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‘’ANALYSIS OF GEOMETRIC DESIGN FACTORS INFLUENCING DRIVER BEHAVIOUR AND ROAD SAFETY: A CASE STUDY OF RWANDA’’

A DISSERTATION

Submitted by

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DECLARATION

I hereby declare that the dissertation entitled **“ANALYSIS OF GEOMETRIC DESIGN FACTORS INFLUENCING DRIVER BEHAVIOUR AND ROAD SAFETY: A CASE STUDY OF RWANDA’’**submitted for the Degree of Master of Science is my original work and the dissertation 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.

Place: Kigali City, Rwanda **Signature:**

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CERTIFICATION

This research thesis has been submitted with approval from the University supervisor (Main supervisor).

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ABSTRACT

This study investigates the influence of geometric design parameters on driver behavior and road safety along the national road linking Kigali to the Western Province known as the **Kigali–Rubavu road (NR2)** which is classified as a **Class II Road** according to the RTDA Road Geometric Design Manual (2014). A total of 40 road segments (20 curved and 20 straight) were assessed through a combination of geometric compliance analysis, statistical modeling, and user perception surveys to understand how design features affect safety outcomes.

The study was guided by the following objectives: (1) to assess the compliance of road geometric elements with RTDA and AASHTO standards; (2) to determine and quantify the impact of geometric parameters such as curve radius, gradient, shoulder width, and lane width on accident frequency using statistical models; (3) to investigate how these design features influence driver behavior and comfort, particularly regarding perceived risk and speed management; and (4) to evaluate the role of geometry in the frequency and severity of accidents on Rwandan national roads.

Geometric assessment revealed widespread non-compliance, especially among curved segments, where substandard curve radii, excessive Superelevation, steep gradients, and limited visibility were prevalent. Notably, the posted speed limits of 60–80 km/h along NR2 exactly match the design speed range recommended for this terrain classification, providing no additional safety buffer. Field observations confirmed that many drivers exceeded these limits shortly after posted signs particularly in the areas without Speed Camera Stations indicating issues with compliance and enforcement.

Quantitative analysis using SPSS showed that a multiple linear regression model explained 93.8% of the variation in accident frequency, with **driver comfort**, **lane width**, and **shoulder width** emerging as significant predictors. Poisson regression analysis confirmed the influence of geometric factors, though with marginal statistical significance. Surveys of 100 drivers and 45 road design engineers further emphasized that **sharp curves**, **steep slopes**, and **visibility limitations** are critical safety concerns. Engineers also reported that accident data and sight distance considerations are often overlooked in practice.

The findings indicate that several segments along NR2 are poorly designed and fall short of compliance, contributing to elevated crash risk. The study recommends enhancing geometric design enforcement, adjusting posted speed limits to include a safety margin, incorporating perception and crash data into the design process, and addressing geometric deficiencies particularly in curved and mountainous terrain to improve road safety in Rwanda.

Furthermore, the study provides a foundation for future research to extend the analysis to other major highways across Rwanda, enabling comparative insights and broader policy implications.

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LIST OF SYMBOLS AND ABBREVIATIONS

- **AASHTO** – American Association of State Highway and Transportation Officials
- **RTDA** – Rwanda Transport Development Agency
- **SPSS** – Statistical Package for the Social Sciences
- **AIC** – Akaike Information Criterion
- **R^2** – Coefficient of Determination, used to indicate the goodness of fit in regression models
- **p-value** – Probability value used to determine statistical significance
- **χ^2 (Chi-square)** – Statistical measure used in the Omnibus test to evaluate model fit
- **Exp(B)** – Exponentiated regression coefficient, representing the rate ratio in Poisson and Negative Binomial models
- **B** – Regression coefficient indicating the strength and direction of predictor influence
- **GLM** – Generalized Linear Model, used for count data analysis like Poisson regression
- **df** – Degrees of Freedom, used in statistical tests and model evaluation
- **m** – Meter, used as a unit of measurement for lengths and distances
- **%** – Percent, used to express gradients, superelevation, and proportions
- **OECD/ITF** – Organization for Economic Co-operation and Development / International Transport Forum
- **IRC** – Indian Roads Congress
- **TRB** – Transportation Research Board
- **VR** – Virtual Reality

1. CHAPTER1: GENERAL INTRODUCTION

1.1. Background

Road safety remains a critical global concern, particularly in developing countries like Rwanda, where rapid urbanization, increasing motorization, and inadequate road infrastructure have contributed to a rising number of traffic accidents. The geometric design of roadways—encompassing elements such as alignment, cross-sectional features, shoulder width, intersection layout, and signage—plays a significant role in influencing driver behaviour and, consequently, traffic safety outcomes.

Globally, road crashes claim **1.19 million lives annually**, making them the leading cause of death among youth aged 5–29 and the 12th leading cause across all ages [1]

At the policy level, Rwanda has aligned itself with the **United Nations Decade of Action for Road Safety (2021–2030)**, which aims to reduce road traffic deaths and injuries by 50%. Nationally, the **Rwanda National Road Safety Policy (2015)** and subsequent strategies developed by the **Rwanda Transport Development Agency (RTDA)** and the **Rwanda National Police (RNP)** emphasize safe road infrastructure, enforcement of traffic regulations, and public awareness campaigns as key pillars for improving safety [2]. The **RTDA Road Geometric Design Manual (2014)** also sets standards for road design to ensure consistency, safety, and efficiency, yet compliance in practice often varies due to topographic, financial, and institutional constraints.

Policymaking reflects these challenges: Rwanda is implementing targeted safety strategies under the **UN Decade of Action (2021–2030)** and **SDG 3.6**. Interventions include addressing **298 critical black spots**, installing improved signage and crash barriers, and investing **Rwf 102 billion** in safer roadway infrastructure and dedicated non-motorized paths [3]

Despite these initiatives, the number of traffic crashes in Rwanda remains high, particularly along major highways such as the Kigali–Rubavu road (NR2), highlighting a gap between policy intentions and practical outcomes. Many accidents are linked to roadway geometric deficiencies, limited consideration of driver behaviour in design, and challenges in applying international standards to Rwanda's local context.

This study aims to investigate the impact of geometric road design on driver behaviour and road safety in Rwanda. By examining localized conditions against both international road safety targets and Rwanda's national policies, the research seeks to provide context-specific insights into how design features can be optimized to reduce traffic accidents and improve overall road safety in the country.

1.2. Problem Statement

Despite continued national efforts to improve road safety in Rwanda, traffic accidents remain a leading cause of injuries and fatalities. While many initiatives have focused on driver education, enforcement, and vehicle condition, the impact of geometric road design on driver behavior and accident occurrence has received comparatively little attention.

In several rural and hilly regions of Rwanda, roads are constructed with substandard or inconsistent geometric features such as sharp horizontal curves, inadequate sight distances, narrow lanes, and steep gradients. These features can compromise driver visibility and reaction time, especially in challenging terrain or poor weather conditions.

For instance, the Kigali–Rubavu road has been the site of multiple fatal crashes in curved sections, particularly during rainy seasons where reduced visibility and slippery surfaces interact dangerously with road geometry. In February 2025, a bus overturned on a sharp bend near KIRENGE **Center**, resulting in 20 fatalities and 32 injuries [4].

Photo 1: Accident site at Rulindo district Rusiga sector.

Although Rwanda's road network is expanding, many existing roads do not consistently follow international geometric design standards such as those outlined in AASHTO. Without sufficient evidence-based guidelines tailored to the Rwandan context, unsafe design features may continue to contribute to avoidable road traffic crashes.

This study aims to examine how specific geometric design elements—such as curvature, lane width, and gradient—influence driver behavior and crash risk. The findings will support safer road design practices that align with both local context and international safety principles.

1.3. Justification for Topic Selection

Existing research on road safety in Rwanda has primarily emphasized enforcement, driver behavior, and vehicle conditions, with limited attention to the role of geometric design standards in accident causation. The few existing local studies, such as the one by Nkurunziza [5], focused mainly on Kigali City, leaving national trunk roads underexplored. By analyzing compliance with RTDA (2014) and AASHTO standards, and statistically quantifying the influence of geometric parameters such as curve radius, gradient, lane width, and shoulder width on accident occurrence, this study fills a critical gap in local literature. The findings will provide evidence-based recommendations to improve road safety through design interventions, thereby contributing to national road safety strategies and regional transport policy.

1.4. Research Objectives

The primary objective of this study is to assess how geometric road design elements influence driver behavior and road safety in Rwanda. Specifically, the study seeks to:

- Assess the compliance of road geometric design elements with national and international design standards (RTDA and AASHTO).
- To determine and quantify the relative impact of geometric design elements such as curve radius, gradient, shoulder width, and lane width on accident frequency, using statistical modeling techniques.
- Investigate the influence of geometric design elements on driver behavior and comfort, particularly in terms of perceived risk, speeding, and maneuvering challenges
- Evaluate the impact of road geometry on the frequency and severity of traffic accidents across different regions of Rwanda.

1.5. Research Questions, Tasks, Associated Outcome

Research Question 1

How compliant are the geometric road design elements along the Kigali–Rubavu road (NR2) with national (RTDA) and international (AASHTO) standards?

Task 1.1: Review of RTDA and AASHTO standards relevant to road class and terrain
Task 1.2: Geometric compliance assessment of selected road based on field-collected data

Expected Outcomes (New Knowledge):

- Baseline assessment of compliance gaps in road geometric design parameters (e.g., curve radius, lane width, gradient, sight distance)
- Identification of critical non-compliant segments that contribute to accident risk, especially in curved and hilly sections

Research Question 2

How do geometric design elements such as curve radius, lane width, shoulder width, and gradient influence driver behavior and perceived safety on NR2?

Task 2.1: Statistical modeling using SPSS (linear regression, Poisson regression) to quantify effects of geometric parameters on accident frequency
Task 2.2: Conduct driver perception surveys and field observations, especially in critical areas (e.g. Hairpin bends), to assess behavioral responses to geometry

Expected Outcomes (New Knowledge):

- Quantify relationships between geometric elements and driver behavior (e.g., overspeeding, risky maneuvers)
- Enhanced understanding of how comfort level and risk perception are influenced by geometry, especially in curved, steep, or visually restricted areas

Research Question 3

How do road geometry and driver comfort correlate with accident frequency and severity on the Kigali–Rubavu road (NR2)?

Task 3.1: Define and measure key geometric parameters and classify segment types
Task 3.2: Compile accident records and classify by type, location, and severity
Task 3.3: Analyze correlation between geometric features, driver comfort scores, and accident data using regression models

Expected Outcomes (New Knowledge):

- Statistical evidence on how curve radius, lane width, and visibility influence accident occurrence
- A localized model linking accident frequency with geometric design and driver feedback
- Insight into design risk zones along NR2 requiring urgent redesign or enforcement measures

Research Question 4

What geometric design improvements and policy interventions can be proposed to enhance road safety and driving behavior on hilly terrain roads in Rwanda?

Task 4.1: Synthesize results from compliance analysis, statistical modeling, and perception surveys
Task 4.2: Develop safety-focused design improvement recommendations and enforcement strategies (e.g., reduced speed limits, signage, visibility enhancements)

Expected Outcomes (New Knowledge):

- Clear guidance on priority design improvements for roads in rolling/mountainous terrain (e.g., NR2)
- Policy recommendations for setting posted speeds below design speeds to restore safety margins

1.6 Research Scope

This study focuses on the Kigali–Rubavu Road (NR2) as a case study to analyze the relationship between geometric design elements, driver behavior, and road safety in Rwanda. The Kigali–Rubavu Road is a major inter-urban corridor with high traffic volumes, including passenger vehicles, commercial trucks, and motorcycles. The road is a two-lane undivided highway without a median, making it susceptible to head-on collisions and risky overtaking maneuvers.

The research specifically targets selected segments of the road that are known for frequent traffic accidents. These segments were identified based on historical accident data and selected for their distinct geometric elements, such as sharp horizontal curves, steep gradients, and limited sight distances. In addition to geometric characteristics, consideration was also given to traffic exposure levels, such as segments with high pedestrian activity or vehicle flow, which further contribute to road safety challenges.

The scope of this study includes:

- Analysis of road geometry parameters (e.g., curve radius, lane width, shoulder width, and gradient).
- Assessment of accident frequency and severity in relation to geometric elements.
- Evaluation of observed or inferred driver behavior (e.g., speeding, lane departure, overtaking) in relation to road design.
- Identification of geometric design deficiencies that may increase crash risk.

The study is limited to the rural and peri-urban segments of the Kigali–Rubavu Road, excluding fully urban areas and intersections with complex traffic control systems. The findings aim to provide insights into how road geometry influences safety outcomes and to inform design improvements, policy decisions, and targeted interventions for road safety enhancement in Rwanda.

1.7 Organization of the Thesis

Chapter one of the thesis establishes the background, problem statement, site selection and description, research motivation, list of objectives along with research question and associated expected outcomes, scope, and the thesis organization.

Chapter two of this thesis presents a comprehensive review of existing literature related to road geometric design and its influence on driver behavior and road safety outcomes. The review is structured to cover the following key areas: definitions and classifications of **road geometry parameters**, the **design standards and practices** used in geometric road design, the relationship between **road conditions and driver characteristics**, and the **impact of geometric design on traffic accidents**.

The chapter begins by defining fundamental road geometry elements such as **horizontal alignment (curves), vertical alignment (gradients), lane and shoulder width, sight distance, and cross-sectional elements**, followed by an overview of international and regional (including Rwandan) design standards used in planning and constructing such features.

Next, the literature explores how **road conditions** (e.g., pavement quality, signage, lighting, and visibility) and **driver characteristics** (e.g., perception-reaction time, driving behavior, compliance with traffic rules, and experience level) interact with geometric design to influence driving safety and behavior. Particular emphasis is placed on how these factors affect driver decisions in challenging segments such as **sharp curves, steep slopes, and narrow lanes**—conditions relevant to the Kigali–Rubavu Road.

The chapter further reviews empirical studies and statistical models used globally and regionally to analyze the correlation between **geometric design elements and accident frequency/severity**. It examines both qualitative and quantitative approaches to understanding accident causation, including **crash prediction models, behavioral studies, and safety audits**.

Finally, the literature review identifies significant **research gaps**, particularly the **limited availability of localized studies** in Rwanda that integrate geometric design, driver behavior, and accident analysis. Most existing research focuses on either infrastructure design or accident reporting separately, without a holistic approach to understanding how road geometry influences driver actions and crash outcomes. This highlights the need for context-specific studies such as the current one, which aims to fill this gap by focusing on accident-prone segments of the Kigali–Rubavu Road.

Chapter three of the thesis explains the methodology followed in the present study.

Chapter four presents the core analysis of the data collected from selected segments of the Kigali–Rubavu Road. The chapter begins by providing an overview of **Road conditions**, including lane size, number of lanes, shoulders width, curve length, radius of the curve, road barriers, average travel speeds under varying geometric and environmental conditions.

This is followed by a detailed **examination of the relationships between road geometry parameters and traffic behavior**, particularly focusing on how elements such as **curve radius, gradient, lane width, and shoulder design** influence **speed choice, and accident occurrences**.

The developed relationships and findings are then subjected to **validation and sensitivity analysis** to test the robustness of the models and identify the **elasticity of key parameters**—i.e., how changes in road geometry impact speed, safety outcomes, and driver behavior. These analyses provide valuable insights into the magnitude of influence that each geometric element exerts on traffic safety and operational efficiency.

The **chapter five** of the thesis summarizes the key findings of the study and presents practical conclusions drawn from the analysis. The chapter highlights the most critical geometric design elements that influence driver behavior and road safety on the Kigali–Rubavu Road. These include elements such as sharp horizontal curves, insufficient lane and shoulder widths, steep gradients, and limited sight distances, all of which were found to significantly contribute to risky driving behavior and higher accident rates.

Based on these findings, the chapter proposes a set of recommendations for improving road design and traffic safety. These include:

- Redesigning high-risk segments to improve geometric consistency,
- Enhancing road markings and signage,

- Implementing speed control measures on sharp curves and steep grades, and
- Prioritizing maintenance on deteriorated road sections.

Finally, the chapter outlines the scope for further research, emphasizing the need for more comprehensive data on driver behavior, real-time speed monitoring, and longitudinal crash data. It also recommends expanding similar studies to other national roads in Rwanda to support evidence-based road design and traffic safety policy formulation.

2. CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction

Geometric road design plays a critical role in shaping driver behavior and ensuring road safety. In Rwanda, where the terrain is hilly and rapid urbanization is placing pressure on road infrastructure, poorly designed roads are contributing to a high number of traffic incidents, especially involving vulnerable users such as pedestrians and motorcyclists. This literature review explores global and localized studies on how geometric design specifically road alignment, curve radius, lane and shoulder width, and signage affect driver behavior and road safety outcomes. The review also investigates pedestrian safety, particularly at crosswalks, and provides insights into data-driven and perceptual approaches to improving road safety.

2.2Key Definitions

a. Design Speed

Design speed is defined as the highest continuous speed at which individual vehicles can travel safely on a highway when weather conditions are favorable [1].

Importance: Influences most other geometric design elements like horizontal and vertical curves, sight distance, and lane width [6].

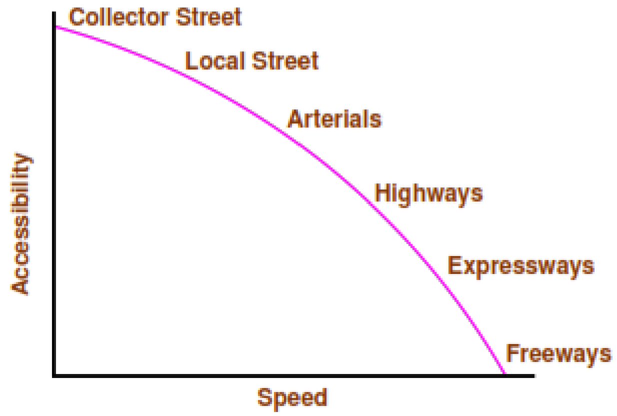


Figure 2-1.Speed vs accessibility.

b. Sight Distance

Sight distance refers to the length of road surface visible to a driver from a specific eye height above the carriageway, allowing them to perceive and respond to potential hazards in time. It plays a critical role in ensuring road safety and is a fundamental parameter in geometric road design. According to Mathew and Rao (2007), there are several key types of sight distance considered during design: Stopping Sight Distance (SSD), which is the minimum required to bring a vehicle to a complete stop safely; Intermediate Sight Distance (ISD), defined as twice the SSD; Overtaking Sight Distance (OSD), which allows for safe overtaking maneuvers; Headlight Sight Distance, relevant for night driving under the illumination of vehicle headlights; and the Safe Sight Distance at intersections, which ensures vehicles can safely enter or cross intersecting roads. Proper consideration of these sight distances is essential to minimize the risk of collisions and support smooth traffic flow [1].

c.Geometric Design

Geometric design involves the dimensioning and layout of various highway elements, including horizontal and vertical curves, cross-sections, truck climbing lanes, bicycle paths, and parking facilities, to ensure safe and efficient road operation [2].

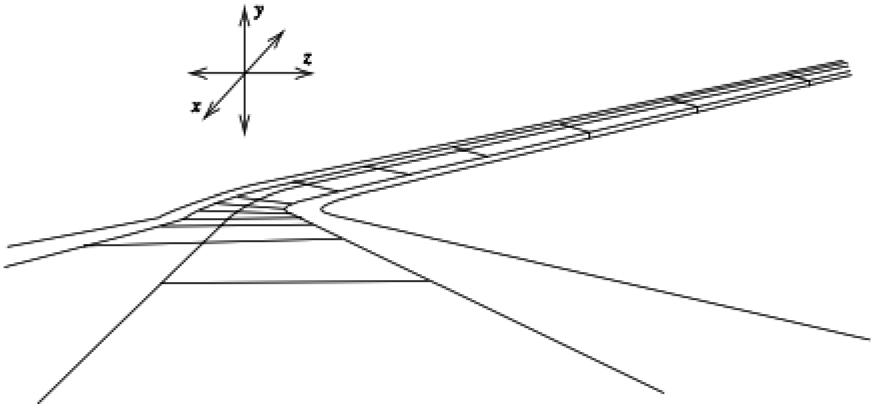


Figure 2-2. Highway alignment in three dimensions. [3]

d. Horizontal Alignment

The horizontal alignment of a roadway consists of straight segments, known as tangents, which are connected by curves designed to ensure a smooth and safe flow of traffic. These curves are typically circular in nature, with radii selected to accommodate comfortable vehicle movement and adequate sight distance [2].

e. Vertical Alignment

The vertical alignment of a highway comprises straight segments, called grades or tangents, which are connected by vertical curves. Designing this alignment involves selecting appropriate grades for the tangents and determining the suitable lengths for the vertical curves. The area's topography significantly influences these design decisions, as it affects both the feasibility and safety of the road layout [2].

f. Cross-Section Elements

Key components of a roadway cross-section are designed to enhance safety, capacity, and functionality. Lane widths typically range between 3.0 to 3.75 meters, depending on the type and classification of the road. Shoulders are provided to offer lateral support to the pavement structure and serve as emergency space for stopped vehicles. Medians are used to separate opposing traffic streams, thereby reducing head-on collision risks, while side slopes refer to the inclined surfaces adjacent to the roadway, contributing to stability and drainage management [3].

g. Roadway Width

The roadway width encompasses the entire cross-sectional width of the road, including all traffic lanes, shoulders, and medians where applicable [3].

h. Super elevation Design

Super elevation is the transverse slope provided on horizontal curves to help counteract the lateral acceleration experienced by vehicles. For high-speed vehicles, it is safer to design superelevation assuming that the centrifugal force is entirely balanced by the component of the vehicle's weight acting due to the roadway's tilt—i.e., without relying on the coefficient of lateral friction. Conversely, for low-speed vehicles, a lower degree of super elevation may be adopted by considering the combined effect of super elevation and the lateral friction between the tires and the pavement surface [1].

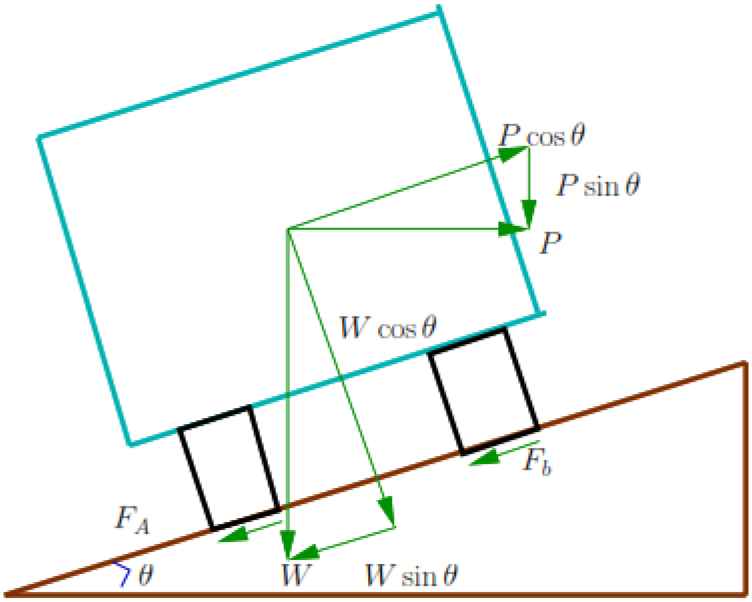


Figure 2-3 Analysis of super-elevation [1]

Where:

P the centrifugal force acting horizontally out-wards through the center of gravity,

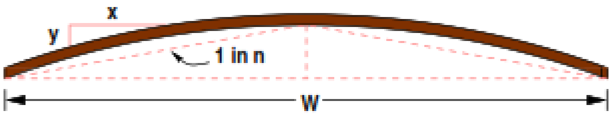
W the weight of the vehicle acting down-wards through the center of gravity, and

F the friction force between the wheels and the pavement, along the surface inward.

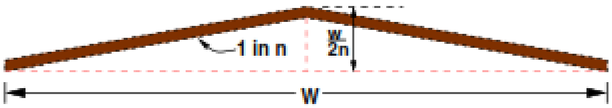
ø is the transverse slope due to Superelevation.

i. camber

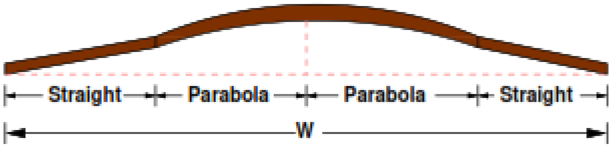
Camber, also known as cant, is the cross slope provided on a road surface to elevate the center relative to the edges, facilitating effective drainage of rainwater from the pavement. This design feature serves multiple purposes: it protects the road surface—especially in gravel and bituminous pavements—by preventing water accumulation; it safeguards the sub-grade by ensuring proper drainage; and it promotes quick drying of the surface, thereby enhancing vehicle safety by reducing the risk of skidding [1].



a. Parabolic camber $y=2x^2/nw$



b. Straight line camber



c. Combination of straight and parabolic camber

Figure 2-4 Different types of camber [1]

j. Clearance

Vertical clearance refers to the minimum height available between the road surface and overhead structures such as bridges, signboards, or tunnels, ensuring that vehicles of legal height can pass safely beneath them. Lateral clearance, on the other hand, is the distance between the edge of the traveled way and any fixed roadside object, allowing sufficient space for vehicle maneuvering and enhancing overall roadside safety [3].

k. Turning Radius and Turning Path

The turning radius and turning path of a vehicle are critical considerations in geometric road design, especially at intersections, roundabouts, terminals, and parking facilities. The minimum turning radius required for a safe maneuver is primarily influenced by the design and classification of the vehicle. During turning, the effective width of the vehicle increases due to the swept path, which must be accounted for to prevent encroachment into adjacent lanes. Adequate turning radii ensure that vehicles can negotiate curves and corners without compromising safety or operational efficiency [1].

l. Drainage and Slopes

Effective drainage is essential in pavement design to ensure durability and safety. The pavement surface must be fully impermeable to prevent water infiltration into the underlying layers, which could weaken the structural integrity of the road. Additionally, the surface geometry and texture should be designed to facilitate rapid removal of water, thereby minimizing the risk of hydroplaning and surface damage [1].

2.3. Road Geometric Design and Driver Behavior

2.3.1. Geometric Design and Driver Behavior

Research has consistently shown that the geometric design of roads plays a vital role in influencing driver perception, decision-making, and overall behavior.

For instance, horizontal and vertical curves that are too sharp or inconsistent can obstruct visibility and limit the driver's ability to respond safely, increasing the risk of accidents [4].

In Rwanda, the terrain is predominantly mountainous, presenting significant challenges for highway design and traffic safety. The Kigali–Rubavu Road corridor, a key national route, includes numerous segments with sharp curves, variable gradients, and constrained right-of-way conditions. While past efforts have focused on improving pavement quality and signage, less attention has been paid to the interaction between geometric features and actual driver behavior under real-world conditions. Moreover, engineering designs often fail to integrate crash data or driver perceptions, which are essential for human-centered and context-sensitive road safety interventions [5].

The Researchers conducted a systematic review of simulator-based experiments and confirmed that geometric features—especially horizontal curves—impact driver performance by altering lateral acceleration, lane deviation, and speed profiles. Their study supports the use of driving simulators as a valuable tool in road safety assessment, especially for understanding the behavioral implications of design alternatives [6].

Geometric road design has a direct influence on driver perception, decision-making, and operational behavior. Sharp horizontal and vertical curves, particularly those with insufficient radii or poor transition design, reduce sight distances and impair driver reaction time, increasing the likelihood of crashes [9].

Geometric designs that fail to meet drivers' cognitive expectations have been linked to unsafe behaviors. The research emphasized that roads must accommodate driver mental models to reduce errors. In LMICs, the consequences of poor geometric consistency are amplified due to limited enforcement, vehicle variability, and constrained road environments [7].

An assessment of road geometry and route alignment along the Mettu-Gore Road in Ethiopia revealed that geometric elements such as curve radius, superelevation, gradient, and sight distance have a significant impact on accident occurrence. By comparing the actual road features with national geometric design standards, the study identified locations where geometric inconsistencies overlapped with accident hotspots, underscoring the role of poor alignment in increasing crash risk [8].

The Highway Safety Manual (HSM) predictive approach, implemented through IHSDM software, was used to evaluate geometrically hazardous rural road segments in Ethiopia. The evaluation showed that engineering interventions on identified hazardous locations led to notable safety improvements, including a 58.94% reduction in crash rate. The study further highlighted the value of performance-based safety assessments and the application of Safety Performance Functions (SPFs) in advancing sustainable transportation planning [8].

A more advanced predictive modelling approach using the Interactive Highway Safety Design Model (IHSDM), aligned with the U.S. Highway Safety Manual (HSM), was employed to assess hazardous segments on rural Ethiopian roads and evaluate the safety impact of geometric design modifications. The findings demonstrated that implementing engineering adjustments on high-risk segments led to a 17.18% reduction in crash frequency and a 58.94% reduction in crash rate. The study emphasized the importance of locally calibrated Safety Performance Functions (SPFs) and advocated for the use of proactive, data-driven tools for road safety assessment in low-income settings [9]

Recent literature has highlighted the need for locally grounded studies that incorporate user perception into design evaluation. In Ethiopia, applied negative binomial regression and found that sharp curve radii, narrow shoulders, and short transitions were statistically significant predictors of crashes. Researchers conducted a study on the Mettu-Gore Road in Ethiopia, where they examined the impact of geometric design and route selection on road safety. Their research emphasized that design elements such as curve radius, superelevation, gradient, and sight distance were significant contributors to accident risk, particularly in identified hotspot zones. These findings support the argument that inadequate geometric design increases the likelihood of accidents; a pattern also observed in the present study [8].

In Rwanda, geometric constraints along hilly corridors such as the Kigali–Rubavu road have prompted concern. However, existing road designs often neglect to incorporate driver feedback or historical accident data [10]. This gap reveals a systemic failure to adapt design practices to user-centered and data-driven standards.

2.3.2. Horizontal and Vertical Alignment

2.3.2.1. Introduction

Research has recently shown that horizontal curves are among the most dangerous road segments. FHWA found that accident rates on curves were significantly higher than on straight segments, particularly in rural areas. Sharp curves reduce visibility and increase the cognitive demands placed on drivers [11]. This is supported by research which reported that crash rates per mile increase on curves, especially with higher traffic volumes. Vertical alignment, when improperly designed, also reduces sight distance and can result in rear-end collisions or loss of vehicle control [12].

In Rwanda, many urban and rural roads are characterized by sharp horizontal curves and abrupt changes in elevation. A study done in Kigali revealed that nearly half of the evaluated curves did not meet superelevation standards, with an average design error of 5%, leading to increased skidding and crashes [13].

2.3.2.2. Lane Width and Shoulder Design

Recent research has reinforced the connection between lane width and crash risk. While Harwood et al. [14] highlighted the dangers posed by lanes narrower than 3.0 meters, recent empirical evidence suggests that wider lanes may also increase crash risk in urban contexts. A comprehensive study by Azin *et al.* [15], based on 320 urban arterial segments in Utah, found that **each additional foot (~0.3 m) of lane width was associated with a 38.3% increase in**

the odds of an injury crash. Additionally, the study showed that wider lanes led to higher operating speeds, with the 85th and 95th percentile speeds increasing by 1.012 mph and 1.088 mph, respectively, for each extra foot of width. These findings support the adoption of **narrower lanes (10–11 ft)** in dense urban areas to improve safety and encourage multimodal transportation.

In Kigali, narrow lanes combined with the absence of road shoulders contribute to unsafe conditions for both drivers and non-motorized users. The lack of shoulders especially affects pedestrian and cyclist safety, as they are forced to share the road with high-speed traffic.

2.3.2.3 Intersection Design and Road Signage

Intersections are frequent points of conflict in road systems, and their design has a direct impact on crash risk. While previous studies such as Hummer *et al.* [16] emphasized that inadequate sight distances and lack of traffic control devices contribute significantly to crashes, recent research by Wang *et al.* [17] offers more localized evidence from Rwanda. Their study identified 25 road traffic crash hotspots in Kigali through spatial analysis and found that locations with poor built environment features such as degraded surfaces, high motor vehicle density, and inconsistent traffic control were significantly associated with higher crash risks. Notably, although many high-risk intersections included pedestrian safety infrastructure, the **dominant contributing factor appeared to be excessive vehicle speed**, especially in areas with insufficient traffic calming measures. These findings highlight a persistent challenge in secondary towns across Rwanda, where **unmarked or poorly signalized intersections** lead to aggressive and unpredictable driver behavior, increasing the likelihood of **side-impact and turning collisions**. Improved intersection design, better enforcement, and built-environment interventions are essential to mitigate these risks.

2.3.2.4 Superelevation and Visual Geometry

Superelevation, the transverse slope provided on curved segments of a roadway, is a critical geometric feature intended to counteract lateral acceleration and improve vehicle stability. When inadequately designed or constructed, superelevation can significantly increase the risk of vehicles skidding or overturning particularly on sharp curves with small radii.

A field study conducted on KN 123 Street in Kigali showed that superelevation values were frequently inconsistent with design expectations. The comparison between calculated values (based on AASHTO 2011 guidelines and actual measurements revealed an average variance of approximately 5% across several segments [5]. While the maximum permissible superelevation for urban collector roads is 6%, many segments failed to comply with this threshold, exposing drivers to hazardous conditions—especially during high-speed curve negotiation.

He et al. [18], introduced the use of Alignment Perspective Skewness (APS) and Kurtosis (APK) to model how drivers visually perceive alignment changes. Using image-based analysis, the study demonstrated that perceptual alignment can be more predictive of crash risk than traditional geometric parameters. This is particularly relevant to Rwanda, where roads are often constructed through visually complex environments such as hilly and curved landscapes.

2.3.2.5. Principle of Highway Alignment

Highway alignment is inherently a three-dimensional task involving spatial coordinates (x, y, and z), which together define the road's precise location within the terrain. From the standpoint of both engineers and road users, this alignment represents the actual path a roadway follows through a given topography (AASHTO, 2018). [9]

Because working directly in three dimensions is often technically demanding and computationally intensive, traditional highway design simplifies the problem by separating it into two two-dimensional components: horizontal alignment and vertical alignment (Kadiyali, 2016) [19]. The horizontal alignment typically shown in a plan view describes the roadway's path across the ground surface, including its curves and directional shifts, usually corresponding to the x and z axes (IRC: 73-1980). On the other hand, the vertical alignment, illustrated in the profile view, represents elevation changes along the road's length, corresponding to the y-axis, and includes features like grades and vertical curves (Khanna & Justo, 2017) [20].

When both horizontal and vertical alignments are designed and combined properly, they provide a comprehensive representation of the road's geometry. This method allows designers to accurately determine the position of any point on the highway without resorting to full-scale

3D modeling, while still maintaining geometric accuracy suitable for construction (AASHTO,2018) [4].

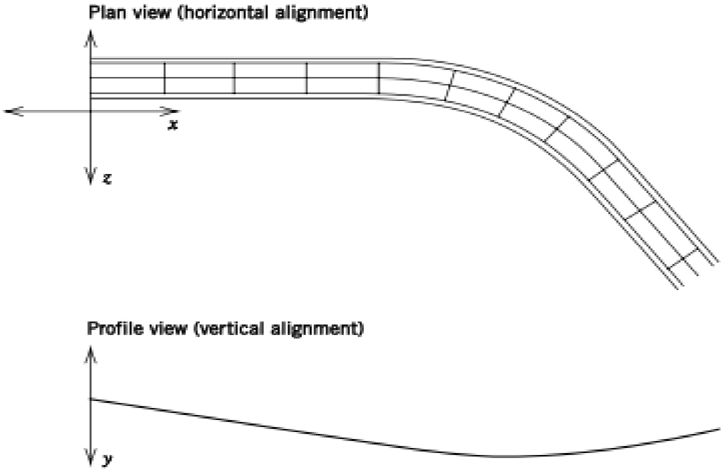


Figure 2-5. ***Highway alignment in two-dimensional views.*** *[21]*

2.3.2.6. Vertical Alignment

2.3.2.6.1. Definition of Vertical Alignment

Vertical alignment describes the elevation profile of a roadway along its length and is critical in ensuring driver safety, comfort, and effective surface drainage. Poor vertical alignment can impair stopping and passing sight distances and increase crash risk on steep grades. It also affects surface runoff, where improper grading may lead to water accumulation, hydroplaning, and long-term pavement deterioration. A study conducted in Kigali found that approximately 10% of vertical curves exceeded the AASHTO-recommended maximum grade of 11%, with some slopes reaching up to 22%, posing significant safety hazards—especially in areas where sharp horizontal curves followed steep ascents or descents [5].

Vertical alignment describes the elevation profile of a roadway along its length and is essential for ensuring driver safety, comfort, and proper drainage. It plays a key role in managing surface runoff and preventing water accumulation on roadways, which can lead to hydroplaning and pavement damage. Inadequate vertical alignment especially at crest curves can significantly reduce stopping sight distance and increase crash risks, particularly when combined with horizontal curvature. This underscores the need for continuous three-dimensional evaluation to ensure safe geometric transitions on roadways [22].

In standard highway engineering practice, vertical curves are commonly designed as equal-tangent curves, where the Point of Vertical Intersection (PVI) lies at the center, and the curve extends equally in both directions (L/2 before and after the PVI). This layout simplifies construction and ensures uniform sight distance and drainage behavior [2]

It is important to note that, in practice, **profile views** such as those shown in Figure 2.2 represent all roadway points, even when **horizontal and vertical curves** occur simultaneously

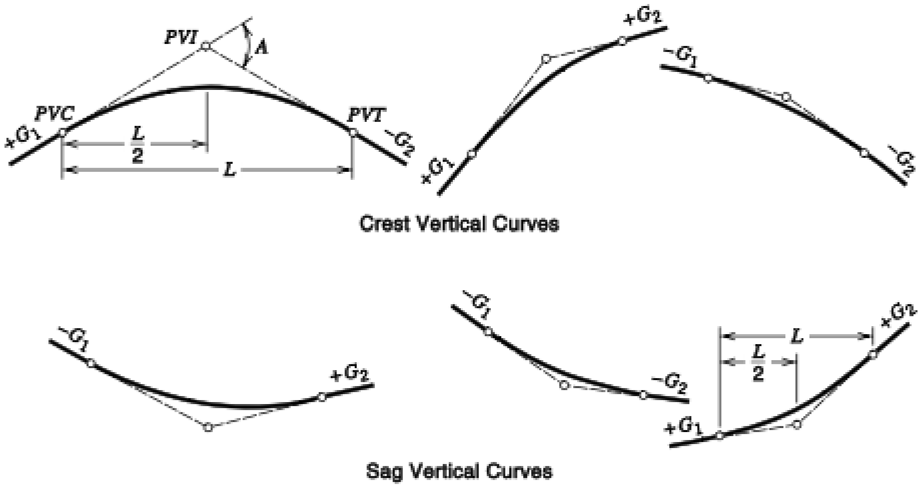


Figure 2-6. ***Types of vertical curves****. [21]*

2.3.2.6.2. Vertical Curve Fundamentals

In the design of vertical alignment, when two roadway grades (tangents) need to be connected, a mathematical function is required to define the elevation of all points—or stations—along the curve. A **parabolic curve** is typically used for this purpose due to its beneficial properties. Most importantly, it ensures a **uniform rate of change in slope**, which contributes to driving comfort and safety. Additionally, it facilitates the use of **equal tangent lengths**, simplifying both design and construction.

where *Y* represents the elevation at a particular station *x*, and *a*, *b*, and *c* are constants determined by the curve's geometry and design constraints. This equation effectively models the vertical profile of a road between two gradients in a smooth and continuous manner [23].

The general equation for a vertical parabolic curve is expressed as:

$$Y=ax^2+bx+c \tag{2.1}$$

where

y = roadway elevation at distance x from the beginning of the vertical curve (the PVC) in stations or ft,

x = distance from the beginning of the vertical curve in stations or ft, a, b = coefficients defined below, and

c = elevation of the PVC (because x = 0 corresponds to the PVC) in ft.

In defining a and b, note that the first derivative of Eq1 gives the slope and is

$$dy/dx=2ax+b \tag{2.2}$$

At the PVC, x = 0, so, using Eq (1. 1),

$$B=dy/dx=G1 \tag{2.3}$$

where G1 is the initial slope in ft/ft, as defined in Figure 2-6. Also note that the second derivative of Eq. (1.2) is the rate of change of slope and is

$$d^2y/dx^2=2a \tag{2.4}$$

However, the average rate of change of slope, by observation of Figure 2-6, can also be written as

$$d^2y/dx^2= \frac{G2-G1}{L} \tag{2.5}$$

Equating Eqs. 4 and 5 gives

$$a= \frac{G2-G1}{2L}(2.6) \tag{2.6}$$

2.3.2.6.3. Stopping Sight Distance

Designing vertical curves often involves substantial construction costs due to the need for extensive earthworks such as cutting and filling of terrain. Consequently, one of the main challenges in vertical curve design is to minimize the length of the curve to reduce these costs. However, this cost-efficiency objective must be carefully balanced with the imperative of ensuring road safety, particularly regarding sight distance requirements (Garber & Hoel, 2014).

A fundamental safety parameter in vertical curve design is the Stopping Sight Distance (SSD)—the minimum distance a driver needs to detect an obstacle and bring the vehicle to a complete stop safely. This is especially critical on crest vertical curves, where the driver's line of sight may be obstructed due to the curvature of the road [23]; [9].

SSD becomes a key constraint in determining the length and shape of vertical curves. If the curve is too short, it may not provide adequate visibility, increasing the risk of rear-end collisions or roadway departures. Thus, maintaining adequate SSD is essential for safe road operation, even if it results in increased construction effort.

Although drainage concerns, particularly in sag curves, also influence vertical alignment design, this section focuses solely on the sight distance aspect. For more details on vertical alignment and drainage integration, refer to AASHTO (2018) [9].

The SSD is generally computed as the sum of two components:

1. The perception-reaction distance—the distance a vehicle travels while the driver perceives a hazard and reacts.
2. The braking distance—the distance required to decelerate the vehicle to a full stop.

The SSD is commonly expressed by the equation:

$$\text{SSD}=\frac{V1^2}{2g\left(\left(\frac{a}{g}\right)\pm G\right)}+\text{v1*tr} \qquad (2.7)$$

Where:

SSD = stopping sight distance in ft,

V= initial vehicle speed in ft/s,

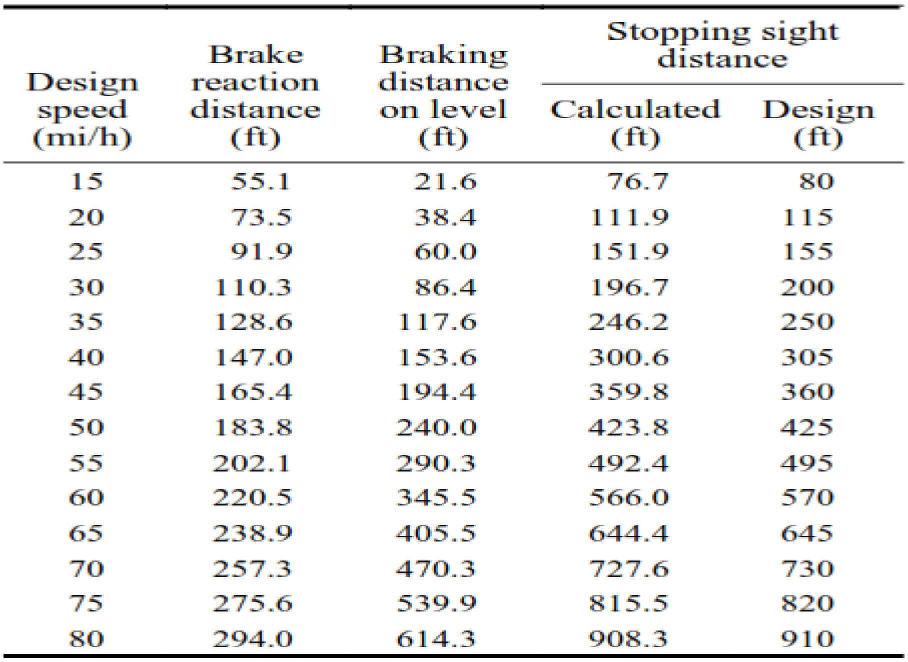
g = gravitational constant, 32.2 ft/s

a = deceleration rate in ft/s

G =roadway grade (+ for uphill and for downhill) in percent/100, and

t= perception/reaction time in s.

Table 2-1Stopping Site Distance [21]



Design speed (mi/h)	Brake reaction distance (ft)	Braking distance on level (ft)	Stopping sight distance	
			Calculated (ft)	Design (ft)
15	55.1	21.6	76.7	80
20	73.5	38.4	111.9	115
25	91.9	60.0	151.9	155
30	110.3	86.4	196.7	200
35	128.6	117.6	246.2	250
40	147.0	153.6	300.6	305
45	165.4	194.4	359.8	360
50	183.8	240.0	423.8	425
55	202.1	290.3	492.4	495
60	220.5	345.5	566.0	570
65	238.9	405.5	644.4	645
70	257.3	470.3	727.6	730
75	275.6	539.9	815.5	820
80	294.0	614.3	908.3	910

2.3.2.6.4. Stopping Sight Distance and Crest Vertical Curve Design

In the geometric design of a crest vertical curve, the curve length (denoted as L) is a fundamental factor in ensuring adequate stopping sight distance (SSD). A longer curve provides improved visibility and safer driving conditions by offering a smoother transition between different gradients. However, longer curves often involve increased construction costs, particularly due to earthwork operations such as cutting and filling. Conversely, while shorter vertical curves are more cost-effective, they may not provide sufficient SSD due to a steeper change in slope, which can obstruct the driver's line of sight, especially on undulating terrain [2].

To resolve this trade-off between safety and cost-efficiency, a mathematical model is used to compute the minimum required length of a vertical curve for a specified SSD. Since crest and sag curves exhibit different visual and physical characteristics, each is treated separately in design procedures [23]; [9].

For crest vertical curves, where sight is limited by the road's curvature, the design follows a parabolic profile with equal tangent lengths. Applying parabolic geometry, two standard equations are used to determine the minimum curve length **Lm** based on the relationship between SSD and curve length:

- Case 1: When SSD is less than the curve length (S < L):

$$\text{Lm} = \frac{AS^2}{200(\sqrt{H1}+\sqrt{H1})^2} \qquad (2.8)$$

- Case 2: When SSD is greater than the curve length (S > L):

$$\text{Lm} = 2S - \frac{200(\sqrt{H1}+\sqrt{H1})^2}{A} \qquad (2.9)$$

Where:

Lm = minimum length of vertical curve in ft, A = absolute value of the difference in grades (|G1G2|), expressed as a percentage, and

For the sight distance required to provide adequate SSD, current AASHTO design guidelines [21] use a driver eye height, H1, of 3.5 ft and a roadway object height, H2, of 2.0 ft (the height of an object to be avoided by stopping before a collision). to determine the minimum length of curve required to provide adequate SSD, we set the sight distance, S, equal to the stopping sight distance, SSD (note that the relatively small distance from the driver's eye position to the front of the vehicle is ignored). Substituting AASHTO guidelines for H1 and H2 and letting S = SSD gives

For SSD < L

$$\text{Lm}= \frac{\text{A}*\text{SSD}^2}{2158} \qquad (2.10)$$

For SSD > L

$$\text{Lm} = 2 * \text{SSD} - \frac{2158}{A} \tag{2.11}$$

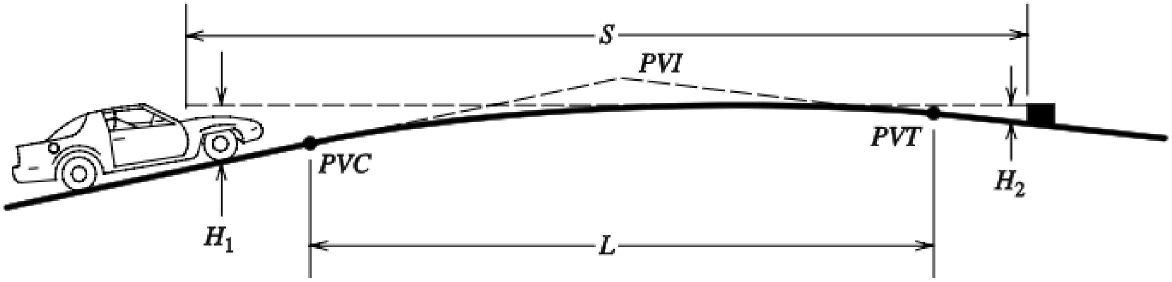


Figure 2-7. ***Stopping sight distance considerations for crest vertical curves*** *[4]****.***

2.3.2.6.5. Stopping Sight Distance and Sag Vertical Curve Design

The design principles for sag vertical curves differ significantly from those used for crest vertical curves, primarily due to the nature of visibility constraints. While crest curves often limit the driver's line of sight due to the physical obstruction caused by the road itself, sight distance on sag curves is generally not restricted during daylight hours. Instead, the critical design condition for sag curves occurs at night, when visibility depends largely on the effective reach of the vehicle's headlights [2]; [9].

In nighttime driving conditions, the available stopping sight distance on a sag curve is determined by the length of the roadway illuminated by the headlights. This length is influenced by two primary factors:

- the height of the headlight above the roadway surface, and
- the upward inclination angle of the headlight beams relative to the horizontal plane of the vehicle [23].

As illustrated in Figure 2.4, the geometry of sag curves involves the beam of light intersecting with the road surface ahead. For the design to be considered safe, the sight distance must be equal to or greater than the distance illuminated by the headlights over the curve. A mathematical relationship is used to determine the minimum required length of a sag vertical curve that ensures adequate sight distance during night driving.

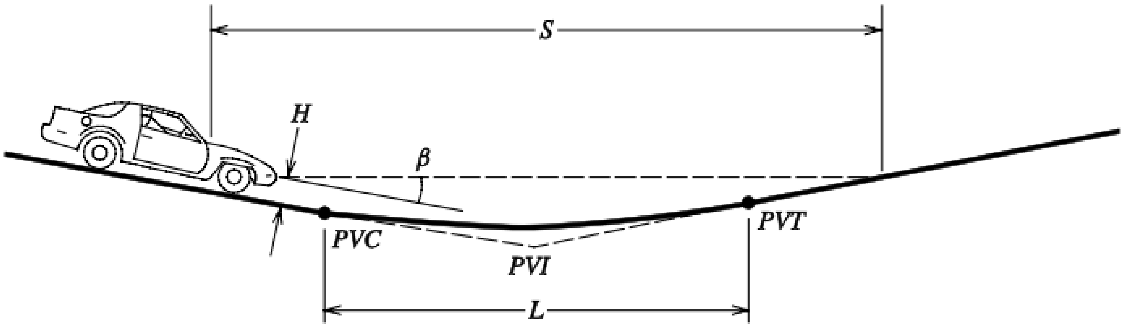


Figure 2-8. ***Stopping sight distance considerations for sag vertical curves.*** *[4]*

S=Sight distance

H=height of headlight in ft
B=inclined angle of headlight beam in

Degrees

L=length of the curve in ft

PVI=point of vertical intersection (intersection of initial and final grades),
PVC=point of the vertical curve (the initial point of the curve)

PVT=point of vertical tangent, which is the final point
of the vertical curve (the point where the curve
returns to the final grade or, equivalently, the
final tangent).

To determine the minimum length of curve for a required sight distance, the properties of a parabola for an equal-tangent curve can be used to show that.

For S<L

$$\text{Lm} = \frac{AS^2}{200(H + S\tan\beta)} \tag{2.12}$$

For S>L

$$\text{Lm} = 2S - \frac{200(H + S\tan\beta)}{A} \tag{2.13}$$

Where:

Lm =minimum length of vertical curve in ft;

A = absolute value of the difference in grades (|G1G2|), expressed as a percentage,

For the purpose of ensuring adequate stopping sight distance (SSD) on sag vertical curves, current AASHTO design standards recommend specific parameters based on typical nighttime driving conditions. According to the AASHTO (2011) guidelines, a headlight height of 2.0 feet above the roadway surface and an upward headlight beam angle of 1 degree are used for standard design assumptions.

By substituting these values into the general sag curve sight distance formula—while setting $S=SSDS = SSD$S=SSD as was done in the crest vertical curve case—and disregarding the relatively small distance from the driver's eye to the front of the vehicle, the equation simplifies to:

For SSD<L

$$\text{Lm} = \frac{AXSSD^2}{400+3.5XSSD} \tag{2.14}$$

For SSD>L

$$\text{Lm} = 2XSSD - \frac{400+3.5XSSD}{A} \tag{2.15}$$

Where:

SSD = stopping sight distance in ft, and
Other terms are as defined previously.

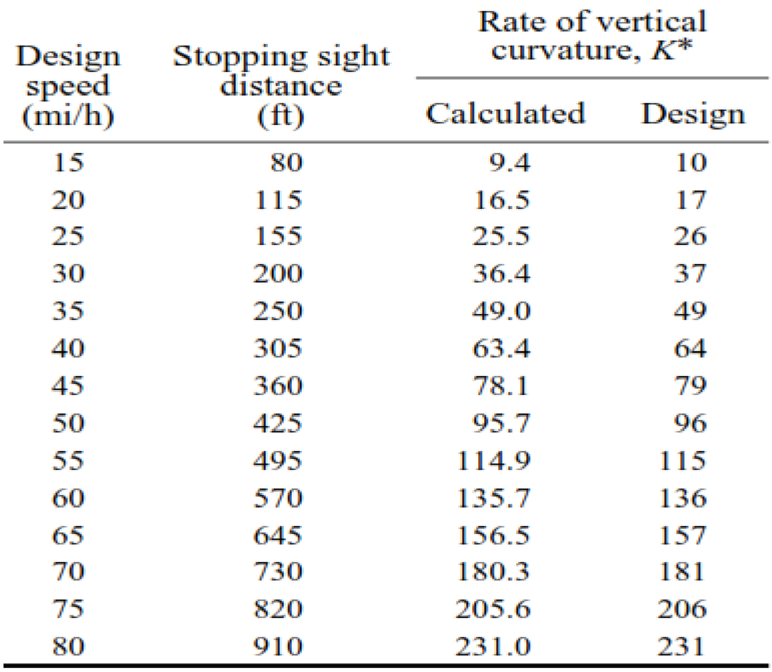
As was the case for crest vertical curves, K-values can be computed by assuming L > SSD, which gives us the linear relationship between Lm and A as shown above in equation1. Thus, for sag vertical curves (with Lm = KA),

$$\text{K} = \frac{SSD^2}{400+3.5XSSD} \tag{2.16}$$

Where: K = horizontal distance, in ft, required to affect a 1% change in the slope

The K-values corresponding to design-speed-based SSDs are presented in Table 2.2. As was the case for crest vertical curves, some caution should be exercised in using this table because the assumption that G = 0 (for determining SSD) is used. Also, assume that L > SSD is a safe, conservative assumption (as was the case for crest vertical curves) and the smallest allowable curve lengths for sag curves are the same as those for crest curves.

Table 2-2 Minimum Radius Using Limiting Values of e and fs. [21]



Design speed (mi/h)	Stopping sight distance (ft)	Rate of vertical curvature, *K**	
		Calculated	Design
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	425	95.7	96
55	495	114.9	115
60	570	135.7	136
65	645	156.5	157
70	730	180.3	181
75	820	205.6	206
80	910	231.0	231

*Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A): K = L/A.

2.3.2.6.6. Passing Sight Distance and Crest Vertical Curve Design

Beyond the requirement for stopping sight distance (SSD), certain roadway situations—particularly on two-lane, two-way highways—necessitate the provision of passing sight distance (PSD) to allow drivers to safely overtake slower-moving vehicles. This becomes a critical safety concern on crest vertical curves, where the curvature may obstruct a driver's ability to see oncoming traffic beyond the peak of the curve [2].

Unlike crest curves, sag vertical curves typically do not limit passing sight distance during daylight, since drivers can generally see along the descending slope. Even at night, oncoming vehicle headlights tend to illuminate the roadway ahead, thereby assisting visibility and reducing the severity of sight distance restrictions [9].

When designing crest vertical curves to accommodate safe passing, the calculation of required PSD is based on geometric sight distance principles similar to those used for SSD, but with adjusted eye and object heights. In this case, both the driver's eye height (h_1) and the object height (h_2) are assumed to be 3.5 feet (or approximately 1.08 meters). This symmetric assumption ensures that both drivers—the one overtaking and the one approaching—have reciprocal visibility: if one can see the other, the condition is satisfied in both directions [23].

The same parabolic geometry used for SSD design applies here, but the larger sight distance required for a full passing maneuver necessitates longer crest curves. Design equations for determining minimum curve length under passing sight distance conditions are derived using these geometric parameters, ensuring that the road allows for a complete and safe overtaking process on crests with limited visibility.

By substituting these height values into the appropriate equations and defining the sight distance S as the passing sight distance (PSD), a functional design equation can be derived to ensure safe overtaking maneuvers on crest vertical curves.

For PSD < L

$$\text{Lm}= \frac{\text{A}*\text{PSD}^2}{2800} \tag{2.17}$$

For SSD > L

$$\text{Lm}= 2 * \text{PSD} - \frac{2800}{A} \tag{2.18}$$

Where:

Lm = minimum length of vertical curve in ft, A = absolute value of the difference in grades (|G1G2|), expressed as a percentage, and

PSD = passing sight distance in ft.

As was the case for stopping sight distance, it is typically assumed that the length of curve is greater than the required sight distance (in this case L > PSD), so

$$\text{K}= \frac{\text{PSD}^2}{2800} \tag{2.19}$$

Where:

K=Horizontal distance in feet, required to effect 1% change in the slop

PSD = passing sight distance in ft.

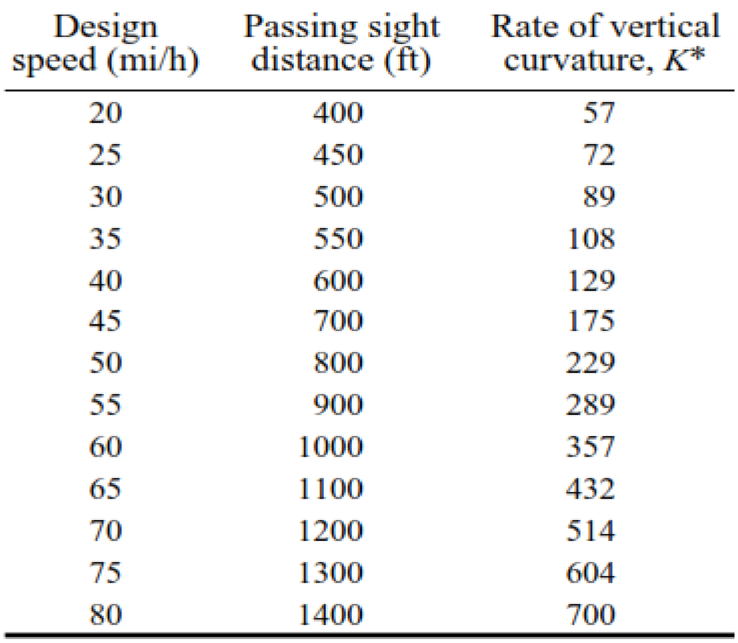
The **passing sight distance (PSD)** used in highway design is made up of **four key components**:

1. The **initial maneuver distance**, which includes the driver's **perception and reaction time**, as well as the time needed for the vehicle to accelerate from its following speed to the point where it begins to move into the **opposing lane**.
2. The **distance traveled while the vehicle is in the opposing lane**, actively completing the **passing maneuver**.
3. A **clearance distance** between the **passing and oncoming vehicles** at the end of the maneuver to ensure a safe buffer.
4. The distance traveled by the **opposing vehicle** during the last two-thirds of the time that the passing vehicle is in the opposite lane.

These distances are calculated based on assumptions about **driver behavior**, **vehicle acceleration**, and the **speeds of the passing, passed, and opposing vehicles**. When these four components are added together, they yield the **total required PSD**. A more detailed explanation of the assumptions used in calculating PSD can be found in **AASHTO (2011)**.

Table 2.3 presents the **minimum PSD values** needed at different **design speeds**, along with the corresponding **K-values**—which are measures of curve flatness. Compared to the **K-values for stopping sight distance (SSD)** shown in Table 2.2, the values for PSD are significantly larger. Consequently, designing **crest vertical curves** that meet PSD requirements often results in much **longer curves**, which can lead to **increased construction costs**.

Table 2-3 Design Controls for Crest Vertical Curves Based on Passing Sight Distance [21]



Design speed (mi/h)	Passing sight distance (ft)	Rate of vertical curvature, *K**
20	400	57
25	450	72
30	500	89
35	550	108
40	600	129
45	700	175
50	800	229
55	900	289
60	1000	357
65	1100	432
70	1200	514
75	1300	604
80	1400	700

*Rate of vertical curvature, K is the length of curve per percent algebraic difference in intersection grades(A):

$$K=L/A \tag{2.20}$$

2.3.2.7 Horizontal Alignment

2.3.2.7.1. introduction to Horizontal Alignment

The horizontal curve is a fundamental element of horizontal alignment, enabling smooth directional changes of a roadway within the horizontal plane. Essentially, it connects two straight sections (tangents) of the road, allowing vehicles to transition between directions safely and comfortably [19].

A key consideration in designing these curves is ensuring that all types of vehicles, ranging from small passenger cars to heavy trucks, can negotiate the turn without difficulty or risk of skidding. In addition to vehicle safety and comfort, adequate drainage along the curve is essential to prevent water accumulation, which could reduce friction and increase accident risk [9].

Highway engineers evaluate vehicle performance on horizontal curves by using simplified design equations that approximate cornering behavior, rather than attempting to model detailed vehicle dynamics. These methods are analogous to the simplified approaches used in vertical alignment design for stopping sight distance, focusing on practical design parameters that ensure safety and operability for all users [24].

2.3.2.7.2. Vehicle Cornering

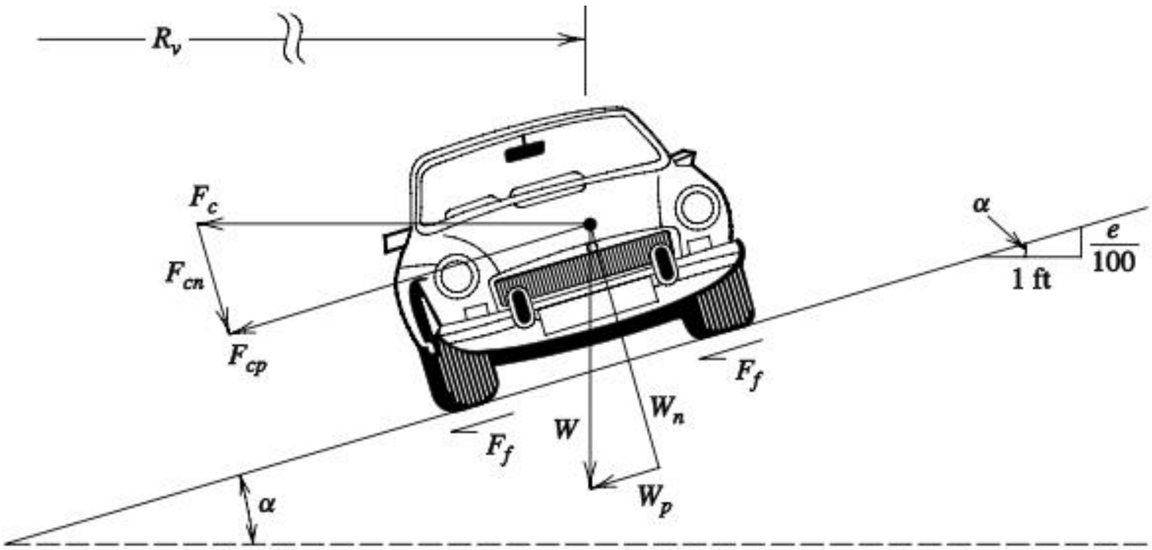


Figure 2-9. ***Vehicle cornering forces*** *[21]*

Rv = radius defined to the vehicle’s traveled path in ft,

α= angle of incline in degrees,

e = number of vertical ft of rise per 100 ft of horizontal distance,

W = weight of the vehicle in lb,

Wn = vehicle weight normal to the roadway surface in lb,

Wp= vehicle weight parallel to the roadway surface in lb,

Ff=side frictional force (centripetal, in lb),

Fc = centripetal force (lateral acceleration × mass, in lb),

Fcp= centripetal force acting parallel to the roadway surface in lb, and

Fcn = centripetal force acting normal to the roadway surface in lb.

Some basic horizontal curve relationships can be derived by noting that:

$W_{P+Ff=Fcp}$

From basic physics this equation can be written as [with Ff = fs (Wn + Fcn)]

$$\mathrm{Wsin}\,\alpha + fs\left(W\cos\alpha + \frac{WV^2}{g\mathrm{R}\upsilon}\sin\alpha\right) = \frac{WV^2}{g\mathrm{R}\upsilon}\cos\alpha$$

(2.21)

Where:

fs = coefficient of side friction (unitless),

V = vehicle speed in ft/s,

g = gravitational constant, 32.2 ft/s

Dividing both sides of Eq. 1 by Wcosα

Gives

$$\tan\alpha + fs = \frac{V^2}{g\mathrm{R}\upsilon}(1 - +\mathrm{fs}\tan\alpha)$$

(2.22)

The term tanα indicates the superelevation of the curve (banking) and can be

expressed in percent; it is denoted e (e = 100 tan α). In words, the superelevation is

the number of vertical feet (meters) of rise per 100 feet (meters) of horizontal distance (see Fig. 2.9). The term fs tan α in Eq.2 is conservatively set equal to zero for practical applications due to the small values that fs and typically assume (this is equivalent to ignoring the normal component of centripetal force). With e =100 tanα

, Eq.2 can be arranged as

$$\mathrm{R}\upsilon = \frac{V^2}{g(fs+\frac{e}{100})} \tag{2.23}$$

With e = 100 tanα

When designing a horizontal curve, engineers must carefully choose appropriate values for both superelevation (e) and the side friction factor (f_s). Selecting the right value for e is especially important, as excessively high superelevation can lead to steering difficulties for vehicles negotiating the curve. This issue becomes even more critical in cold climates, where icy road conditions can significantly reduce the available side friction. In such cases, vehicles traveling below the design speed may lose control and slide inward on curves that are too steeply banked due to the effect of gravity.

To guide these decisions, AASHTO offers standardized recommendations for selecting e and f_s values, as summarized in Table 2.4. This table categorizes values according to five levels of maximum superelevation, which vary depending on the type of roadway. For instance, higher maximum superelevation rates are allowed on freeways compared to arterial or local roads, in line with their functional classifications and prevailing design practices.

The limiting values of the side friction factor (f_s) are primarily determined by the design speed of the roadway. Additionally, Table 2.4 includes the calculated minimum curve radii based on given values of speed, superelevation, and side friction, assisting engineers in selecting appropriate curve geometries that balance safety, comfort, and performance.

2.3.2.7.3. Horizontal Curve Fundamentals

When connecting two straight (tangent) segments of a roadway, engineers can select from several types of horizontal curves depending on alignment requirements and terrain constraints. The simplest and most commonly used is the simple circular curve, characterized by a constant radius along its length, which provides predictable and stable vehicle steering [19].

Other curve types include reverse curves, compound curves, and spiral curves. A reverse curve consists of two consecutive curves bending in opposite directions, usually with equal radii, and is often employed to laterally shift the alignment. However, due to the sharp change in direction, reverse curves can challenge drivers' ability to maintain lane position safely and are generally discouraged in highway design [2].

Compound curves are formed by two or more connected curves with different radii, offering flexibility in complex alignment scenarios such as interchange ramps or roads through rugged terrain. It is important to avoid large disparities between successive radii, as abrupt radius changes can affect vehicle control and driver comfort. [9]

Spiral curves differ by having a radius that varies continuously along the curve length, transitioning smoothly from an infinite radius at the tangent point to the radius of the adjoining circular curve. Spiral curves are often used on high-speed roadways to provide gradual lateral acceleration and allow for progressive superelevation, improving vehicle stability and comfort before entering a horizontal curve [23].

This study will focus primarily on the simple circular curve to explain the basic principles of horizontal curve design. For more detailed treatments of reverse, compound, and spiral curves, readers are referred to authoritative texts such as, Kadiyali (2016) [19], and AASHTO (2018) [4]. The main components of a simple horizontal curve are illustrated in Figure 2-10**.**

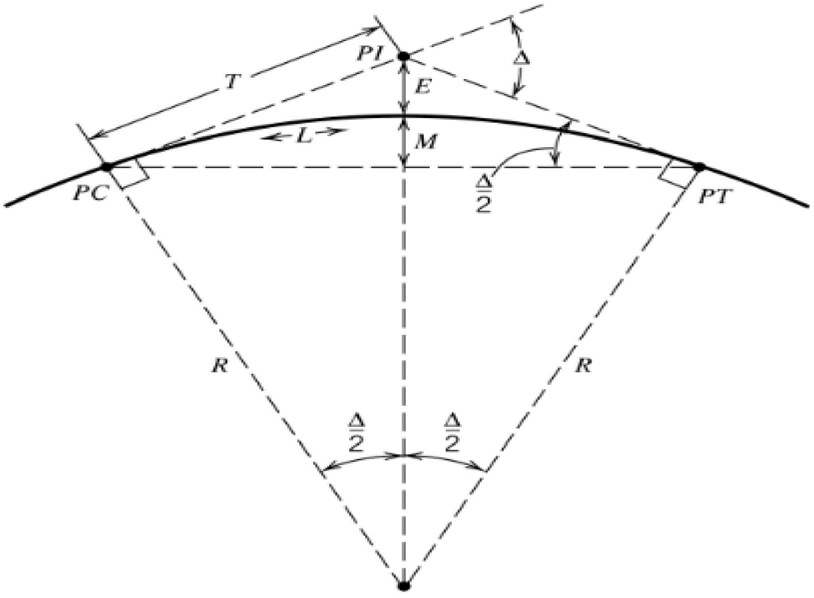


Figure 2-10 ***. Elements of a simple circular horizontal curve.*** *[21]*

R = radius, usually measured to the centerline of the road, in ft,

Δ = central angle of the curve in degrees, PI = point of tangent intersection, T = tangent length in ft, PT = point of tangent (the ending point of the horizontal E = external distance in ft, curve), and M = middle ordinate in ft, L = length of curve in ft

Another important term is the degree of curve, which is defined as the angle subtended by a 100-ft arc along the horizontal curve. It is a measure of the sharpness of the curve and is frequently used instead of the radius in the construction of the curve. The degree of curve is directly related to the radius of the horizontal curve by

$$D=\frac{100(\frac{180}{\pi})}{R}=\frac{18000}{\pi R} \qquad (2.24)$$

Where:

D = degree of curve [angle subtended by a 100-ft arc along the horizontal curve],

Note that the quantity 180/ converts from radians to degrees. Geometric and trigonometric analyses of Fig. 3.13 reveal the following relationships:

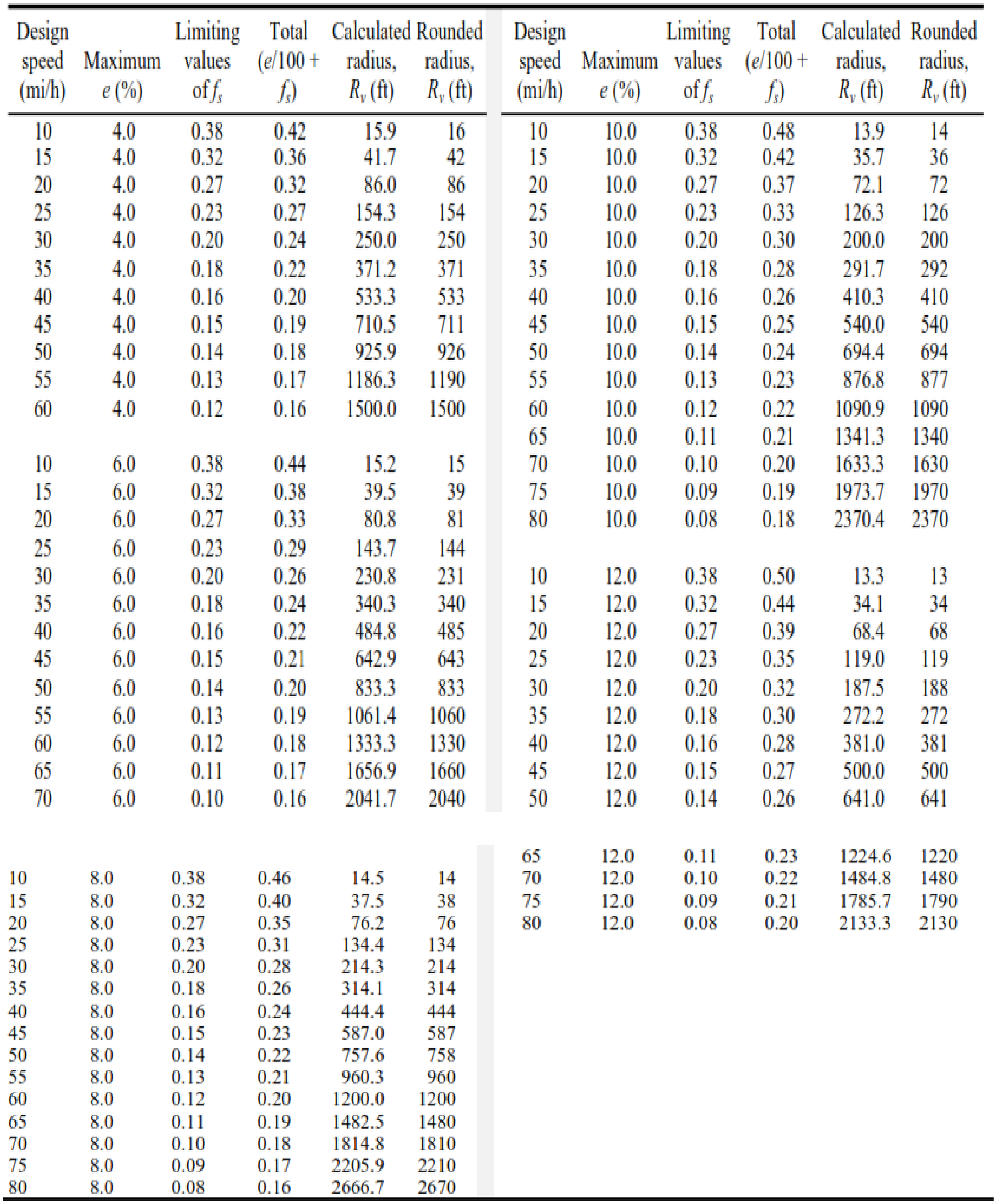
$$T= R\tan\frac{\Delta}{2} \qquad E=R(\frac{1}{\cos(\frac{\Delta}{2})}-1) \qquad (2.25)$$

$$M=R(1-\cos\Delta/2) \qquad (2.26)$$

$$L=\frac{\pi}{180}R\Delta \qquad (2.27)$$

where all terms are as defined in Fig. 2.6. It is important to note that horizontal curve stationing, curve length, and curve radius (R) are usually measured to the centerline of the road. In contrast, the radius determined on the basis of vehicle forces (Rv in Eq1) is measured from the innermost vehicle path, which is assumed to be the midpoint of the innermost vehicle lane. Thus, a slight correction for lane width is required in equating the Rv of Eq1with the R in Eq 2 through 6.

Table 2-4 Minimum Radius Using Limiting Values of e and fs [21]



Design speed (mi/h)	Maximum e (%)	Limiting values of f_s	Total (e/100 + f_s)	Calculated radius, R_v (ft)	Rounded radius, R_v (ft)
10	4.0	0.38	0.42	15.9	16
15	4.0	0.32	0.36	41.7	42
20	4.0	0.27	0.32	86.0	86
25	4.0	0.23	0.27	154.3	154
30	4.0	0.20	0.24	250.0	250
35	4.0	0.18	0.22	371.2	371
40	4.0	0.16	0.20	533.3	533
45	4.0	0.15	0.19	710.5	711
50	4.0	0.14	0.18	925.9	926
55	4.0	0.13	0.17	1186.3	1190
60	4.0	0.12	0.16	1500.0	1500
10	6.0	0.38	0.44	15.2	15
15	6.0	0.32	0.38	39.5	39
20	6.0	0.27	0.33	80.8	81
25	6.0	0.23	0.29	143.7	144
30	6.0	0.20	0.26	230.8	231
35	6.0	0.18	0.24	340.3	340
40	6.0	0.16	0.22	484.8	485
45	6.0	0.15	0.21	642.9	643
50	6.0	0.14	0.20	833.3	833
55	6.0	0.13	0.19	1061.4	1060
60	6.0	0.12	0.18	1333.3	1330
65	6.0	0.11	0.17	1656.9	1660
70	6.0	0.10	0.16	2041.7	2040
10	8.0	0.38	0.46	14.5	14
15	8.0	0.32	0.40	37.5	38
20	8.0	0.27	0.35	76.2	76
25	8.0	0.23	0.31	134.4	134
30	8.0	0.20	0.28	214.3	214
35	8.0	0.18	0.26	314.1	314
40	8.0	0.16	0.24	444.4	444
45	8.0	0.15	0.23	587.0	587
50	8.0	0.14	0.22	757.6	758
55	8.0	0.13	0.21	960.3	960
60	8.0	0.12	0.20	1200.0	1200
65	8.0	0.11	0.19	1482.5	1480
70	8.0	0.10	0.18	1814.8	1810
75	8.0	0.09	0.17	2205.9	2210
80	8.0	0.08	0.16	2666.7	2670
10	10.0	0.38	0.48	13.9	14
15	10.0	0.32	0.42	35.7	36
20	10.0	0.27	0.37	72.1	72
25	10.0	0.23	0.33	126.3	126
30	10.0	0.20	0.30	200.0	200
35	10.0	0.18	0.28	291.7	292
40	10.0	0.16	0.26	410.3	410
45	10.0	0.15	0.25	540.0	540
50	10.0	0.14	0.24	694.4	694
55	10.0	0.13	0.23	876.8	877
60	10.0	0.12	0.22	1090.9	1090
65	10.0	0.11	0.21	1341.3	1340
70	10.0	0.10	0.20	1633.3	1630
75	10.0	0.09	0.19	1973.7	1970
80	10.0	0.08	0.18	2370.4	2370
10	12.0	0.38	0.50	13.3	13
15	12.0	0.32	0.44	34.1	34
20	12.0	0.27	0.39	68.4	68
25	12.0	0.23	0.35	119.0	119
30	12.0	0.20	0.32	187.5	188
35	12.0	0.18	0.30	272.2	272
40	12.0	0.16	0.28	381.0	381
45	12.0	0.15	0.27	500.0	500
50	12.0	0.14	0.26	641.0	641
65	12.0	0.11	0.23	1224.6	1220
70	12.0	0.10	0.22	1484.8	1480
75	12.0	0.09	0.21	1785.7	1790
80	12.0	0.08	0.20	2133.3	2130

2.3.2.7.4. Stopping Sight Distance and Horizontal Curve Design

Just as with vertical alignment, ensuring adequate stopping sight distance (SSD) is a critical component in the design of horizontal curves. Sight distance limitations on horizontal curves typically result from physical obstructions located on the inside of the curve—such as natural terrain features, vegetation, retaining walls, or built structures [9]. These obstructions are especially prevalent where expanding the right-of-way is either prohibitively expensive or constrained by environmental and topographic conditions [19].

When such obstructions exist, SSD is evaluated along the horizontal arc of the curve, starting from the center of the driver's lane, which approximates the line of sight. To maintain safety, it is essential that the entire arc length representing the required SSD remains visible to the driver [2].

To ensure this, a specific clearance zone—known as the middle ordinate (often denoted as Ms)—must remain free of visual obstructions. As illustrated in Figure 3.14, this middle ordinate represents the perpendicular distance between the driver's line of sight (chord of the arc) and the obstruction along the inside of the curve. Maintaining this clear sight triangle is vital to allow drivers enough distance to perceive a hazard and safely stop their vehicle within the curve's limits [23].

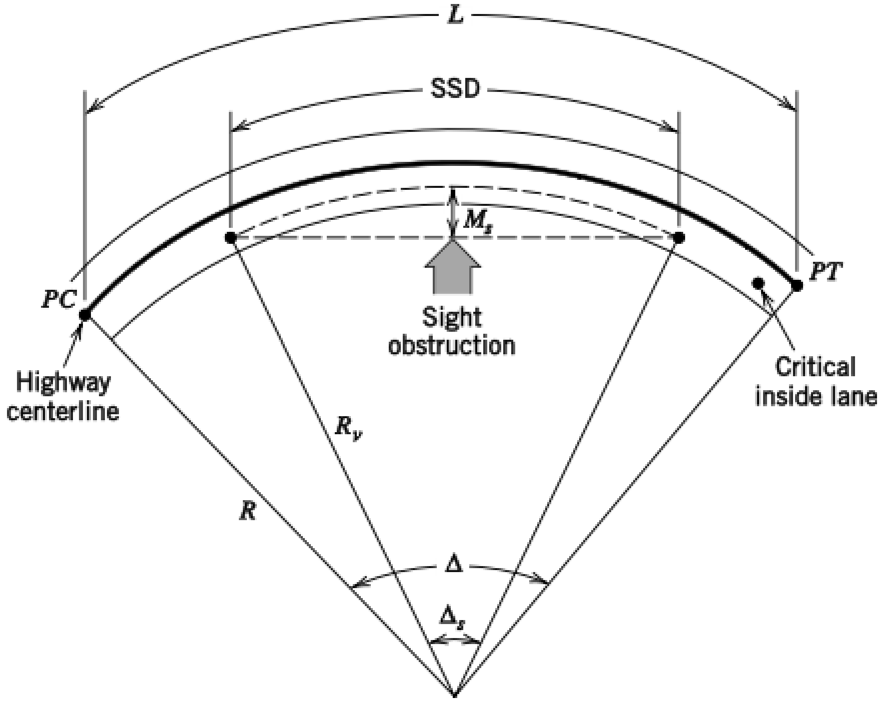


*Figure 2-11**. Stopping sight distance considerations for horizontal curves** [21]*

R = radius measured to the centerline of the road in ft,

Rv = radius to the vehicle's traveled path (usually measured to the center of the innermost lane of the road) in ft,

Δ= central angle of the curve in degrees,

Δ*s* = angle (in degrees) subtended by an arc
equal in length to the required stopping
sight distance (SSD),
L = length of curve in ft,

Ms = middle ordinate necessary to provide adequate stopping sight distance (SSD) in ft.

SSD = stopping sight distance in ft,

PT = point of tangent (the ending point of the horizontal curve).

PC = point of curve (the beginning point of the Horizontal curve)

The final formula to calculate the Stopping Sight Distance is the following:

$$\text{SSD}=\frac{\pi R\upsilon}{90}\left[\cos^{-1}\left(\frac{R\upsilon-Ms}{R\upsilon}\right)\quad\right] \tag{2.28}$$

2.3.2.8. Combined vertical and Horizontal Alignment

Up to this point, the discussion of highway alignment has treated horizontal and vertical curves as separate design elements. However, in real-world applications, these elements are frequently combined within the same roadway segment, especially in mountainous regions, urban corridors, and interchange ramps, where significant changes in both elevation and direction are required over relatively short distances.

According to AASHTO (2018) [9], designing such combined alignments typically involves addressing two distinct two-dimensional problems—the horizontal alignment in plan view and the vertical alignment in profile view. Although treated separately during the design process, these two alignments are ultimately integrated to form a three-dimensional roadway alignment, ensuring consistency in safety, comfort, and functionality. The following figure illustrates the relationship between the vertical and horizontal curves and how they are coordinated in geometric highway design.

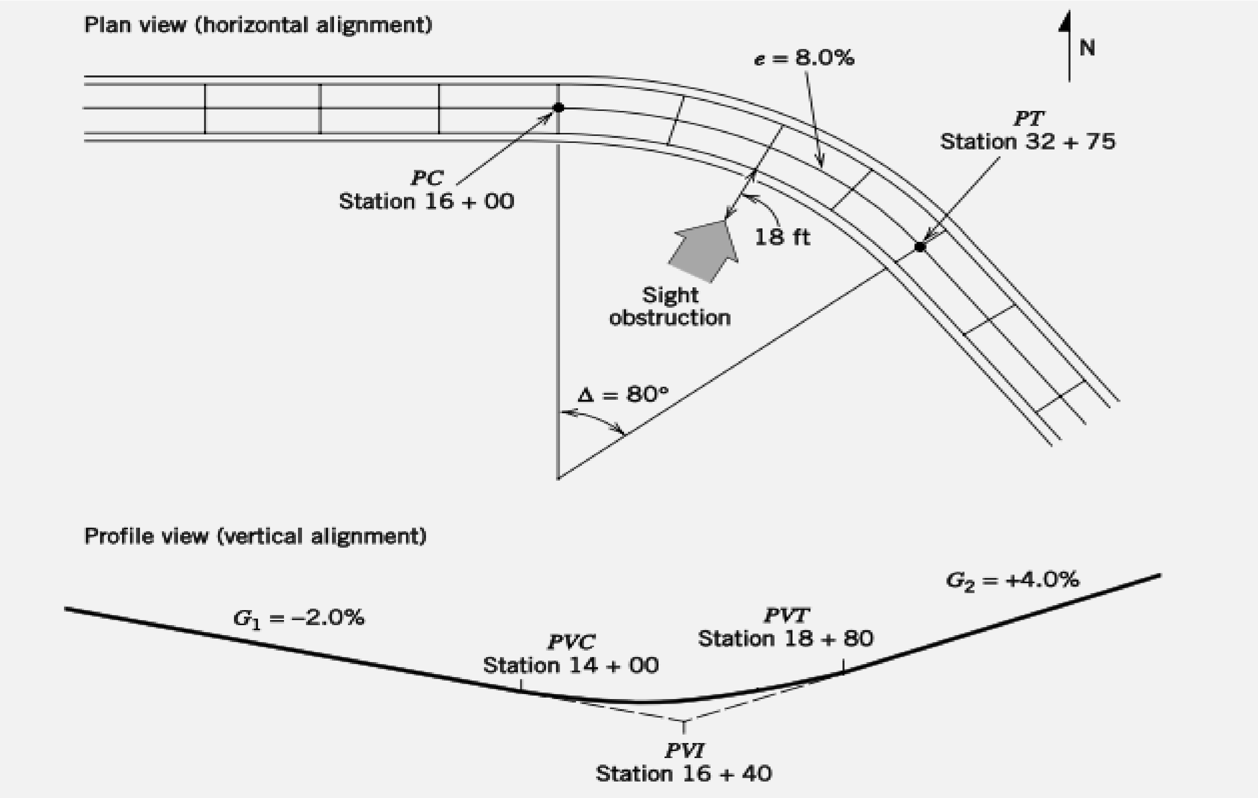


Figure 2-12. ***Combined Horizontal and vertical alignment*** *[21]*

2.4. Pedestrian Infrastructure and Safety

2.4.1. Infrastructure Deficiencies

A study by Nkurunziza and Tafahomi (2020), [25] highlighted significant deficiencies in pedestrian infrastructure in Kigali, including a lack of designated footpaths, non-functional signals, and poor signage. These shortcomings force pedestrians to walk near high-speed vehicle lanes, increasing the risk of pedestrian-vehicle conflicts.

Additionally, infrastructure often neglects vulnerable populations such as the elderly or physically challenged. The absence of overpasses, ramps, or auditory signals at crossings reveals a systemic bias toward motorized users.

2.4.2. Driver Yielding Behavior at Crosswalks

Nkurunziza, Tafahomi, and Faraja (2023), [10] observed over 10,000 pedestrian crossings and found that 82.4% of drivers did not yield at zebra crossings, despite legal obligations. Motorcyclists were the least compliant, while private car drivers had moderate compliance. Interestingly, vehicle density was positively correlated with yielding behavior—drivers were more likely to yield in slower-moving, denser traffic conditions.

This is supported by findings from Ghana, where Sogbe (2023), [26] noted that only 28% of drivers yielded at uncontrolled crosswalks. Older pedestrians and larger pedestrian groups were more likely to be respected by drivers.

2.4.3. Technology and Behavioral Interventions

Park et al. (2024), [27] explored the use of real-time pedestrian detection systems using VR simulations and eye-tracking. Drivers showed improved braking behavior and heightened attention when warned of high pedestrian density. Such systems could be piloted in busy Kigali intersections, where pedestrian volumes are high and visibility is poor.

Driving simulators have increasingly been used as valuable tools to assess how road geometry affects driver behavior in a controlled environment. Bobermin et al. (2021), [6] conducted a systematic review of simulator-based studies examining the influence of geometric design elements—particularly horizontal curves—on driver performance. Their findings indicated that, despite variations in experimental design and limitations in cross-study comparability, simulators provide consistent insights into driver behavior that may not be captured through traditional field observations. This suggests that simulator-based research can play a critical role in informing safer road design, especially when evaluating behavioral responses to geometric changes.

2.5. Data-Driven and Low-Cost Safety Assessment Tools

2.5.1 Surrogate Safety Measures

In regions with poor crash data availability, surrogate safety measures (SSMs) offer a valuable alternative. Nadimi et al. (2025), [28] used decision trees and machine learning models to assess curve safety without needing detailed crash records. Such methods are well-suited to Rwanda's rural areas, where under-reporting is common.

2.5.2 DEM-Based Hazard Detection

The planning and generation of Digital Elevation Models (DEMs) must begin with a clear definition of project-specific requirements and intended applications. According to the World Bank’s guidance on DEM creation [29], accurate hazard identification through DEMs depends heavily on technical attributes such as point spacing, vertical and horizontal accuracy, source data type (e.g., LiDAR, photogrammetry), surface treatments, and resolution. These parameters determine a DEM’s ability to capture critical geometric features such as slopes, curves, and elevation variations that influence road safety. For example, terrain requiring flood risk modeling or road gradient analysis should adopt a fine resolution (e.g., 1–5 m post spacing) and low vertical Root Mean Square Error (RMSE) to effectively detect subtle but hazardous geometric features. The guidance also stresses the need for proper metadata documentation and quality assurance throughout the DEM lifecycle from acquisition planning to post-processing especially when DEMs are used in safety-critical fields like transportation planning.

Complementing this framework, Hu et al. [30] demonstrated how DEMs and road network data can be integrated within GIS platforms to classify road segments based on horizontal curvature and vertical gradient. Their approach enabled automated identification of crash-prone segments and revealed that not only sharp curves and steep grades but also subtle geometric transitions are associated with increased crash frequencies. The study employed a Zero-Inflated Negative Binomial (ZINB) model to confirm that both curve radius and grade classification significantly predict crash risk, even in low-gradient or wide-radius segments, where driver misperception may occur due to seemingly safe road geometry.

However, the effectiveness of DEM-based hazard detection is highly dependent on the accuracy and quality of the DEMs employed. Mesa-Mingorance and Ariza-López [31] critically reviewed 30 years of DEM accuracy assessment practices and identified widespread inconsistencies in how elevation accuracy is measured and reported. They emphasized that many studies fail to assess whether a DEM is “fit for use,” which can lead to unreliable safety analyses—particularly when terrain features are subtle or when coarse-resolution DEMs are used. Their findings call for standardized, application-specific accuracy assessments to improve reliability in transportation safety modeling.

Together, these three studies highlight that while DEMs offer cost-effective and scalable tools for geometric hazard detection, their utility hinges on adherence to rigorous acquisition protocols [31], statistical validation [29], and contextual accuracy standards [30].

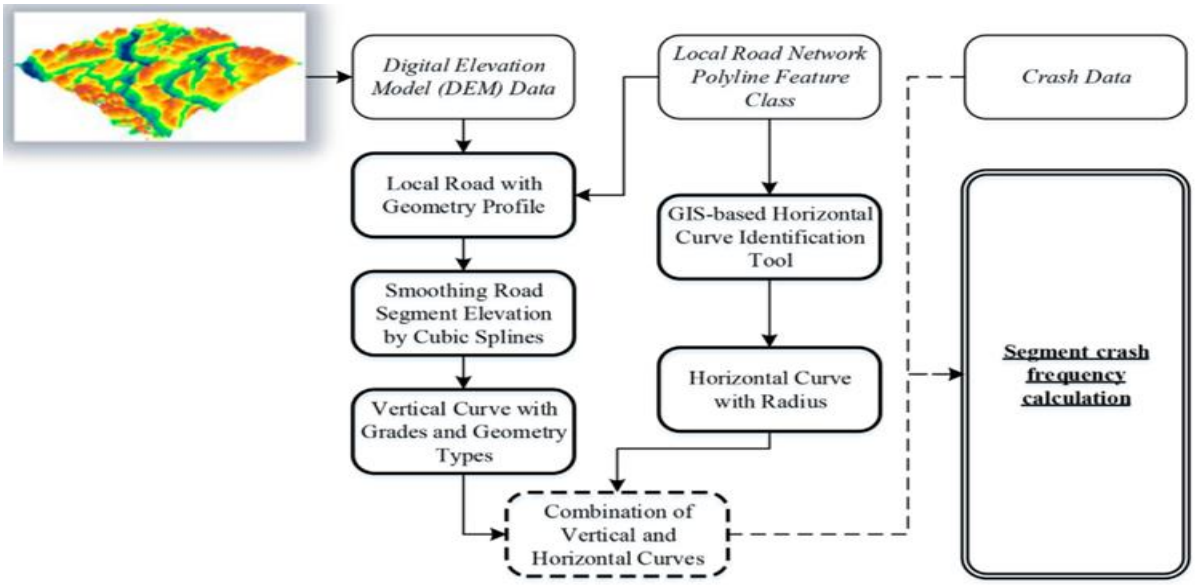


Figure 2-13Flow chart for GIS-based vertical and horizontal curve identification and merging with crashes [30]

2.6. Road Safety in Rwanda

2.6.1 National Accident Trends

According to Rwanda National Police (2022) [32], the main causes of accidents are speeding, failure to yield, and infrastructure deficiencies. While urban areas like Kigali experience frequent but lower-severity crashes, rural roads report higher fatality rates due to speed and delayed emergency response.

2.6.2 Inconsistencies with International Standards

Many urban roads in Rwanda, particularly in Kigali, do not fully comply with international geometric design standards such as those outlined by the American Association of State Highway and Transportation Officials (AASHTO). One notable example is **KN 123 Street** [5], where sharp, unmarked curves, insufficient lane widths, and inadequate stopping sight distances have been observed. These geometric inconsistencies are linked with elevated crash occurrences, especially at curves and intersections with limited visibility.

Such deficiencies are not isolated. As highlighted by Nkurunziza et al. [5], various roads in Kigali exhibit non-compliance with AASHTO's minimum requirements, particularly regarding horizontal alignment and pedestrian safety provisions. The study found that these geometric shortcomings significantly influence driver behavior and are associated with increased accident risks

2.7. Gaps in the Literature

Despite growing research on road safety in Rwanda, significant gaps remain:

While extensive international research has examined the relationship between road geometry and traffic safety, few studies have focused specifically on developing countries with hilly terrains such as Rwanda. Existing models are often based on flat terrain or urban settings, limiting their applicability to regions like the Kigali–Rubavu Road, which features rural, mountainous conditions and a high frequency of accidents. This study addresses these gaps by focusing on hilly terrain road segments and combining behavioral data with geometric features and accident records. Despite growing interest in road safety in Rwanda, significant gaps remain — including the limited exploration of the interactive effects of road design and driver behavior. To enhance relevance and accuracy, this study also adapts established global analytical models such as Poisson and Negative Binomial to the local context.

2.8. Implications for This Study

This review confirms that road geometry significantly affects both driver and pedestrian safety. The integration of conventional geometric analysis with modern perception-based and machine learning tools can offer more predictive and context-appropriate safety interventions for Rwanda.

3. CHAPTER3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research design, methodology, and procedures employed to analyze the impact of geometric design elements on driver behavior and road safety. The chapter details each step taken to meet the study objectives, including the selection of the study area, sample determination, data collection tools and techniques, and analytical approaches. A mixed-methods strategy was adopted to incorporate both quantitative and qualitative data for a comprehensive understanding of the problem.

3.2 Methodology Followed in the Present Research

This study adopted a mixed-methods approach that integrates engineering standards, statistical analysis, and perception-based evaluation. The methodology comprised three complementary components:

- **Geometric Assessment**: Road segments were evaluated for compliance with **RTDA, Road Geometric Design Manual (2014)** design standards, focusing on key parameters such as curve radius, gradient, lane width, Super-elevation, and sight distance to identify critical deviations related to safety.
- **Quantitative Modelling**: Statistical analyses were performed using SPSS 26.0, specifically Poisson and Negative Binomial regression models, to determine the relationship between geometric variables and accident occurrences.
- **Qualitative Analysis**: Structured questionnaires were used to assess driver and road design professionals' perceptions regarding the influence of road geometry on driving behaviour and safety.

The methodological process included the following steps:

Literature Review

A comprehensive review of international and local research was conducted to identify gaps in existing studies and guide the development of the present research.

Site Selection and Description

The study was conducted along the Kigali–Rubavu Road, a 150-kilometer national corridor linking Kigali to Rubavu at the DRC border. The road was selected for its strategic importance, challenging geometry, and high accident frequency, particularly in hilly and curved sections. For analysis, the corridor was divided into short segments (150–400 m) characterized by varying shoulder widths (1.0–2.0 m), gradients (up to 10%+), and curve radii (straight to <60 m), with some locations having limited visibility (<150 m) and different intersection types. Representative segments, such as SEG029 at Pfunda with a 34.85 m curve radius, 8.6% gradient, and poor visibility, were georeferenced using GPS and analysed in detail. These parameters, combined with crash history and driver perception data, formed the basis for assessing how geometric design influences driver behaviour and road safety.

Sampling Framework

A total of 40 road segments was selected (20 curved and 20 straight), along with a suitable number of drivers and engineering professionals for the perception-based component.

Field Data Collection: On-site surveys measured geometric parameters including curve radius, gradient, lane width, and sight distance.

Compliance Evaluation: Each geometric parameter was checked against the corresponding **RTDA** design standards to identify non-compliant sections, which served as a foundational step for subsequent analysis.

Crash and Behavioural Data Collection

Crash data were sourced from authorities, and perception data were gathered through questionnaires with drivers and road design professionals.

Data Analysis: The analysis assessed whether road segment geometries met RTDA (2014) safety standards. Segments found non-compliant were flagged for further investigation.

Quantitative Modelling: Using SPSS 26.0, crash frequency was modelled against geometric parameters using Poisson and Negative Binomial regression to explore statistically significant relationships.

Perception Analysis:

Responses from the questionnaires were analysed using descriptive statistics and trend identification to assess how drivers and professionals perceive the safety implications of geometric design.

Synthesis and Interpretation

Results from the compliance evaluation, statistical models, and perception survey were integrated to form a comprehensive understanding of how geometric design influences road safety, and to generate evidence-based recommendations.

3.3. Data Collection Method

This study employed a multi-source data collection strategy aligned with its **mixed-methods approach**. Data were obtained from three key streams to support the geometric assessment, quantitative analysis, and qualitative perception evaluation:

- Geometric Parameter Measurement using Shape files from RTDA, field observation and survey tools, with results compared against **RTDA, Road Geometric Design Manual (2014)** design standards.
- Accident Records collected from relevant authorities for modelling crash occurrences.
- Perception Surveys conducted through structured questionnaires targeting both drivers and road design professionals.

3.3.1 Geometric and Crash Data Collection

Quantitative physical data were gathered from 40 selected road segments (20 curved and 20 straight) exhibiting varying geometric characteristics. The following procedures were used:

- Field Surveys: Geometric features such as curve radius, gradient, lane width, and sight distance were measured using standardized field techniques and equipment.

- Compliance Check: Each parameter was evaluated for conformity to **RTDA, Road Geometric Design Manual (2014)** guidelines, serving as a basis for identifying high-risk road segments.

- Crash Records: Historical road crash data were collected from police and transport agencies corresponding to the selected segments to support regression modelling in SPSS.
- To ensure accuracy and consistency during field data collection, a range of tools and equipment were used for verifying geometric parameters, documenting site observations, and ensuring safety. The tools supported measurements of road geometry (such as gradients, lane widths, and curve radii) as well as location referencing and documentation. The list of equipment and their respective functions is summarized in Table 3-1

Table 3-1 Table 1: Equipment and Tools Used During the Research

Tool	**Use**	**Tool**	**Use**
Safety vest	To enhance visibility during road inspection	Camera	To document site observations
Tape measure	To measure longitudinal and sectional lengths	Speedometer	To record vehicle speeds
Dumpy level	To record road center-line elevations	GPS handle	To benchmark segment coordinates
Checklists	To guide the inspection process systematically	Computer	To record and analyze collected data

- This set of tools ensured that the data collected were both accurate and standardized for effective evaluation against **RTDA, Road Geometric Design Manual (2014)** guidelines and for use in further statistical analysis.

3.3.2 Data Collection Instrument for Questionnaire

A structured questionnaire served as the main tool for collecting perception-based data. It was designed to elicit both quantitative and qualitative insights related to driver behaviour, safety concerns, and the perceived impact of road geometry.

The questionnaire was divided into two tailored sections:

- Part A: For drivers regularly using Rwandan roads, focusing on their experience with road design features (e.g., curves, slopes) and their perceived impact on driving behaviour and safety.
- Part B: For road engineers and transport professionals, focusing on their evaluation of geometric design adequacy, familiarity with RTDA standards, and insights into challenges in geometric compliance and safety implementation.

3.3.3 Structure of the Questionnaire

The questionnaire included a mix of:

- Close-ended questions to gather categorical and demographic data,
- Likert-scale items to assess attitudes and perceptions quantitatively,
- Open-ended questions to allow for more detailed professional or experiential input from respondents.

This perception data complemented the objective geometric and crash data by providing user and expert insights into how road geometry influences safety and behaviour, allowing for triangulated analysis across all three methodological approaches

Table 3-2.Questionnaire Structure for Drivers (Part A)

Section	**Purpose**	**Type of Data**
Section 1: Demographic Information	Understand age, gender, driving experience, and road usage	Categorical

Section 2: Perception of Road Design	Rate road features such as curvature, width, visibility	Ordinal (1–5 scale)
Section 3: Driver Behavior & Road Features	Frequency of behaviors on difficult segments	Ordinal (Likert scale)
Section 4: Pedestrian & Safety Considerations	Frequency of yielding, challenges with pedestrian infrastructure	Categorical, Multiple choice
Section 5: Perception of Geometric Factors	Identify critical geometry-related safety issues	Categorical, Short answer
Section 6: Speed and Geometry Relationship	Explore links between geometry and speed perception	Ordinal & open-ended

*Table 3-3. **Engineer/Planner Questionnaire (Part B)***

Section	**Purpose**	**Type of Data**
Section 1: Professional Background	Gather professional qualifications and project locations	Categorical
Section 2: Technical Insight	Identify design practices, challenges, and recommendations	Categorical, Open-ended

3.3.3. Questionnaire Administration

The questionnaire was designed and administered using Google Forms to facilitate online distribution.

Distribution was conducted via email, social platforms, and in-person requests where applicable.

Responses were collected over a period of 2 weeks, from 16th June 2025 to 30th June 2025.Participation was voluntary and anonymity was assured.

3.3.4. Questionnaire Target Population and Sampling

- Driver respondents were selected based on their use of key Rwandan roads, including urban and rural routes such as NR2.

- Engineer respondents were targeted through professional networks including RTDA, consultants, and road contractors.
- The sample size was determined to ensure representativeness while considering time and accessibility.

3.4. Determination of Sample Size

3.4.1 Driver Survey Sample

Using **Cochran's formula** for sample size estimation in large populations:

$$N= \frac{Z^2.p.(1-p)}{e^2} \tag{3.1}$$

Where:

- Z = 1.645 for 90% confidence level
- p = 0.5 (assumed proportion)
- e = 0.1 (margin of error)

The calculated minimum sample size was 68 drivers. To enhance the reliability of the findings, a total of 100 drivers were surveyed. These included commercial bus, truck, and taxi drivers who are familiar with the Kigali–Rubavu route.

3.4.2 Road Segments Sample

Road segments were categorized based on their geometric characteristics into straight and sharp curve segments. A total of 40 segments were sampled along a 150 km stretch, comprising 20 straight segments and 20 sharp curve segments. The geometric data were obtained from the Rwanda Transport Development Agency (RTDA) in the form of **shape files**, which were processed using GIS software. Segment selection was guided by accident data provided by the Rwanda National Police in past 5 years, while driver comfort information was collected through a questionnaire administered to drivers. Both segments were analyzed using SPSS software.

3.4.3 Sampling Techniques and Sample Selection

A combination of **purposive** and **stratified random sampling** techniques was employed:

- **Purposive sampling** for selecting the **Kigali–Rubavu Road** based on known accident records and complex terrain.
- **Stratified sampling** to ensure representation of all road geometry types (curves, gradients, intersections).
- For driver surveys, **convenience sampling** was used at bus parks, truck stops, and driver cooperatives.

3.5 Field Observation and Sample Collection

Field teams conducted detailed road geometry measurements and driver behaviour observations:

Figure 3-1 Site Data Collection Photos at Different Segments of Road Corridor

3.5.1 Road Geometry Data Collection

- Instruments: GPS devices, measuring tapes, digital inclinometers.
- Data Collected: Segment length, lane width, curvature radius, gradient, superelevation, intersection types, shoulder width, and visibility.
- Data verified with **technical drawings and as-built designs** from RTDA and project contractors.

3.5.2 Traffic Accident Data Collection

- Sources: Rwanda National Police, district stations, Ministry of Infrastructure.
- Parameters: Location, date, time, accident type, severity, lighting, road surface, and suspected cause.
- Cross-verification ensured data accuracy.

3.5.3 Driver Behaviour Survey

- Questionnaires covered demographics, driving experience, perception of safety, difficulty in curved segments, and accident history.
- Minimum target: 68 drivers; achieved: 100.

3.6 Methodology for Selection of Roads and Survey Stretches

The **Kigali–Rubavu Road** was selected due to:

- High variability in geometric design (e.g., steep gradients, curves).
- Frequent accident records.
- Importance as a major transport corridor linking Kigali to western provinces.

Survey stretches were categorized based on:

- Geometric complexity.
- Accident frequency.
- Terrain classification (hill, slope, flat).

3.7 Data Analysis Methodology

The data analysis phase of this research followed a structured, three-pronged approach aligned with the overall mixed-methods design. It involved:

1. **Compliance checks of geometric parameters with RTDA, Road Geometric Design Manual (2014) standards**,
2. **Statistical modelling** of crash frequency and design factors using SPSS, and
3. **Behavioural and perceptual analysis** of responses from road users and professionals.

3.7.1 Geometric Compliance Assessment

As the **primary analytical step**, all collected geometric parameters such as horizontal curve radius, gradient, lane width, super-elevation and sight distance were assessed for compliance with **RTDA, Road geometric design manual (2014)** design guidelines. Segments failing to meet the minimum thresholds were classified as **non-compliant** and flagged for further safety concern analysis. This audit established a foundational understanding of safety risks inherent in road design deviations.

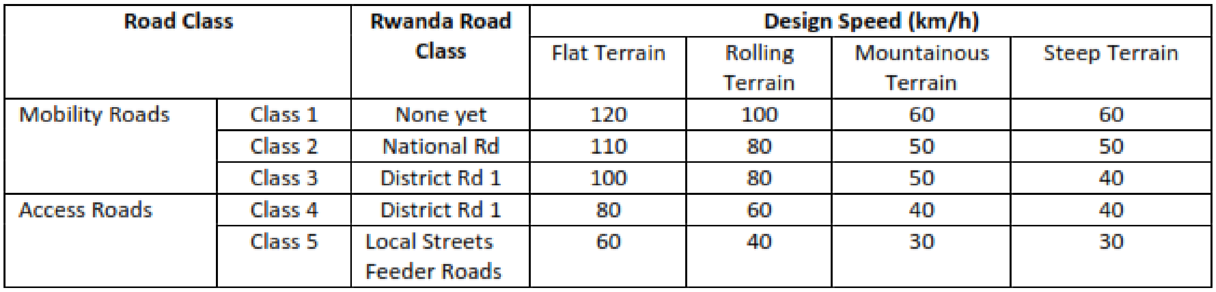
3.7.1.1. Summary of RTDA, Road geometric design manual (2014) Guidelines on Road Geometric Design Parameters

This study references the **RTDA, Road geometric design manual (2014)** as the standard guideline for evaluating and interpreting geometric road design features. These parameters influence driver behaviour and road safety outcomes and are essential in analysing accident risk across different terrain types.

a) Design Speed

Design speed determines the basis for all other geometric elements. **RTDA, Road geometric design manual (2014)** recommends design speeds based on terrain classification:

Table 3-4 Design Speed vs. Road Classification and Terrain Type



Road Class		**Rwanda Road Class**	**Design Speed (km/h)**			
			Flat Terrain	Rolling Terrain	Mountainous Terrain	Steep Terrain
Mobility Roads	Class 1	None yet	120	100	60	60
	Class 2	National Rd	110	80	50	50
	Class 3	District Rd 1	100	80	50	40
Access Roads	Class 4	District Rd 1	80	60	40	40
	Class 5	Local Streets Feeder Roads	60	40	30	30

Design speed is a critical control parameter that influences curve radius, sight distance, and superelevation rate.

Due to the nature of the NR2 road, which includes sections of rolling and mountainous terrain, the adopted design speeds in this study are **80 km/h** for rolling terrain and **60 km/h** for mountainous terrain, respectively.

b) Horizontal Curve Radius

The minimum horizontal curve radius ensures safe vehicle navigation through curves without skidding. It is derived using the formula:

$$\mathrm{Rmin} = \frac{V^2}{127(0.01emax + fmax)} \qquad (3.2)$$

Where:

- R = minimum curve radius (m)
- V = design speed (m/s)
- g = gravitational acceleration (9.81 m/s²)
- e = rate of superelevation (decimal)
- f= side friction factor

c) Superelevation (e)

Superelevation counteracts lateral acceleration on curves by tilting the roadway. For national roads, RTDA recommends:

- **Rolling Terrain:** 6% (emax)
- **Mountain Terrain:** 6% (emax)

d) Longitudinal Gradient

The maximum allowable gradient varies by terrain and road class:

Terrain Type	maximum gradient (%)
Rolling	5-7
Mountainous	7-9

Longitudinal slopes must be designed considering vehicle speed, load, and stopping distance.

e) Stopping Sight Distance (SSD)

SSD is the minimum visibility distance required for a driver to perceive a hazard and safely stop. The general AASHTO equation is:

$$\text{SSD}= 0.278Vt + 0.039\frac{V^2}{a} \qquad (3.3)$$

Where:

- V = speed (m/s)
- t= perception-reaction time (typically 2.5 sec)
- f= coefficient of friction (fmax=0.19)
- a = grade as a decimal (+ uphill, − downhill)

f) Lane and Shoulder Widths

As per RTDA standards, the lane and shoulder widths for national roads are specified as follows: 3.5 meters and 1.5 meters, respectively, for rolling terrain, and 3.5 meters and 1.5meter, respectively, for mountainous terrain. [33]

Table 3-5 ***Parameter Definition and Safety Design Criteria (Based on RTDA, 2014)***

Parameter	**Definition**	**Safety Design Criteria (AASHTO 2011)**
1. Lane Width	Lane width influences lateral clearance between vehicles, maneuvering space, and driver comfort. Narrow lanes may limit evasive actions and increase side-swipe risks.	For national roads, RTDA recommends a lane width of 3.5 **m** for rolling and mountainous terrain roads.
2. Curve Radius	Horizontal curves enable directional changes and must be designed to reduce lateral skidding and overturning. Smaller radii increase crash risk, especially on higher-speed roads.	Rmin=$\frac{V^2}{127(0.01emax+fmax)}$ (3.4) For a design speed of 80 km/h and 60km/h, **minimum curve radius = 201.5 m and 114m respectively**, assuming **superelevation = 6% (0.06)** and **side friction factor = 0.19**.for hairpin bends curves, **Rmin=60m**
3. Sight Distance	Sight distance determines how far ahead a driver can see an obstacle. Two key types: - SSD: Distance required to perceive and stop safely. -PSD: Distance required to safely overtake slower vehicles.	SSD= $0.278Vt + 0.039\frac{V^2}{a}$ (3.5) For 80 km/h and 60km/h speeds: - **SSD (Stopping Sight Distance) = 130 m and 83m respectively**, based on **t = 2.5 s**, **a = 3.4 m/s²**. - **PSD (Passing Sight Distance) = 573 m and 407m respectively**.
4. Superelevation	Superelevation (e) is the transverse slope of the road, which offsets the	RTDA allows **emax = 6%** for national road with rolling and mountainous

	lateral acceleration on curves and helps maintain vehicle stability. Insufficient superelevation leads to skidding or overturning.	terrain. Superelevation is calculated using this relation: $\frac{0.01e+f}{1-0.01ef}=\frac{V2}{gR}=\frac{0.0079V2}{R}=\frac{V^2}{127R}$ (3.6)
5. Grades	Grade is the longitudinal slope (% rise/fall). Steeper grades affect braking, acceleration, and sight distance especially under wet or heavy-load conditions.	For national **roads** in **rolling and mountainous terrain** at 8**0 km/h and 60km/h speeds**, RTDA specifies a **maximum grade of 7% and 9%** respectively for safety and vehicle control.

3.7.2 Statistical Models

To investigate the relationship between road geometry and accident occurrence, **count-based regression models** were applied using **SPSS 26.0**. The approach included:

- **Poisson regression** for modelling accident counts under the assumption that the mean equals the variance.
- In cases of **overdispersion** (i.e., when variance exceeded the mean), the more flexible **Negative Binomial regression** model was used to improve fit and reliability.
- For perception data that involved scaled responses (e.g., Likert scores), **linear regression** and descriptive summaries were utilized to explore relationships between design features and perceived risk or discomfort.

3.7.3 Statistical Tests

To support the quantitative component of this research, a range of **statistical tests and models** were applied to assess relationships between **road geometric parameters**, **crash occurrences**, and **driver behaviour**, based on both field-measured and survey-collected data. The tests were conducted using **SPSS 26.0**, with significance thresholds set at **$\alpha = 0.05$**. The analysis was conducted in three key stages: evaluating associations between categorical variables using **Chi-square tests**, modelling binary outcomes with **logistic regression**, and identifying key predictors of crash frequency using **count regression models** as discussed in Section 3.7.

3.7.3.1 Chi-Square Test of Independence

The **Pearson Chi-square test** was used to examine the potential **association between categorical variables**, such as segment type (curved vs. straight) and reported driver perceptions (Driver comfort). This test evaluated whether knowledge of one variable (e.g., curve type, curve radius, gradient etc) provided statistically significant insight into another (e.g., Accident count). [34], [35]

The hypotheses tested were:

- **H_0 (Null Hypothesis):** The variables are independent (no association exists).
- **H_1 (Alternative Hypothesis):** The variables are dependent (an association exists).

The Chi-square statistic (χ^2) was computed by comparing the **observed frequencies** of each variable combination with the **expected frequencies** assuming independence. The formula used was:

$$X^2 = \sum_{i,j} \frac{(Oij - Eij)^2}{Eij} \tag{3.7}$$

Where:

- Oij= observed frequency in cell *i, j*
- Eij= expected frequency in cell *i, j* under the null hypothesis

The test statistic was then compared against a **critical value** based on the degrees of freedom (df=(r−1) (c−1)) and significance level (**$\alpha = 0.05$**). A test statistic greater than the critical value led to **rejection of the null hypothesis**, confirming a statistically significant association between the variables.

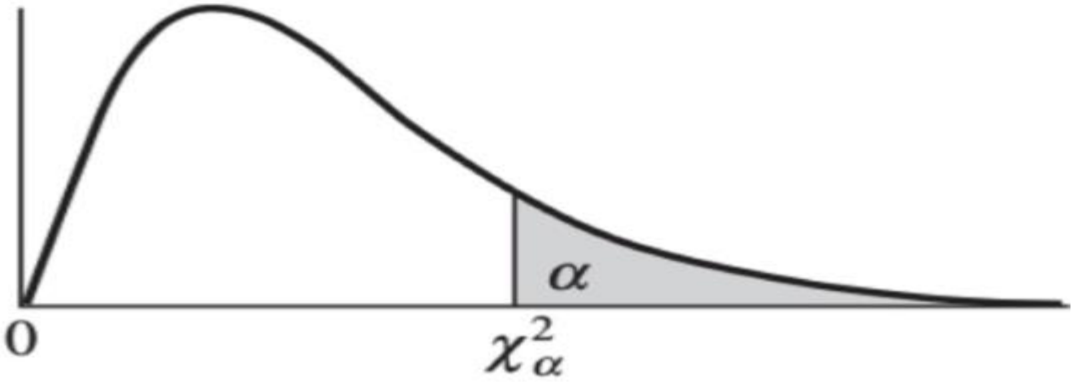


Figure 3-2. Chi-square distribution. [36]

This analysis was particularly useful in identifying whether geometric non-compliance (e.g., insufficient sight distance or sharp curve radius) had a significant relationship with drivers' reported perceptions of safety.

3.7.3.2 Count Data Regression Models

To model the relationship between road geometric features and accident frequency, the study employed **Generalized Linear Models (GLMs)** using **SPSS 26.0**. The dependent variable was **accident count per segment**, a non-negative integer, best suited for count models.

a) Poisson Regression

The **Poisson regression model** assumes that the mean and variance of the accident count are equal. It was initially used with the following predictors:

- **Segment Type** (curved = 1, straight = 0)
- **Curve Radius** (Low = 0, High = 1)
- **Gradient** (Low = 0, High = 1)

The model used a **log link function** to estimate the effect of each parameter on the expected number of accidents. However, **overdispersion** was detected (variance greater than mean), which violated Poisson assumptions.

b) Negative Binomial Regression

To address overdispersion, the study employed **Negative Binomial regression**, which introduces an extra dispersion parameter. This model provided a better fit for the data, as confirmed by lower values of:

- **Akaike Information Criterion (AIC)**
- **Log-likelihood**
- **Pearson Chi-Square / df**

3.7.3.3 Behavioral and Perception Analysis

Survey data collected from drivers and road engineers/planners were analysed to extract trends in behaviour and perception. The analysis focused on:

- **Quantifying perceptions** using a 5-point Likert scale to measure discomfort, visibility issues, and perceived safety across different geometric scenarios.
- **Identifying critical segments** based on recurring reports of discomfort or hazard perception, especially in segments flagged as non-compliant with AASHTO standards.
- **Cross-comparing professional and driver responses** to validate trends and highlight differences in user versus expert viewpoints.

3.7.4 Tools Used

A combination of field tools and software was utilized throughout the data collection and analysis process. These tools supported the measurement of road geometry, analysis of crash data, perception trends, and documentation. Key tools include:

- **SPSS 25.0**: Used for advanced statistical modelling, including Poisson and Negative Binomial regressions, correlation analysis, and evaluation of overdispersion in accident count data.
- **Microsoft Excel / Google Sheets**: Used extensively for data organization, calculation of summary statistics, perception analysis, and **graphical representation** of selected geometric evaluations. Specifically, **Figure 6: Checking for Curve Super-Elevations**

was developed using Excel to illustrate variations and compliance in super-elevation values across curved segments.

- **Field Equipment** *(see Table 3.1)*: Tools such as tape measures, dumpy level, GPS handle, and speedometer were used to collect accurate field data on curve radii, cross slopes, and elevations, which are essential for checking super-elevation and other geometric standards.
- **Camera and Checklists**: Assisted in documenting road segment conditions and ensuring consistency during field inspections.

This integrated toolkit ensured comprehensive and verifiable data capture, analysis, and presentation throughout the research process.

3.8 Statistical Modelling Approach

To analyse the influence of geometric design parameters on accident occurrence, multiple statistical models were employed using SPSS. These included linear regression, Poisson regression, and negative binomial regression. The selection of models was guided by the distribution of the accident count data and the nature of the predictors. The following statistical tests and criteria were used to validate the models:

3.8.1 Coefficient of Determination (R^2 and Adjusted R^2)

The **R-Square (R^2)** indicates the proportion of the variance in the dependent variable (accident count) explained by the independent variables. It is calculated as:

$$R^2 = 1 - \frac{SS\ residual}{SStotal} \tag{3.8}$$

The **Adjusted R^2** adjusts for the number of predictors:

$$Adjusted\ R^2 = 1 - (\frac{1-R^2}{n-k-1})(n-1) \tag{3.9}$$

Where is the sample size and is the number of predictors. Values close to 1 indicate strong explanatory power [37].

3.8.2 F-Test (ANOVA)

Used in the linear regression model to assess the joint significance of all predictors:

$$F=\frac{MSregression}{MS\ residual} \tag{3.10}$$

Where MS denotes mean square. A significant F-statistic ($p < 0.05$) indicates that the model explains a significant portion of the variance in the outcome [38].

3.8.3 Wald Chi-Square Test

In Poisson and Negative Binomial regression, the Wald test evaluates the significance of individual coefficients:

$$X^2 = (\frac{\beta}{SE(\beta)})^2 \tag{3.11}$$

A significant p-value ($p < 0.05$) suggests the predictor has a meaningful effect on accident count [39].

3.8.4 Omnibus Test (Likelihood Ratio Chi-Square)

This test compares the full model with all predictors against a null model with only an intercept:

$$X^2 = -2x(logLnull - \log Lfull) \tag{3.12}$$

A significant result ($p < 0.05$) implies that the model improves prediction compared to the null [40].

3.8.5 Akaike Information Criterion (AIC)

AIC assesses model quality by balancing fit and complexity:

$$AIC = 2k - 2\log{(L)} \tag{3.13}$$

Where is the number of parameters and is the likelihood. Lower AIC values indicate a better model fit [41].

3.8.6 Deviance and Scaled Deviance

Deviance measures the goodness of fit for GLMs. It is computed as:

$$D = 2(logLsaturated - \log Lmodel) \quad (3.14)$$

A deviance/df value near 1 suggests a good fit [42].

3.8.7 Degrees of Freedom (df)

Used to determine the shape of F or Chi-square distributions:

$$df = n - k - 1 \quad (3.15)$$

It reflects the number of values that are free to vary given the number of estimated parameters [43].

3.8.8 Significance Level (p-value or Sig.)

The significance level (alpha) defines the threshold for rejecting the null hypothesis. Standard thresholds are:

- $p < 0.05$: significant
- $p < 0.01$: highly significant
- $p > 0.05$: not significant [44]

3.9 Data Ethics and Validation

To ensure ethical standards and data reliability, the following measures were implemented:

- **Informed Consent**: All survey participants were fully briefed on the study's objectives and voluntarily agreed to participate.
- **Anonymity**: Respondent identities were anonymized during data processing and reporting.
- **Verification of Accident Records**: Cross-validated using multiple sources (e.g., traffic police, transport authorities).

- **Measurement Validation**: Field-obtained geometric data were cross-checked with official design plans or drawings wherever available to confirm accuracy.

3.10 Summary

This chapter detailed the robust methodology adopted in this study, encompassing **geometric design compliance checks**, **statistical modelling of crash data**, and **perception-based behavioural evaluation**. By integrating physical measurements, analytical modelling, and human insights, the research provides a **multi-dimensional understanding** of how geometric design influences road safety and driver behaviour. This comprehensive approach forms a strong foundation for the findings and interpretations discussed in the subsequent chapters.

4. CHAPTER 4: DATA ANALYSIS AND INTERPRETATION

4.1 Introduction

This chapter presents and interprets the results obtained through the three-part methodological approach: geometric compliance assessment, statistical modelling using SPSS, and perception analysis from drivers and road design professionals. The goal is to triangulate findings and provide a holistic understanding of how geometric road design influences accident occurrence and driver behaviour on the Kigali–Rubavu Road.

4.2. Data Collection

4.2.1 Road Geometry and Condition Survey

The road segments (n = 40) were assessed for geometric characteristics including lane width, shoulder width, curve radius, gradient, and Superelevation. Observations were recorded using GPS, inclinometer, and direct measurements.

Table 4-1: Road Geometry Data Collected at Each Segment

Segment ID	Segment Name	Location (GPS)	Segment Length (m)	Shoulder Width (m)	Lane width(m)	Curve Radius (m)	Gradient (%)	Intersection Type	Visibility (m)	Superelevation (%)	Notes
SEG001	GITIKINYONI	1°56'55.63"S 30°01'19.87"E	150	1.5	3.5	N.A	5	Y-intersection	241	1	Flat
SEG002	GITIKINYONI	1°56'55.63"S 30°01'19.87"E	**200**	**1.5**	**3.5**	**66.4**	**16.5**	**Y**	191	**17.8**	**Hilly**
SEG003	GATARE	1°55'58.02"S 30°01'30.33"E	**200**	**1.5**	**3.5**	**47.85**	**13.9**	**N. A**	164	**12.5**	**Hilly**
SEG004	GS. KANYINYA	1°54'01.83"S 29°59'38.70"E	**200**	**2.0**	**3.5**	**N. A**	**6.9**	**N. A**	364	**6.2**	**Flat**
SEG005	KAGARAMIRA	1°52'53.41"S 29°59'00.66"E	**200**	**1.5**	**3.5**	**205**	**6**	**N. A**	**181**	**12**	**Hilly**
SEG006	SHYORONGI	1°52'01.11"S 29°58'50.74"E	**200**	**1.5**	**3.5**	**N. A**	**9.2**	**Y**	381	**3**	**Flat**

SEG007	RUSASA	1°51'24.18"S 29°57'51.49"E	**200**	**1.5**	**3.5**	**101**	**10**	**N. A**	204	**22.7**	**Hilly**
SEG008	KWAGATSIBAGE	1°48'12.08"S 29°56'09.42"E	**200**	**1.5**	**3.5**	**100**	**13.5**	**N. A**	147	**15**	**Hilly**
SEG009	KINYANZI-TABA	1°48'08.29"S 29°55'59.12"E	**200**	**1.5**	**3.5**	**N. A**	**8.3**	**N. A**	185	**19**	**Flat**
SEG010	KINYANZI-TABA	1°47'55.33"S 29°55'54.98"E	**200**	**1.5**	**3.5**	**144**	**10.2**	**N. A**	209	**11.3**	**Flat**
SEG011	KIRENGE CENTER	1°47'47.14"S 29°55'44.35"E	**200**	**1.5**	**3.5**	**N. A**	**8.6**	**T**	184	**14.7**	**Flat**

SEG012	KIRENGE CENTER	1°47'14.28"S 29°55'33.69"E	**200**	**1.5**	**3.5**	**45**	**12.7**	**N. A**	169	**7**	**Hilly**
SEG013	KININI	1°45'02.98"S 29°55'17.13"E	**200**	**1.5**	**3.5**	**150**	**6.4**	**N. A**	214	**8.2**	**Hilly**
SEG014	GASIZA MARKET	1°43'48.18"S 29°55'08.33"E	**200**	**2.0**	**3.5**	**N. A**	**7**	**T**	196	**13**	**Flat**
SEG015	BASE	1°39'33.69"S 29°49'42.57"E	**200**	**1.0**	**3.5**	**102.5**	**3.5**	**N. A**	150	**4**	**Flat**
SEG016	GEKENKE	1°38'49.47"S 29°47'26.33"E	**200**	**1.5**	**3.5**	**N. A**	**7.5**	**N. A**	204	**15**	**Hilly**
SEG017	GAKENKE CENER	1°38'48.86"S 29°47'12.62"E	**200**	**1.5**	**3.5**	**65**	**6.1**	**N. A**	178	**4**	**Hilly**
SEG018	KIZIBA	1°38'57.78"S 29°46'35.55"E	**200**	**1.5**	**3.5**	**42**	**4.2**	**Y**	130	**3.5**	**Hilly**

SEG019	BURANGA	1°38'00.22"S 29°46'10.49"E	**250**	**1.5**	**3.5**	**95.5**	**17.1**	**N. A**	109	**4.2**	**Hairpin, Hilly**
SEG020	BURANGA CENTER	1°36'40.31"S 29°46'05.38"E	**250**	**1.5**	**3.5**	**96**	**8**	**T**	125	**8.6**	**Hairpin, Hilly**
SEG021	KIVURUGA	1°35'45.72"S 29°45'19.24"E	**200**	**1.5**	**3.5**	**51.7**	**18**	**T**	138	**5.6**	**Hilly**
SEG022	MUSANZE	1°30'31.63"S 29°38'31.71"E	**400**	**1.5**	**3.5**	**N. A**	**2.6**	+	481	**3**	**Flat**
SEG023	PRIME CEMENT	1°30'49.83"S 29°35'52.22"E	**250**	**1.5**	**3.5**	**90.5**	**6.7**	**N. A**	196	**9.5**	**Hilly**
SEG024	GATARAGA	1°31'57.94"S 29°34'05.37"E	**200**	**1.0**	**3.5**	**92.8**	**11.5**	**N. A**	200	**12.4**	**Hilly**
SEG025	MUKAMIRA (NR2, NR16	1°36'52.25"S 29°30'06.01"E	**200**	**1.0**	**3.5**	**N. A**	**1**	**T**	250	**3.8**	**Flat**

	JUNCTION)										
SEG026	BIGOGWE CENTER	1°38'18.63"S 29°24'03.07"E	**200**	**1.5**	**3.5**	**N. A**	**2.7**	**N. A**	176	**3.7**	**Hilly**
SEG027	NYAKIRIBA	1°40'25.07"S 29°21'25.45"E	**200**	**1.5**	**3.5**	**128**	**8**	**N. A**	289	**9**	**Hilly**
SEG028	MAHOKO	1°41'54.65"S 29°20'39.28"E	**200**	**1.5**	**3.5**	**N. A**	**1.5**	**T**	200	**1**	**Hilly**
SEG029	PFUNDA	1°41'56.68"S 29°19'04.34"E	**200**	**1.5**	**3.5**	**34.85**	**8.6**	**Y**	218	**7**	**Hilly**
SEG030	RUBAVU (ROUND ABOUT	1°39'55.31"S 29°15'44.15"E	**150**	**1.5**	**3.5**	**N. A**	**1**	**Round About**	224	**1.25**	**Hilly**
SEG031	CAFÉ INGANJI - SHYORONGI	1°54'12.66"S 29°59'44.46"E	**300**	**1.5**	**3.5**	**N. A**	**3.5**	**N. A**	225	**3.4**	**Hilly**

SEG032	MUKAMIRA	1°36'24.19"S 29°30'38.81"E	**300**	**1.5**	**3.5**	**N. A**	**1.76**	**N. A**	201	**1.5**	**Flat**
SEG033	RWINTARE CENTER	1°50'07.18"S 29°57'08.16"E	**300**	**1.5**	**3.5**	**N. A**	**3.5**	**N. A**	196	**7.4**	**Flat**
SEG034	MIZINGO-BIGOGWE	1°38'12.87"S 29°24'17.42"E	**300**	**1.5**	**3.5**	**N. A**	**0.7**	**N. A**	188	**1.2**	**Hilly**
SEG035	RULINDO	1°41'02.76"S 29°53'35.05"E	**300**	**1.5**	**3.5**	**N. A**	**3.5**	**N. A**	197	**10.5**	**Flat**
SEG036	RUGERERO	1°41'36.85"S 29°18'20.87"E	**300**	**1.5**	**3.5**	**N. A**	**2**	**N. A**	201	**0.5**	**Hilly**
SEG037	BYANGABO	1°33'37.05"S 29°33'09.45"E	**300**	**1.5**	**3.5**	**N. A**	**3.2**	**N. A**	321	**5.6**	**Flat**

SEG038	RWANKERI	1°34'49.55"S 29°31'40.23"E	**300**	**1.5**	**3.5**	**N. A**	**4.1**	**N. A**	209	**3.2**	**Hilly**
SEG039	RUGERERO	1°41'16.04"S 29°16'48.85"E	**200**	**1.0**	**3.5**	**80**	**8.6**	**N. A**	197	**8.3**	**Flat**
SEG040	BURANGA	1°38'17.59"S 29°46'13.48"E	**200**	**1.0**	**3.5**	**62.7**	**23.75**	**N. A**	131	**11.4**	**Hilly**

Observation: Segments with radius < 60 m and gradient > 7% showed visually reduced sight distance and reduced shoulders.

4.2.2 Traffic Accident Data Collection

Traffic accident records were collected from Rwanda National Police and local authorities between 2021–2025. These included time, location, severity, cause, and environmental conditions.

Table 4-2: Traffic Accident Data Collection

year	**Location (Segment ID)**	**Geometric Location**	**Slope (%)**	**Severity (Fatal/Serious/Minor)**	**Type (Head-on/Rear-end/etc.)**	**Weather**	**Lighting**	**Road Condition**	**Suspected Cause**	**Number of Accidents**

2021-2025	GITIKINYONI	At Tangent	5	Serious	Head-on	Sun	Daylight	Dry	**Rollover accident**	**2**
2021-2025	GITIKINYONI	**At Curve**	**16.5**	Serious	Head-on	**Sun**	**Daylight**	**Wet**	**Side-swipe collisions**	**5**
2021-2025	GATARE	**At Curve**	**13.9**	Serious	**Head-on**	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due curve severity	**6**
2021-2025	GS. KANYINYA	At Tangent	**6.9**	Serious	**Brake failure**	**sun**	**Daylight**	**Wet**	**Brake failure**	**3**
2021-2025	KAGARAMIRA	**At Curve**	**6**	Serious	Head-on	**sun**	**Daylight**	**Dry**	**Head-on collisions**	**4**
2021-2025	SHYORONGI	At Tangent	**9.2**	Serious	Head-on	**sun**	**Daylight**	**Dry**	**Not stop at Cross walks**	**4**
2021-2025	RUSASA	**At Curve**	**10**	Serious	**Rear-end**	**sun**	**Daylight**	**Wet**	**Rear-end collision**	**4**
2021-2025	KWAGATSIBAGE	**At Curve**	**13.5**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**4**
2021-2025	KINZANZI-TABA	At Tangent	**8.3**	Serious	Head-on	**sun**	**Daylight**	**Wet**	**Rollover accident**	**4**

2021-2025	KINYANZI-TABA	**At Curve**	**10.2**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**4**
2021-2025	KIRENGE CENTER	At Tangent	**8.6**	Serious	Head-on	**sun**	**Daylight**	**Wet**	**Head-on collision**	**4**
2021-2025	KIRENGE	**At Curve**	**12.7**	Serious	Head-on	**sun**	**Daylight**	**Wet**	**Head-on collisions**	**6**
2021-2025	KININI	**At Curve**	**6.4**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due curve severity	**4**
2021-2025	GASIZA MARKET	At Tangent	**7**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**3**
2021-2025	BASE	**At Curve**	**3.5**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**4**
2021-2025	GEKENKE	At Tangent	**7.5**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**4**

2021-2025	GAKENKE CENER	**At Curve**	**6.1**	Serious	Head-on	**sun**	**Daylight**	**Dry**	. Vehicle leaves the road due Over speeding	**4**
2021-2025	KIZIBA	**At Curve**	**4.2**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**7**
2021-2025	BURANGA	**At Curve**	**17.1**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Negotiating tight curve.	**5**
2021-2025	BURANGA CENTER	**At Curve**	**8**	Serious	Head-on	**sun**	**Daylight**	**Wet**	**Head-on collisions**	**4**
2021-2025	KIVURUGA	**At Curve**	**18**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Negotiating tight curve.	**6**
2021-2025	MUSANZE	At Tangent	**2.6**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**2**

2021-2025	PRIME CEMENT	**At Curve**	**6.7**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Negotiating tight curve.	**4**
2021-2025	GATARAGA	**At Curve**	**11.5**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**4**
2021-2025	MUKAMIRA (NR2, NR16 JUNCTION)	At Tangent	**1**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Negotiating tight curve.	**2**
2021-2025	BIGOGWE CENTER	At Tangent	**2.7**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**2**
2021-2025	NYAKIRIBA	**At Curve**	**8**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve, Vehicle leaves the road due Over speeding,	**4**

2021-2025	MAHOKO	At Tangent	**1.5**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	PFUNDA	**At Curve**	**8.6**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**8**
2021-2025	RUBAVU (ROUND ABOUT	At Tangent	**1**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	CAFÉ INGANJI-SHYORONGI	At Tangent	**3.5**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**2**
2021-2025	MUKAMIRA	At Tangent	**1.76**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	RWINTARE CENTER	At Tangent	**3.5**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	MIZINGO-BIGOGWE	At Tangent	**0.7**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**2**

2021-2025	RULINDO	At Tangent	**3.5**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	RUGERERO	At Tangent	**2**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**2**
2021-2025	BYANGABO	At Tangent	**3.2**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Vehicle leaves the road due Over speeding	**2**
2021-2025	RWANKERI	At Tangent	**4.1**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Vehicle leaves the road due Over speeding	**2**
2021-2025	RUGERERO	**At Curve**	**8.6**	Serious	Head-on	**sun**	**Daylight**	**Wet**	Negotiating tight curve.	**4**
2021-2025	BURANGA	**At Curve**	**23.75**	Serious	Head-on	**sun**	**Daylight**	**Dry**	Negotiating tight curve.	**5**

Insight: Most accidents occurred during rainfall, on tight curves, and in areas lacking shoulder space.

4.2.3. Driver Perception and Behavior Survey

A structured questionnaire was administered to 100 Private and commercial drivers. The survey captured their driving experience, perceptions of road safety, difficulty on curves, and accident history.

4.2.3.1. Structure of the Questionnaire

The questionnaire includes close-ended questions, Likert-scale questions, and a few open-ended items to allow for elaboration.

Part A: Driver Questionnaire

Section	Purpose	Type of Data
Section 1: Demographic Information	Understand age, gender, driving experience, and road usage	Categorical
Section 2: Perception of Road Design	Rate road features such as curvature, width, visibility	Ordinal (1–5 scale)
Section 3: Driver Behavior & Road Features	Frequency of behaviors on difficult segments	Ordinal (Likert scale)
Section 4: Pedestrian & Safety Considerations	Frequency of yielding, challenges with pedestrian infrastructure	Categorical, Multiple choice
Section 5: Perception of Geometric Factors	Identify critical geometry-related safety issues	Categorical, Short answer
Section 6: Speed and Geometry Relationship	Explore links between geometry and speed perception	Ordinal & open-ended

Part B: Engineer/Planner Questionnaire

Section	Purpose	Type of Data
Section 1: Professional Background	Gather professional qualifications and project locations	Categorical

Section	Purpose	Type of Data
Section 2: Technical Insight	Identify design practices, challenges, and recommendations	Categorical, Open-ended

4.2.3.2. Questionnaire Administration

- The questionnaire was designed and administered using Google Forms to facilitate online distribution.
- Distribution was conducted via email, social platforms, and in-person requests where applicable.
- Responses were collected over a period of 2weeks weeks, from 16th June 2025to 30th June 2025.
- Participation was voluntary and anonymity was assured.

4.2.3.3. Target Population and Sampling

- Driver respondents were selected based on their use of key Rwandan roads, including urban and rural routes such as NR2.
- Engineer respondents were targeted through professional networks including RTDA, consultants, and road contractors.
- The sample size was determined to ensure representativeness while considering time and accessibility.

4.3. Data Analysis

4.3.1. Geometric Assessment

4.3.1.1 Introduction

Road geometry data collected from 40 segments—comprising 20 curved and 20 straight segments—were analyzed separately to capture the distinct geometric characteristics and safety implications associated with each segment type. Each segment's geometric parameters, including lane width, shoulder width, horizontal curve radius, longitudinal gradient, sight distance, and Superelevation, were assessed for compliance with the thresholds specified in the RTDA Road Geometric Design Manual (2014). Where necessary, key parameters such as minimum curve radius, stopping sight distance, and Superelevation were computed using standard engineering formulas prescribed in the manual to allow for direct comparison with the design criteria. This compliance assessment aimed to identify non-conforming segments that may pose increased safety risks, and served as a foundational step for further statistical modeling and safety analysis.

4.3.1.2 Curved Segments

a. Lane and Shoulder width

Table 4-3.Lane and Shoulder width for Curved Segments

SN	**Segment Name**	Segment Length (m)	Field Shoulder Width (m)	Field Lane width(m)	Recommended Shoulder Width(m)	Recommended Lane Width(m)
1	GITIKINYONI	200	1.5	3.5	1.5	3.5
2	GATARE	200	1.5	3.5	1.5	3.5
3	KAGARAMIRA	200	1.5	3.5	1.5	3.5
4	RUSASA	200	1.5	3.5	1.5	3.5
5	KWAGATSIBAGE	200	1.5	3.5	1.5	3.5
6	KINYANZI-TABA	200	1.5	3.5	1.5	3.5
7	KIRENGE CENTER	200	1.5	3.5	1.5	3.5
8	KININI	200	1.5	3.5	1.5	3.5
9	BASE	200	1.0	3.5	1.0	3.5
10	GAKENKE CENER	200	1.5	3.5	1.5	3.5
11	KIZIBA	200	1.5	3.5	1.5	3.5
12	BURANGA	250	1.5	3.5	1.5	3.5
13	BURANGA CENTER	250	1.5	3.5	1.5	3.5

14	KIVURUGA	200	1.5	3.5	1.5	3.5
15	PRIME CEMENT	250	1.5	3.5	1.5	3.5
16	GATARAGA	200	1.0	3.5	1.0	3.5
17	NYAKIRIBA	200	1.5	3.5	1.5	3.5
18	PFUNDA	200	1.5	3.5	1.5	3.5
19	RUGERERO	200	1.0	3.5	1.5	3.5
20	BURANGA	200	1.0	3.5	1.5	3.5

As shown on Table 4-3,**the followings are the key findings:**

- All lane widths for curved segments are 3.5 m, which is compliant with RTDA recommendations for a 60–80 km/h road.
- Shoulder widths are mostly 1.5 m, but three segments (BASE, GATARAGA, RUGERERO, and BURANGA) show 1.0 m, which is not-compliant with RTDA Geometric Design Manual (2014) guidelines for rolling and mountainous terrain for national road.
- This suggests that shoulder width is the main area of non-compliance in this category, not lane width.

b. Curve Radius and Superelevation

Table 4-4. Curve Radius and Superelevation for Curved Segments

SN	**Segment Name**	Segment Length (m)	Measured Curve Radius (m)	Rmin for v=60km/h	Rmin for v=80km/h	Superelevation (%)	emax (%)
1	GITIKINYONI	200	66.4	114m	201.5m	17.8	6
2	GATARE	200	47.85	114m	201.5m	12.5	6
3	KAGARAMIRA	200	205	114m	201.5m	12	6
4	RUSASA	200	101	114m	201.5m	22.7	6
5	KWAGATSIBAGE	200	100	114m	201.5m	15	6
6	KINYANZI-TABA	200	144	114m	201.5m	11.3	6
7	KIRENGE CENTER	200	45	114m	201.5m	7	6
8	KININI	200	150	114m	201.5m	8.2	6
9	BASE	200	102.5	114m	201.5m	4	6
10	GAKENKE CENER	200	65	114m	201.5m	4	6
11	KIZIBA	200	42	114m	201.5m	3.5	6
12	BURANGA	250	95.5	114m	201.5m	4.2	6
13	BURANGA CENTER	250	96	114m	201.5m	8.6	6
14	KIVURUGA	200	51.7	114m	201.5m	5.6	6
15	PRIME CEMENT	250	90.5	114m	201.5m	9.5	6
16	GATARAGA	200	92.8	114m	201.5m	12.4	6

17	NYAKIRIBA	200	128	114m	201.5m	9	6
18	PFUNDA	200	34.85	114m	201.5m	7	6
19	RUGERERO	200	80	114m	201.5m	8.3	6
20	BURANGA	200	62.7	114m	201.5m	11.4	6

Interpretation of Table 4-4:

- According to RTDA (2014) and AASHTO guidelines, for:
    - **60 km/h**: Minimum curve radius (Rmin) ≈ **114 m**
    - **80 km/h**: Rmin ≈ **201.5 m**
    - **Maximum allowable Super elevation (emax)** = **6%**

Key Findings:

- **Only one segment (KAGARAMIRA)** exceeds the **201.5 m** minimum for 80 km/h, making it suitable for higher speeds.
- Many segments (e.g., GATARE, KIRENGE CENTER, KIZIBA, PFUNDA) have **curve radii much smaller than 114 m**, indicating **non-compliance** and **high crash risk** at speeds over **60 km/h**.
- Superelevation values for **most segments exceed 6%**, which **violates design standards** and may result in vehicle instability, especially in wet conditions. For example:

- RUSASA (22.7%), GITIKINYONI (17.8%), KWAGATSIBAGE (15%), etc.

Conclusion:

Many curves are **too sharp** for the intended speed, and **super elevation is often too high**, posing **a major safety concern**.

c. visibility, Passing Site Distance and Gradient

Table 4-5. visibility, Passing Site Distance and Gradient for Curved Segments

SN	**Segment Name**	Segment Length (m)	Field Gradient (%)	Gmax (%) for v=60km/h	Gmax (%) for v=80km/h	Visibility(m)	PSDmin(m) for v=60km/h	PSDmin (m)for v=80km/h
1	GITIKINYONI	200	16.5	9	7	191	407	573
2	GATARE	200	13.9	9	7	164	407	573
3	KAGARAMIRA	200	6	9	7	181	407	573
4	RUSASA	200	10	9	7	204	407	573
5	KWAGATSIBAGE	200	13.5	9	7	147	407	573
6	KINYANZI-TABA	200	10.2	9	7	209	407	573
7	KIRENGE CENTER	200	12.7	9	7	169	407	573
8	KININI	200	6.4	9	7	214	407	573
9	BASE	200	3.5	9	7	150	407	573
10	GAKENKE CENER	200	6.1	9	7	178	407	573
11	KIZIBA	200	4.2	9	7	130	407	573

12	BURANGA	250	17.1	9	7	109	407	573
13	BURANGA CENTER	250	8	9	7	125	407	573
14	KIVURUGA	200	18	9	7	138	407	573
15	PRIME CEMENT	250	6.7	9	7	196	407	573
16	GATARAGA	200	11.5	9	7	200	407	573
17	NYAKIRIBA	200	8	9	7	289	407	573
18	PFUNDA	200	8.6	9	7	218	407	573
19	RUGERERO	200	8.6	9	7	197	407	573
20	BURANGA	200	23.75	9	7	131	407	573

Interpretation of Table 4-5:

- **Gradient limits**: 9% (for v=60km/h), 7% (for v=80km/h)
- **Passing Sight Distance (PSD)** required:
  - 407 m (v=60 km/h)
  - 573 m (v=80 km/h)

Key Findings:

- **Gradient:**
  - 7 segments exceed the 9% limit (e.g., GITIKINYONI 16.5%, BURANGA 17.1%, KIVURUGA 18%, BURANGA 2: 23.75%) → **non-compliant**, especially dangerous when combined with curves.

- **Visibility:**
    - All segments have **visibility < 407 m**, with some as low as 109–150 m (e.g., BURANGA, KIZIBA, BASE).
    - Indicates **insufficient stopping/passing distance**, which compromises safety.

4.3.1.3 Straight Segments

a. Lane and Shoulder width

Table4-6. Lane and Shoulder width for Straight Segments

SN	**Segment Name**	Segment Length (m)	Field Shoulder Width (m)	Field Lane width(m)	Recommended Shoulder Width(m)	Recommended Lane Width(m)
1	GITIKINYONI	300	1.5	3.5	1.5	3.5
2	GS. KANYINYA	300	2.0	3.5	1.5	3.5
3	SHYORONGI	300	1.5	3.5	1.5	3.5
4	KINZANZI-TABA	300	1.5	3.5	1.5	3.5
5	KIRENGE CENTER	300	1.5	3.5	1.5	3.5
6	GASIZA MARKET	300	2.0	3.5	1.5	3.5
7	GEKENKE	200	1.5	3.5	1.5	3.5
8	MUSANZE	400	1.5	3.5	1.5	3.5
9	MUKAMIRA (NR2, NR16 JUNCTION)	200	1.0	3.5	1.0	3.5
10	BIGOGWE CENTER	200	1.5	3.5	1.5	3.5
11	MAHOKO	200	1.5	3.5	1.5	3.5
12	RUBAVU (ROUND ABOUT	300	1.5	4.0	1.5	3.5
13	CAFÉ INGANJI-SHYORONGI	300	1.5	3.5	1.5	3.5
14	MUKAMIRA	300	1.5	3.5	1.5	3.5
15	RWINTARE CENTER	300	1.5	3.5	1.5	3.5

16	MIZINGO-BIGOGWE	300	1.0	3.5	1.0	3.5
17	RULINDO	300	1.5	3.5	1.5	3.5
18	RUGERERO	300	1.5	3.5	1.5	3.5
19	BYANGABO	300	1.0	3.5	1.5	3.5
20	RWANKERI	300	1.0	3.5	1.5	3.5

Interpretation of Table4-6:

- **Lane widths** are mostly **3.5 m**, compliant with design standards.
- **Shoulder width:** Segments like **MUKAMIRA**, **BYANGABO**, **RWANKERI**, and **MIZINGO-BIGOGWE** have **1.0 m**, which may be **non-compliant** for 1.5 m as the minimum recommended from design standards.

b. visibility, Passing Site Distance and Gradient

Table 4-7 visibility, Passing Site Distance and Gradient for Straight Segments

SN	**Segment Name**	Segment Length (m)	Field Gradient (%)	Gmax (%) for v=60km/h	Gmax (%) for v=80km/h	Visibility(m)	PSDmin(m) for v=60km/h	PSDmin (m)for v=80km/h
1	GITIKINYONI	300	5	9	7	241	407	573
2	GS. KANYINYA	300	6.9	9	7	364	407	573
3	SHYORONGI	300	9.2	9	7	381	407	573
4	KINZANZI-TABA	300	8.3	9	7	185	407	573
5	KIRENGE CENTER	300	8.6	9	7	184	407	573
6	GASIZA MARKET	300	7	9	7	196	407	573
7	GEKENKE	200	7.5	9	7	204	407	573
8	MUSANZE	400	2.6	9	7	481	407	573

9	MUKAMIRA (NR2, NR16 JUNCTION)	200	1.0	9	7	250	407	573
10	BIGOGWE CENTER	200	2.7	9	7	176	407	573
11	MAHOKO	200	1.5	9	7	200	407	573
12	RUBAVU (ROUND ABOUT	300	1.0	9	7	224	407	573
13	CAFÉ INGANJI-SHYORONGI	300	3.5	9	7	225	407	573
14	MUKAMIRA	300	1.76	9	7	201	407	573
15	RWINTARE CENTER	300	3.5	9	7	196	407	573
16	MIZINGO-BIGOGWE	300	0.7	9	7	188	407	573
17	RULINDO	300	3.5	9	7	197	407	573
18	RUGERERO	300	2.0	9	7	201	407	573
19	BYANGABO	300	3.2	9	7	321	407	573
20	RWANKERI	300	4.1	9	7	209	407	573

Interpretation of Table 4-7:

- **Gradient**: All segments are **below 9%**, hence **compliant**.
- **Visibility**: None of the straight segments meet the **407 m minimum PSD** for 60 km/h.
    - Best cases (e.g., MUSANZE: 481 m, SHYORONGI: 381 m) are close but still **under the 573 m** required for 80 km/h.
    - **Most segments range between 176 m to 250 m**, showing **insufficient visibility** for safe overtaking or emergency stops.

Table4-8 **General Observations and Implications of Collected data**

Aspect	Curved Segments	Straight Segments
Lane Width	Compliant in all cases (3.5 m)	Compliant (3.5 m)
Shoulder Width	Some non-compliance (1.0 m instead of 1.5 m)	More frequent 1.0 m values — shoulder non-compliance more common here
Curve Radius	Most non-compliant for v = 60–80 km/h	Not applicable
Superelevation	Majority exceed 6% — dangerous	Not applicable
Gradient	7+ curved segments exceed max 9%, especially BURANGA (23.75%)	All straight segments compliant
Visibility/PSD	All curved segments fall short of PSD requirements **— major safety concern**	All straight segments also fall short **of PSD, though a few are close (e.g., MUSANZE, SHYORONGI)**

4.3.2. Quantitative Modelling

4.3.2.1. Introduction

Road geometry data were collected from 40 road segments, comprising both curved and straight sections. Key geometric variables included lane width, shoulder width, curve radius, gradient, Superelevation, visibility, and intersection type. For ease of analysis in SPSS, the dataset was carefully prepared and standardized in an Excel sheet to ensure that all variables were properly coded and interpretable by the software.

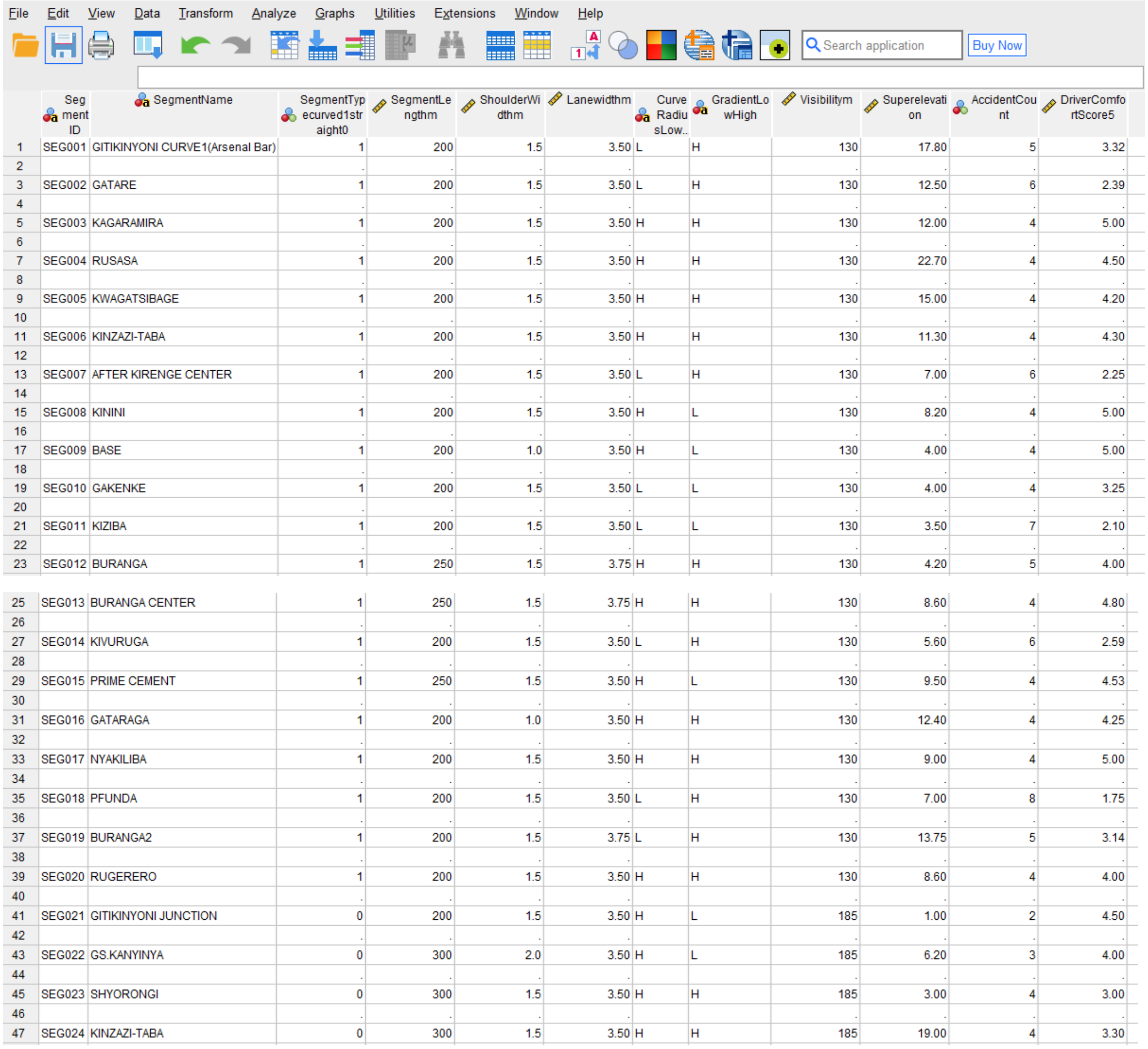
In the dataset, **curve radius** was classified into two categories: *Low* and *High*. Curves with a radius of **less than 60 meters** were classified as *Low*, based on geometric design standards from **AASHTO** and **Rwanda Transport Development Agency (RTDA)**, which recommend a **minimum radius of 60 meters for hairpin bends**. Radii greater than or equal to 60 meters were categorized as *High*. Similarly, **gradient** was classified into *Low* and *High* categories: segments with a gradient of **7% or less** were considered *Low*, while those exceeding **7%** were classified as *High*, again in accordance with AASHTO and RTDA standards. [33]

In addition, a **Driver Comfort Score** was calculated based on responses from a structured driver questionnaire. This perception-based score was incorporated into the dataset and factored alongside curve radius and gradient, as questionnaire responses consistently indicated that **driver discomfort was higher on sharp curves and steep gradients**.

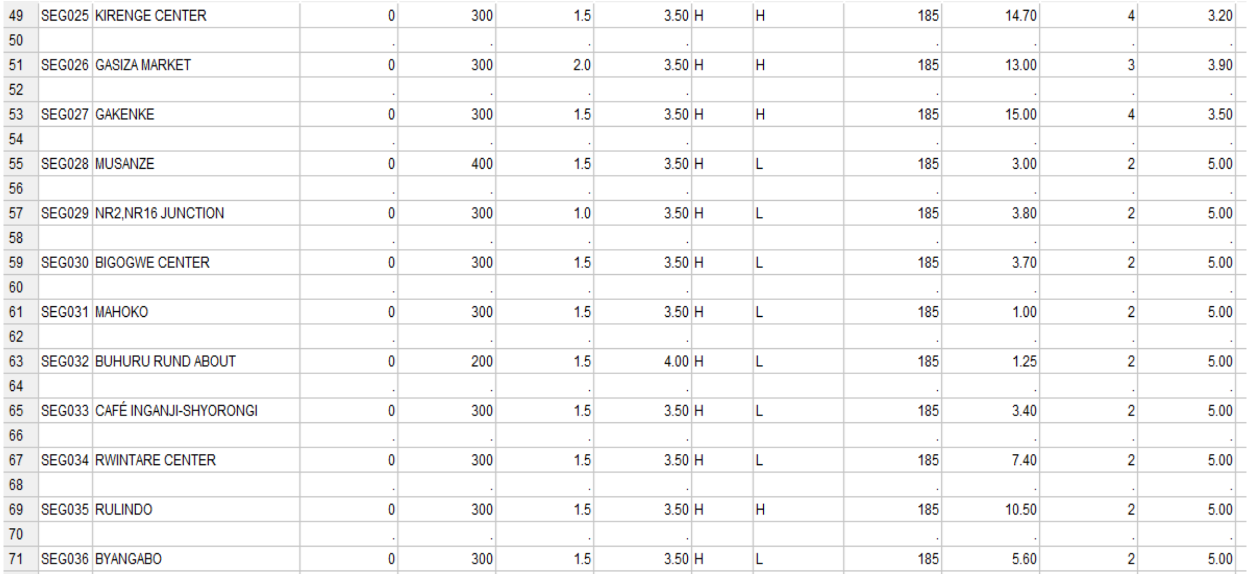
The adjusted dataset thus enabled effective analysis in SPSS, supporting both statistical modeling and interpretation of how geometric design elements and driver perception influence road safety. The

Table 4-9 below shows the exact format used for importing data into SPSS.

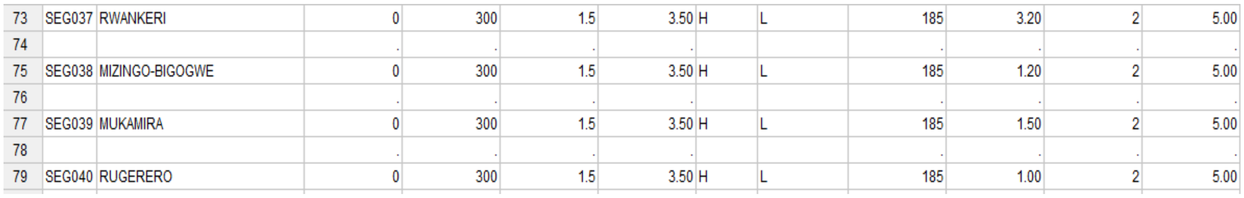
Table 4-9. SPSS Imported Data for Analysis



	Segment ID	SegmentName	SegmentTypecurved1straight0	SegmentLengthm	ShoulderWidthm	Lanewidthm	Curve RadiusLow..	GradientLowHigh	Visibilitym	Superelevation	AccidentCount	DriverComfortScore5
1	SEG001	GITIKINYONI CURVE1(Arsenal Bar)	1	200	1.5	3.50	L	H	130	17.80	5	3.32
2			.	.	.	.			.	.	.	.
3	SEG002	GATARE	1	200	1.5	3.50	L	H	130	12.50	6	2.39
4			.	.	.	.			.	.	.	.
5	SEG003	KAGARAMIRA	1	200	1.5	3.50	H	H	130	12.00	4	5.00
6			.	.	.	.			.	.	.	.
7	SEG004	RUSASA	1	200	1.5	3.50	H	H	130	22.70	4	4.50
8			.	.	.	.			.	.	.	.
9	SEG005	KWAGATSIBAGE	1	200	1.5	3.50	H	H	130	15.00	4	4.20
10			.	.	.	.			.	.	.	.
11	SEG006	KINZAZI-TABA	1	200	1.5	3.50	H	H	130	11.30	4	4.30
12			.	.	.	.			.	.	.	.
13	SEG007	AFTER KIRENGE CENTER	1	200	1.5	3.50	L	H	130	7.00	6	2.25
14			.	.	.	.			.	.	.	.
15	SEG008	KININI	1	200	1.5	3.50	H	L	130	8.20	4	5.00
16			.	.	.	.			.	.	.	.
17	SEG009	BASE	1	200	1.0	3.50	H	L	130	4.00	4	5.00
18			.	.	.	.			.	.	.	.
19	SEG010	GAKENKE	1	200	1.5	3.50	L	L	130	4.00	4	3.25
20			.	.	.	.			.	.	.	.
21	SEG011	KIZIBA	1	200	1.5	3.50	L	L	130	3.50	7	2.10
22			.	.	.	.			.	.	.	.
23	SEG012	BURANGA	1	250	1.5	3.75	H	H	130	4.20	5	4.00
25	SEG013	BURANGA CENTER	1	250	1.5	3.75	H	H	130	8.60	4	4.80
26			.	.	.	.			.	.	.	.
27	SEG014	KIVURUGA	1	200	1.5	3.50	L	H	130	5.60	6	2.59
28			.	.	.	.			.	.	.	.
29	SEG015	PRIME CEMENT	1	250	1.5	3.50	H	L	130	9.50	4	4.53
30			.	.	.	.			.	.	.	.
31	SEG016	GATARAGA	1	200	1.0	3.50	H	H	130	12.40	4	4.25
32			.	.	.	.			.	.	.	.
33	SEG017	NYAKILIBA	1	200	1.5	3.50	H	H	130	9.00	4	5.00
34			.	.	.	.			.	.	.	.
35	SEG018	PFUNDA	1	200	1.5	3.50	L	H	130	7.00	8	1.75
36			.	.	.	.			.	.	.	.
37	SEG019	BURANGA2	1	200	1.5	3.75	L	H	130	13.75	5	3.14
38			.	.	.	.			.	.	.	.
39	SEG020	RUGERERO	1	200	1.5	3.50	H	H	130	8.60	4	4.00
40			.	.	.	.			.	.	.	.
41	SEG021	GITIKINYONI JUNCTION	0	200	1.5	3.50	H	L	185	1.00	2	4.50
42			.	.	.	.			.	.	.	.
43	SEG022	GS.KANYINYA	0	300	2.0	3.50	H	L	185	6.20	3	4.00
44			.	.	.	.			.	.	.	.
45	SEG023	SHYORONGI	0	300	1.5	3.50	H	H	185	3.00	4	3.00
46			.	.	.	.			.	.	.	.
47	SEG024	KINZAZI-TABA	0	300	1.5	3.50	H	H	185	19.00	4	3.30



49	SEG025	KIRENGE CENTER	0	300	1.5	3.50	H	H	185	14.70	4	3.20
50			.	.	.	.			.	.	.	.
51	SEG026	GASIZA MARKET	0	300	2.0	3.50	H	H	185	13.00	3	3.90
52			.	.	.	.			.	.	.	.
53	SEG027	GAKENKE	0	300	1.5	3.50	H	H	185	15.00	4	3.50
54			.	.	.	.			.	.	.	.
55	SEG028	MUSANZE	0	400	1.5	3.50	H	L	185	3.00	2	5.00
56			.	.	.	.			.	.	.	.
57	SEG029	NR2,NR16 JUNCTION	0	300	1.0	3.50	H	L	185	3.80	2	5.00
58			.	.	.	.			.	.	.	.
59	SEG030	BIGOGWE CENTER	0	300	1.5	3.50	H	L	185	3.70	2	5.00
60			.	.	.	.			.	.	.	.
61	SEG031	MAHOKO	0	300	1.5	3.50	H	L	185	1.00	2	5.00
62			.	.	.	.			.	.	.	.
63	SEG032	BUHURU RUND ABOUT	0	200	1.5	4.00	H	L	185	1.25	2	5.00
64			.	.	.	.			.	.	.	.
65	SEG033	CAFÉ INGANJI-SHYORONGI	0	300	1.5	3.50	H	L	185	3.40	2	5.00
66			.	.	.	.			.	.	.	.
67	SEG034	RWINTARE CENTER	0	300	1.5	3.50	H	L	185	7.40	2	5.00
68			.	.	.	.			.	.	.	.
69	SEG035	RULINDO	0	300	1.5	3.50	H	H	185	10.50	2	5.00
70			.	.	.	.			.	.	.	.
71	SEG036	BYANGABO	0	300	1.5	3.50	H	L	185	5.60	2	5.00



73	SEG037	RWANKERI	0	300	1.5	3.50	H	L	185	3.20	2	5.00
74			.	.	.	.			.	.	.	.
75	SEG038	MIZINGO-BIGOGWE	0	300	1.5	3.50	H	L	185	1.20	2	5.00
76			.	.	.	.			.	.	.	.
77	SEG039	MUKAMIRA	0	300	1.5	3.50	H	L	185	1.50	2	5.00
78			.	.	.	.			.	.	.	.
79	SEG040	RUGERERO	0	300	1.5	3.50	H	L	185	1.00	2	5.00

4.3.2.2. Road Geometry, Accident Data and Driver Comfort Analysis for Road Segments

This section presents an in-depth analysis of the relationship between road geometric characteristics, accident occurrence, and driver comfort across 40 selected road segments. The data used include geometric parameters such as **lane width, shoulder width, visibility, segment length, Superelevation, curve radius**, and **gradient**, as well as **accident count** and **driver comfort scores** obtained through a structured questionnaire. Both curved and straight segments were included in the analysis to allow for a comprehensive comparison.

To evaluate how these variables, interact and influence road safety outcomes, three statistical methods were employed:

1. **Correlation analysis** was conducted to assess the strength and direction of relationships between key variables (segment type, Superelevation, accident count and driver comfort)
2. **Linear regression analysis** was used to determine the predictive power of geometric features and comfort scores on accident count.

3. **Poisson regression analysis** was applied as a count-based model to account for the distributional characteristics of accident data and model the relationship between geometric design elements and crash frequency.

Each model provides unique insights into how road geometry and driver perception contribute to accident patterns. The results of these models are presented in the following sections and used to draw conclusions on critical design factors affecting road safety.

Correlations

		Segment Type (curved=1, straight=0)	Superelevation (%)	Accident Count	Driver Comfort Score(/5)
Segment Type(curved=1, straight=0)	Pearson Correlation	1	.356*	.754**	-.384*
	Sig. (2-tailed)		.024	<.001	.014
	N	40	40	40	40
Superelevation (%)	Pearson Correlation	.356*	1	.360*	-.274
	Sig. (2-tailed)	.024		.023	.087
	N	40	40	40	40
Accident Count	Pearson Correlation	.754**	.360*	1	-.849**
	Sig. (2-tailed)	<.001	.023		<.001
	N	40	40	40	40
Driver Comfort Score(/5)	Pearson Correlation	-.384*	-.274	-.849**	1
	Sig. (2-tailed)	.014	.087	<.001	
	N	40	40	40	40

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Pearson Correlations

🟩 **Highly Positive :** *(None)*

🟩 **Positive :** *(Segment Type(curved=1,straight=0) <---> Superelevation (%)), (Segment Type(curved=1,straight=0) <---> Accident Count), (Superelevation (%) <---> Accident Count)*

🟨 **No Linear Correlation :** *(None)*

🟥 **Negative :** *(Segment Type(curved=1,straight=0) <---> Driver Comfort Score(/5)), (Superelevation (%) <---> Driver Comfort Score(/5)), (Accident Count <---> Driver Comfort Score(/5))*

🟥 **Highly Negative :** *(None)*

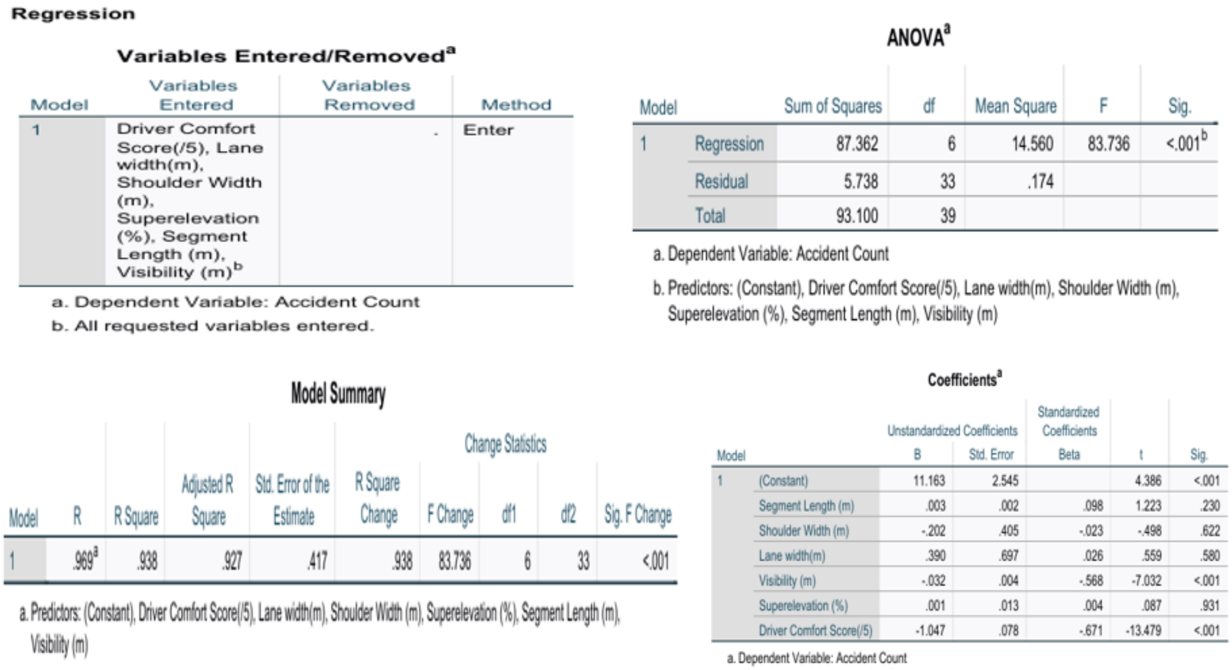
*Figure 4-1****. Correlation Analysis for Road Segments (SPSS Outputs)***

Error! Reference source not found. shows Pearson correlation results between accident count, segment type, driver comfort, and superelevation as shown from **Figure** 4-1. Accident count was strongly positively correlated with segment type (r = 0.754, p < 0.001), suggesting more crashes in curved segments. Driver comfort score showed a strong negative correlation with accident count (r = -0.849, p < 0.001), indicating that lower comfort is associated with higher accident rates. Superelevation had a moderate positive correlation with accident count (r = 0.360, p = 0.023).

Table 4-10 ***Pearson Correlation Matrix***

Variables	**Segment Type**	**Superelevation (%)**	**Accident Count**	**Driver Comfort Score (/5)**
Segment Type	1	0.356*	0.754**	-0.384*
Superelevation (%)	0.356*	1	0.360*	-0.274
Accident Count	0.754**	0.360*	1	-0.849**
Driver Comfort Score (/5)	-0.384*	-0.274	-0.849**	1

*p < 0.05, **p < 0.01



Regression

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Driver Comfort Score(/5), Lane width(m), Shoulder Width (m), Superelevation (%), Segment Length (m), Visibility (m)[b]	.	Enter

a. Dependent Variable: Accident Count

b. All requested variables entered.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	87.362	6	14.560	83.736	<.001[b]
	Residual	5.738	33	.174		
	Total	93.100	39			

a. Dependent Variable: Accident Count

b. Predictors: (Constant), Driver Comfort Score(/5), Lane width(m), Shoulder Width (m), Superelevation (%), Segment Length (m), Visibility (m)

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.969[a]	.938	.927	.417	.938	83.736	6	33	<.001

a. Predictors: (Constant), Driver Comfort Score(/5), Lane width(m), Shoulder Width (m), Superelevation (%), Segment Length (m), Visibility (m)

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	11.163	2.545		4.386	<.001
	Segment Length (m)	.003	.002	.098	1.223	.230
	Shoulder Width (m)	-.202	.405	-.023	-.498	.622
	Lane width(m)	.390	.697	.026	.559	.580
	Visibility (m)	-.032	.004	-.568	-7.032	<.001
	Superelevation (%)	.001	.013	.004	.087	.931
	Driver Comfort Score(/5)	-1.047	.078	-.671	-13.479	<.001

a. Dependent Variable: Accident Count

*Figure 4-2****. Regression Analysis for Road Segments (SPSS Outputs)***

The Figure 4-2 shows the output of a multiple linear regression analysis performed in SPSS to investigate how several geometric design elements and driver comfort influence accident count**.** Below is a detailed interpretation of each section:

1. **Variables Entered**

- Dependent Variable**:** Accident Count
- Independent (Predictor) Variables:
    - Driver Comfort Score
    - Lane Width (m)
    - Shoulder Width (m)
    - Superelevation (%)
    - Segment Length (m)
    - Visibility (m)

All variables were entered using the "Enter" method (standard multiple regression).The Results are interpreted in Table 4-11,Table 4-12 and Table4-13below.

Table 4-11. Regression Analysis Model Summary Table

Metric	**Value**	**Interpretation**
R	0.969	Strong correlation between predictors and accident count
R²	0.938	93.8% of the variation in accident count is explained by the model
Adjusted R²	0.923	Adjusted for number of predictors—still very high, meaning good model generalization
Std. Error	0.417	Standard deviation of residuals; lower means better fit
R² Change	0.938	Same as R² since it's the first model
F Change	83.736	F-test for overall significance (very high)
Sig. F Change	<0.001	Model is statistically significant at $p < 0.001$

General Interpretation: The model is highly significant and explains a large proportion of accident count variability.

Table 4-12.ANOVA Table

Source	SS	df	MS	F	Sig.
Regression	87.362	6	14.560	83.736	<0.001
Residual	5.738	33	0.174		
Total	93.100	39			

Interpretation: The F-value (83.736) and Sig. < 0.001 confirm that the model significantly predicts accident count. This means at least one of the predictors contributes significantly.

Table4-13 Coefficients Table

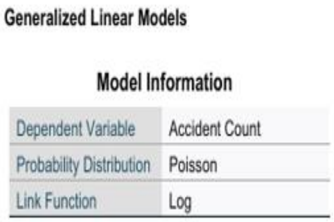
Variable	**B (Unstandardized)**	**Beta (Standardized)**	**t**	**Sig.**
(Constant)	8.116	–	5.254	<0.001
Segment Length	0.202	0.138	1.288	0.207
Shoulder Width	-0.200	-0.252	-2.291	0.029
Lane Width	-0.392	-0.394	-3.594	0.001
Visibility	-0.003	-0.052	-0.386	0.702
Superelevation	-0.014	-0.067	-0.470	0.641
Driver Comfort Score	-0.281	-0.715	-5.796	<0.001

Interpretation:

- **Significant predictors** ($p < 0.05$):
  - Driver Comfort Score**:** Strongest negative predictor (Beta = -0.715), as comfort improves, accidents decrease.
  - Lane Width: Negative impact, narrower lanes associated with higher accidents.
  - Shoulder Width: Negative impact, wider shoulders reduce accident count.
- Non-significant predictors ($p > 0.05$):
  - Segment Length, Visibility, Superelevation, these do not significantly predict accident count in this model.

Conclusion:

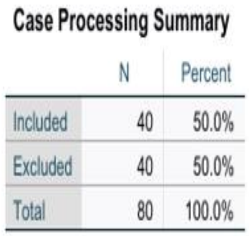
- The regression model is statistically significant and explains **~94%** of the variation in accident count.
- The most important variables influencing accident count are:
  - Driver Comfort Score (most significant)
  - Lane Width
  - Shoulder Width
- Recommendations can be made to improve driver comfort and ensure adequate lane and shoulder widths for enhancing road safety.



Generalized Linear Models

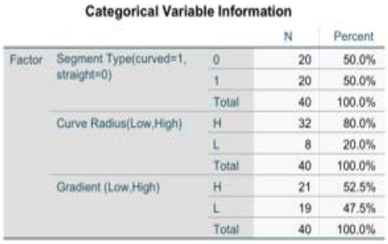
Model Information

Dependent Variable	Accident Count
Probability Distribution	Poisson
Link Function	Log



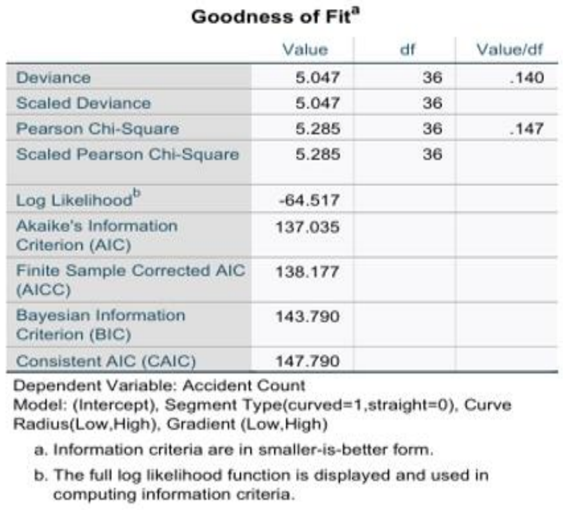
Case Processing Summary

	N	Percent
Included	40	50.0%
Excluded	40	50.0%
Total	80	100.0%



Categorical Variable Information

			N	Percent
Factor	Segment Type(curved=1, straight=0)	0	20	50.0%
		1	20	50.0%
		Total	40	100.0%
	Curve Radius(Low,High)	H	32	80.0%
		L	8	20.0%
		Total	40	100.0%
	Gradient (Low,High)	H	21	52.5%
		L	19	47.5%
		Total	40	100.0%



Goodness of Fit[a]

	Value	df	Value/df
Deviance	5.047	36	.140
Scaled Deviance	5.047	36	
Pearson Chi-Square	5.285	36	.147
Scaled Pearson Chi-Square	5.285	36	
Log Likelihood[b]	-64.517		
Akaike's Information Criterion (AIC)	137.035		
Finite Sample Corrected AIC (AICC)	138.177		
Bayesian Information Criterion (BIC)	143.790		
Consistent AIC (CAIC)	147.790		

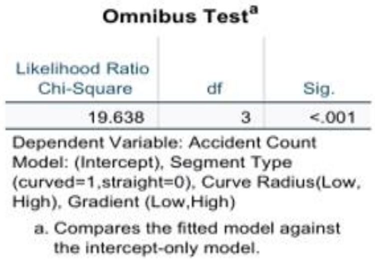
Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,High), Gradient (Low,High)

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Accident Count	40	2	8	3.65	1.545

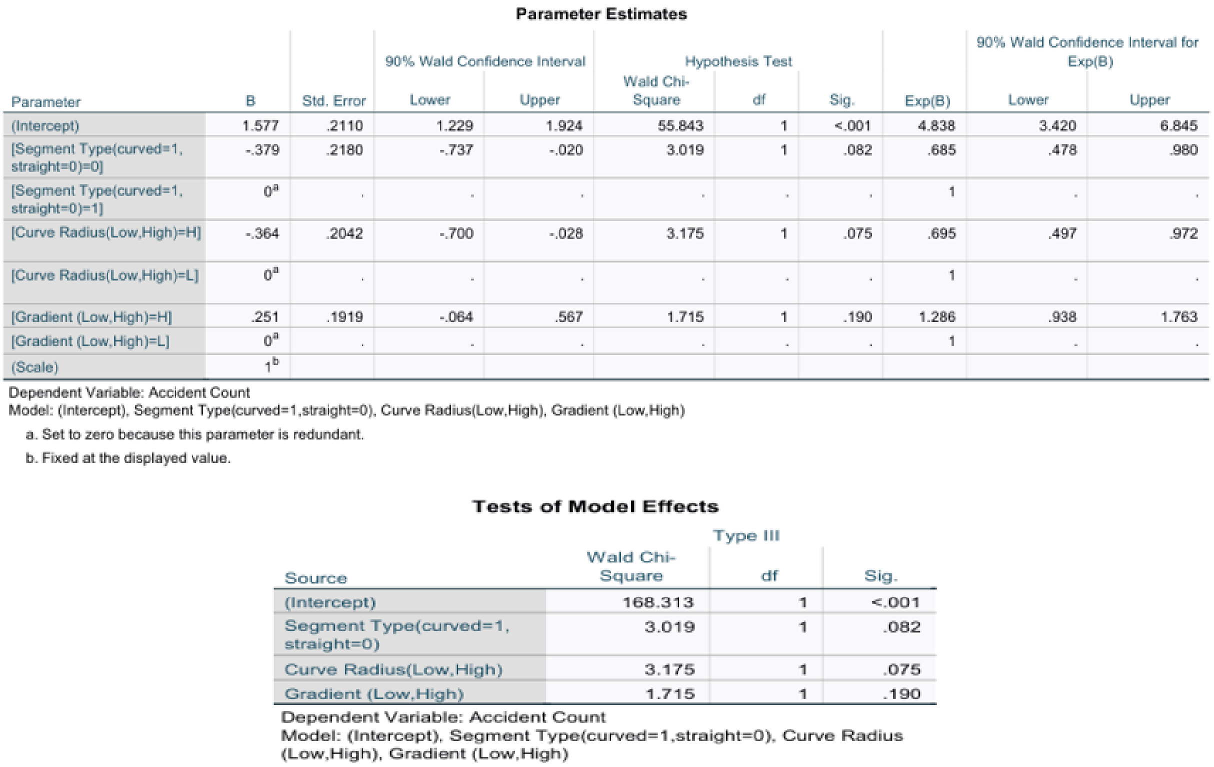


Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
19.638	3	<.001

Dependent Variable: Accident Count
Model: (Intercept), Segment Type (curved=1,straight=0), Curve Radius(Low, High), Gradient (Low,High)

a. Compares the fitted model against the intercept-only model.



Parameter Estimates

Parameter	B	Std. Error	90% Wald Confidence Interval Lower	90% Wald Confidence Interval Upper	Hypothesis Test Wald Chi-Square	Hypothesis Test df	Hypothesis Test Sig.	Exp(B)	90% Wald Confidence Interval for Exp(B) Lower	90% Wald Confidence Interval for Exp(B) Upper
(Intercept)	1.577	.2110	1.229	1.924	55.843	1	<.001	4.838	3.420	6.845
[Segment Type(curved=1, straight=0)=0]	-.379	.2180	-.737	-.020	3.019	1	.082	.685	.478	.980
[Segment Type(curved=1, straight=0)=1]	0[a]	.	.	.	.	.	.	1	.	.
[Curve Radius(Low,High)=H]	-.364	.2042	-.700	-.028	3.175	1	.075	.695	.497	.972
[Curve Radius(Low,High)=L]	0[a]	.	.	.	.	.	.	1	.	.
[Gradient (Low,High)=H]	.251	.1919	-.064	.567	1.715	1	.190	1.286	.938	1.763
[Gradient (Low,High)=L]	0[a]	.	.	.	.	.	.	1	.	.
(Scale)	1[b]									

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,High), Gradient (Low,High)

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Tests of Model Effects

Source	Type III Wald Chi-Square	Type III df	Type III Sig.
(Intercept)	168.313	1	<.001
Segment Type(curved=1, straight=0)	3.019	1	.082
Curve Radius(Low,High)	3.175	1	.075
Gradient (Low,High)	1.715	1	.190

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius (Low,High), Gradient (Low,High)

Figure 4-3. ***Poisson Regression Analysis for Road Segments (SPSS Outputs)***

The Figure 4-3shows the output of a poison regression analysis performed in SPSS to investigate how several geometric design elements and driver comfort influence accident count**.** Below is a detailed interpretation of each section:

1.Model Information:

Dependent Variable**:** Accident Count

Distribution: Poisson (used for count data)

Link Function: Log

2. Case Processing Summary

- **N = 40 cases** included (no missing data)
- The data consists of 50% curved and 50% straight segments**.**

3. Categorical & Continuous Variables

- **Categorical Predictors**:

    - Segment Type: Curved (1), Straight (0)
    - Curve Radius: Low (1), High (0)
    - Gradient: Low (1), High (0)
- **Continuous Dependent Variable**: Accident Count (Range: 2–8, Mean: 3.65)

4.Goodness of Fit Table

Table 4-14 Goodness of Fit

Measure	Value	df	Sig.
Deviance	5.047	36	0.140
Pearson Chi-Square	5.285	36	0.147
AIC (Akaike)	137.035	–	–
Log Likelihood	-64.517	–	–

Interpretation:

- Deviance and Pearson Chi-Square p-values > 0.05 → good model fit; no significant lack of fit.
- Lower AIC and BIC values suggest better model parsimony (smaller = better)**.** Omnibus Test of Model Coefficients

Table 4-15 ***Omnibus Test of Model Coefficients***

Likelihood Ratio Chi-Square	**df**	**Sig.**
19.638	3	<0.001

Interpretation: The overall model is **statistically significant** compared to a null model (no predictors). The included predictors improve prediction of accident count.

Table 4-16 Parameter Estimates

Predictor	B	Sig.	Exp(B)	Interpretation
(Intercept)	1.577	<0.001	4.838	Baseline incident rate (straight, high radius, high gradient)

Segment Type (curved=1)	-0.379	0.082	0.685	Curved segments have fewer accidents (but **not significant**)
Curve Radius (Low=1)	-0.364	0.075	0.695	Low-radius curves reduce accidents **(borderline)**
Gradient (Low=1)	0.251	0.190	1.286	Low gradient increases accident rate (but **not significant**)

Interpretation:

- None of the predictors are statistically significant at $p < 0.05$, although **curve radius** and **segment type** are close.
- **Exp(B)** shows:
    - Curved segments have ~31.5% fewer accidents (1 - 0.685).
    - Low radius curves have ~30.5% fewer accidents.
    - Low gradient segments show a 28.6% increase in accidents.

Table 4-17 Tests of Model Effects (Type III Wald Chi-Square

Effect	Chi-Square	df	Sig.
Segment Type	3.019	1	0.082
Curve Radius	3.175	1	0.075
Gradient	1.715	1	0.190

Interpretation:

- None of the predictors are individually significant, though segment type and curve radius are near significance (at $p < 0.10$).

Conclusion and Recommendations

- The Poisson regression model fits well overall and is statistically significant (Omnibus test $p < 0.001$).
- However, individual predictors are not statistically significant at the 5% level.

- Curved segments and low-radius curves tend to be safer, though this trend is only borderline significant.

These findings support that curved segments and smaller radii contribute to higher accident risks, as echoed by [45, 46], although statistical significance weakens when overdispersion is accounted for.

4.3.2.3 Model Validation

The linear regression model demonstrates a strong fit ($R^2 = 0.938$,Figure 4-2) indicating that geometric design and perception factors explain a significant portion of the variability in accident count. Among the predictors, visibility and driver comfort score were statistically significant. Increased visibility and improved driver comfort are associated with a notable reduction in accident counts. Other geometric variables such as segment length, lane and shoulder widths, and Superelevation did not show significant influence individually in this model.

A Poisson regression model was applied to examine the effect of geometric design elements on accident count. The predictors included segment type (curved or straight), curve radius (low or high), and gradient (low or high). The model demonstrated a good fit (AIC = 137.035, Deviance/df = 0.140), and the omnibus test was statistically significant ($\chi^2 = 19.638$, $p < 0.001$), indicating that the predictors collectively improved the model compared to the intercept-only model.

Among the predictors, both **segment type** and **curve radius** were marginally significant ($p = 0.082$ and 0.075, respectively), suggesting that straight segments and high-radius curves are associated with fewer accidents. The gradient variable was not statistically significant ($p = 0.190$). These findings align with roadway design expectations, where sharp curves and curved segments generally pose higher accident risks due to limited visibility and increased centrifugal force.

4.3.3. Qualitative Analysis

4.3.3.1. Accident Pattern Analysis

From police records and local authority databases, a total of 146 accidents were recorded across the selected segments between 2021 and 2025. Most common types included Vehicle leaves the road due to high speed, negotiating tight curve, head-on collisions and rear-end crashes, with rainy conditions and poor visibility as aggravating factors.

Table 4-18: Accident Frequency by Segment Type

Segment Type	Avg. Accidents/Year
Sharp Curves	19.2
Straight Sections	10

4.3.3.2 Driver Perception and Road Design Engineers' Perspectives on Road Geometry and Safety

To complement the quantitative analysis of geometric data and crash records, this section presents insights from a perception survey conducted among **100 drivers** and **45 road geometry** design engineers. The objective was to assess how road users and professionals perceive the influence of geometric design on driver behavior and road safety.

a. Driver Perception Analysis

The majority of drivers reported discomfort when navigating road segments with sharp curves and steep gradients. Key findings include:

- **78%** of drivers reported **frequent sudden braking** when approaching sharp curves.
- **62%** rated visibility as **poor (less than 3 out of 5)**, especially in areas with dense vegetation or steep descents.
- **41%** of drivers admitted to **previous accident involvement** on the assessed routes.
- **Driver category breakdown**: 50% were private vehicle drivers, 21.7% commercial truck drivers, 22.8% bus drivers, and 1% motorcycle operators.

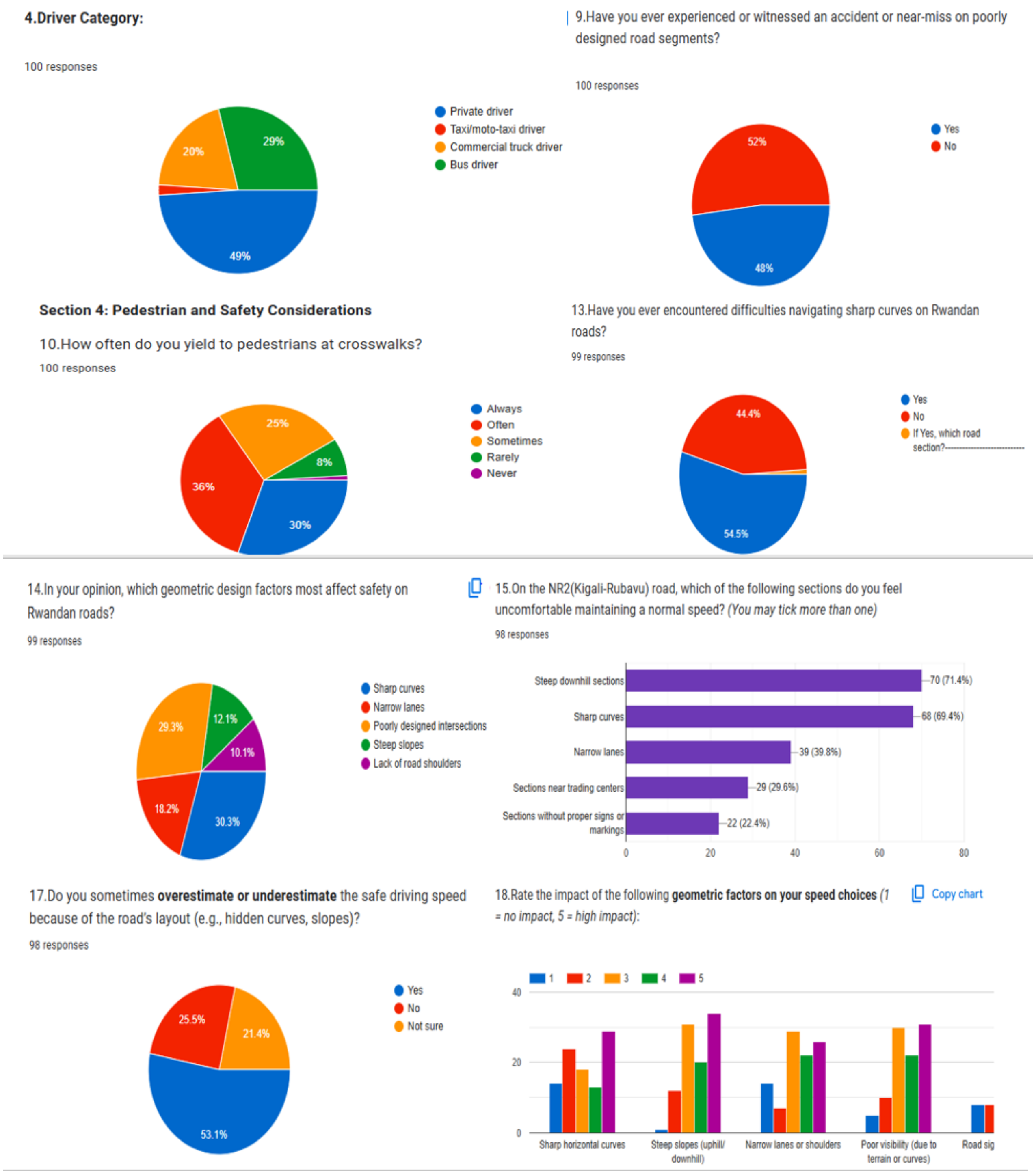
- **51%** of the drivers had **experienced or witnessed an accident or near-miss** on poorly designed road segments.
- **57.6%** encountered **difficulties navigating sharp curves**, with the **Buranga area** being reported as particularly problematic.
- **31.2%** of respondents identified **sharp curves** as the most critical geometric design factor affecting safety on Rwandan roads, followed by **poorly designed intersections**.
- For roads like **NR2 (Kigali–Rubavu)**, drivers reported that **steep downhills and sharp curves** significantly impact their ability to maintain normal speeds.
- **53.2%** of drivers admitted to **overestimating or underestimating speed** due to road layout features such as **hidden curves and steep slopes**.
- Overall, **sharp curves, steep gradients, and poor visibility** were consistently highlighted as the **most influential factors** affecting drivers' speed choices and overall comfort.

b. Road Design Engineers' Perspectives

A total of **45 road geometry design engineers** participated in the survey. The findings reflect challenges and gaps in current road design practices in Rwanda:

- **85%** of respondents were **civil engineers by profession**.
- **66%** have worked or are currently working on **road projects in Rwanda**.
- Over **95%** reported using **RTDA design standards and AASHTO guidelines** for road geometry design.
- The most commonly cited challenges in geometric design for Rwanda's **hilly terrain** were:
    - Controlling slope gradients
    - Minimizing sharp curves
- Alarmingly, **around 50%** of engineers reported that accident data is not considered during the design process.
- Additionally, sight distance and shoulder width were reported as being neglected by approximately 40% of designers when planning road geometry**.**

These findings underline the need for integrating accident data, perception studies, and safety audits into road geometric design—especially in topographically complex regions such as Rwanda.



4.Driver Category:

100 responses

9.Have you ever experienced or witnessed an accident or near-miss on poorly designed road segments?

100 responses

Section 4: Pedestrian and Safety Considerations

10.How often do you yield to pedestrians at crosswalks?

100 responses

13.Have you ever encountered difficulties navigating sharp curves on Rwandan roads?

99 responses

14.In your opinion, which geometric design factors most affect safety on Rwandan roads?

99 responses

15.On the NR2(Kigali-Rubavu) road, which of the following sections do you feel uncomfortable maintaining a normal speed? *(You may tick more than one)*

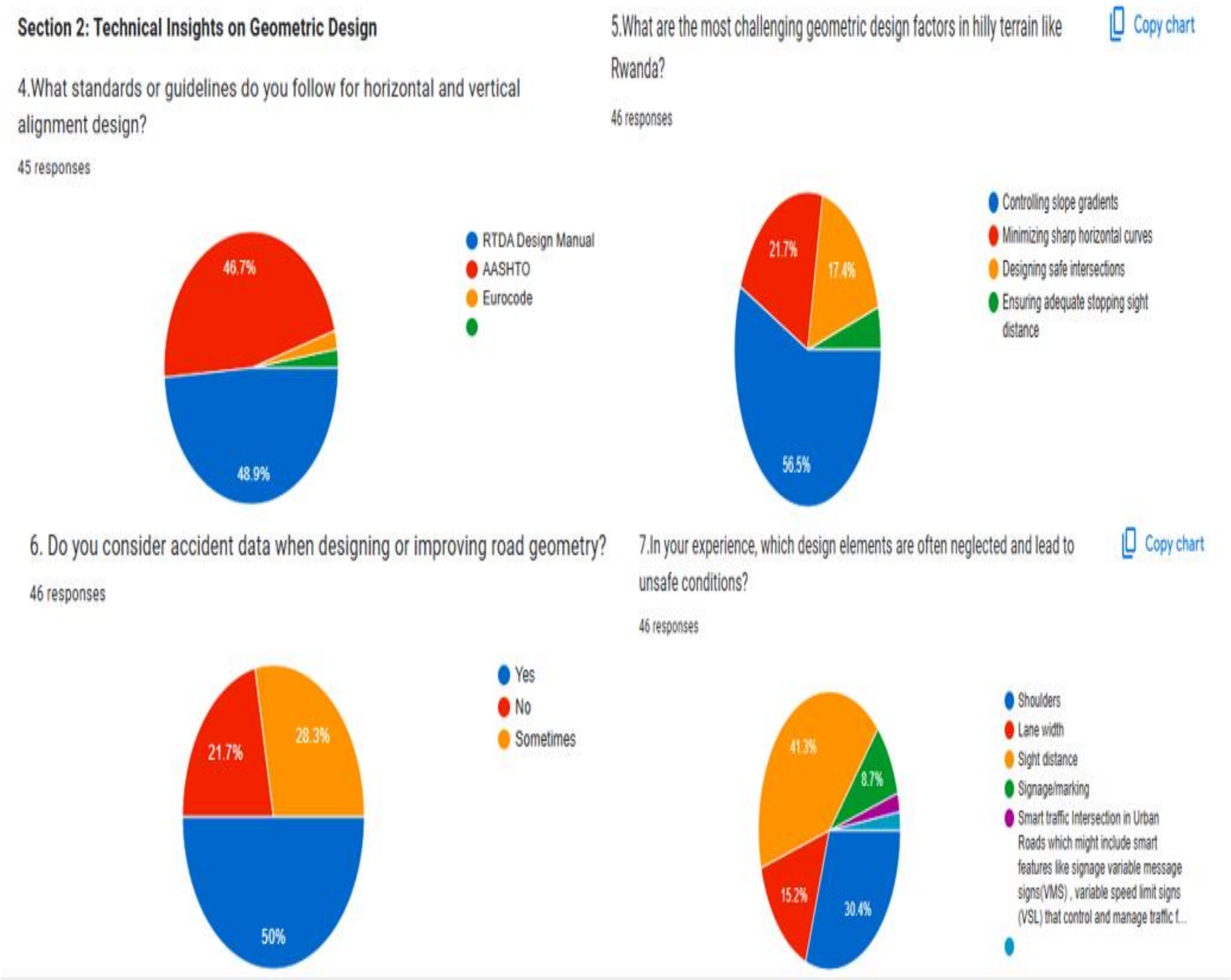
98 responses

17.Do you sometimes **overestimate or underestimate** the safe driving speed because of the road's layout (e.g., hidden curves, slopes)?

98 responses

18.Rate the impact of the following **geometric factors on your speed choices** *(1 = no impact, 5 = high impact)*:

Figure 4-4. ***Some diagrams&Histograms from Driver Questionnaire Responses.***



Section 2: Technical Insights on Geometric Design

4.What standards or guidelines do you follow for horizontal and vertical alignment design?

45 responses

5.What are the most challenging geometric design factors in hilly terrain like Rwanda?

46 responses

6. Do you consider accident data when designing or improving road geometry?

46 responses

7.In your experience, which design elements are often neglected and lead to unsafe conditions?

46 responses

*Figure 4-5****. Some diagrams from Road Design Engineers Questionnaire Responses.***

4.4. Achievement of Specific Objectives

To ensure that the study objectives were successfully addressed, the following section outlines the methods employed and results obtained for each specific objective:

Objective 1: Assess the compliance of road geometric design elements with national and international design standards (RTDA and AASHTO).

Method Applied:

Geometric Road data were initially obtained from the Rwanda Transport Development Agency (RTDA) in the form of shape files. These data were counter verified through field measurements conducted on 40 road segments using dumpy levels, measuring tapes, and GPS receivers. Parameters such as lane width, shoulder width, horizontal curve radius, longitudinal gradient, sight distance, and superelevation were measured and evaluated. The segments were purposefully selected along the NR2 (Kigali–Rubavu) corridor based on documented accident frequency to ensure the inclusion of both high-risk and representative segments. The collected data were then compared against the thresholds set in the RTDA Road Geometric Design Manual (2014) and the AASHTO (2011) guidelines to assess design compliance and road safety implications.

Result Summary:

The geometric compliance assessment revealed widespread non-compliance, especially on curved segments. Notable findings included:

- Curve radii below minimum thresholds for the design speed.
- Superelevation exceeding the 6% limit in several segments.
- Several segments with gradients steeper than 9%.
- Sight distances were below acceptable levels, particularly on curved roads.
- The analysis revealed significant non-compliance, especially on curved segments. Curve radii and superelevation values were often below standard thresholds. Gradients exceeding 7–9% were common in mountainous areas, and shoulder widths were consistently deficient in both segment types.

Objective 2: Determine and quantify the impact of geometric design elements (curve radius, gradient, shoulder width, and lane width) on accident frequency using statistical modeling.

Method Applied:

Accident data and geometric variables were analyzed using Pearson **Correlation, Regression Analysis** and **Poisson regression** in SPSS to evaluate relationships between geometric parameters and crash frequency. Model fit statistics (AIC, deviance, Wald Chi-square) were used for model evaluation.

Result Summary:

- Curve radius and gradient were statistically significant predictors of accident count ($p < 0.05$).
- Segments with wider lanes and shoulders recorded fewer crashes.
- Curved segments exhibited higher accident frequencies than straight segments.
- Linear regression revealed a strong model fit with **$R^2 = 0.938$**. Driver comfort, lane width, and shoulder width were the most significant predictors of accident frequency. Curve radius and segment type were statistically significant in Poisson regression, albeit marginally. These findings confirm that poor geometric design contributes to increased crash risk.

Objective 3: Investigate the influence of geometric design elements on driver behavior and comfort.

Method Applied:

- Perception data were collected from drivers and road engineers using a structured **Google Forms** questionnaire. The questionnaire included Likert-scale items to capture views on discomfort, visibility, speed adaptation, and road conditions.

- Structured perception surveys were administered to both drivers and engineers. Drivers provided feedback on comfort, control, and perceived danger across various segments, while engineers assessed the design feasibility and challenges.

Result Summary:

- Over 70% of drivers expressed discomfort on segments with sharp curves and steep slopes.
- Poor visibility and inadequate superelevation were major contributors to driver discomfort.

- Survey data showed that drivers felt reduced comfort and control on sharp curves and steep gradients.

- Engineers acknowledged that geometric design challenges in hilly terrain often limit compliance with standards and are not always informed by crash history. This confirmed a link between design quality and perceived driving risk.

Objective 4: Evaluate accident frequency and severity across different road segment types in Rwanda.

Method Applied:

- Descriptive statistics and regression analysis were used to compare accident data between curved and straight segments.

- Recommendations were derived from the integrated findings of the compliance assessment, statistical models, and perception surveys. Priority was given to measures that address both physical design and behavioral enforcement.

Result Summary:

- Curved segments recorded significantly higher accident frequency and severity.
- Straight segments showed relatively fewer crashes but still experienced safety concerns where visibility and shoulder width were insufficient.

Key recommendations include enforcing speed management strategies (e.g., speed cameras and buffer between design and operating speeds), retrofitting high-risk segments, and aligning future design standards with real-world driver behavior and crash history.

Objective 5: Provide design and policy recommendations to improve geometric safety on national roads.

Method Applied:

- A triangulated approach combining geometric compliance results, regression findings, and user perceptions was used to formulate practical recommendations.

Result Summary:

- Recommendations include improving curve radii, maintaining appropriate shoulder width (≥1.5 m), limiting superelevation to ≤6%, and ensuring adequate sight distances.
- Policy suggestions include routine geometric compliance checks, enhancement of crash data reporting systems, and capacity-building for road designers and engineers.
- Key recommendations include enforcing speed management strategies (e.g., speed cameras and buffer between design and operating speeds), retrofitting high-risk segments, and aligning future design standards with real-world driver behavior and crash history. These were compiled in Chapter 5 to guide policy and design improvements.

5. CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study assessed the impact of geometric design elements on road safety across 40 road segments (20 curved, 20 straight) in Rwanda. Using geometric compliance evaluation, statistical modeling, and perception surveys, the study found widespread non-compliance and statistically significant links between road geometry and accident patterns.

Geometric assessment revealed:

- Frequent violations of design standards, especially in curved segments where curve radii, Superelevation, and visibility distances were often below recommended thresholds.
- Gradient values exceeding allowable limits (7–9%) in several locations, particularly on curved segments in hilly areas.
- Shoulder width deficiencies were noted in both curved and straight segments.

During fieldwork, it was observed that posted speed limits (60 km/h and 80 km/h) matched the design speeds set by the RTDA Geometric Design Manual (2014) for rolling and mountainous terrain. This implies no margin of safety between design speed and operating speed. A critical observation at area without speed camera (SOFIA) station showed that many drivers fail to comply with posted speed limits, effectively nullifying the safety assumptions made during road design.

From the statistical models, key findings include:

- Driver comfort was the strongest predictor of accident frequency, followed by lane and shoulder width.
- Segment type and curve radius were also related to accident risk, though with marginal significance in the Poisson model.
- Linear regression explained 93.8% of the variation in accident count, indicating that geometric design and perception are strong determinants of crash risk.

Driver and engineer surveys reinforced the above findings, showing that drivers often feel discomfort and reduced control on segments with sharp curves and steep gradients. Engineers cited the difficulty of applying standards in hilly terrains and admitted limited consideration of crash history in geometric planning.

In summary, most surveyed curved road segments are **poorly designed**, **do not comply with geometric standards**, and when combined with **lack of driver speed discipline**, pose substantial road safety risks. The alignment between **design speed and posted speed limit**, without a buffer, exacerbates these risks—particularly when geometric design is substandard.

5.2 Recommendations

Based on the findings, the following unified recommendations are made:

- Introduce a design-operating speed buffer: Given that the design speed equals the posted speed limit, introduce a lower operating speed (e.g., by 40–60 km/h) through updated traffic signs and road marking to enhance safety margins, particularly on substandard segments.
- Enhance enforcement of speed limits: Deploy and increase number of **automated speed** enforcement (Speed camera/SOFIA) stations especially in high-risk segments like Buranga, Kivuruga and Shyorongi (Bwimo), where driver compliance is low.
- Strict adherence to geometric design standards: Ensure all new and rehabilitated roads conform to RTDA and AASHTO guidelines for curve radius, Superelevation, gradient, and visibility, especially for roads in mountainous terrain.
- Conduct targeted safety audits: Focus on segments with historical crash data and poor geometry to prioritize redesign or retrofitting.
- Integrate perception-based data and accident records into design: Ensure that the realities of driver behavior and crash history inform future road design, not just theoretical standards.
- Improve visibility and signage: Clear vegetation, install reflective markers and warning signs before curves and steep descents.
- Engineer training and accountability: Strengthen capacity-building for engineers to incorporate both compliance checks and behavior-based safety into geometric design.

- Phased retrofitting strategy: For cost-effective implementation, begin with **high-risk** segments and adopt context-sensitive design in hilly regions.

5.3 Limitations

- No safety buffer between design and posted speeds: The speed limits observed on-site (60–80 km/h) match the design speeds for rolling and mountainous terrain, leaving **zero t**olerance for driver error, road condition variability, or weather factors.
- Driver non-compliance: Although this study observed widespread speeding, this behavior was not directly measured or quantified, limiting the precision of its influence on safety.
- The study sample is limited to 40 segments, potentially restricting generalizability.
- Traffic volume, time of day, and weather conditions were not included in the statistical models.

5.4 Final Remarks

This study confirms a strong relationship between poor geometric design and increased accident occurrence, especially on curved segments. The lack of safety margin between posted and **design** speeds, combined with driver non-compliance, elevates crash risk even further. Improving road safety in Rwanda requires a combination of rigorous design standard enforcement, behavior-based traffic control, and context-sensitive design strategies. Policy and practice must evolve to include real-world driver behavior, especially in hilly terrains with complex geometry.

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7.APPENDICES

APPENDIX – 1

PHOTOGRAPHIC FOR DIFFERENT ROAD CONDITIONS AT DIFFERENT LOCATIONS DURING SURVEY PERIOD

Figure 1: BEGINNING OF NR2 CORRIDOR AT GITIKINYONI INTERSECTION – SEGMENT 1

Figure2: TRAFFIC VOLUME AT GITIKINYONI INTERSECTION

Figure 3: ROAD SEGMENT 2 IMMEDIATELY AFTER GITIKINYONI BRIDGE

Figure 4.A: HAIRPIN CURVES ALONG THE BWIMO HILL ROAD SECTION

FIGURE 4.B: SPEED LIMIT SIGN AT BWIMO HAIRPIN BEND WITH LIMITED VISIBILITY

Figure 4.C: VEHICLE NAVIGATION ON UPHILL CURVES AT BWIMO HILL

Figure 5: SETTING UP DI-GPS INSTRUMENT FOR DATA COLLECTION ALONG THE ROAD CORRIDOR

Figure 6:DATA COLLECTION AT GS KANYINYA-CRASH PRONE SEGMENT WITH HIGH STUDENT PEDESTRIAN ACTIVITY

Figure 7: UNSAFE PEDESTRIAN CROSSING BEHAVIOR ON A LONG STRAIGHT SEGMENT WITH 80KM/H SPEED LIMIT

Figure 8: STRAIGHT ROAD SEGMENT AT SHYORONGI WITH GOOD VISIBILITY AND 80KM/H SPEED LIMIT

Figure 9: KINGAZI–TABA–RUSIGA SECTOR NEAR KIRENGE CENTER – ACCIDENT-PRONE AREA WITH HIGH FATALITIES IN 2025; SPEED LIMIT IS 80 KM/H. NOTE: BARRIERS WERE RECENTLY INSTALLED FOLLOWING TWO SERIOUS FATAL ACCIDENTS IN 2025.

Figure 10: TWO RECENT SERIOUS ACCIDENTS AT KINGAZI–TABA IN 2025

Figure 11: DATA COLLECTION AT COMMERCIAL CENTERS ALONG THE NR2 ROAD

Figure12: KIRENGE-RULINDO ROAD GEOMETRY CURVES

Figure13: DATA COLLECTION AT SHYORONGI CENTER

Figure 14: ROUTINE MAINTENANCE ACTIVITY – ROAD CLEANING OPERATIONS

Figure 15. ROAD GEOMETRY AT GAKENKE

Figure 16: GEOMETRIC CHARACTERISTICS OF THE ROAD AT BURANGA HILL

Figure 17: GEOMETRIC CHARACTERISTICS OF THE ROAD AT KIVURUGA HILL

Figure 18: ROAD SAFETY BARRIERS INSTALLED AT HIGH-RISK SECTIONS

Figure: TYPICAL CRASH INCIDENT ON THE STUDY CORRIDOR

APPENDIX-2

Questionnaire: Geometric Road Design and Driver Behavior in Rwanda

Part A

Section 1: Demographic Information

1. **Age:**
   ☐ Under 18
   ☐ 18–30
   ☐ 31–45
   ☐ 46–60
   ☐ above 60
2. **Gender:**
   ☐ Male
   ☐ Female
3. **Driving Experience:**
   ☐ Less than 2 years
   ☐ 2–5 years
   ☐ 6–10 years
   ☐ More than 10 years
4. **Driver Category:**
   ☐ Private driver
   ☐ Taxi/moto-taxi driver
   ☐ Commercial truck driver
   ☐ Bus driver
   ☐ Other (please specify): ___________
5. **Main roads regularly used (select all that apply):**
   ☐ Kigali–Rubavu
   ☐ Kigali–Musanze
   ☐ Kigali–Muhanga
   ☐ Urban Kigali roads
   ☐ Rural roads
   ☐ Other: ___________

Section 2: Perception of Road Design Features

6. How would you rate the following features on most roads you use?
(Scale: 1 = Very Poor, 5 = Excellent)

Feature	**1**	**2**	**3**	**4**	**5**
Road curvature/alignment	☐	☐	☐	☐	☐
Lane width	☐	☐	☐	☐	☐
Shoulder width	☐	☐	☐	☐	☐
Visibility (sight distance)	☐	☐	☐	☐	☐
Road signage and markings	☐	☐	☐	☐	☐
Intersection layout and clarity	☐	☐	☐	☐	☐
Pedestrian infrastructure	☐	☐	☐	☐	☐

Section 3: Driver Behavior in Relation to Road Design

7. Have you ever had difficulty navigating a road due to:
(Select all that apply)
☐ Sharp curves
☐ Narrow lanes
☐ Poor signage
☐ Steep slopes
☐ Poor visibility
☐ Confusing intersections
☐ None

8. On roads with sharp curves or poor visibility, how often do you:
(Scale: 1 = Never, 5 = Always)

Behavior	**1**	**2**	**3**	**4**	**5**
Reduce speed	☐	☐	☐	☐	☐
Cross into opposite lane	☐	☐	☐	☐	☐
Brake suddenly	☐	☐	☐	☐	☐
Rely on memory rather than signs	☐	☐	☐	☐	☐
Feel unsure about the safest driving action	☐	☐	☐	☐	☐

9. Have you ever experienced or witnessed an accident or near-miss on poorly designed road segments?
   ☐ Yes
   ☐ No
   If yes, please describe the location and cause briefly:

Section 4: Pedestrian and Safety Considerations

10. How often do you yield to pedestrians at crosswalks?
    ☐ Always
    ☐ Often
    ☐ Sometimes
    ☐ Rarely
    ☐ Never

11. What prevents you from yielding more often? (Select all that apply)
    ☐ Crosswalks not visible
    ☐ Speeding vehicles behind
    ☐ Poor pedestrian visibility
    ☐ No enforcement or penalties
    ☐ Unawareness of rules
    ☐ Other: ___________

12. In your opinion, what road design improvements would most enhance safety? (Select up to three)
    ☐ Widening lanes
    ☐ Adding or improving shoulders
    ☐ Better signage and markings
    ☐ Clearer intersections
    ☐ Improving curve alignment
    ☐ Dedicated pedestrian paths
    ☐ Speed calming features (e.g., humps, signs)
    ☐ Lighting and visibility
    ☐ Other: ___________

Section 5: Perception of Road Geometry and Driving Behavior

13.Have you ever encountered difficulties navigating sharp curves on Rwandan roads?

- ☐ Yes
- ☐ No
- If yes, which road sections? ________________

14.In your opinion, which geometric design factors most affect safety on Rwandan roads?

  - ☐ Sharp curves
  - ☐ Narrow lanes
  - ☐ Poorly designed intersections
  - ☐ Steep slopes
  - ☐ Lack of road shoulders
  - ☐ Others: _____________

Section 6: Speed Perception and Road Geometry

15.On the NR2(Kigali-Rubavu) road, which of the following sections do you feel uncomfortable maintaining a normal speed? *(You may tick more than one)*

  - ☐ Steep downhill sections
  - ☐ Sharp curves
  - ☐ Narrow lanes
  - ☐ Sections near trading centers
  - ☐ Sections without proper signs or markings

16.In which road segments of NR2(Kigali-Rubavu) do you feel a need to **reduce your speed significantly** due to geometric conditions?

17.Do you sometimes **overestimate or underestimate** the safe driving speed because of the road's layout (e.g., hidden curves, slopes)?

  - ☐ Yes
  - ☐ No
  - ☐ Not sure

18.Rate the impact of the following **geometric factors on your speed choices** *(1 = no impact, 5 = high impact)*:

  - Sharp horizontal curves: ☐1 ☐2 ☐3 ☐4 ☐5
  - Steep slopes (uphill/downhill): ☐1 ☐2 ☐3 ☐4 ☐5
  - Narrow lanes or shoulders: ☐1 ☐2 ☐3 ☐4 ☐5
  - Poor visibility (due to terrain or curves): ☐1 ☐2 ☐3 ☐4 ☐5
  - Road signs & markings: ☐1 ☐2 ☐3 ☐4 ☐5

Part B: Questionnaire for Engineers / Road Designers

Section 1: Professional Background

1. Profession:
    - ☐ Civil Engineer
    - ☐ Road Safety Officer
    - ☐ Transport Planner
    - ☐ Other: ___________
2. Years of Experience in Road Design/Planning:
    - ☐ < 2 years
    - ☐ 2–5 years
    - ☐ 6–10 years
    - ☐ >10 years
3. Have you worked on road projects in Rwanda?
    - ☐ Yes
    - ☐ No
    - If yes, specify the region or road: _____________

Section 2: Technical Insights on Geometric Design

4. What standards or guidelines do you follow for horizontal and vertical alignment design?
    - ☐ RTDA Design Manual
    - ☐ AASHTO
    - ☐ Eurocode
    - ☐ Other: ____________
5. What are the most challenging geometric design factors in hilly terrain like Rwanda?
    - ☐ Controlling slope gradients
    - ☐ Minimizing sharp horizontal curves
    - ☐ Designing safe intersections
    - ☐ Ensuring adequate stopping sight distance
    - ☐ Others: _______________

6. Do you consider accident data when designing or improving road geometry?
    - ☐ Yes
    - ☐ No
    - ☐ Sometimes
7. In your experience, which design elements are often neglected and lead to unsafe conditions?
    - ☐ Shoulders
    - ☐ Lane width
    - ☐ Sight distance
    - ☐ Signage/marking
    - ☐ Others: ____________
8. What solutions would you recommend to improve road safety through better geometric design in Rwanda?

    ....

APPENDIX – 3 QUESTIONNAIRE RESPONSES FROM RESPONDENTS(DRIVERS&ROAD ENGINEERS)

Impact of Geometric Road Design on Driver Behavior and Road Safety in Rwanda

101 responses

Publish analytics

PART A

Section 1: Demographic Information

1.Age Group

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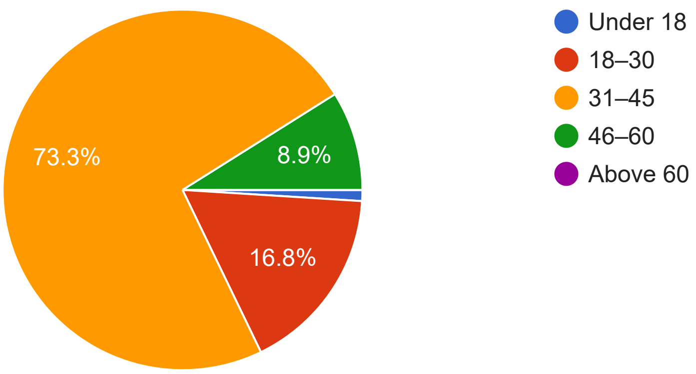
101 responses



2.Gender

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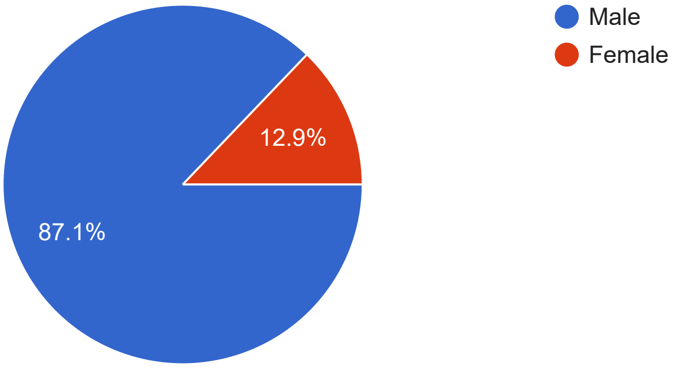
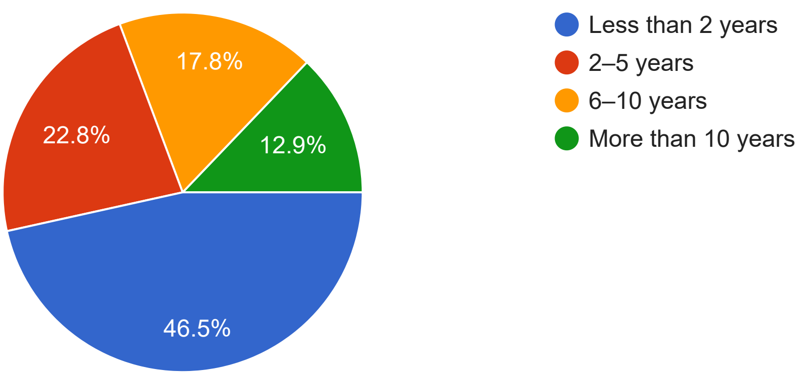
101 responses



3.Driving Experience:

Copy

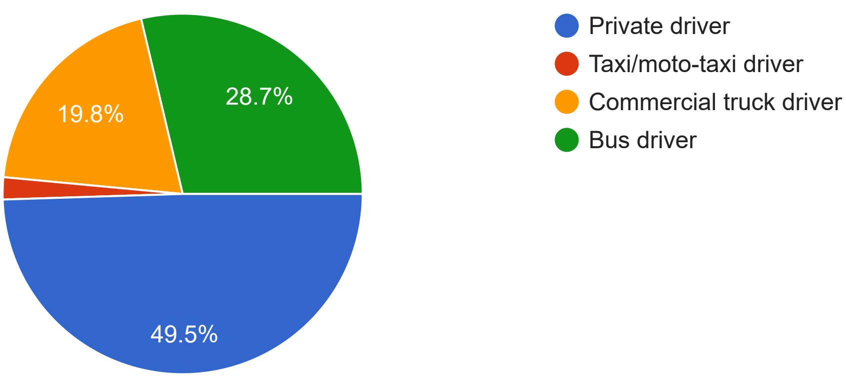
101 responses



4.Driver Category:

Copy

101 responses



Other (please specify):

5 responses

Not applicable

Travel bicycle driver

Moto-taxi driver

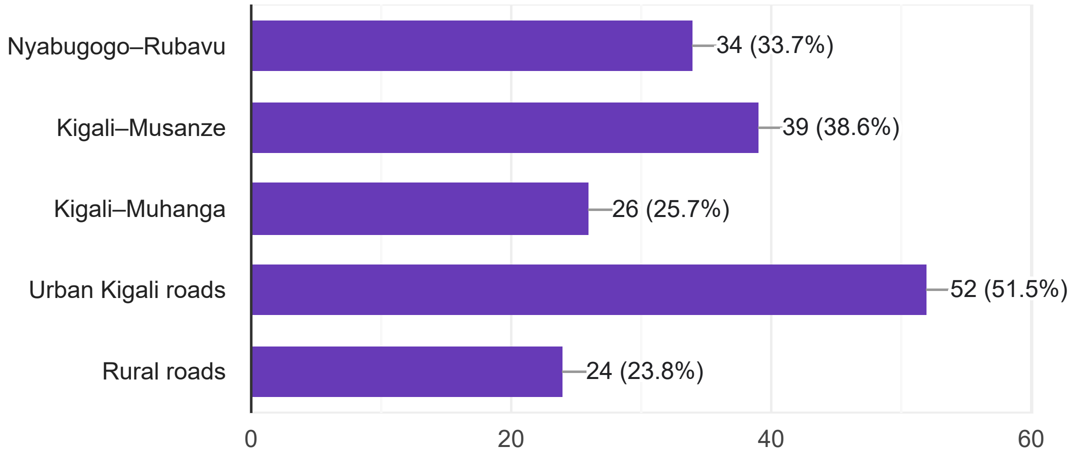
Not driver

NA

5.Main roads regularly used (select all that apply):

Copy

101 responses



Other(please specify):

8 responses

Kigali to East

city to rural roads

Kigali-nyagatare

Nobe

Rural roads

Kigali-Kirehe

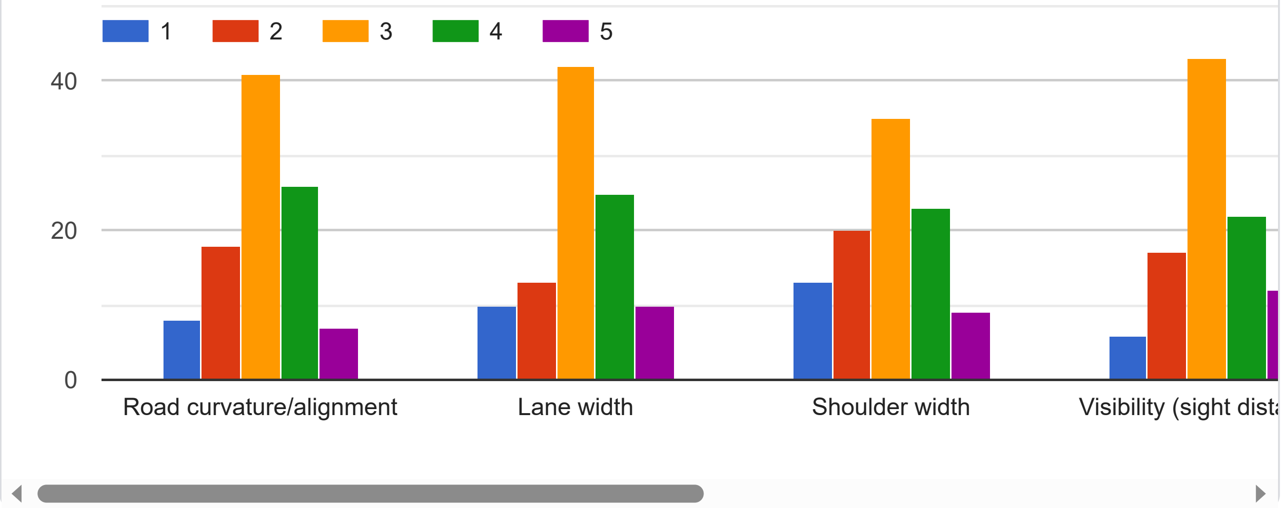
Kigali Bugesera

Kigali bugesera

Copy

Section 2: Perception of Road Design Features

6.How would you rate the following features on most roads you use?
(Scale: 1 = Very Poor, 5 = Excellent

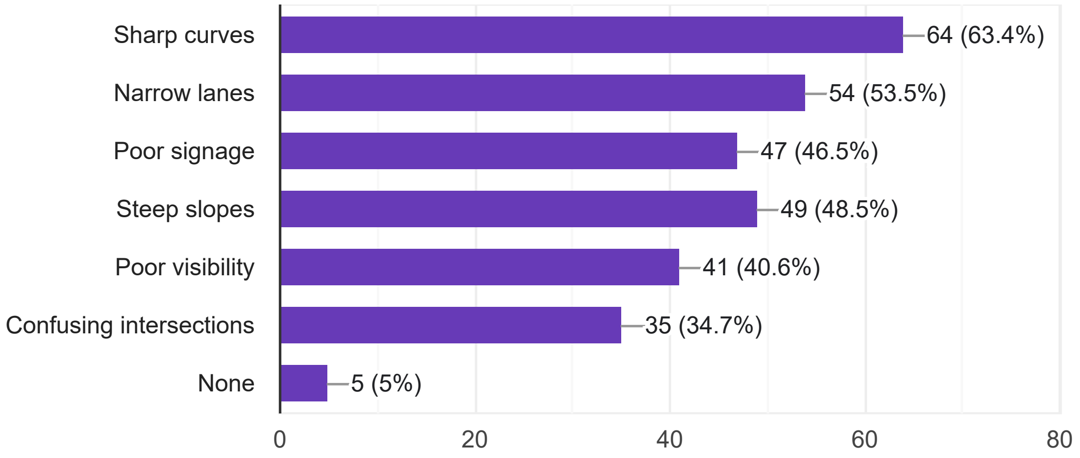


Copy

Section 3: Driver Behavior in Relation to Road Design

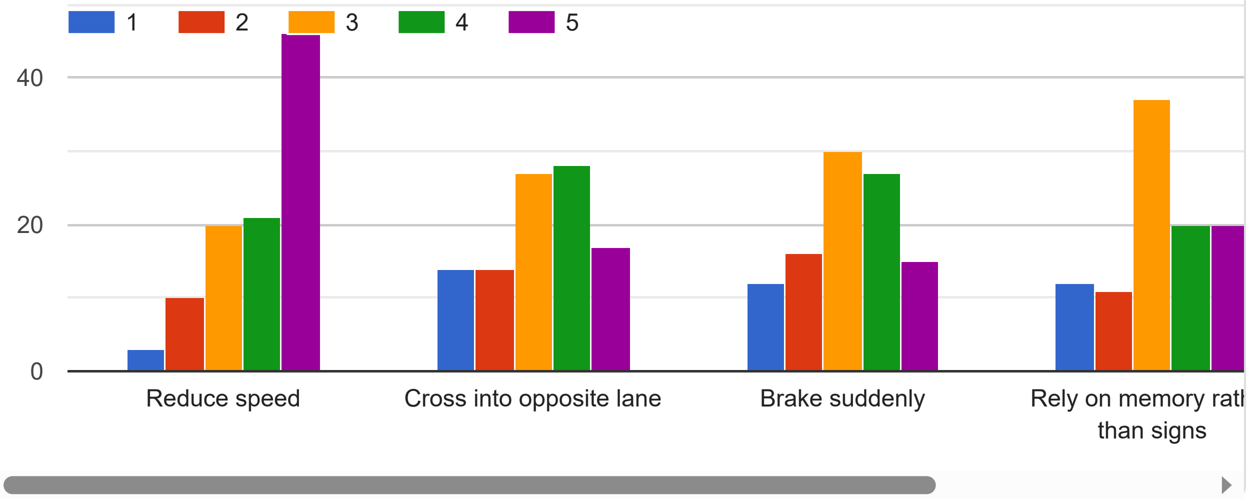
7.Have you ever had difficulty navigating a road due to:
(Select all that apply)

101 responses



8.On roads with sharp curves or poor visibility, how often do you: (Scale: 1 = Never, 5 = Always)

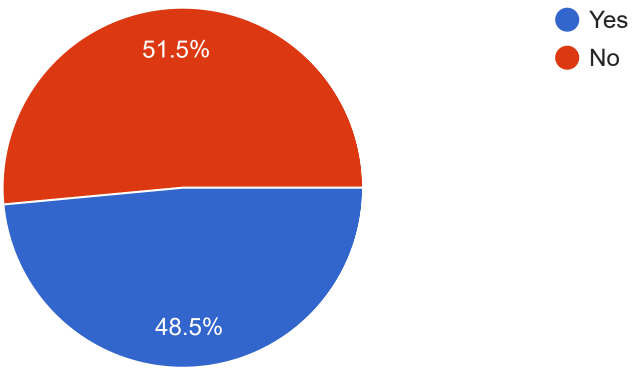
Copy



9.Have you ever experienced or witnessed an accident or near-miss on poorly designed road segments?

Copy

101 responses



If yes, please describe the location and cause briefly:

36 responses

Nyakiriba section due to poorly designed road segment

Curves from Karongi to Nyamasheke.

Poor visibility

Ruyenzi

buringa

out side kigali in karongi district

MUKAMIRA

GATARE

Nyamata

Buranga Slope in Gakenke (the cause is overtaking and speed)

RUGERERO

GASIZA

Nyabugogo CBD road intersection area due to inadequate traffic sign operation

Kigali-bugesera

Kigali-kanombe near military hospital juction

Mushonyi

MIZINGO

KIRENGE

Rulindo

Nyabugogo, poor road sign

While traveling from Kigali to Musanze, I encountered a turning issue -specifically on the approach to Musanze—that appeared to have a tighter turning radius than what is typically recommended.

I have not.

Between Giticyinyoni and Ruliba

At km 47 Called Rwezamenyo where there is charp curve and no visibility .

Muhanga

Road Giporoso to Kabuga

Gataraga

Gakenke Center

Nyabugogo,kanogo

Bigogwe

GAKENKE

Buranga

Nyabugogo intersection, muhanga roundbout, shyorongi and Buranga steep curves

Kabeza due to poor visibility

KWAGATSIBAGE

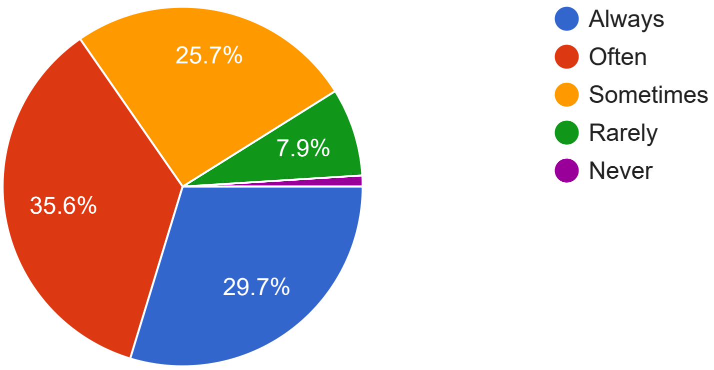
Mahoko

Copy

Section 4: Pedestrian and Safety Considerations

10.How often do you yield to pedestrians at crosswalks?

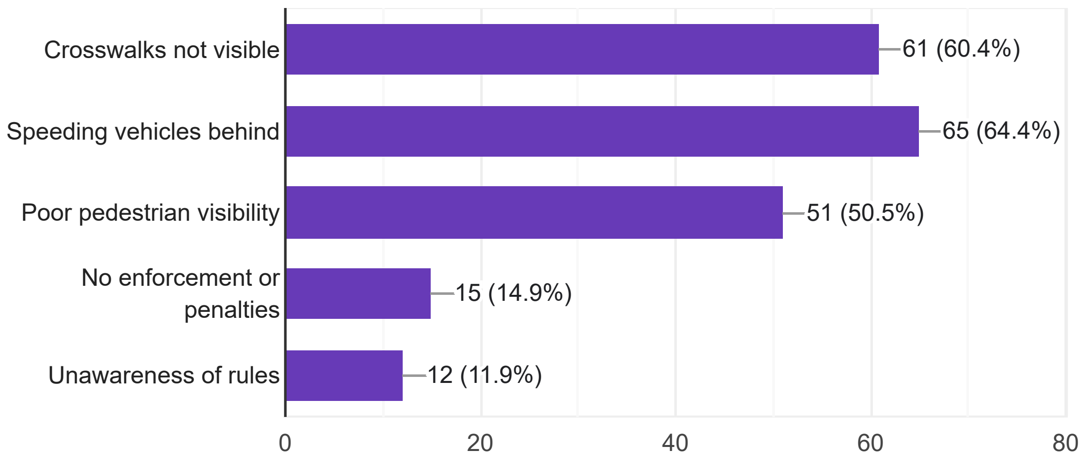
101 responses



11.What prevents you from yielding more often? (Select all that apply)

Copy

101 responses



Other(Please specify):

6 responses

Pedestrian enters when the car is already there

unawareness, low skills

Inefficient operation of smart traffic lights that prioritize the traffic based on real time traffic big data that should prioritize the traffic based on demand of traffic

No

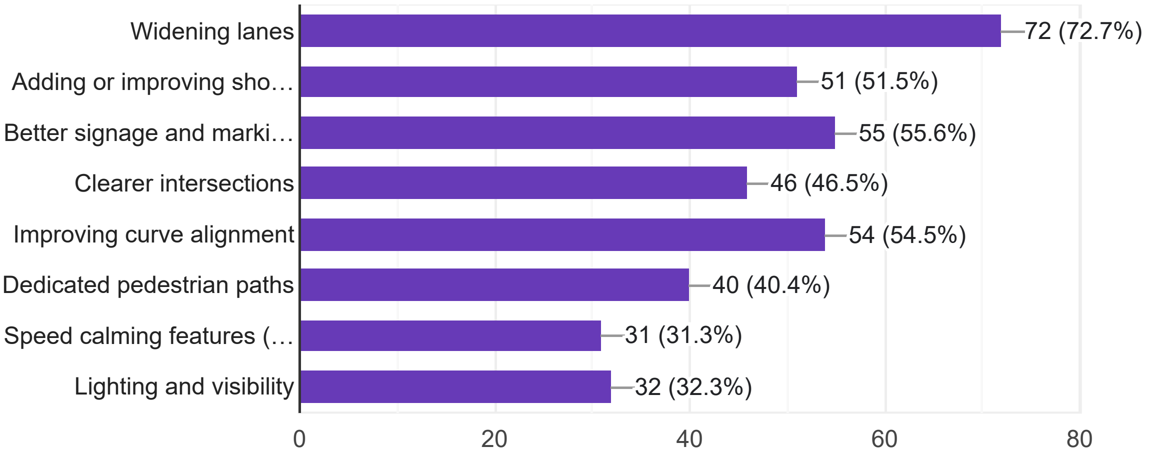
The issue typically arises when pedestrians begin entering the roadway while I’m already crossing within the marked crosswalk

Poor roads

12.In your opinion, what road design improvements would most enhance safety? (Select up to three)

Copy

99 responses



Other(please specify):

4 responses

congestion of vehicles

Speed calming

Repaired roads

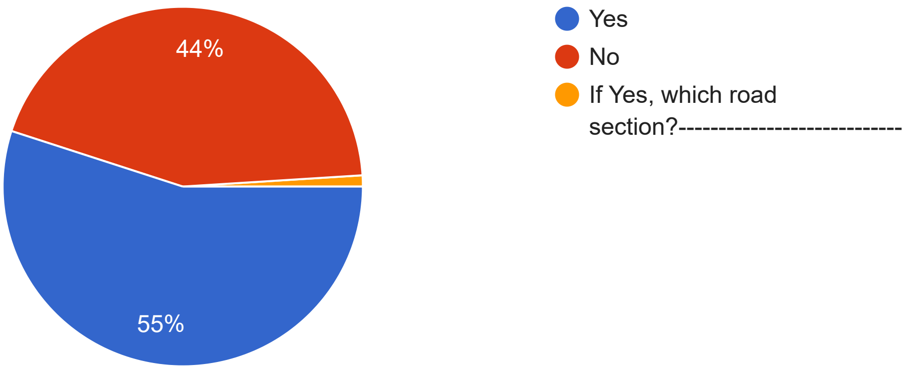
Provision of suspended bridge to pedestrians and cyclists

Copy

Section 5: Perception of Road Geometry and Driving Behavior

13.Have you ever encountered difficulties navigating sharp curves on Rwandan roads?

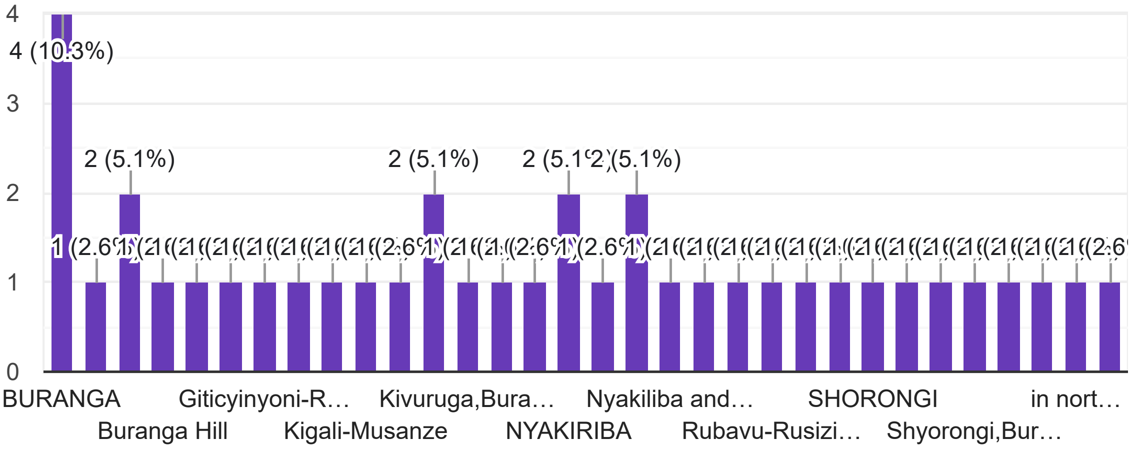
100 responses



If yes, which road sections?

Copy

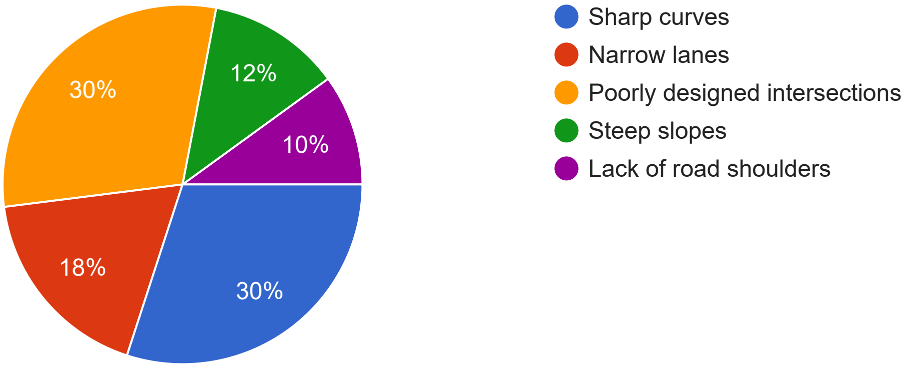
39 responses



14.In your opinion, which geometric design factors most affect safety on Rwandan roads?

Copy

100 responses



Others(please specify):

4 responses

very difficult to memorise

Uncalified engineer

Steep sloping road

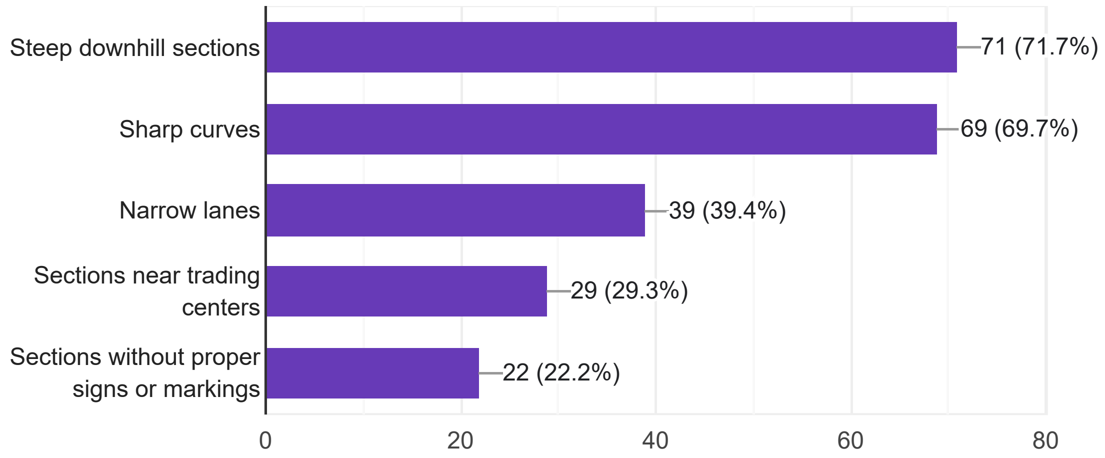
Sharp curves

Copy

Section 6: Speed Perception and Road Geometry

15.On the NR2(Kigali-Rubavu) road, which of the following sections do you feel uncomfortable maintaining a normal speed? *(You may tick more than one)*

99 responses



16.In which road segments of NR2(Kigali-Rubavu) do you feel a need to **reduce your speed significantly** due to geometric conditions?

99 responses

Buranga

Shyorongi

BURANGA

Yes

Nyakiliba

buranga

KIVURUGA

Pfunda

Rusiga

Shyorongi

None

Shorongi

Nyakiliba and Buranga and shorongi

I don’t remember the name of that road

Shyorongi to Giti kinyoni

Kivu peace view hotel side

Musambira

Rulindo and gakenke curves.

Across the river reaches to Musanze

Buranga and kivuruga sections

Narrow lane

SHYORONGI

Giticyinyoni- Shyorongi

in sharp cuves

Burnga, kivuruga, Shyorongi

Shyorongi segment

Steep downhill section

KIZIBA

Buranga in Gakenke District

Speed reduction

Shyorongi,Buranga

Shyorongi mukoto

Some area of Buranga, Shyorongi..

Dont recall

Kabari

At Gakenke

KWIKORA

Shyorongi Buranga

A Buranga in Gakenke district

When you pass bazirete center dow there.

Buranga and shyorongi,..

No

Buranga Downhill

kuvuruga and kirenge

Shyorongi,Buranga&Kivuruga

Lane width

Bwimo

Buranga,Kiziba

Shyorongi mountain, Buranga Mountain

Buranga,Kivuruga

Not well remember

Steep down hill section

Gakenke

SHYORONGI AND BURANGA

Giti cy' inyoni

Ryabazira

Nyirangarama-buranga-kivuruga

Proper Road Signs

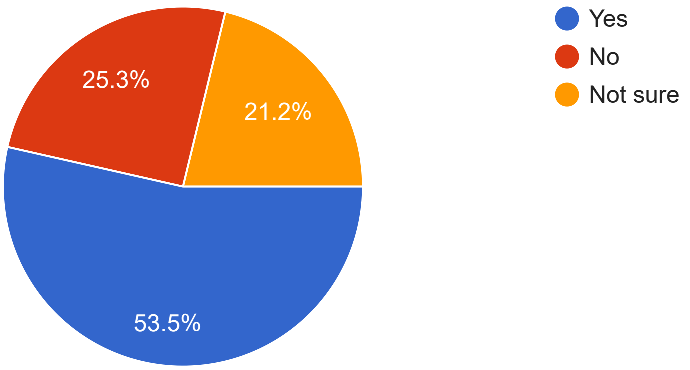
Gakenye

Yeah of course!

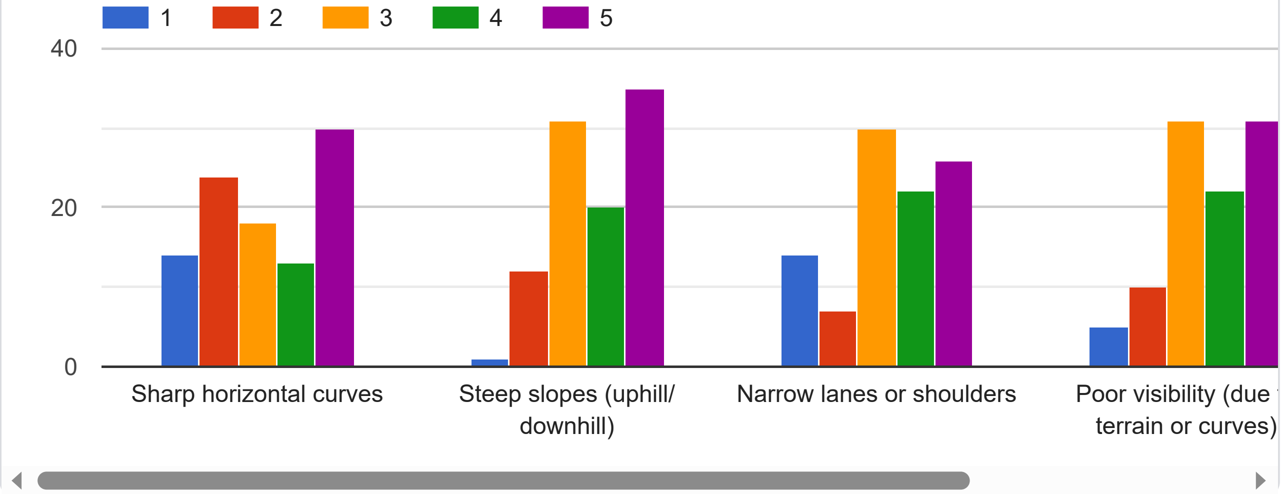
17.Do you sometimes **overestimate or underestimate** the safe driving speed because of the road's layout (e.g., hidden curves, slopes)?

Copy

99 responses



18.Rate the impact of the following **geometric factors on your speed choices** *(1 = no impact, 5 = high impact)*:

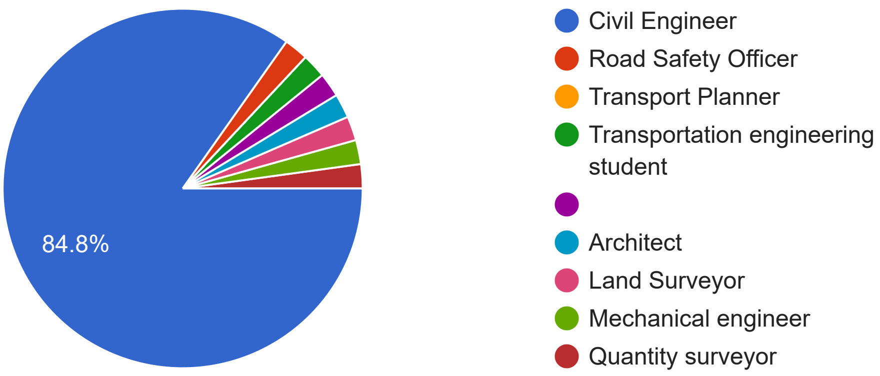


✅ Part B: Questionnaire for Engineers / Road Designers

Section 1: Professional Background

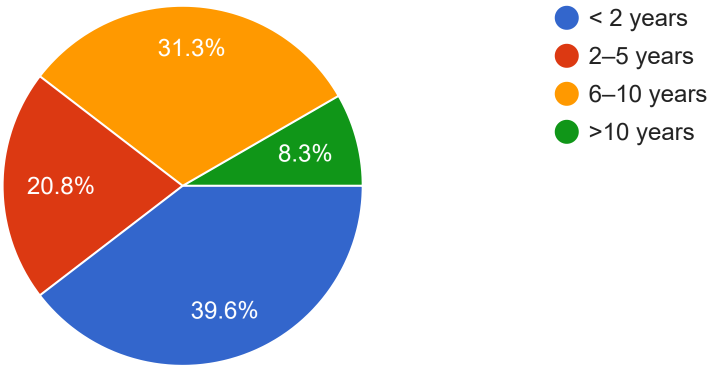
1.Profession:

46 responses



2.Years of Experience in Road Design/Planning:

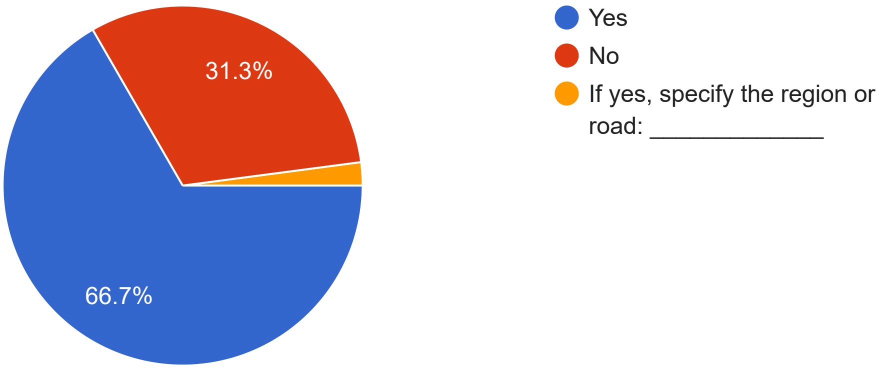
48 responses



3. Have you worked on road projects in Rwanda?

Copy

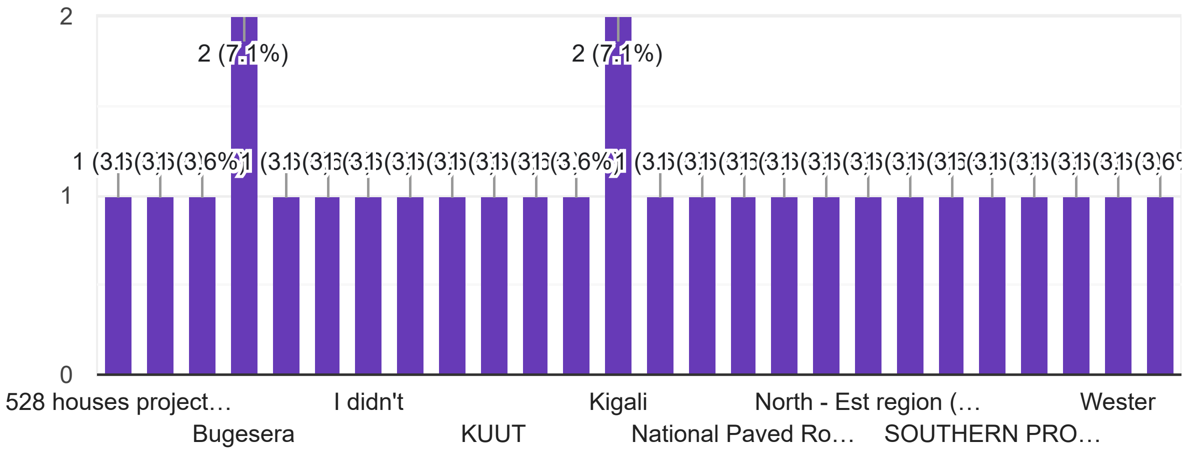
48 responses



If yes, specify the region or road:

Copy

28 responses

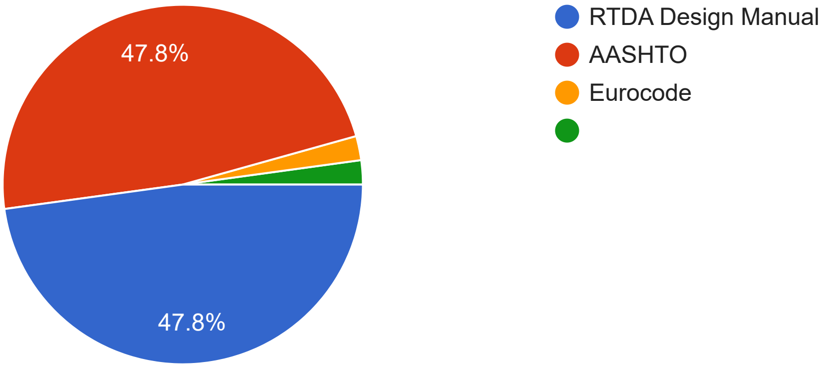


Copy

Section 2: Technical Insights on Geometric Design

4.What standards or guidelines do you follow for horizontal and vertical alignment design?

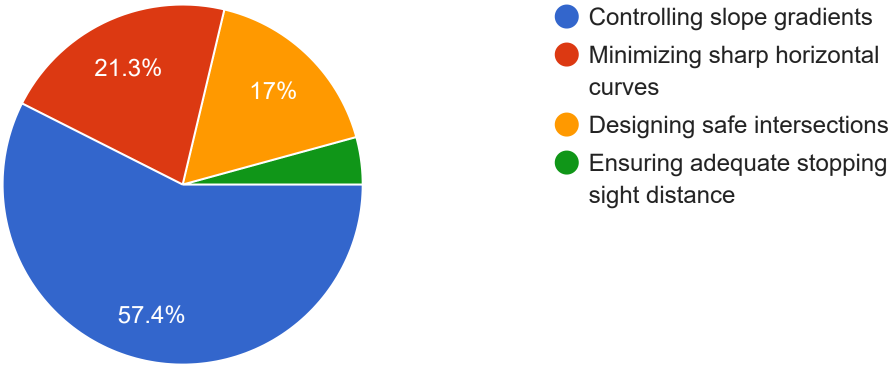
46 responses



5.What are the most challenging geometric design factors in hilly terrain like Rwanda?

Copy

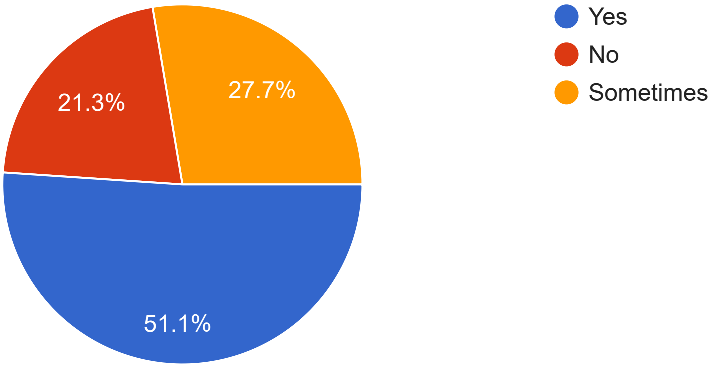
47 responses



6. Do you consider accident data when designing or improving road geometry?

Copy

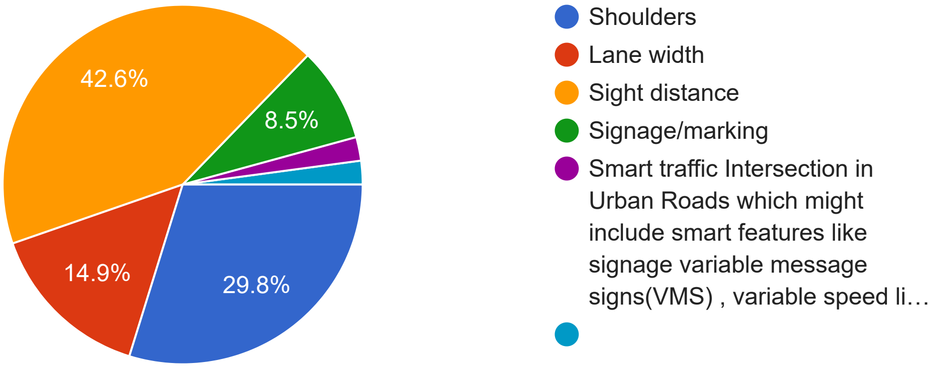
47 responses



7.In your experience, which design elements are often neglected and lead to unsafe conditions?

Copy

47 responses



8.What solutions would you recommend to improve road safety through better geometric design in Rwanda?

39 responses

Provide Rwandan safety code to follow in design

To improve road safety in Rwanda , I recommend to all road planners, designers and engineers to ensure the road is fully completed with all key components and safety systems are put in place.,

Consider the situations for each region not to take any single design to all region

Traffic calming features should be highly adapted

Use international standard in design

I would recommend making sure that lanes are wide enough and pedestrians have dedicated pathways providing gentler slopes

Following up construction specifications, and care on construction materials

Widening the existing and more intersection including fly over bridges.

Improve lane width

Include Non Motorized Transport features in the design and contraction of roads

Incorporate traffic smart features such as VLS and VMS especially in Kigali City for public transport that rely on real time traffic data controlled by traffic management data center, this will enhance safety of road users including pedestrians and drivers. also for rural intercity road area beside Kigali city, to strongly consider the horizontal sharp curves and most of our terrain area mountainous area also considering the shoulder paths, and emphasizing the design consideration of Non motorized Transport Facilities that prioritize walking and cycling for pedestrians, this will minimize the accidents and increase traffic safety on road users

As a solution,designer should have skills due to design roads and have special equipments.

Consider widening of road lanes; minimize slope in the design

Consider Accident Data in design

I would recommend that during the design, engineers shall consider more the design speeds, in curves

Ensure that lanes are wide enough, ensure that horizontal curves are not so sharp

Enforce signage/marking

Following the standards

Increase horizontal and vertical sight visibility

To invest in roads construction, hiring the skilled labors in roads construction and offer more training to the team members.

Improve road design considering pedestrian concern and geometric designs.

Better communication to All belonging team during in constuction stage

Clear road signages and their visibility

Increasing lane width

To increase the lane width and shoulders of the roads and make 4 lanes where possible, especially for the roads linking Kigali and surrounding areas

RTDA to enforce the use of lisenced softwares in design. To have the expert in geometric design who will validate the geometric design of all prject in Rwanda

they must put much effort by emphasizing on the study of soil , they going to design, make a deep survey on the using of load like in 50 years means they should consider life span of 50 years .i can also recommend the teams for roads maintenance.

To follow road design and construction standard

Lane width

Regular road safety audits

Provide Propoer shoulders,ensure Proper safe stopping sight distance

trying to increase visibility of the road through building good curves

To consider Accident Data During Design

Standard lanes, provisions of standard shoulder

Increase lane width and thickness of asphalt course due to type of car use that road

Increase the width of lanes, reduce the slope gradient, provision of pedestrians walkways, reduction of humps

Capacity building to design engineers, standardized design processes and New Technology adoption

Better design

We can flowing the procedure, how design the roads and construction progress, walk way, hand raill same where needed,..

APPENDIX – 4 SPSS OUT PUT REPORTS

Correlations

Correlations

		Segment Type (curved=1, straight=0)	Superelevation (%)	Accident Count	Driver Comfort Score(/5)
Segment Type(curved=1, straight=0)	Pearson Correlation	1	.356*	.754**	-.384*
	Sig. (2-tailed)		.024	<.001	.014
	N	40	40	40	40
Superelevation (%)	Pearson Correlation	.356*	1	.360*	-.274
	Sig. (2-tailed)	.024		.023	.087
	N	40	40	40	40
Accident Count	Pearson Correlation	.754**	.360*	1	-.849**
	Sig. (2-tailed)	<.001	.023		<.001
	N	40	40	40	40
Driver Comfort Score(/5)	Pearson Correlation	-.384*	-.274	-.849**	1
	Sig. (2-tailed)	.014	.087	<.001	
	N	40	40	40	40

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Pearson Correlations

🟩 **Highly Positive :** *(None)*

🟩 **Positive :** *(Segment Type(curved=1,straight=0) <---> Superelevation (%)), (Segment Type(curved=1,straight=0) <---> Accident Count), (Superelevation (%) <---> Accident Count)*

🟨 **No Linear Correlation :** *(None)*

🟪 **Negative :** *(Segment Type(curved=1,straight=0) <---> Driver Comfort Score(/5)), (Superelevation (%) <---> Driver Comfort Score(/5)), (Accident Count <---> Driver Comfort Score(/5))*

🟥 **Highly Negative :** *(None)*

Note: Curated Help is calculated based on actual cell values, not the formatted values.

Generalized Linear Models

Model Information

Dependent Variable	Accident Count
Probability Distribution	Negative binomial (1)
Link Function	Log

Case Processing Summary

	N	Percent
Included	40	50.0%
Excluded	40	50.0%
Total	80	100.0%

Categorical Variable Information

			N	Percent
Factor	Segment Type(curved=1, straight=0)	0	20	50.0%
		1	20	50.0%
		Total	40	100.0%
	Curve Radius(Low,Medium, High)	H	32	80.0%
		L	4	10.0%
		M	4	10.0%
		Total	40	100.0%
	Gradient (Low,Medium,High)	H	21	52.5%
		L	8	20.0%
		M	11	27.5%
		Total	40	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Accident Count	40	2	8	3.65	1.545

Goodness of Fit[a]

	Value	df	Value/df
Deviance	.748	34	.022
Scaled Deviance	.748	34	
Pearson Chi-Square	.746	34	.022
Scaled Pearson Chi-Square	.746	34	
Log Likelihood[b]	-94.515		
Akaike's Information Criterion (AIC)	201.029		
Finite Sample Corrected AIC (AICC)	203.575		
Bayesian Information Criterion (BIC)	211.163		
Consistent AIC (CAIC)	217.163		

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,Medium,High), Gradient (Low,Medium,High)

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
4.625	5	.463

Dependent Variable: Accident Count
Model: (Intercept), Segment Type (curved=1,straight=0), Curve Radius(Low, Medium,High), Gradient (Low,Medium, High)

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	18.024	1	<.001
Segment Type(curved=1, straight=0)	.480	1	.488
Curve Radius(Low,Medium, High)	.664	2	.717
Gradient (Low,Medium,High)	.688	2	.709

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius (Low,Medium,High), Gradient (Low,Medium,High)

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence ...
			Lower	Upper	Wald Chi-Square	df	Sig.		Lower
(Intercept)	1.429	.6395	.175	2.682	4.990	1	.025	4.173	1.191
[Segment Type(curved=1, straight=0)=0]	-.327	.4713	-1.250	.597	.480	1	.488	.721	.286
[Segment Type(curved=1, straight=0)=1]	0^a	.	.	.	.	.	.	1	.
[Curve Radius(Low,Medium, High)=H]	-.194	.6361	-1.440	1.053	.093	1	.761	.824	.237
[Curve Radius(Low,Medium, High)=L]	.313	.7671	-1.191	1.816	.166	1	.684	1.367	.304
[Curve Radius(Low,Medium, High)=M]	0^a	.	.	.	.	.	.	1	.
[Gradient (Low,Medium, High)=H]	.232	.4303	-.611	1.076	.291	1	.589	1.261	.543
[Gradient (Low,Medium, High)=L]	-.215	.5989	-1.389	.959	.129	1	.719	.806	.249
[Gradient (Low,Medium, High)=M]	0^a	.	.	.	.	.	.	1	.
(Scale)	1^b								
(Negative binomial)	1^b								

Parameter Estimates

Parameter	95% Wald Confidence ... Upper
(Intercept)	14.614
[Segment Type(curved=1, straight=0)=0]	1.817
[Segment Type(curved=1, straight=0)=1]	.
[Curve Radius(Low,Medium, High)=H]	2.866
[Curve Radius(Low,Medium, High)=L]	6.147
[Curve Radius(Low,Medium, High)=M]	.
[Gradient (Low,Medium, High)=H]	2.932
[Gradient (Low,Medium, High)=L]	2.608
[Gradient (Low,Medium, High)=M]	.
(Scale)	
(Negative binomial)	

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,Medium,High), Gradient (Low,Medium,High)

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Generalized Linear Models

```
[DataSet4]
```

Model Information

Dependent Variable	Accident Count
Probability Distribution	Poisson
Link Function	Log

Case Processing Summary

	N	Percent
Included	40	50.0%
Excluded	40	50.0%
Total	80	100.0%

Categorical Variable Information

			N	Percent
Factor	Segment Type(curved=1, straight=0)	0	20	50.0%
		1	20	50.0%
		Total	40	100.0%
	Curve Radius(Low,High)	H	32	80.0%
		L	8	20.0%
		Total	40	100.0%
	Gradient (Low,High)	H	21	52.5%
		L	19	47.5%
		Total	40	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Accident Count	40	2	8	3.65	1.545

Goodness of Fit[a]

	Value	df	Value/df
Deviance	5.047	36	.140
Scaled Deviance	5.047	36	
Pearson Chi-Square	5.285	36	.147
Scaled Pearson Chi-Square	5.285	36	
Log Likelihood[b]	-64.517		
Akaike's Information Criterion (AIC)	137.035		
Finite Sample Corrected AIC (AICC)	138.177		
Bayesian Information Criterion (BIC)	143.790		
Consistent AIC (CAIC)	147.790		

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,High), Gradient (Low,High)

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
19.638	3	<.001

Dependent Variable: Accident Count
Model: (Intercept), Segment Type (curved=1,straight=0), Curve Radius(Low, High), Gradient (Low,High)

[a] Compares the fitted model against the intercept-only model.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	168.313	1	<.001
Segment Type(curved=1, straight=0)	3.019	1	.082
Curve Radius(Low,High)	3.175	1	.075
Gradient (Low,High)	1.715	1	.190

Dependent Variable: Accident Count
Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius (Low,High), Gradient (Low,High)

Parameter Estimates

Parameter	B	Std. Error	90% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.577	.2110	1.229	1.924	55.843	1	<.001
[Segment Type(curved=1, straight=0)=0]	-.379	.2180	-.737	-.020	3.019	1	.082
[Segment Type(curved=1, straight=0)=1]	0[a]	.	.	.	.	.	.
[Curve Radius(Low,High)=H]	-.364	.2042	-.700	-.028	3.175	1	.075
[Curve Radius(Low,High)=L]	0[a]	.	.	.	.	.	.
[Gradient (Low,High)=H]	.251	.1919	-.064	.567	1.715	1	.190
[Gradient (Low,High)=L]	0[a]	.	.	.	.	.	.
(Scale)	1[b]						

Dependent Variable: Accident Count

Model: (Intercept), Segment Type(curved=1,straight=0), Curve Radius(Low,High), Gradient (Low,High)

[a] Set to zero because this parameter is redundant.

[b] Fixed at the displayed value.