categories.

The study generated comprehensive results that are grounded in data and have contextual significance by combining statistical and thematic analysis.

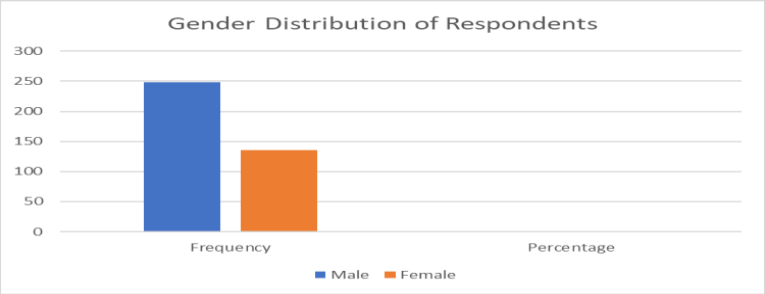
This chapter presents the results of the questionnaire survey and observational data collected from 384 respondents and various road sections across CBD, KN1, and RN1 leading to Giticyinyoni in Kigali City. The data are organized into frequency tables and visualized using bar charts for easier interpretation. Key findings on demographic characteristics, crash experiences, perceived crash causes, and effectiveness of engineering and management strategies are analysed and discussed in line with the study objectives.

4.2 Gender distribution of respondents

This section presents the gender breakdown of respondents using the KN1–RN1 Giticyinyoni corridor.

Table 4-1: Gender distribution of respondents

Gender	Frequency	Percentage
Male	248	64.6%
Female	136	35.4%



Source: Primary data, 2025

Among the 384 respondents surveyed, a majority were male (64.6%) compared to 35.4% female. This gender gap reflects the high representation of male road users, particularly in modes like motorcycling, trucking, and informal public transport common in urban corridors like Nyabugogo. The observed dominance of males also aligns with earlier traffic exposure statistics in Kigali, where male travelers and drivers typically outnumber female users due to occupational roles and vehicle access. This imbalance has implications for road safety strategies, suggesting that gender-targeted interventions and public education may be necessary. Moreover, it highlights the importance of ensuring both genders are considered in transport planning, especially concerning vulnerable groups such as female pedestrians and cyclists.

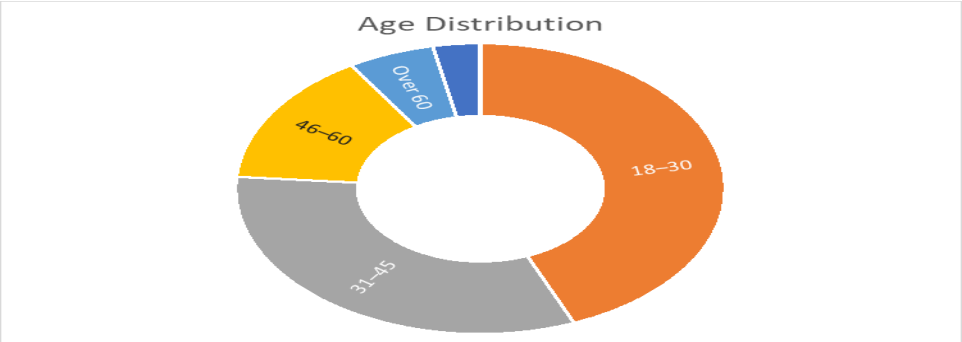
4.3 Age distribution of respondents

This section displays the distribution of respondents across different age categories along the CBD–KN1–RN1–Giticyinyoni corridor.

Table 4-2: Age distribution of respondents

Age group	Frequency	Percentage
Under 18	12	3.1%
18–30	168	43.8%
31–45	125	32.6%
46–60	57	14.8%
Over 60	22	5.7%

Source: Primary data, 2025



The majority of respondents (43.8%) were aged between 18 and 30, followed by 32.6% in the 31–45 age range. Only a small fraction (3.1%) were under 18, and 5.7% were over 60. These results reflect an active, working-age road user population that predominantly engages in commuting, transport services, or market-related movement. This finding is consistent with urban mobility studies showing that the youth and middle-aged groups are more likely to engage in high-frequency travel and also exhibit greater exposure to road safety risks (WHO, 2018). The relatively low participation of older age groups may indicate mobility limitations or less reliance on informal transport. The dominant presence of young adults, especially in motorcycle and pedestrian activity around Nyabugogo, underscores the need for targeted enforcement and awareness programs for these high-mobility and higher-risk groups.

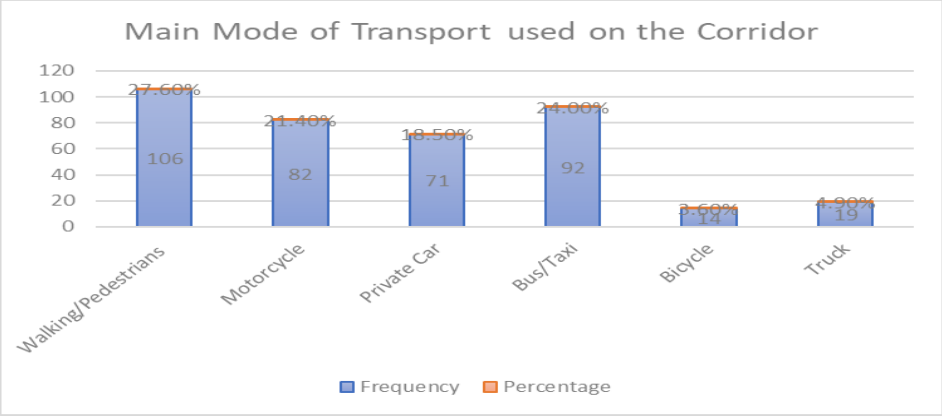
4.4 Main mode of transport used on the corridor

This section shows the most common transport modes used by road users along the CBD–KN1 RN1–Giticyinyoni corridor.

Table 4-3: Main mode of transport used on the corridor

Mode of transport	Frequency	Percentage
Walking/Pedestrians	106	27.6%
Motorcycle	82	21.4%
Private Car	71	18.5%
Bus/Taxi	92	24.0%
Bicycle	14	3.6%
Truck	19	4.9%

Source: Primary data, 2025



Walking was the most reported mode of transport, accounting for 27.6% of users, followed by bus/taxi passengers (24.0%) and motorcycle riders (21.4%). These results reflect a corridor dominated by vulnerable road users (VRUs), particularly in the Nyabugogo zone where informal and pedestrian-based activity is concentrated. The absence of pedestrian and cycling infrastructure on the RN1–Giticyinyoni stretch exacerbates safety risks for these groups. Although truck drivers make up only 4.9% of users, their involvement in serious crashes especially near the sharp curve with superelevation raises safety concerns that require targeted engineering measures. The data confirm patterns observed in other urban African corridors where pedestrian, public, and motorcycle transport dominate (Mbandi et al., 2021; WHO, 2022), highlighting the urgent need for user-sensitive road design and enforcement mechanisms.

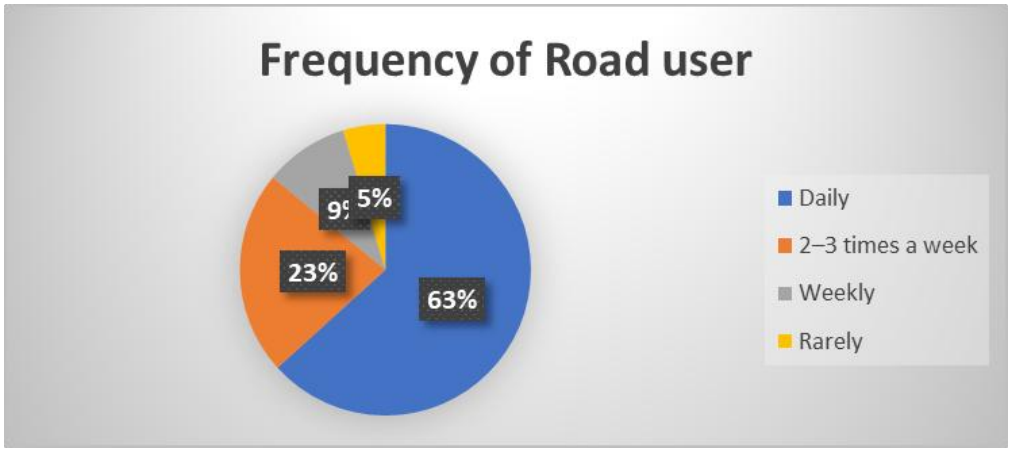
4.5 Frequency of road use

This section illustrates how frequently respondents use the CBD–KN1–RN1 Giticyinyoni road corridor.

Table 4-4: Frequency of road use

Usage frequency	Frequency	Percentage
Daily	243	63.3%
2–3 times a week	87	22.7%
Weekly	36	9.4%
Rarely	18	4.7%

Source: Primary data, 2025



Most respondents (63.3%) reported using the corridor daily, while 22.7% used it several times a week. This shows that the corridor is a heavily used route for commuters and businesses, especially in the urban section connecting Nyabugogo and CBD. The high daily traffic increases the risk of crashes, especially for VRUs navigating areas without sidewalks or proper crossings. Such consistent traffic flow requires not only well-maintained infrastructure but also strong enforcement and management to address peak-hour risks. These findings align with previous research stating that high usage frequency is linked to higher crash risk if mitigation measures are weak (World Health Organization, 2022).

4.6 Crash experience by section of road mostly used

This section analyses the relationship between the section of the corridor mostly used and the likelihood of experiencing or witnessing a crash.

Table 4-5: Cross-tabulation of section mostly used and crash experience

Road Section	Experienced Crash	No crash	Total
CBD Roundabout–KN1–RN1	92	52	144
RN1–Giticyinyoni	75	26	101
Entire Corridor	103	36	139
Total	**270**	**114**	**384**

Source: Primary data, 2025

Results show that the majority of crash-experienced respondents (103) use the entire corridor, which includes both urban and peri-urban risk zones. Notably, 75 crash reports were linked to the RN1–Giticyinyoni section, a stretch lacking pedestrian or cycling infrastructure and featuring a hazardous curve with high superelevation. The CBD–KN1–RN1 section had 92 crash experiences, mostly near the malfunctioning signalized roundabout. Overall, 70% of those using RN1–Giticyinyoni experienced crashes compared to 63.9% on the CBD side.

These figures suggest that exposure to infrastructure-deficient sections correlates with increased crash likelihood. A Chi-square test ($\chi^2 = 6.53$, $p < 0.05$) confirmed a statistically significant association between road section used and crash experience. This supports the need for location-specific engineering interventions and targeted enforcement (Mbandi *et al.,* 2021).

4.7 Type of crash experienced by mode of transport

This section explores the relationship between respondents' primary mode of transport and the type of crash they reported experiencing or witnessing along the CBD–KN1–RN1 Giticyinyoni corridor.

Table 4-6: Cross-tabulation of mode of transport and type of crash experienced

Mode Transport	Pedestrian-involved	Motorcycle Crash	Vehicle Collision	Truck Rollover	Total
Walking	61	4	3	0	68
Motorcycle	12	54	10	1	77
Private Car	5	11	48	2	66
Bus/Taxi	9	12	24	3	48
Bicycle	7	1	1	0	9
Truck	2	4	6	10	22

Source: Primary data, 2025

From the data, pedestrians mostly experienced pedestrian-involved crashes (61), motorcyclists were frequently involved in motorcycle crashes (54), and private car users mainly encountered vehicle collisions (48). Notably, truck rollover incidents were reported predominantly by truck drivers (10), especially near the RN1-Giticyinyoni curve with high superelevation. These results illustrate a strong correlation between transport mode and crash type, with each user group encountering risks that reflect their unique vulnerabilities. The distribution also highlights the structural mismatch between road design and diverse user needs.

A Chi-square test ($\chi^2 = 112.48$, $p < 0.001$) confirmed a significant relationship between mode of transport and crash type. These insights reinforce calls for mode-specific safety interventions such as pedestrian overpasses, protected motorcycle lanes, and improved signage for heavy trucks (UN-Habitat, 2021).

4.8 Perceived causes of road crashes on the corridor

This section presents respondents' perceptions of the leading causes of crashes along the KN1-RN1 Giticyinyoni road corridor.

Table 4-7: Perceived causes of crashes

Cause	Frequency	Percentage
Speeding	282	73.4%
Careless driving	266	69.3%
Lack of pedestrian lanes	240	62.5%
Poor enforcement	218	56.8%
No cycling infrastructure	196	51.0%
Pedestrian violations	202	52.6%
Sharp curve/superelevation	188	49.0%
Poor signage	175	45.6%

Source: Primary data, 2025

Speeding (73.4%) and careless driving (69.3%) emerged as the two most commonly perceived causes of crashes along the corridor, particularly in high-traffic areas like the Nyabugogo market and the RN1–Giticyinyoni stretch. The lack of pedestrian lanes (62.5%) and poor enforcement (56.8%) were also highly cited, pointing to institutional and design-based challenges. A significant share (51%) also noted the absence of cycling infrastructure, indicating that non-motorized transport users are routinely neglected in road planning.

Sharp curve/superelevation issues especially on the RN1–Giticyinyoni segment were recognized by nearly half of respondents, reflecting frequent truck rollovers at that location. These findings are supported by previous research emphasizing the correlation between speed management, road design, and enforcement in reducing crash severity (Ackaah & Salifu, 2020). The data underscore the multifaceted nature of road safety and the importance of combining engineering design improvements with behavioral and enforcement measures.

According to the road users experience they have identified the main cause of traffic fatalities and Severe injuries in Asphalt roads of Kigali, those causes are:

- Unsafe driver behavior, such as, such as speeding and careless maneuvers.
- Inadequate road infrastructure, particularly for vulnerable road users (VRUs) like

pedestrians and cyclists.

- Inadequate road infrastructure, particularly for vulnerable road users (VRUs) like pedestrians and cyclists.
- Enforcement deficits, including infrequent patrols, unreliable traffic signal management, and limited use of automated technologies.
- Design flaws, such as the sharp curve at Giticyinyoni, contribute to repeated crashes, especially involving heavy trucks.
- The patterns of crashes show:
- High involvement of VRUs (pedestrians and motorcyclists).
- Specific locations (e.g., RN1–Giticyinyoni, CBD roundabout) emerging as crash hotspots.
- Higher crash likelihood for frequent road users and users of corridors lacking safe infrastructure.

4.9 Perception of road infrastructure quality by user group

This section presents the mean ratings of various road infrastructure features by different user groups and evaluates whether these perceptions significantly differ using one-way ANOVA.

Table 4-8: Average infrastructure ratings by road user group (1 = Very Poor, 5 = Excellent)

User group	Surface quality	Pedestrian facilities	Cyclist lane	Curve visibility	Signage &markings	Signal function	Lighting
Pedestrian	3.2	2.1	1.4	2.3	2.5	2.2	2.8
Motorcyclist	3.4	2.6	1.5	2.7	2.9	2.6	3.1
Private Car	4.1	3.2	2.0	3.6	3.7	3.4	3.9
Bus/Taxi	3.7	2.8	1.6	3.1	3.4	3.0	3.2
Truck	3.9	2.7	1.7	3.0	3.3	3.1	3.0

Source: Primary data, 2025

ANOVA results indicate statistically significant differences in perceived infrastructure quality among user groups, especially for road surface ($F = 12.74$, $p < 0.01$), signage and markings ($F = 9.12$, $p < 0.01$), and traffic signal functionality ($F = 8.56$, $p < 0.05$). Private car users consistently rated infrastructure features more positively than vulnerable road users, who expressed concern about the lack of pedestrian and cycling infrastructure. Pedestrians and cyclists gave the lowest scores to pedestrian facilities (2.1) and cycling lanes (1.4), reflecting

critical design deficiencies. These disparities highlight how perceptions vary depending on the vulnerability and exposure of each group. Such feedback reinforces the need for inclusive road design, as recommended by recent urban safety frameworks (UN-Habitat, 2021; WHO, 2022), and underscores the demand for urgent upgrades to non-motorized infrastructure along RN1–Giticyinyoni.

4.10 Observation of traffic enforcement along the corridor

This section presents the frequency with which respondents reported observing traffic enforcement activities along the KN1–RN1 Giticyinyoni corridor.

Table 4-9: Observation of traffic enforcement

Observation Frequency	Respondents	Percentage
Always	48	12.5%
Often	102	26.6%
Rarely	153	39.8%
Never	81	21.1%

Source: Primary data, 2025

The majority of respondents indicated that they rarely (39.8%) or never (21.1%) observe traffic enforcement along this corridor. Only a small portion of road users stated they always (12.5%) or often (26.6%) notice enforcement presence. These findings suggest a gap between intended enforcement strategies and their actual visibility or consistency on the ground. Poor visibility of enforcement undermines deterrence and contributes to rule violations such as speeding, wrong-way driving, and pedestrian non-compliance.

According to Elvik and Vaa (2020), the perceived presence of enforcement plays a critical role in driver behavior, especially in corridors with high traffic conflict points. Moreover, the World Bank (2022) highlights that sustained and visible enforcement is a proven component of successful urban traffic safety systems, particularly in rapidly motorizing cities. The results therefore emphasize the need for more visible and strategically deployed traffic enforcement, especially in hotspot locations like Nyabugogo and Giticyinyoni.

4.11 Perception of police effectiveness when traffic signals fail

This section examines how respondents perceive police performance in managing traffic flow when signals at the CBD roundabout malfunction.

Table 4-10: Perception of police effectiveness during signal failure

Response	Frequency	Percentage
Yes	123	32.0%
Partially	147	38.3%
No	89	23.2%
Not Sure	25	6.5%

Source: Primary data, 2025

A significant proportion of respondents (38.3%) believed that police partially manage traffic effectively when signals at the CBD roundabout are not functioning, while only 32% affirmed full effectiveness. However, 23.2% reported that police intervention was ineffective, and 6.5% were unsure. These mixed ratings reflect user frustration with inconsistent or unclear traffic direction, especially during peak congestion hours. As noted by Gwilliam and Kumar (2021), manual traffic management often lacks predictability, particularly in fast-growing urban environments.

4.12 Effectiveness of road safety awareness campaigns

This section analyses the perceived effectiveness of road safety awareness campaigns as reported by road users along the KN1–RN1 Giticyinyoni corridor, based on a revised scale of assessment.

Table 4-11: Effectiveness of road safety awareness campaigns

Effectiveness level	Frequency	Percentage
Very effective	62	16.1%
Somewhat effective	144	37.5%
Not effective	108	28.1%
Not noticed any campaign	70	18.2%

Source: Primary data, 2025

Findings show that only 16.1% of respondents rated the campaigns as “very effective,” while the largest group (37.5%) considered them “somewhat effective.” A combined 46.3% of participants either found them ineffective or had not noticed any campaign at all, indicating major gaps in visibility and community engagement. This suggests that while some safety

messaging exists, its reach, frequency, or relevance may be inadequate particularly in high-risk areas like Nyabugogo and the Giticyinyoni corridor.

According to Mutiso *et al.* (2021), the effectiveness of awareness campaigns depends not only on their presence but also on message clarity, audience targeting, and reinforcement mechanisms. Standalone awareness programs without visual reminders, institutional support, or concurrent enforcement tend to have limited impact in low-resource urban environments. These results highlight the need for integrated communication strategies including signage, school education, and real-time messaging to improve behavioral change among all user groups.

4.13 Suggested improvements to traffic management

This section presents respondents' views on which traffic management strategies should be prioritized to enhance road safety along the CBD-KN1–RN1 Giticyinyoni corridor.

Table 4-12: Suggested traffic management improvements

Suggested improvement	Frequency	Percentage
Traffic signal repair and maintenance	216	56.2%
More police deployment	202	52.6%
Installation of speed limiters or cameras	198	51.6%
Public awareness campaigns	174	45.3%
Better crash reporting systems	151	39.3%

Source: Primary data, 2025

The results show that the most frequently suggested improvement was traffic signal repair and maintenance (56.2%), reflecting challenges at the CBD signalized intersection where signals often fail and require manual police intervention. Increased police deployment (52.6%) and installation of speed limiters or traffic cameras (51.6%) were also highly recommended, particularly for high-risk areas like the Giticyinyoni curve. These suggestions indicate that respondents favor visible, preventive, and technological enforcement measures. Public awareness campaigns (45.3%) and improved crash reporting systems (39.3%) were also cited, revealing a demand for both proactive education and more efficient post-crash data systems.

As emphasized by the World Bank (2022), effective urban traffic management requires a balanced combination of enforcement, engineering, and education, supported by timely information systems. Likewise, Elvik (2020) argue that sustainable safety frameworks must prioritize system-level interventions, especially in contexts with mixed traffic and infrastructure deficits. The findings suggest that respondents are well-aware of current gaps and Favor both behavioral and infrastructural reforms.

4.14 Thematic discussion: Open-ended suggestions from road users

Open-ended responses provided rich insights into the specific engineering and enforcement solutions that road users believe would improve safety along the KN1–RN1 Giticyinyoni corridor. These responses were coded and categorized into major themes to support deeper interpretation and policy relevance.

The most commonly suggested intervention was the installation of pedestrian overpasses and safe crossings, cited by 23.2% of respondents. This reflects users' concern about pedestrian vulnerability in high-traffic areas such as Nyabugogo and the CBD signalized intersection. The presence of high pedestrian traffic combined with the absence of grade-separated crossings puts pedestrians at significant risk, particularly during peak hours. This suggestion aligns with urban mobility principles in Sub-Saharan Africa, which stress the need for context-appropriate pedestrian infrastructure (UN-Habitat, 2021).

Creating separate cycling lanes was the second most cited theme (19.8%), particularly among users of the RN1–Giticyinyoni section where bicycles, motorcycles, and heavy trucks all share a single undivided carriageway. Respondents emphasized that the absence of protected lanes exposes cyclists to collisions and road edge instability. The call for infrastructure equity is consistent with global findings that integrated non-motorized transport (NMT) design significantly reduces injury risk (WHO, 2022).

Another priority emerged from the call to redesign the sharp Giticyinyoni curve (17.7%), a location infamous for repeated truck overturning incidents due to steep superelevation and poor visibility. Participants recommended geometric modifications such as widening, barrier installation, and signage improvements. This aligns with recommendations in Ackaah & Salifu (2020), which emphasize engineering correction of high-risk curves in crash-prone corridors.

Technical upgrades like installing reflective signage and clear road markings (14.1%) were also noted, pointing to issues of visibility especially at night or during adverse weather conditions. Similarly, permanent traffic cameras and automated enforcement systems (18.8%) were suggested as ways to reduce reliance on manual policing and improve driver discipline. These recommendations reflect users' desire for consistent, technology-driven enforcement to curb speeding and dangerous maneuvers, as supported by empirical studies (World Bank, 2022).

Lastly, community road safety education appeared in 61 responses (15.9%), underlining the need for behavior change strategies alongside physical improvements. Users emphasized that awareness must go beyond mass media and reach cyclists, informal drivers, and school children through tailored programs and local campaigns.

Collectively, these themes illustrate a demand for a multi-pronged safety strategy that blends infrastructure, enforcement, and education. The diversity of suggestions confirms that end-users are well-informed of corridor-specific risks and possess valuable knowledge that can guide participatory planning and evidence-based design.

CHAPTER 5: CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of findings

This study investigated the utilization of engineering and management strategies to minimize traffic fatalities and severe injuries along the KN1–RN1 Giticyinyoni road corridor in Kigali City. Using a mixed-methods approach, data were collected from 384 road users through questionnaires, field observations, and key informant interviews. The analysis combined descriptive statistics, Chi-square tests, ANOVA, and thematic analysis to identify critical risk factors and intervention needs.

The demographic profile showed that most road users were male, aged between 18 and 45, and primarily relied on walking, motorcycles, or public buses as their main mode of transport. Crash experience was significantly associated with occupation and transport mode. Pedestrians and motorcyclists were the most affected, particularly at Nyabugogo intersection, CBD roundabout, and the Giticyinyoni curve.

Perceived causes of crashes included speeding, careless driving, lack of pedestrian and cycling infrastructure, poor signage, and sharp curve geometry. Most respondents rated road infrastructure as fair to poor, particularly pedestrian and cycling facilities. ANOVA revealed significant differences in perception among user groups, with vulnerable users (pedestrians, cyclists) expressing greater dissatisfaction. Enforcement visibility was rated as low, and while many acknowledged the role of the police during signal failures, there was skepticism about consistency and effectiveness. Awareness campaigns were seen as present but limited in visibility and impact.

Respondents suggested improvements including signal maintenance, police deployment, speed limiters, crash reporting systems, and educational campaigns. Open-ended responses also emphasized the need for pedestrian overpasses, dedicated cycling lanes, redesign of hazardous sections like Giticyinyoni, and technological enforcement tools.

5.2 Conclusion

The study concludes that road safety challenges on this corridor stem from a combination of poor infrastructure design, inadequate enforcement, and limited awareness. Vulnerable road users bear the brunt of these challenges, particularly in congested and poorly designed segments. While management strategies exist, their implementation and visibility remain insufficient to produce consistent safety outcomes. The integration of engineering solutions with proactive enforcement and public engagement is necessary to reduce traffic-related injuries and fatalities.

5.3 Recommendations

To address the key safety concerns identified, this study proposes the following set of integrated recommendations:

Firstly, under engineering improvements, it is recommended that pedestrian overpasses be constructed near the Nyabugogo and CBD intersections to reduce conflict between pedestrians and vehicles. The Giticyinyoni curve, known for truck rollovers, should be redesigned to improve superelevation, visibility, and safety signage. Additionally, dedicated lanes for bicycles and motorcycles should be established along the RN1 section to separate vulnerable users from heavy traffic. The corridor also requires upgraded road signage with reflective paint to enhance visibility and guidance, particularly at night.

Secondly, in terms of enforcement strategies, installing permanent speed cameras and other automated enforcement systems is advised to deter dangerous behavior. Traffic signal reliability should be improved with integrated backup systems to maintain flow during power outages. Furthermore, the deployment of trained traffic police at known high-risk points should be increased to ensure proactive enforcement and conflict resolution.

Thirdly, under education and awareness, targeted road safety campaigns should be launched for vulnerable road users such as cyclists and pedestrians. Community radio, market hubs, and schools should be utilized as platforms for raising awareness, supported by culturally tailored safety messages. Integration of traffic safety modules into school curricula would ensure long-term behavior change beginning from a young age.

Finally, regarding policy and management, the development of a centralized crash data reporting and management system is essential for tracking incidents and evaluating interventions. Stakeholder engagement should be institutionalized by involving community

representatives in transport planning and decision-making processes. Periodic road safety audits and corridor-level evaluations should be conducted to monitor progress and adjust strategies accordingly.

5.4 Areas for further research

Future research could explore the long-term effects of targeted interventions, such as the installation of camera-based enforcement systems, improved pedestrian and cyclist infrastructure, and enhanced signal timing strategies. Evaluating how these measures influence crash reduction, traffic flow, and road user behavior over time would provide valuable data for evidence-based planning.

Further studies might also consider a comparative assessment of multiple high-risk corridors within Kigali, enabling a broader understanding of spatial safety disparities across the city. Such work could support the development of a city-wide framework for prioritizing engineering and management interventions within the urban transport network.

REFERENCES

1. Adeloye, D., Thompson, J. Y., Akanbi, M. A., Azuh, D., Samuel, V., Omoregbe, N., & Ayo, C. K. (2016). The burden of road traffic crashes, injuries and deaths in Africa: A systematic review and meta-analysis. *Bulletin of the World Health Organization*, 94(7), 510–521A. https://doi.org/10.2471/BLT.15.163121

2. Australian Government, Bureau of Infrastructure and Transport Research Economics. (2021). *Road trauma Australia: 2021 statistical summary*. https://www.bitre.gov.au/publications/2021/statistical-summary

3. Carter, D. (2017). *Road safety fundamentals: Concepts, strategies, and practices that reduce fatalities and injuries on the road*. Federal Highway Administration, Office of Safety. https://rspcb.safety.fhwa.dot.gov/rsf/

4. Centers for Disease Control and Prevention (CDC). (2023). *Global road safety*. https://www.cdc.gov/injury/features/global-road-safety/index.html

5. GBD 2013 Mortality and Causes of Death Collaborators. (2015). Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: A systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*, 385(9963), 117–171. https://doi.org/10.1016/S0140-6736(14)61682-2

6. Gold, P. A. (1999). *Traffic safety: Using engineering to reduce accidents*. Inter-American Development Bank.

7. Gupta, M., Menon, G. R., Devkar, G., & Thomson, H. (2015). Regulatory and road engineering interventions for preventing road traffic injuries and fatalities among vulnerable (non-motorised and motorised two-wheel) road users in low- and middle-income countries. *Cochrane Database of Systematic Reviews*, 2015(1), 1–59. https://doi.org/10.1002/14651858.CD011495/full

8. Hadelin, V. (2014). *Development of a simple road safety audit procedure suitable for road condition in Rwanda* [Master's thesis, University of Rwanda]. Kigali, Rwanda.

9. JICA. (2023). *Transport improvement and safety strategies in Rwanda*. Kigali: Japan International Cooperation Agency.
10. Khayesi, M., & Peden, M. (2015). Neglect of road safety in development aid. *World Health Organization*.
11. Mbandi, A., et al. (2021). Mixed-traffic corridors in African cities. *Urban Transport and Road Safety Bulletin*, 10(3), 33–47.
12. Mutiso, J., et al. (2021). Impact of road safety campaigns in East Africa. *Regional Transport Policy Review*, 7(2), 21–30.
13. Ndagijimana, A. (2021). *Effect of speed governors on public transport safety in Rwanda* [Master's thesis, University of Rwanda].
14. Nkurunziza, A., & Tafahomi, R. (2020). Assessment of pedestrian mobility and safety in Kigali. *Journal of African Transport Planning*, 4(1), 42–56.
15. OECD. (2008). *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach*. International Transport Forum.
16. OECD. (2022). *Road Safety Annual Report 2022*. Paris: International Transport Forum. https://www.itf-oecd.org/
17. Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A. A., Jarawan, E., & Mathers, C. (Eds.). (2004). *World report on road traffic injury prevention*. World Health Organization.
18. Pembuain, A., Priyanto, S., & Suparma, L. B. (2019). The effect of road infrastructure on traffic accidents. *Advances in Engineering Research*, 186, 147–153. Atlantis Press.
19. Public Health Ontario. (2023). *Effectiveness of engineering interventions on road safety*. Ontario Agency for Health Protection and Promotion. https://www.publichealthontario.ca
20. Shakil, R., Akbar, M., Sayan, M., Mafijul, H., & Saifur, R. (2023). Global traffic deaths estimation and prediction. *International Journal of Road Safety Research*, 8(2), 101–110.
21. The New Times. (2023, March). RNP raises alarm as motorcycle, bicycle accidents soar. https://www.newtimes.co.rw/article/5891/news/rnp-raises-alarm-as-motorcycle-bicycle-accidents-soar
22. Tingvall, C., & Haworth, N. (1999). *Vision Zero: An ethical approach to safety and mobility*. Monash University Accident Research Centre.
23. UN-Habitat. (2021). *Urban transport and non-motorized transport planning in Africa*. Nairobi: United Nations Human Settlements Programme.
24. UNESCAP. (2022). *Road safety management and education in developing countries*. United Nations Economic and Social Commission for Asia-Pacific.

25. Verjus, H. (2014). *Development of a basic road safety audit procedure* [Master's thesis, University of Rwanda].
26. Welle, B., et al. (2020). *Road safety strategies in African cities: A synthesis report*. World Resources Institute.
27. WHO. (2022). *Vulnerable road user protection policies*. Geneva: World Health Organization.
28. World Bank. (2020). *Saving Lives Through Safe Roads: The Safe System Approach*. https://www.worldbank.org/
29. World Bank. (2023). *Road Safety Performance Review: Rwanda*. World Bank Group.
30. World Health Organization (WHO). (2023). *Global status report on road safety 2023*. Geneva: WHO. https://www.who.int/publications/i/item/9789240077615

APPENDICES

Appendix A: INTERVIEW GUIDE

Instructions:

- Attempt all questions from the questionnaire.
- Ready clearly the question and understand it before to answer.
- Please put a tick "√" mark for those answers that you think are right, and fill the gap (……..) by the precise and short answer.
- Your frank response is vital for the success of the study.
- This research is designed to collect information only for academic purpose.

SECTION A: RESPONDENT PROFILE

1. **Gender:**

a) Male

b) Female

2. Age:

a) Under 18

b) 18–30

c) 31–45

d) 46–60

e) Over 60

3. Main Mode of Transport on This Road:

a) Walking

b) Motorcycle

c) Private Car

d) Bus/Taxi

e) Bicycle

f) Truck

g) Other: _____

4. How frequently do you use this road corridor?

a) Daily

b) 2–3 times a week

c) Weekly

d) Rarely

5. Section mostly used:

a) CBD Roundabout–KN1–RN1

b) RN1–Giticyinyoni

c) Entire corridor

SECTION B: ROAD USE EXPERIENCE

6. Have you ever experienced or witnessed a crash along this corridor?

a) Yes

b) No

If yes, what type?

i) Pedestrian-involved

ii) Motorcycle crash

iii) Vehicle collision

iv) Truck rollover

v) Other: _____

7. At which location do crashes mostly occur? (Tick one or more)

a) Nyabugogo Intersection

b) Signalized intersection (CBD Roundabout)

c) Sharp curve near Giticyinyoni

d) Pedestrian crossings

e) Along RN1–Giticyinyoni stretch

8. In your opinion, what are the major causes of crashes on this road? (Tick all that apply)

a) Speeding

b) Poor enforcement

c) Lack of pedestrian lanes

d) No cycling infrastructure

e) Careless driving (motorcycles, bicycles)

f) Pedestrian violations

g) Poor signage

h) Sharp curve/superelevation

i) Other: _____

SECTION C: ROAD INFRASTRUCTURE PERCEPTION

9. How do you rate the following features along this corridor? (Please tick one box per feature)

Road Feature	a) Excellent	b) Good	c) Fair	d) Poor	e) Not Available
Road surface quality	☐	☐	☐	☐	☐
Pedestrian facilities	☐	☐	☐	☐	☐
Bicycle/cyclist lane	☐	☐	☐	☐	☐
Visibility at curve	☐	☐	☐	☐	☐
Road signage and markings	☐	☐	☐	☐	☐
Traffic signal function	☐	☐	☐	☐	☐
Street lighting (at night)	☐	☐	☐	☐	☐

SECTION D: MANAGEMENT AND ENFORCEMENT

10. How often do you observe police enforcing traffic laws on this corridor?

a) Always

b) Often

c) Rarely

d) Never

11. When traffic signals fail at the CBD Roundabout, do you think police management is effective?

a) Yes

b) Partially

c) No

d) Not sure

12. Do you think road safety awareness campaigns are adequate in this area?

a) Yes

b) No

c) Not aware

13. What management issues should be improved on this corridor? (Tick all that apply)

a) Traffic signal repair and maintenance

b) More police deployment

c) Public awareness campaigns

d) Better crash reporting systems

e) Installation of speed limiters or cameras

14. What engineering solutions would improve safety on this road?

……

……

……

15. What enforcement or management actions do you recommend?

……

……

……

……

Appendix B: OBSERVATIONAL CHECKLIST TEMPLATE

Category	Observation Item	Observed? (✓/✗)	Comments
1. Road Infrastructure	Presence of clear lane markings		
	Road surface condition (potholes, cracks)		
	Availability of pedestrian walkways/footpaths		
	Presence of drainage facilities		
	Adequate road signage (speed limits, warning signs)		
2. Traffic Calming Measures	Speed humps present		
	Roundabouts installed at intersections		

	Zebra crossings visible and respected		
	Chicanes or narrowing lanes for speed reduction		
3. Smart Infrastructure	Presence of functioning traffic signals		
	CCTV or surveillance installed		
	Intelligent Transport System (ITS) elements visible		
4. Pedestrian Safety	Pedestrian crossings adequately marked and located		
	Footbridges or underpasses available		
	Refuge islands present on wide roads		
	Pedestrians observed using designated crossing points		
5. Road User Behavior	Motorists stopping at pedestrian crossings		
	Motorcyclists wearing helmets		
	Drivers respecting speed limits		
	Instances of jaywalking observed		
6. Traffic Management	Presence of traffic police officers		
	Traffic control signs adhered to by drivers		
	Congestion level during observation (Low/Medium/High)		
	Accident-prone spots observed		
7. Time and Location Details	Date of observation		
	Time (Morning/Afternoon/Evening)		
	Location/Intersection name		

Appendix C: Data Collection Authorization Letter

Republic of Rwanda

City of Kigali

Ref. No 6704/07.01.16/25

Kigali, on..... 26 MAY 2025

Niyomugabo Jean Damascene
University of Rwanda
College of Science & Technology
Tell: 0788611485
Email: njdamas10@yahoo.fr

Dear Sir,

Re: Your request for data collection authorization

Reference is made to your letter dated 04th April 2025 requesting for permission to collect data from the City of Kigali, for performing your research on the topic entitled **"Utilization of engineering and management strategies to minimize traffic facilities and several injuries on asphalt in Rwanda", a case of the City of Kigali;**

We would like to inform you that your request is hereby granted. However, before starting your research, you are kindly requested to introduce you to the **City Engineering** and clarifying your research needs.

Sincerely,

for

Restituta MUKANTAGANZWA
Director of HR & Administration

UMUJYI WA KIGALI

Gerard ABIYINGOMA
Director General of Corporate Services

Cc:

- **City Manager, City of Kigali**
- **City Engineer/ City of Kigali**

KIGALI