

**“ASSESSING JUNCTIONS PERFORMANCE THROUGH ROAD USERS’ BEHAVIOR:  
CASE STUDY OF KIGALI CITY”**

**A DISSERTATION**

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## **DECLARATION**

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## **DEDICATION**

I dedicate this work to my family, colleagues, friends and to all those who never stopped believing in me. Your support, and encouragement have been the foundation of my journey. I really appreciate.

## **ACKNOWLEDGMENT**

First and foremost, I would like to thank the Almighty God for granting me the strength, wisdom, and perseverance throughout this journey. I extend my heartfelt gratitude to my supervisor and co-supervisor for their invaluable guidance, constructive feedback, and support during the preparation of this thesis. My sincere thanks go to the academic staff and colleagues at university of Rwanda for their support, encouragement, and insightful discussions. Finally, I am grateful to my family and friends for their constant motivation, patience, and understanding throughout this academic journey.

## **ABSTRACT**

This study investigates the performance of junction through road user crossing behavior and the influence of road geometry on this behavior at selected junctions within Kigali City, Rwanda. The primary objectives were to assess existing road user crossing behaviors, establish the relationship between road geometric features and these behaviors, and ultimately evaluate the performance of the observed junctions.

The methodology involved [e.g., direct observation of road user movements, collection of geometric data, and qualitative assessment]. Key geometric parameters considered included the presence of traffic lights, medians (traffic islands), and lane widths, all of which are critical elements in urban intersection design. The study collected data on a diverse range of road users, encompassing pedestrians, cyclists, motorcyclists, and various vehicle types, reflecting the typical traffic composition in Kigali.

Study showed that for Behavioral Compliance, Giporoso Junction achieved near-perfect scores (20/20) due to high signal adherence (96.3% pedestrian compliance), while Nyabugogo (18.25/20) showed gaps in motorcyclist discipline (16.3% illegal overtaking)

Findings revealed that road geometry significantly impacts road user behavior. For instance, signalized intersections generally contributed to more structured crossing patterns, while the inclusion of medians provided crucial safe refuge areas for pedestrians, enhancing their safety during crossings. Lane width also played a role in influencing vehicle speeds and the perceived safety environment for vulnerable road users. Regression models confirmed traffic control ( $R^2 = 0.986$ ) as the dominant factor over geometry. The study underscores the need for integrated design and enforcement to mitigate conflicts in rapidly urbanizing contexts.

In conclusion, effective road geometric design, complemented by appropriate traffic control and management strategies, is paramount for improving road safety and optimizing junction performance in urban environments like Kigali. The study offers valuable insights for urban planners and traffic engineers seeking to enhance pedestrian safety, reduce conflicts, and improve the overall efficiency of road networks.

Keywords: Junction, Behavior and Performance

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## **CHAPTER 1. GENERAL INTRODUCTION**

### **1.1 Background**

Urban road junctions play a critical role in the overall functionality of transportation networks. In Kigali City, where rapid urban growth has increased traffic volumes and user diversity, the performance of junctions has become a key factor in ensuring road safety and comfort mobility.

In recent years, Kigali has experienced a sharp rise in motorization. The number of registered vehicles in Rwanda increased from 268,537 in 2021 to over 360,000 by the end of 2023, representing a growth of more than 34% in just three years. Motorcycles alone accounted for 177,187 registered units in 2023 (World Health Organization, 2023). This growth has placed immense pressure on existing road infrastructure and junction capacity. Simultaneously as of 2022, the city's population has reached approximately 1.74 million, reflecting a consistent annual growth rate of over 3% in recent years (National Institute of Statistics of Rwanda, 2022)

To accommodate this growth and enhance mobility, the government has launched several infrastructure development programs. The Kigali Infrastructure Project (KIP), initiated in 2022, targets the construction of 57 roads and bridges covering over 215 km by 2026 (City of Kigali, 2024). One of its key components is the development of ring roads to divert traffic from the congested city center and improve the efficiency of junctions and corridors.

Understanding how road users behave at different types of junctions, and how this behavior affects junction performance, can reveal deeper insights into underlying issues of safety, efficiency, and infrastructure design. This study seeks to assess the performance of selected junctions in Kigali through the lens of user behavior focusing especially on crossing behavior.

### **1.2 Problem Statement**

Kigali City is undergoing rapid transformation due to increased urbanization, population growth, and motorization. In response, the Government of Rwanda has implemented various strategies to expand infrastructure, including transport infrastructure, across the city. Among the key components of this network are road junctions, which serve as critical points where traffic flows intersect. These junctions must be well-designed to effectively accommodate all categories of road users, including pedestrians, cyclists, motorcyclists, and drivers, each of whom exhibits different behaviors and expectations.

Although major infrastructure projects such as the Kigali Infrastructure Project (KIP) are underway to improve urban mobility, there remains a need to better understand how road users interact at junctions in

real-world conditions. Traditional methods of evaluating junction performance tend to focus primarily on vehicle flow metrics (Transportation research board, 2010) often neglecting user behavior—especially crossing behavior—which can provide valuable insights into safety, accessibility, and operational effectiveness.

This study seeks to assess selected junctions in Kigali through direct observation of user behavior, with a focus on crossing movements. The findings will be used to develop a behavioral performance scoring framework, enabling the ranking of junctions and supporting evidence-based recommendations for improving the safety and efficiency of urban junction design and management.

### **1.3 Research Objectives**

#### **1.3.1 Main Objective**

Assessing junction performance through road users' behavior: case study of Kigali city.

#### **1.3.2 Specific Objectives**

- ✓ To identify the main type of junction in Kigali city and characterize their geometric features
- ✓ To assess road users crossing behavior in each junction
- ✓ To assess the performance score of each junction through the different road users crossing behavior
- ✓ To provide recommendations for improving junction performance based on the assessment results through geometric design or management

#### **1.3.3 Research Questions**

- ✓ What are the predominant types of junctions in Kigali, and what are their key geometric features?
- ✓ How do different road users (pedestrians, cyclists, motorcyclists, and drivers) behave when crossing at various junctions?
- ✓ What is the performance score of each junction based on the different road users crossing behavior?
- ✓ What recommendations can be made to improve junction performance based on the different road users crossing behavior?

### **1.4 Methodology**

This study adopts observational, descriptive and advanced statistical analysis approach aimed at assessing the performance of selected junctions in Kigali through road user crossing behavior. The approach

combines field observation, geometric documentation, and road users behavior-based performance scoring.

### **1.5 Case study**

The research will be conducted at selected road junctions within Kigali City. These junctions will be chosen to represent the most common intersection types, including T-junctions, roundabouts, and signalized intersections. The selection criteria will consider factors such as the location of the junction, volume of traffic, diversity of road users, and the presence of different traffic control devices. This will ensure a representative analysis across different urban contexts within the city

### **1.6 Data Collection Method**

To address the first objective, which seeks to identify the main types of junctions in Kigali and characterize their geometric features, physical site visits to observe and document junction layouts will be conducted. This will include direct measurement of features such as the number of legs, lane widths, and presence of crosswalks, medians, signage, and traffic control devices. In addition, photographic documentation and sketches will be used to complement the data collected in the field. Where available, city planning maps and approved road design drawings will also be consulted to confirm the geometric configurations

To achieve the second objective, which involves assessing road user crossing behavior, short video footage will be recorded at each selected junction during three peak periods morning, midday, and evening. Each recording session will last 15 minutes. The video data will be used to analyze how different categories of road users including pedestrians, cyclists, motorcyclists, and drivers interact at the junction, particularly during crossing movements. A structured observation checklist will guide the behavioral analysis, capturing key aspects designed in observational checklist

### **1.7 Data analysis**

The collected video footage will be reviewed and coded using a structured observation checklist to categorize user behavior according to mode of transport pedestrians, cyclists, motorcyclists, and drivers. For each road user group, frequencies of specific behaviors such as compliance with signals, use of marked crossings, and risky maneuvers will be recorded and summarized using descriptive statistics, including percentages, tables, and charts.

In addition to descriptive analysis, the study will employ **regression analysis** to examine the relationship between junction geometric features and road user behavior for each mode of transport. Independent variables will include junction characteristics such as number of legs, presence of medians, lane widths, and type of control (signalized or not). Dependent variables will be specific behavioral indicators

identified during observation (e.g., rate of jaywalking for pedestrians, illegal maneuvering by motorcycles, etc.). This analysis will help determine whether, and to what extent, the design of a junction influences the behavior of different road users.

Furthermore, regression models will also be used to analyze the relationship between junction geometry and the computed performance scores. This will allow for deeper insight into whether certain design elements are associated with better or worse behavioral performance, thereby informing more targeted recommendations for junction improvement.

Through both descriptive and inferential analysis, the study aims to build a comprehensive understanding of how junction design affects user behavior and overall performance.

## **1.8 Expected outcome**

This study is expected to produce the following outcomes:

### **1. A list of typical junction in Kigali City**

A detailed inventory and classification of the most common junction types across Kigali will be established, including their geometric and control features. This will provide a baseline understanding of how junctions are designed and distributed across the city.

### **2. Documented Patterns of Road User Behavior at Junctions**

Through systematic observation, the study will reveal key behavioral patterns of different road user groups (pedestrians, motorcyclists, drivers, and cyclists) at selected junctions. These findings will include levels of compliance with traffic controls, crossing habits, common violations, and user interactions.

### **3. Behavior-Based Performance Scores for Selected Junctions**

Each junction will be assigned a performance score based on observed user behavior using a standardized scoring framework. This will allow for comparison and ranking of junctions according to their effectiveness in promoting safe and orderly crossing behavior.

### **4. Statistical Relationship between Junction Geometry and User Behavior**

Using regression analysis, the study will identify which geometric or design features of junctions significantly influence road user behavior and performance scores. This will offer evidence-based insight into how specific infrastructure elements affect behavior.

### **5. Recommendations for Behavior-Informed Junction Design**

Based on observed behavior, performance ranking, and regression results, the study will propose practical recommendations to improve the safety and functionality of junctions. These may include adjustments in design, signage, crossing facilities, or enforcement strategies.

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Introduction**

An intersection, or junction, is the general area where two or more roads join, or cross, within which are included the carriageway and roadside facilities for traffic movement in that area.

An intersection is a critical part of a road because the efficiency, safety, speed, cost of roads operation, and capacity of the road depends on the intersection design. The main objective of intersection design is to reduce the severity of potential conflicts between vehicles, bicycles, and pedestrians. In addition, the intersection design should facilitate the convenience, ease, and comfort of people travelling through the intersection and, at the same time, assure ease of drivers in making the necessary manoeuvres.

Although each intersection may have unique physical characteristics that distinguish from another intersection, Designers should adhere to uniform standards presented here in so as to avoid violation of driver expectancy. (Ebenezer R. Mollel, 2011)

Most of the intersection-accidents occur at the very lightly trafficked at-grade intersections and from a traffic-safety aspect these lightly trafficked intersections require as much attention as do those intersections where heavier conflicting traffic movements occur. Good intersection design should allow transition from one route to another or through movement on the main route and intersecting route with minimum delay and maximum safety. The layout and operation of the intersection should be obvious to the driver, with good visibility between conflicting movements. Crests, gradients and curves should be avoided and if absolutely inevitable, T-intersections on the outside of a curve will have much better visibility than those that are located on the inside of a curve. Furthermore, the number of intersections should be kept as low as possible consistent with traffic demands and their spacing should be as big as possible.

Intersections should not be located where it is difficult or expensive to provide adequate visibility or driving comfort. Locations which should be avoided are for example where earthworks are heavy, near bridges, on small radius curves, on the outside of super-elevated curves, on high embankments, steep grades (>3%) or on crests. (Ebenezer R. Mollel, 2011)

This chapter describes the design of basic types of at-grade intersections and the various criteria that should be considered. Grade separated intersections are not described as my thesis only covered those intersections which are at grade.

### **2.2 Types of Intersection**

Different at-grade intersection types will be appropriate under different circumstances depending on traffic flows, speeds, and site limitations.

The three basic types of at-grade intersections are the T intersection (with variations in the angle of

approach), the **four-leg** intersection, and the **multi-leg** intersection. In each particular case the type is determined by the number of legs, the topography, the character of the intersecting roads, the traffic patterns and speeds, and the desired type of operation. Multi-leg intersection should be avoided whenever practical. (Ebenezer R. Mollel, 2011)

### 2.3 Classification of at grade intersection

At grade intersections can be classified into two main intersection categories based on the type of control used. For each category, there are a number of different intersection types as per the table below

**Table 1 Types of at-grade Intersections**

Intersection Category	Traffic control		Intersection types
	Major road	Minor road	
Priority intersection	Priority	Stop or give away sign	- Unchannelised T-intersection -Partly Channelized T intersection - Channelized T-intersection
Control intersection	Traffic signals or give away sign		- Roundabout - Signalized intersection

#### 2.3.1 Priority Intersections

Priority intersections will be adequate in most rural situations. Three types of T intersections are given below:

##### 2.3.1.1 Unchannelised T-intersection

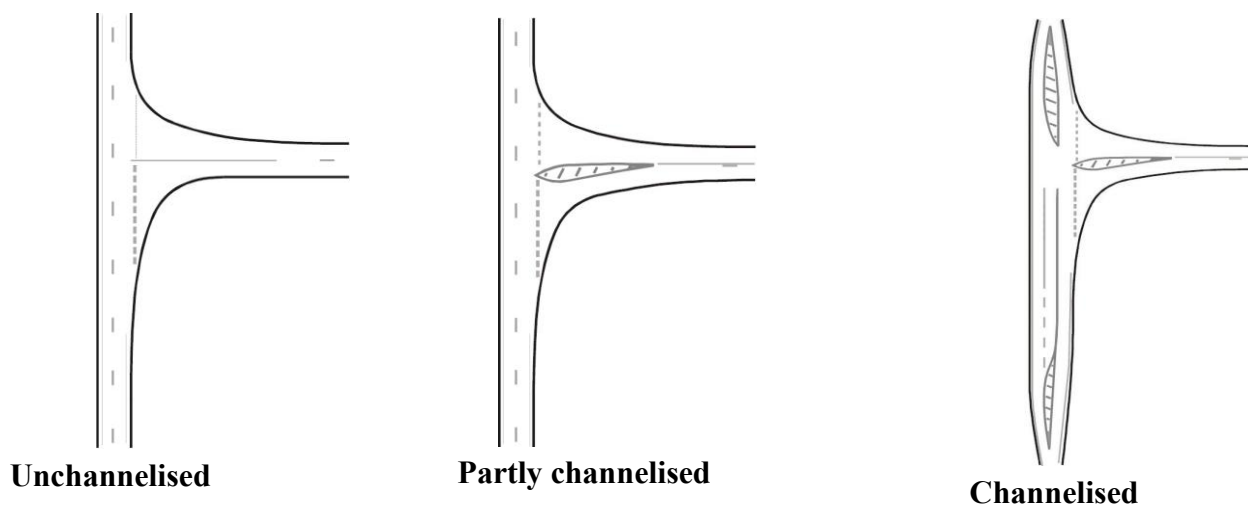
The unchannelised design is suitable for intersections where there is a very small amount of turning traffic. It is the simplest design and has no traffic islands.

##### 2.3.1.2 Partly channelized T-intersection (Type B)

The partly channelized design is for intersections with a moderate volume of turning traffic. It has a traffic island in the minor road arm. In urban areas, the traffic island would normally be kerbed in order to provide a refuge for pedestrians crossing the road. (Scott S. Washburn, 2012)

##### 2.3.1.3 Channelized T-intersection (Type C)

The fully channelized design is for intersections with a high volume of turning traffic or high speeds. It has traffic islands in both the minor road and the main road.



**Figure 1 Typical T-intersections. Source:** (Ebenezer R. Mollel, 2011)

### 2.2.2 Control Intersections

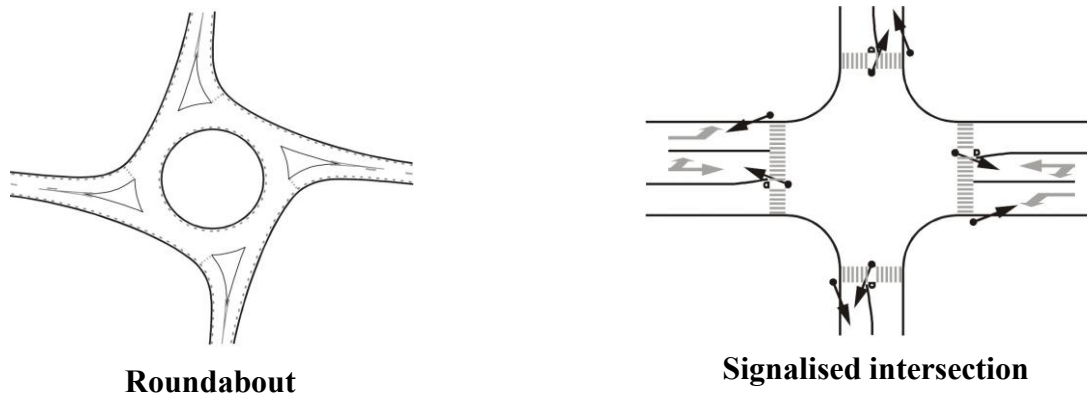
Control intersections are mostly used in towns and trading centre. However, roundabouts can be used in rural areas in intersections between major roads or other intersections with high traffic volumes. A basic requirement for all controlled intersections is that drivers must see the control device soon enough to perform the action it indicates. There are two types of control intersections:

#### 2.2.2.1 Roundabout

Roundabouts are controlled by the rule that all entry traffic must give way to circulating traffic. The ratio of minor road incoming traffic to the total incoming traffic should preferably be at least 10 to 15%. Roundabouts can be of normal size, i.e. with central island radius of 10m or more or small size, i.e. with a central island radius less than 10 m.

#### 2.2.2.2 Signalized intersection

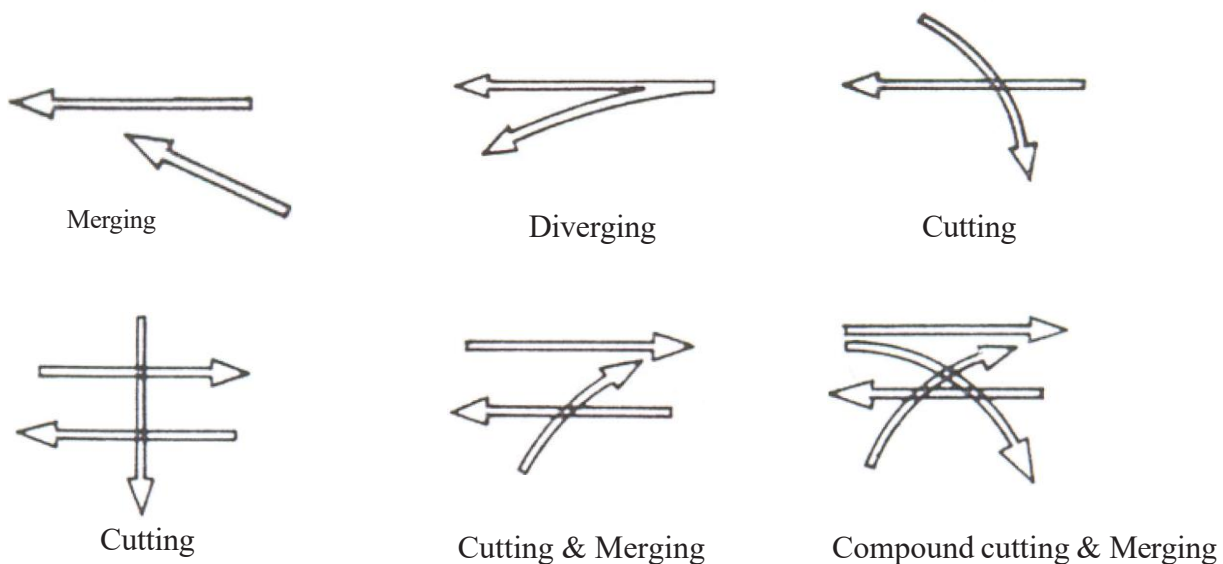
Signalised intersections have conflicts separated by traffic signals. No conflicts are allowed between straight through traffic movements. (Ebenezer R. Mollel, 2011)



**Figure 2 Typical layouts for control intersections. Source: (Ebenezer R. Mollel, 2011)**

### 2.4 Intersection Manoeuvres

Three basic movements or manoeuvres occur at intersections, namely merging, cutting and diverging. These manoeuvres are illustrated below.



**Figure 3 Intersection Manoeuvres. Source: (Ebenezer R. Mollel, 2011)**

### 2.5 Intersection Design Speed

The Intersection Design Speed, which is the principal design parameter upon which the geometrical layout and capacity of an intersection is based, is the design speed of the major road in the vicinity of the intersection. This design speed will not necessarily be the same as the average major road design speed but may be higher or lower. Therefore, the designer must give careful consideration to the selection of the appropriate Intersection Design Speed as this will greatly affect both the safety and efficiency of the intersection and the construction cost.

### 2.6 Design requirements

The design of at-grade intersections must take account of the following basic requirements:

- Safety;

- Operational comfort for the users;
- Capacity; and,
- Economy.

### **2.6.1 Safety and Operational Comfort**

An intersection is considered safe when it is perceptible, comprehensible and maneuverable. These three requirements can generally be met by complying with the following guidelines. (Adewoyin, 2021)

#### **2.6.1.1 Perception**

- The intersection should be sited so that the major road approaches are readily visible.
- Early widening of the intersection approaches.
- The use of traffic islands in the minor road to emphasize a “yield” or “stop” requirement.
- The use of early and eye-catching traffic signs.
- Optical guidance by landscaping and the use of road furniture, especially where a intersection must be located on a crest curve.
- The provision of visibility splays which ensure unobstructed sight lines to the left and right along the major road.
- The angle of intersection of the major and minor roads should be between 70 and 110 degrees.
- The use of single lane approaches is preferred on the minor road in order to avoid mutual sight obstruction from two vehicles waiting next to each other to turn or cross the major road. (Wu, 2001)

#### **2.6.1.2 Comprehension**

- The right of way should follow naturally and logically from the intersection layout.
- The types of intersections used throughout the whole road network should be as similar as possible.
- The provision of optical guidance by the use of clearly visible kerbs, traffic islands, road markings, road signs and other road furniture.

#### **2.6.1.3 Maneuverability**

- All traffic lanes should be of adequate width for the appropriate vehicle turning characteristics. To accommodate truck traffic, turning radii should be at least 15 metres.
- The edges of traffic lanes should be clearly indicated by road markings.
- Traffic islands and kerbs should not conflict with the natural vehicle paths.

### **2.6.2 Capacity**

The operation of uncontrolled intersections depends principally upon the frequency of gaps which naturally occur between vehicles in the main road flow. These gaps should be of sufficient duration to permit vehicles from the minor road to merge with, or cross, the major road flow. In consequence intersections are limited in capacity, but this capacity may be optimized by, for example, channelization or the separation of manoeuvres. (Wu, 2001)

Adequate capacity shall be a primary design requirement for controlled intersections. Designers shall use acceptable procedures such as those published by HCM to estimate capacity.

### **2.6.3 Economy**

An economical intersection design generally results from minimization of the construction, maintenance and operational costs. Delay can be an important operational factor and the saving in time otherwise lost may justify a more expensive and even grade separated intersection. Loss of lives, personal injuries and damage to vehicles caused by intersection-accidents are considered as operational “costs” and should be taken into account. (Wu, 2001)

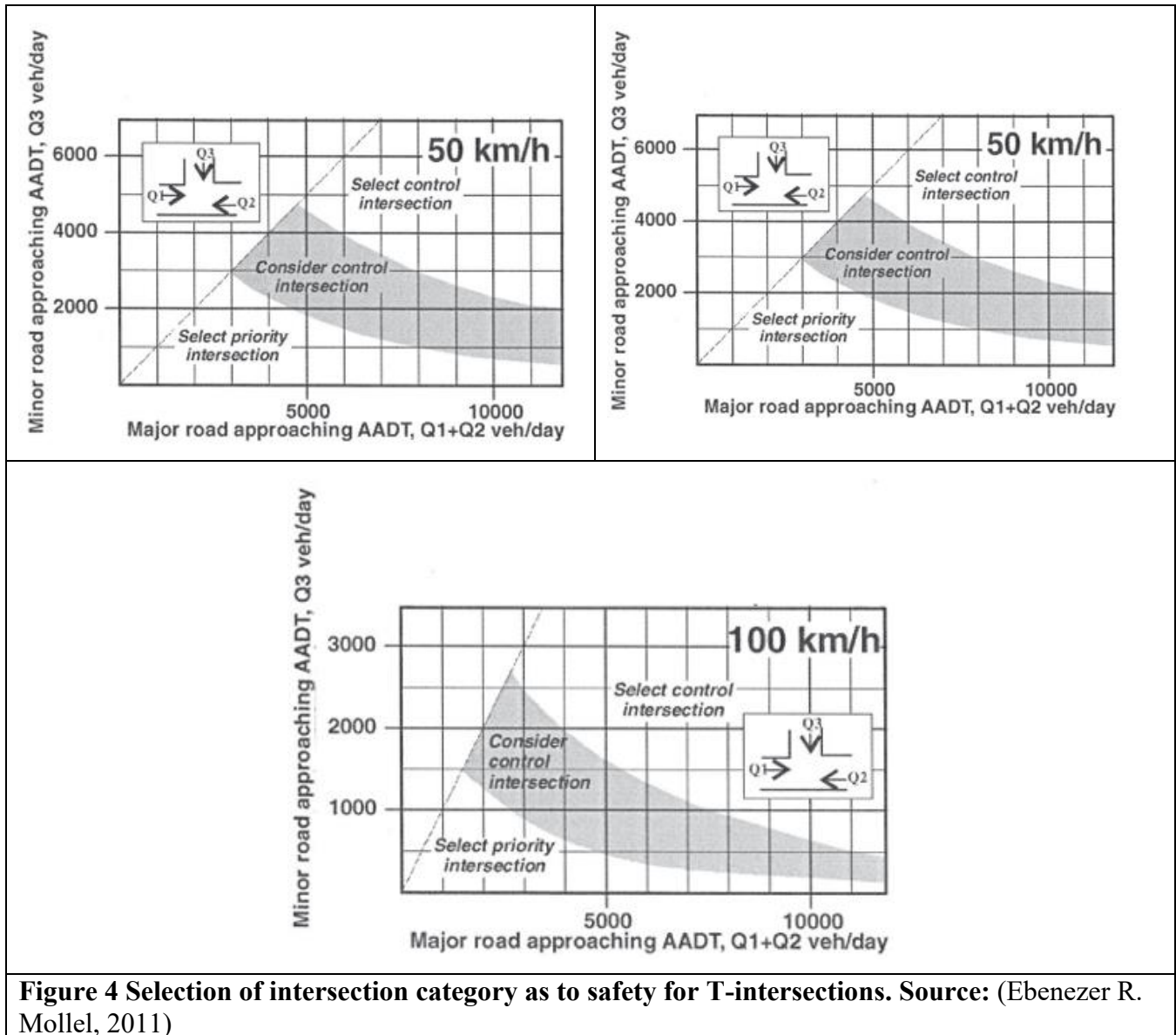
## **2.7 Selection of intersection type**

The selection is divided into two steps; selection of intersection category (priority or control) and selection of intersection type. It is based on the following assumptions:

- Priority intersections can be safe and give sufficient capacity for certain traffic volumes and speed limits;
- If a priority intersection is not sufficient for safety and capacity, the major road traffic must also be controlled; and,
- Depending on location, traffic conditions and speed limits, different types of priority or control intersection should be selected.

### **1. Safety**

The selection of intersection category should mainly be based on safety. The selection can be made by using diagrams with the relationships between the safety levels and the average annual daily approaching traffic volumes (AADT in veh/day) based on accident statistics. The diagrams shown in Figure 7-5 are for T-intersections on 2-lane roads with 50, 80 and 100 km/h design speed. (Rodegerdts, 2010)

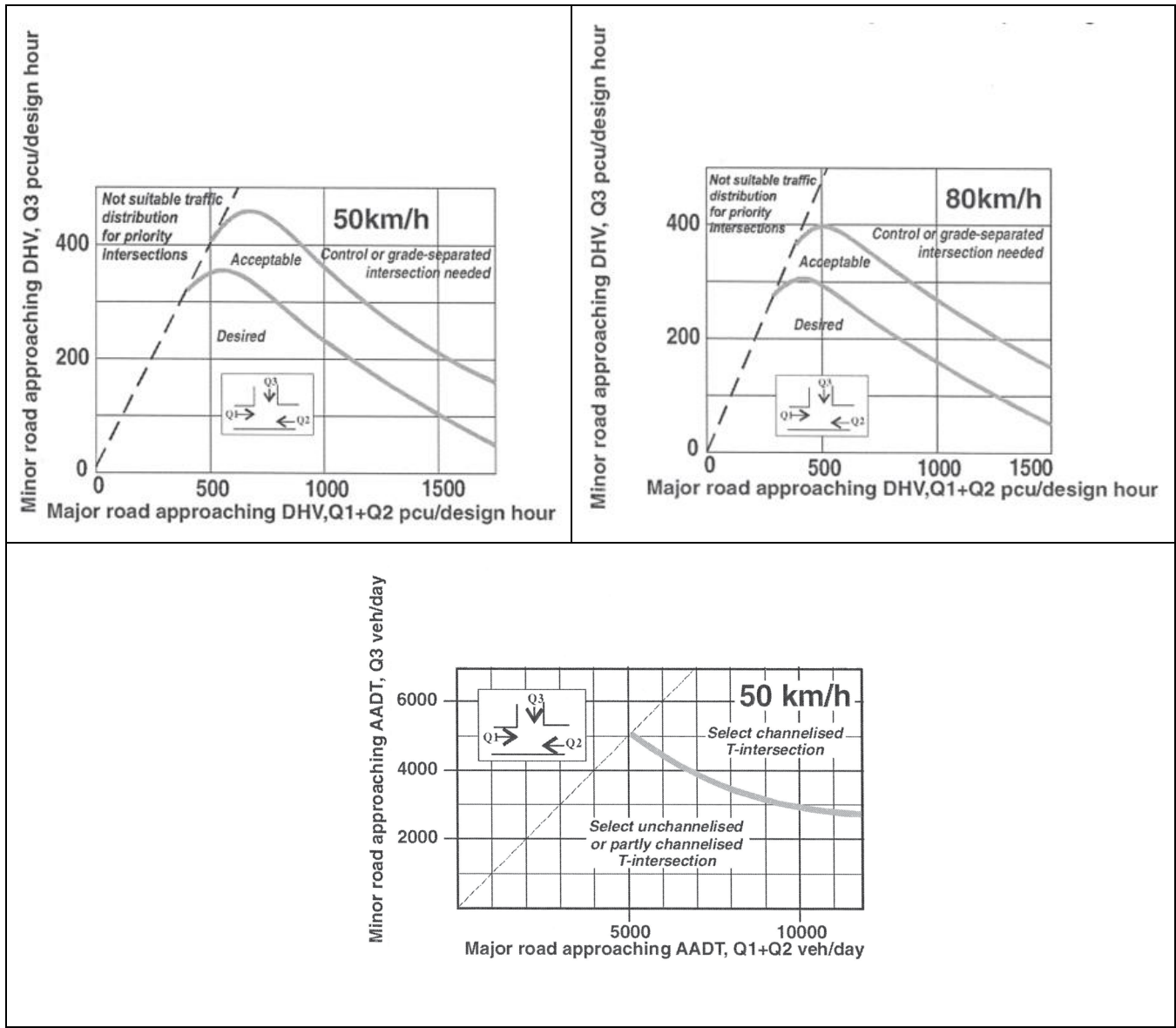


**Figure 4 Selection of intersection category as to safety for T-intersections. Source: (Ebenezer R. Mollel, 2011)**

## 2. Capacity

The selection of intersection category based on safety should be checked for capacity. It can be made by using diagrams with the relationships between the capacity and the approaching traffic volumes during the design hour (DHV in pcu/design hour). The diagrams shown in Figure 7-6 are for T-intersections on 2-lane roads with 50, 80 and 100 km/h speed limit.

The desired level refers to a degree of saturation (actual traffic flow/capacity) of 0.5. The acceptable level refers to a degree of saturation of 0.7. Capacity could be checked more in detail using standard capacity software. (Ebenezer R. Mollel, 2011)

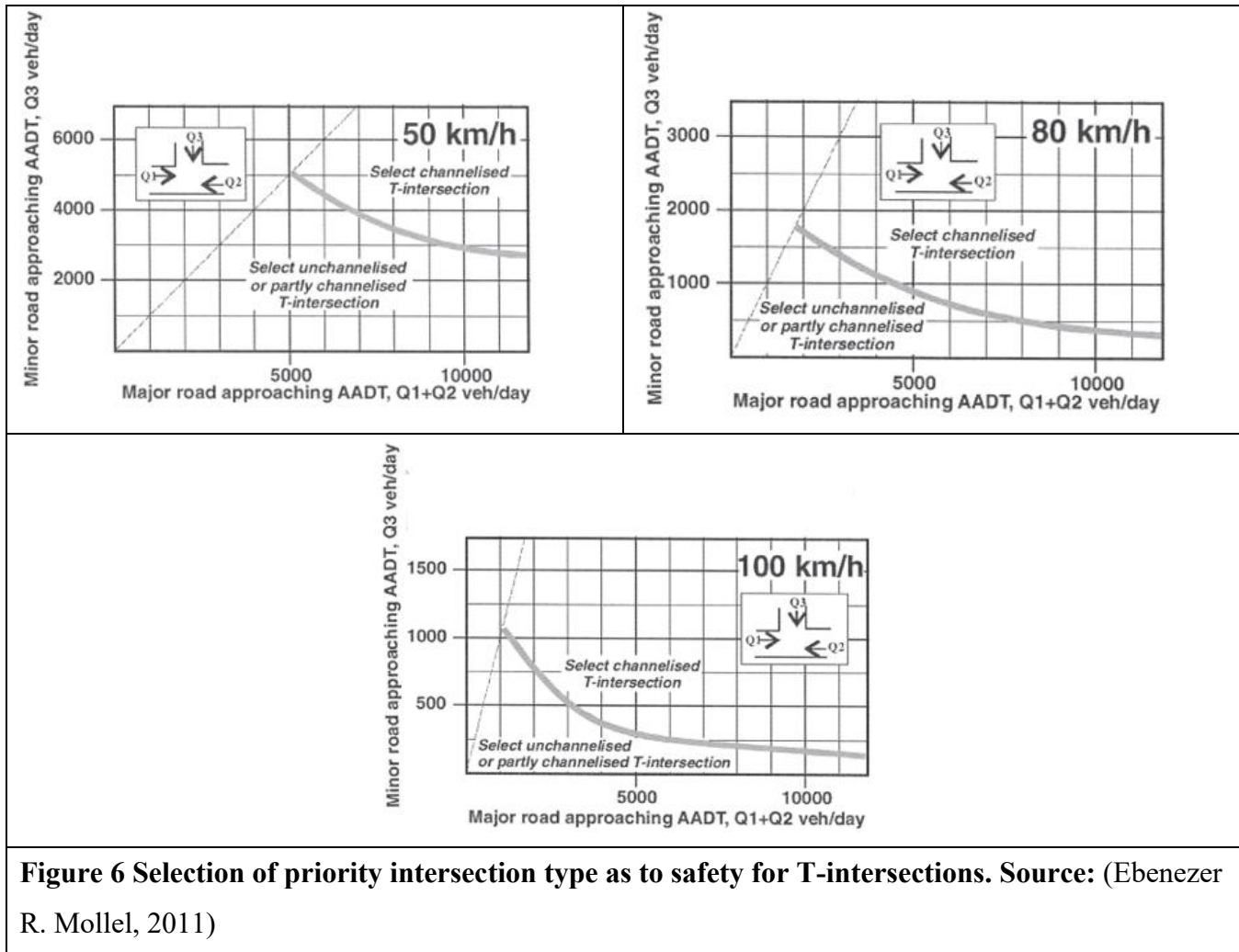


**Figure 5 Selection of intersection category as to capacity for T-intersection. Source (Ebenezer R. Mollel, 2011)**

### 3. Priority intersections

The selection of priority intersection type should mainly be based on safety. The selection can be made by using diagrams with the relationships between the safety levels and the average annual daily approaching traffic volumes (AADT in veh/day) based on accident statistics. The diagrams shown in Figure 9 are for T-intersections on 2-lane roads with 50, 80 and 100 km/h design speed. Crossroads should be avoided. The number of right turners should obviously also impact the decision.

The diagrams are based on general European findings on safety effects of right turn lanes. Note however they are only a starting point for determining the most appropriate form of intersection. (Ebenezer R. Mollel, 2011)

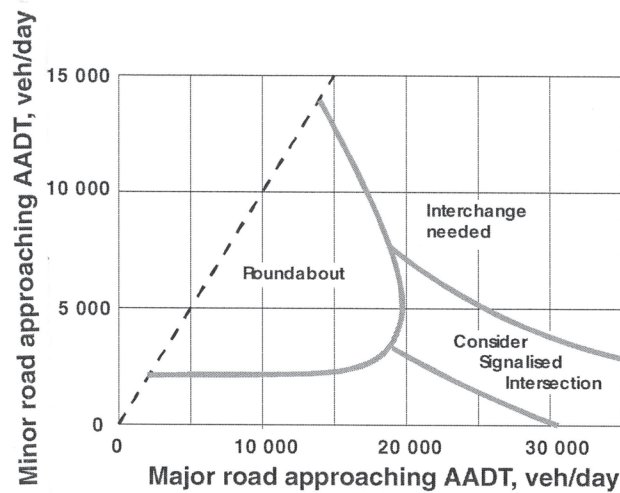


**4. Control intersections**

Roundabouts are suitable for almost all situations, provided there is enough space. Roundabouts have been found to be safer than signalized intersections and are suitable for both low and medium traffic flows. At very high traffic volumes they tend to become blocked due to drivers failing to obey the priority rules. Well-designed roundabouts slow traffic down, which can be useful at the entry to a built-up area, or where there is a significant change in road standard, such as the change from a dual carriageway to a single carriageway.

Traffic signals are the favoured option in the larger urban areas. Co-ordinated networks of signals (Area Traffic Control) can bring major improvements in traffic flow and a significant reduction in delays and stoppages. However, they must be demand-responsive, in order to get the maximum capacity from each intersection.

For some traffic distributions, for example high traffic volumes on the major road, the total delay can be shorter in a signalized intersection than in a roundabout. The diagram in Figure 7-8 shows the traffic conditions for which signalized intersections are most suited, based on Kenyan and UK experience.



**Figure 7 Selection of control intersection type. Source:** (Ebenezer R. Mollel, 2011)

If a signalized intersection is considered based on planning conditions or traffic volumes, capacity analysis and economic analysis should be made. This should include road construction and maintenance costs, accident costs, travel time costs, vehicle operating costs and environmental costs. (Transportation Research Board, 2016)

## 2.7 Intersection design procedure

The design procedure should be used for new intersections as well as for upgrading existing intersections. Intersection design is normally done in two stages i.e. preliminary design and detailed design.

The objective with the preliminary design is to select the intersection type and location and to make a draft intersection drawing and traffic control plan. The objective with the detailed design is to do the geometric design and to make detailed intersection drawing and traffic control plan. As with all road projects, it is required that a safety audit be done before the scheme is finalized and built. The procedure to be used for intersection design involves four basic steps which are as follows:

- (i) Data collection
- (ii) Define the major road and determine the intersection design speed
- (iii) Select intersection category and type and check that it offers adequate safety and capacity for the predicted traffic maneuver's
- (iv) Refine and modify the basic intersection layout to meet the safety and operational requirements. This is done by applying the principles of intersection design which are:
  - (a) Distance between adjoining intersections
  - (b) Visibility splays
  - (c) Turning lanes

- (d) Major Road Cross Section
- (e) Central reserves
- (f) Traffic islands and minor road widening
- (g) Alignment and Widening of the major road

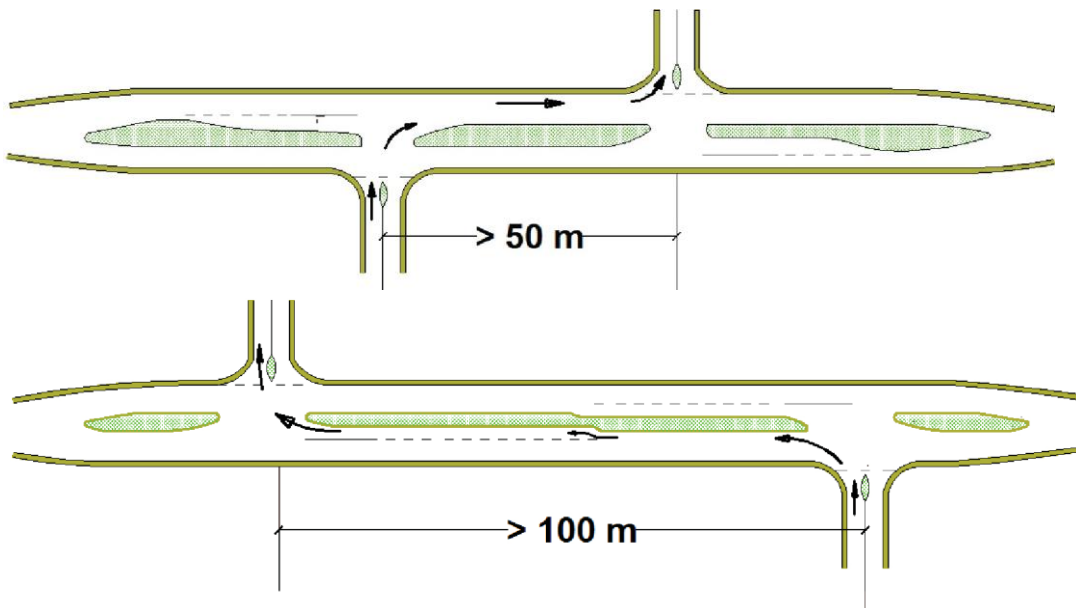
### 2.7.1 Data Collection

The following data will be required to ensure that a safe, economic and geometrically satisfactory design is produced: (Adewoyin, 2021)

- ✓ A plan to a scale of at least 1:500, showing all topographical details.
- ✓ Characteristics of the crossing or joining roads, i.e. horizontal and vertical alignments, distances to adjoining intersections, cross-sectional data, vehicle operating speeds, etc.
- ✓ Characteristics of the predicted volumes and compositions of the various traffic streams.
- ✓ Other factors affecting the design, such as topographical or geotechnical peculiarities, locations of public utilities, pedestrian movements, adjacent land usage, etc.
- ✓ Traffic accident data, especially where the reconstruction of an existing intersection is involved.

### 2.7.2 Basic Intersection Layout

The basic junction layout (intersection type) for both single and dual carriageway roads is the T-junction with the major road traffic having priority over the minor road traffic. Crossroads, although not recommended, may also be used but only on single carriageway roads where traffic flows are very low and where site conditions will not permit the use of staggered T-junctions. Where staggered T-junctions are used to replace a crossroads, the right-left stagger as indicated in Figure 11 is preferred to the left-right stagger and the minimum stagger should be 50m. On traffic grounds this is because in the latter case opposing queues of right-turning vehicles from the major road will have to wait side by side with the consequent possibility of the whole junction locking. In a left/right staggered intersection the minimum distance should be at least 100 meters and should be longer in order to allow the provision of right turn lanes in the major road. The length of the right turn lane depends on the junction design speed and traffic turning right in pcu/h. Where there is a lot of cross traffic (from one minor road to the other) the right/left stagger is preferable. This is because, once the driver has turned into the main road, he can proceed to the exit without impeding other traffic. The left/right stagger involves vehicles turning right out of the main road across the path of oncoming traffic, and this is a particularly hazardous maneuver.



**Figure 8 Right/Left and Left/Right staggered intersections and their respective minimum distance.** Source: (Ebenezer R. Mollel, 2011)

Where more complex junction layouts involving the intersection of four or more roads are encountered, these should be simplified by realigning the approaches, to safer, more comprehensible and maneuverable layouts. For safety and economic reasons, intersection roads shall meet at or nearly 90 degrees. Examples of such simplifications are given in Figure. (Scott S. Washburn, 2012)

Complex Layout (Undesirable)	Simplified Layout (Depending up on major traffic stream)			
1 	1a 	1b 	1c 	1d 
2 	2a 	2b 	2c 	2d 
3 	3a 	3b 	3c 	
4 	4a 	4b 	4c 	

**Figure 9 Example of the Simplification of Complex Junctions.** Source: (Ebenezer R. Mollel, 2011)

## 2.8 Principle of intersection design

The basic principles of good intersection design are:

- ✓ Minimize the number of conflict points, and thus the risk of accidents.
- ✓ Give priority to major traffic movements, through alignment, signing and traffic control.
- ✓ Separate conflicts in space or time.
- ✓ Control the angle of conflict; crossing streams of traffic should intersect at a right angle or near right angle.
- ✓ Define and minimize conflict areas.
- ✓ Define vehicle paths.
- ✓ Ensure adequate sight distances.
- ✓ Control approach speeds using alignment, lane width, traffic control or speed limits.
- ✓ Provide clear indication of right-of-way requirements.
- ✓ Minimize roadside hazards.
- ✓ Provide for all vehicular and non-vehicular traffic likely to use the intersection, including goods vehicles, public service vehicles, pedestrians and other vulnerable road users.
- ✓ Simplify the driving task, so that road users have to make only one decision at a time; and,
- ✓ Minimize road user delay. (Jacqueline Nyirajana, 2021)

Having selected the basic junction layout and checked that it offers sufficient capacity, it is necessary to adapt this basic layout in accordance with the following principles to ensure that a safe, economic and geometrically satisfactory design will be produced.

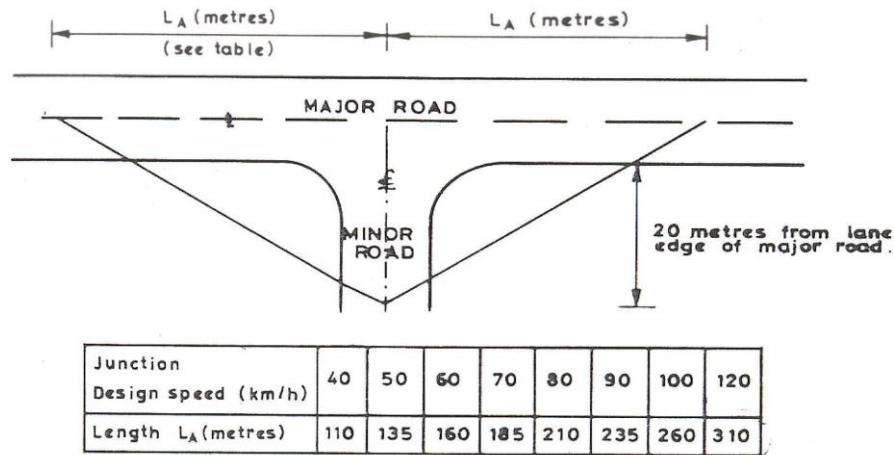
### 2.8.1 Distance Between Adjoining Intersections

The minimum distance between consecutive intersections shall preferably be equal to  $(10 \times VD)$  metres; where  $VD$  is the major road design speed in km/h. Where it is impossible to provide this minimum spacing, then the design shall incorporate either, or both, of the following:

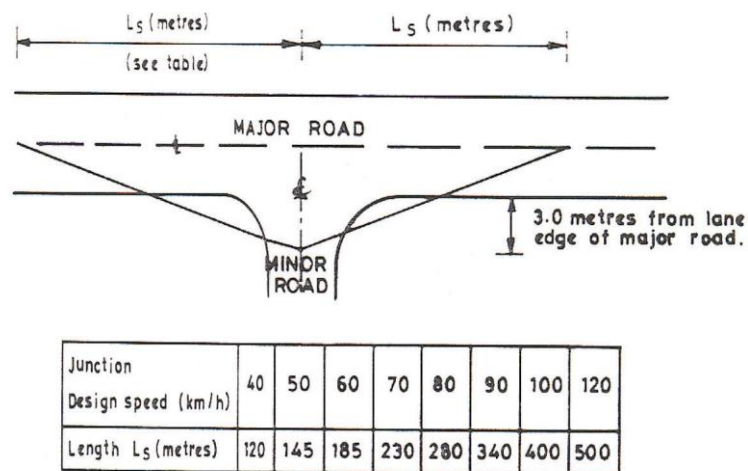
- (i) A distance between minor road centerlines equal to the passing sight distance appropriate for the Junction Design Speed plus half the length of the widened major road sections at each junction, or
- (ii) A grouping of minor road junctions into pairs to form staggered T-junctions and a distance between pairs as in (i) above. (Vorgelegt von, 2013)

### 2.8.2 Visibility Splays

At major/minor priority junctions visibility splays to the standards described below should be provided at all new junctions and should be aimed at for existing junctions. The visibility splays for both the “Approach Conditions” (Figure 10) and the “Stop Conditions” (Figure 11) should be provided.

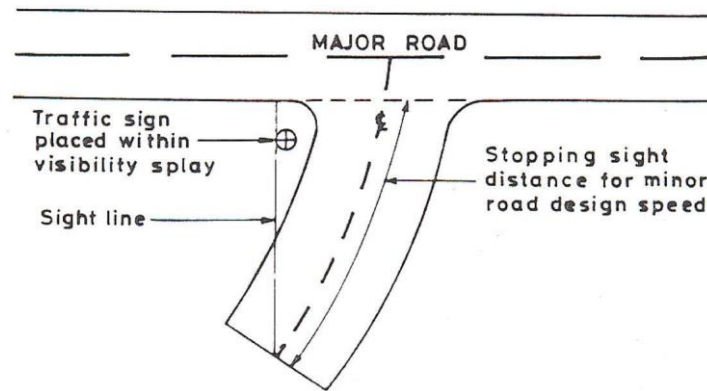


**Figure 10 Visibility Splays for “Approach” or “Yield” Conditions. Source:** (Ebenezer R. Mollel, 2011)



**Figure 11 Visibility Splays for “Stop” Conditions. Source:** (Ebenezer R. Mollel, 2011)

On the minor road, particularly where the approach to the junction is on a horizontal curve, the visibility of traffic signs is essential and a visibility splay in accordance with Figure 7-13 must be provided.



**Figure 12 Minor Road Approach Visibility Requirements. Source:** (Ebenezer R. Mollel, 2011)

Where site conditions make it impossible to improve an existing junction to these standards, at least the visibility splays for the “Stop Condition” must always be provided. (Ebenezer R. Mollel, 2011)

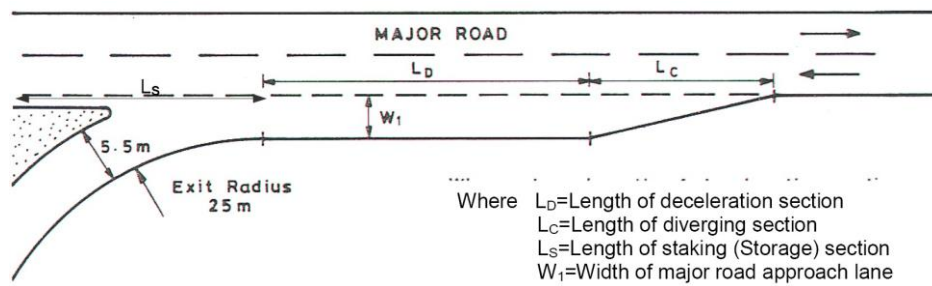
### 2.8.3 Turning Lanes

Left and right turning lanes are of particular value on higher speed roads when a vehicle slowing down to turn and leaving the major road and may impede following vehicles. (Kaparias, 2015)

#### 1. Left Turn Lanes

Left turn lanes, comprising diverging sections and deceleration sections, shall be provided under any of the following conditions:

- (a) On dual carriageway roads.
- (b) When the Junction Design Speed is 100 km/h or greater and the AADT on the major road in Design Year 10 is greater than 2,000 pcu.
- (c) When the AADT of the left turning traffic in Design Year 10 is greater than 800 pcu.
- (d) Where junctions are sited on left-hand bends and perception of the junction for major road traffic would be greatly improved by its inclusion.
- (e) On four or more lane undivided highways.



**Figure 13 Layout for Left Turn Lane. Source: (Kaparias, 2015)**

The minimum lengths for diverging sections are given in Table 2 and shall be formed by direct tapers. However, very long tapers should be avoided as through drivers tend to use them as through lane especially on a horizontal curve. (Ebenezer R. Mollel, 2011)

**Table 2 Minimum Length of Diverging Section (Lc)**

Junction design speed (km/h)	120	100	80	≤ 70
Length of diverging section (m)	60	50	40	30

The minimum lengths for deceleration sections are dependent upon the Junction Design Speed, the exit radius from the major road into the minor road and the approach gradient of the major road. Where left turn lanes are required, the exit radius shall be 25 meters and the minimum length of deceleration sections shown in Table 3 shall be used. (Ebenezer R. Mollel, 2011)

The lengths given in Table 3 apply for approach gradients of -2% to +2%; where approach gradients greater than 2% are encountered the lengths from Table 3 shall be multiplied by the adjustment factor given in Table 4 but the adopted lengths must never be less than 30 meters. The width of the deceleration lane shall be the same as the major road approach lane. (Ebenezer R. Mollel, 2011)

**Table 3 Minimum Lengths for Left Turn Deceleration LD (for approach gradient of -2% to 2%)**

Junction design speed (km/h)	120	100	80	≤ 70
Length of deceleration section (m)	110	70	50	30

Note: Where vehicles are required to stop before entering the minor road, the deceleration section length should be equal to that used for a right turn lane as given in Table 5. (Ebenezer R. Mollel, 2011)

**Table 4 Adjustment Factors for Approach Gradient Greater Than 2%**

Adjustment factor	% Downgrade				% Upgrade			
	6	5	4	3	3	4	5	6
	1.4	1.3	1.25	1.2	0.9	0.9	0.85	0.8

Stacking section or area ( $L_S$ ) is normally 10 meters long.

Stacking/storage length may be based on the number of vehicles likely to arrive in an average of 2 minutes during peak hour. The stacking area shall accommodate at least two cars or one car and a truck under excessive heavy vehicle volumes conditions. (Adewoyin, 2021)

ii) Right Turn Lanes

A separate lane for right turning traffic (i.e. traffic turning right from the major road into the minor road) shall be provided under any of the following conditions:

- (a) On dual carriageway roads.
- (b) When the Junction Design Speed is 100 km/h or greater and the A.A.D.T, on the major road in Design Year 10 is greater than 1500 p.c.u.
- (c) When the ratio of the major road flow being cut to the right turning flow exceeds the values given on Figure 17.
- (d) On four, or more lane undivided roads. (Ebenezer R. Mollel, 2011)

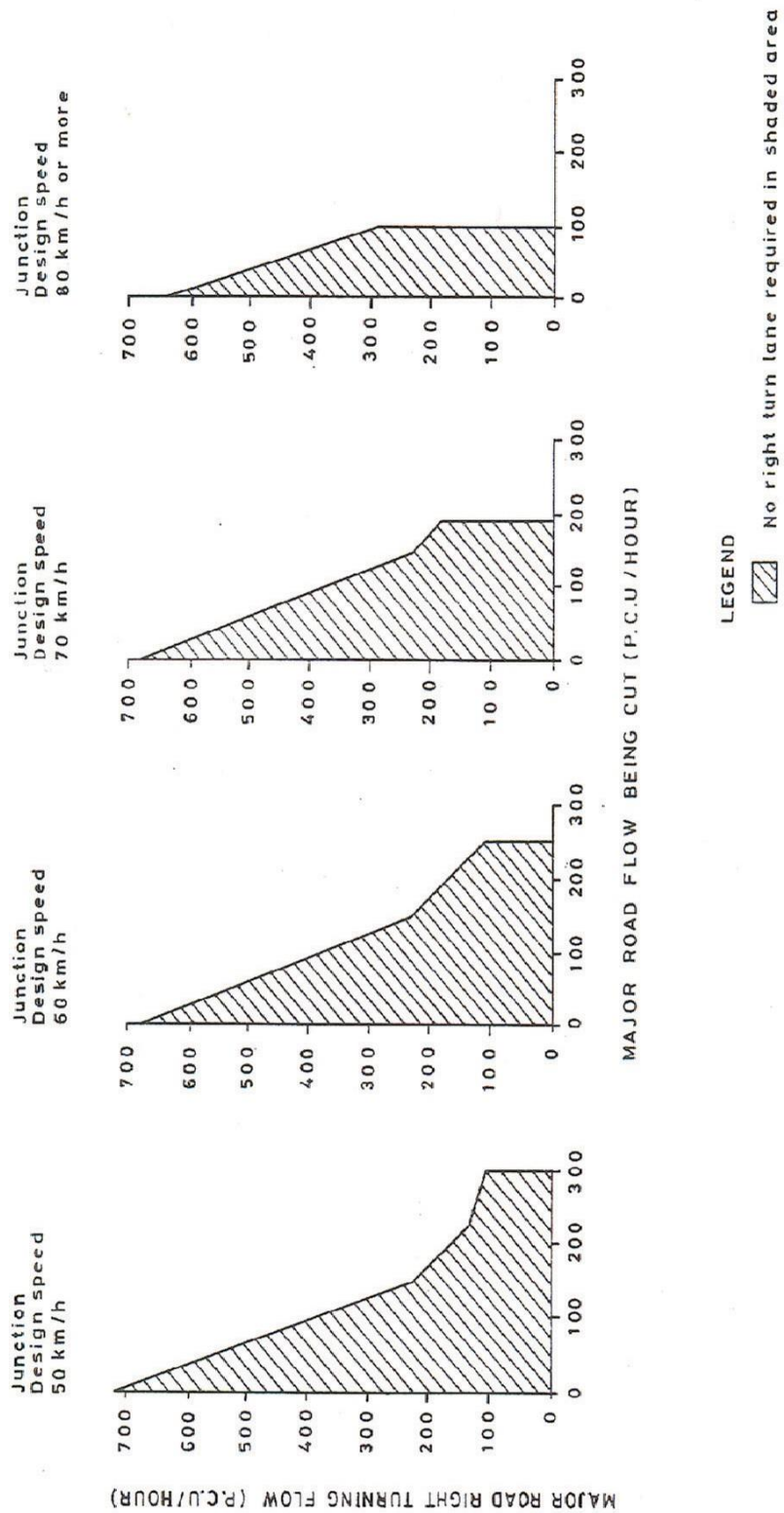


Figure 14 Criteria for Determining the Provision of Right Turn Lane. Source: (Ebenezer R. Mollel, 2011)

A right turn lane will consist of a diverging (taper) section, a deceleration section and a storage section. The minimum lengths for diverging sections are as for left turn lanes and are given in Table 2 and shall be formed by direct tapers.

The minimum lengths for deceleration sections for approach gradients of -2% to +2% are given in Table 5. For approach gradients greater than 2% the adjustment factors given in Table 4 for left turn lanes shall be applied but the adopted lengths shall never be less than 30 metres. (Ebenezer R. Mollel, 2011)

**Table 5 Minimum Length for Right Turn Deceleration Section (for approach gradients of -2% to 2%)**

Junction design speed (km/h)	120	100	80	70	60	50	40
Length of deceleration section (m)	160	105	85	75	70	50	30

The lengths of storage sections for right turning traffic are given in Table 6.

**Table 6 Length of Storage Section for Right Turning Traffic**

Traffic Turning Right [pcu/h]	Length of Storage Section [m]
0 -150	20
151 - 300	40
over 300	$N \times 9.75$ (where N is number of pcu turning right per two minutes) (Factor must be checked).

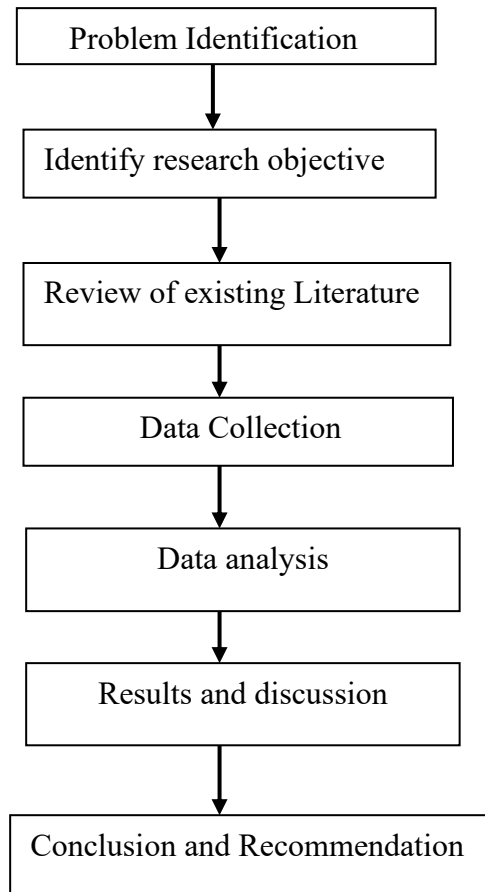
The width of the deceleration and storage sections shall be 3.0 meters. For details of the carriageway widening to accommodate right turning lanes.

On single carriageway roads where a right turn lane is to be provided, a painted channelizing island shall be used to separate the lane from the opposing traffic. (Transportation Research Board, 2016)

## CHAPTER 3: METHODOLOGY

### 3.1 Research Design

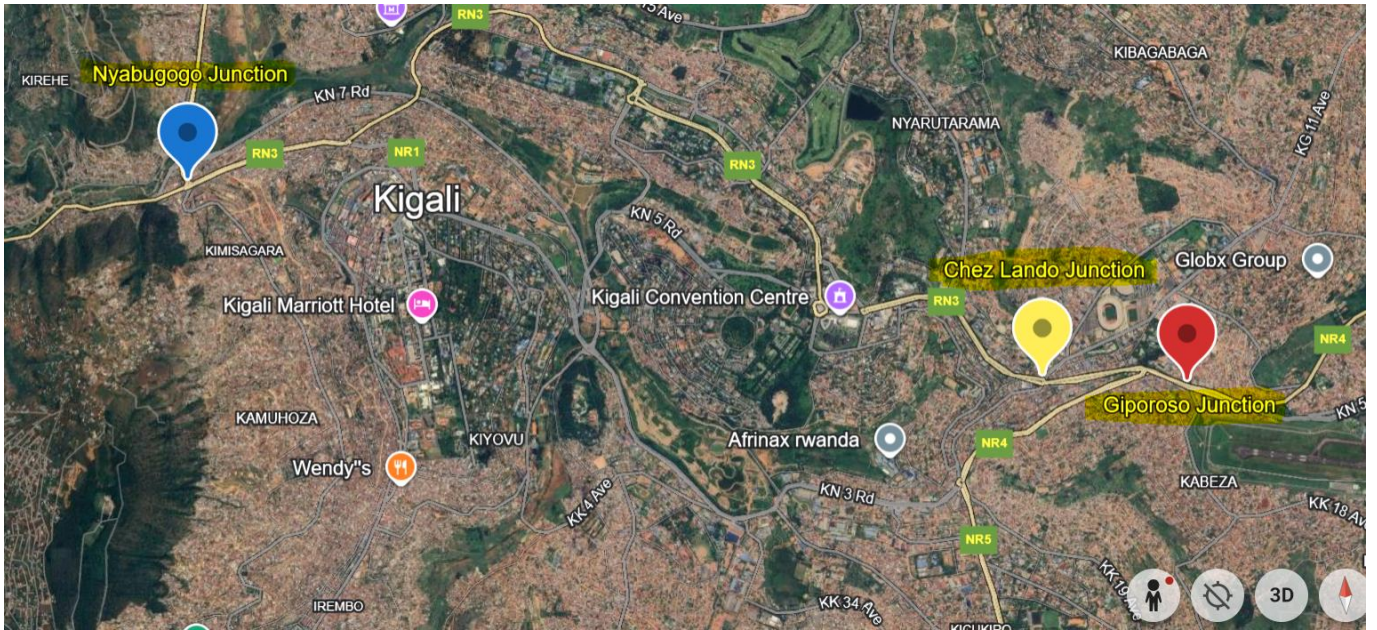
This study adopted a mixed-method approach, combining descriptive field observation, geometric data collection, and quantitative statistical analysis. The goal is to assess how road user behavior, especially crossing movements, influences junction performance in Kigali City. The approach allows triangulation between physical characteristics of junctions, behavioral observation, and statistical inference.



**Figure 15 Framework of Research**

### 3.2 Study Area and Junction Selection

The study has been conducted in Kigali City, Rwanda's capital. Junctions have been selected to represent various types, including signalized, unsignalized, and roundabouts. Selection will consider location, traffic volume, road user diversity, and traffic control types.



**Figure 16 Study Area, Giporoso\_Chez Lando\_Nyabugogo Junction (Kigali city)**

### 3.3 Data Collection Methods

This study has utilized both field-based measurements and behavioral observation techniques to collect comprehensive data on junction characteristics and road user behaviors. The data collection methods are aligned with the study's specific objectives and are structured into two main components:

#### 3.3.1 Geometric and Infrastructure Data

To assess the physical and operational characteristics of each selected junction, systematic field surveys have been conducted. These surveys aimed to document all relevant geometric features that may influence road user behavior. The following data points have been collected:

- Number of legs
- Lane configuration and widths (measured using tape measures)
- Presence and type of pedestrian infrastructure (e.g., marked crosswalks, pedestrian islands, sidewalks)
- Traffic control devices (signals, signage, roundabout features)
- Presence of medians or channelizing islands
- Visibility and sight distance conditions

Data has been collected using field observation, manual measurements, and photographic documentation. In addition, available secondary data such as Google maps and GIS maps have been reviewed to validate and supplement field findings.

This geometric inventory has been used not only to characterize each junction but also to serve as input variables in later statistical analyses exploring their effect on user behavior.

### 3.3.2 Road User Behavior Observation

To understand how different categories of road users interact within junction spaces, particularly during crossing and turning movements, video-based behavioral and free eye observations have been conducted.

The procedure will follow the steps below:

- **Video Footage Collection:** prior to recording free eye observation has conducted with the aim of assessing the site to know which place to position at so that I can cover the whole movement in junction.
  - ✓ Each junction has been recorded during **three peak periods:**
    - Morning peak (07:00–09:00)
    - Midday peak (12:00–14:00)
    - Evening peak (17:00–19:00)
  - ✓ Each session has been captured by **at least 15 minutes** of continuous activity, ensuring a reliable sample of behavior.
- **Behavioral Categories Observed:**
  - ✓ **Pedestrians** (e.g., use of crosswalks, signal compliance)
  - ✓ **Cyclists** (e.g., riding behavior, use of correct paths)
  - ✓ **Motorcyclists** (e.g., lane discipline, overtaking maneuvers)
  - ✓ **Drivers** (e.g., yielding, speeding)
- **Observation Tool:**
  - ✓ A **structured behavioral checklist** (provided in table below) has been used to systematically code observed behaviors. This tool allows the quantification of various user behaviors for later statistical analysis.

**Table 7 Behavior checklist**

Road User	Behavior Observed	Description
Pedestrian	Signal Compliance	Waiting for green pedestrian light
Pedestrian	Use of Zebra Crossing	Crossing on marked zebra crossing
Pedestrian	Walk in groups	Crossing in friendly groups or possibly following each other's lead

Pedestrian	Using Phone While Crossing	Talking, texting, or distracted by phone during crossing
Pedestrian	Looks Both Ways Before Crossing	Visibly checks traffic direction before crossing (indicator of caution)
Pedestrian	Sudden or Running Crossing	Starts crossing abruptly, possibly due to perceived time pressure
Motorcyclist	Use of proper Lane	Staying within lanes, avoiding sidewalks or medians
Motorcyclist	Yielding to Pedestrians	Giving way at pedestrian crossings
Motorcyclist	Illegal Overtaking	Cutting ahead or squeezing between vehicles unsafely
Motorcyclist	Turning Without Signaling	Making a turn without warning other road users
Motorcyclist	Respecting road signs and symbols	Compliance with road signs or traffic lights
Driver	Yielding to Pedestrians	Giving way at pedestrian crossings
Driver	Turning Without Signaling	Making a turn without warning other road users
Driver	Speed Behavior at Junction	Respect appropriate speed near junctions
Driver	Respecting road signs and symbols	Compliance with road signs or traffic lights
Cyclist	Following Road Rules	Compliance with road signs and safe crossing behavior

- **Equipment and Setup:**

- Phone Camera has been positioned at elevated and wide-angle viewpoints to ensure full visibility of all user interactions without interfering with traffic.
- The observer who was also the holder of mobile telephone which has been used as camera has ensured the camera is functioning well and recorded his voice in the video any supplementary field notes.

The collected video data has been reviewed multiple times in a controlled setting to ensure accurate coding and classification of behaviors.

### 3.4 Data Analysis methodology

Data analysis involved both descriptive and inferential statistical methods to achieve the research objectives. The aim was to extract meaningful patterns from observed behaviors, quantify the performance of junctions, and identify the influence of geometric characteristics on road user behavior.

#### 3.4.1 Descriptive Statistics

Descriptive analysis has been used to summarize and interpret the observed behavior of different road users at each junction.

- **Data Compilation:** All video footage has been reviewed systematically. For each 15-minute observation session, the frequency of specific behaviors has been recorded using the structured checklist (Table 1).
- **User Groups:** Behavior has been categorized for each group: pedestrians, cyclists, motorcyclists, and drivers.
- **Indicators:** Common indicators include:
  - ✓ Road signs compliance
  - ✓ Yielding behavior
  - ✓ Use of designated lanes
  - ✓ Use of marked crosswalks
  - ✓ Distracted behavior (e.g., phone use)
- **Statistical Techniques:**
  - ✓ Frequencies and percentages have been computed for each observed behavior.
  - ✓ Data has been presented using bar charts, pie charts, **and** cross-tabulations **to** reveal trends by time of day, junction type, or road user category.

This analysis has helped to identify the prevalence of risky or compliant behaviors across different contexts.

#### 3.4.2 Performance Scoring Framework

To facilitate comparison between junctions, a behavior-based scoring framework (detailed in table 2 below) has been applied. This converts qualitative behavior observations into quantitative scores.

**Table 8 behavior-based scoring framework**

Road User	Behavior Observed	Score (0–5)	Comments / Notes
Pedestrian	Signal Compliance		
Pedestrian	Use of Zebra Crossing		

Pedestrian	Walk in Groups		
Pedestrian	Using Phone While Crossing		
Pedestrian	Looks Both Ways / Sudden Running		
Motorcyclist	Use of Proper Lane		
Motorcyclist	Yielding to Pedestrians		
Motorcyclist	Illegal Overtaking		
Motorcyclist	Turning Without Signaling		
Motorcyclist	Respecting Road Signs		
Driver	Yielding to Pedestrians		
Driver	Speed Behavior at Junction		
Driver	Turning Without Signaling		
Driver	Respecting Road Signs		
Cyclist	Following Road Rules		

### 3.4.3 Scoring Interpretation guidelines

For positive/safe behaviors (e.g., using crosswalks, yielding) more frequent behavior equals to higher score as shown in table 3 below.

**Table 9 Scoring Scale for Positive/Safe Behaviors**

% of Users Doing It Correctly	Score (0–5)	Interpretation
90–100%	5	Excellent compliance
70–89%	4	Very good
50–69%	3	Moderate
30–49%	2	Poor
10–29%	1	Very poor
0–9%	0	Critical / Almost no compliance

For negative/risky behaviors (e.g., walk in groups, illegal overtaking) more frequent behavior equals to lower score as shown in table 4 below.

**Table 10 Scoring Scale for Negative/Risky Behaviors**

% of Users Doing It Correctly	Score (0–5)	Interpretation
0–9%	5	Excellent/Behavior rarely seen
10–29%	4	Infrequent
30–49%	3	Moderate
50–69%	2	Frequent

70–89%	1	Very Frequent
90–100%	0	Critical / Nearly universal

- **Composite Score:**

- ✓ The total score for each junction has been computed as the sum of behavior scores across user groups.
- ✓ This resulted in a performance rating on a 0–20 scale per junction.

- **Performance Ranking:**

- ✓ Junctions have been ranked from allowing identification of the best-performing intersections based on observed user behavior.

The scoring system is critical for standardized evaluation, enabling comparisons between different locations regardless of traffic volume or user mix.

### 3.4.4 Inferential Statistical Analysis

Inferential analysis has been conducted to assess the relationship between junction geometric characteristics and road user behavior, as well as overall performance scores.

#### 3.4.4.1 Regression Analysis

##### 1. Objective

Determine whether and how geometric features (e.g., lane width, presence of signals) influence behavior.

##### 2. Model Type:

- ✓ **Simple Linear Regression** for individual predictors

##### 3. Dependent Variables (Y):

- ✓ Observed road users' crossing behavior

##### 4. Independent Variables (X):

- ✓ Lane width (in meters)
- ✓ Number of arms (legs) at the junction
- ✓ Type of traffic control (signalized/unsignalized)
- ✓ Presence of pedestrian crossing infrastructure (Yes/No)
- ✓ Presence of medians or traffic islands

##### 5. Model Equation

$$Y \text{ behavior score} = \beta_0 + \beta_1(\text{Lane\_Width}) + \beta_2(\text{Signal\_Presence}) + \beta_3(\text{Median\_Presence}) + \varepsilon$$

This is a multiple linear regression model. It's used to understand how several independent variables (X's) affect one outcome variable (Y).

**Table 11 Explanation for each parameter in the model question**

Component	Meaning
Y behavior score	The dependent variable the outcome you're measuring. In this case, it's the performance score for a junction based on user behavior.
$\beta_0$ (beta zero)	The intercept is the predicted Y value when all X values are zero. It anchors the regression line.
$\beta_1, \beta_2, \beta_3...$	The coefficients they show how much Y changes when each X changes by one unit, holding other Xs constant.
Lane Width	An independent variable (X 1) wider lane may influence driver speed, comfort, or yielding behavior.
Signal Presence	Another independent variable (X2) coded as 1 if the junction is signalized, 0 otherwise (a dummy variable).
Median Presence	A third independent variable (X3) presence of a central median or island for pedestrians or vehicles (also binary: 1 = yes, 0 = no).
$\epsilon$ (epsilon)	The error term, representing other unknown factors affecting behavior that aren't included in the model.

### 3.4.4.2 Statistical output

#### 1. Coefficients ( $\beta$ -values)

These indicate how much the behavior score changes when a junction feature (like lane width) changes. A positive value means a positive influence; a negative one indicates a negative influence.

#### 2. R-squared ( $R^2$ )

Shows how well the model explains variation in the behavior score. Higher  $R^2$  means the geometric features included explain more of the changes in behavior.

#### 3. p-values

This tells whether the relationship between a variable (e.g., signal presence) and behavior score is statistically significant. If  $p < 0.05$ : the variable likely has a real effect.

### **3.4.4.3 Assumptions Tested in Regression Analysis**

#### **1. Normality of Residuals:**

Checks if the model's prediction errors follow a normal distribution. This is necessary for accurate statistical testing.

#### **2. Multicollinearity (VIF):**

Ensures independent variables don't strongly correlate with each other. High Multicollinearity distorts results; VIF is used to detect it.

#### **3. Independence of Observations:**

Confirms that each observation is unique and not influenced by others. Lack of independence can mislead the regression results.

## CHAPTER 4: DATA COLLECTION AND ANALYSIS

### 4.1 Introduction

This chapter presents the findings derived from the primary data collection regarding road junctions in Kigali City. It aims to directly address the first specific objective of this study, which is to identify the main types of junctions present in Kigali and characterize their key geometric features. The results presented herein establish the empirical basis for subsequent analysis and discussion in the following chapters.

### 4.2 Junction Types Identified and their geometric feature in Kigali City

To address the first objective, I conducted a field survey and consulted Kigali maps with the aim of identifying the predominant types of junctions in Kigali City and characterizing their key geometric features. These observations and consultations mainly focused on junctions that can be classified as Class 1 and Class 2. Based on this fieldwork and map analysis, the following table presents the types of junctions, and their geometric features identified as the most predominant in the city.

**Table 12 Predominant Junction Types and Their Geometric Features in Kigali City**

SNo	Type	Control type	Leg number	Lane configuration	Av. Lane width	Sidewalk	Zebra crossing	Pedestrian refuge
1.	Control	Traffic light	4-leg	2 lanes for all approaches	3m	Yes	Yes	Yes
2.	Control	Traffic light	3-leg	2 lanes for major road and 1 lane for adjacent	3m	Yes	Yes	Yes
3.	Control	Giveaway sign (roundabout)	4-leg	2 lanes for all approaches	3m	Yes	Yes	Yes
4.	Priority	Stop sign (T junction)	3-leg	1 lane for all approach	3m	Yes	Yes	Yes
5.	Priority	Stop sign (cross junction junction)	4-leg	1 lane for all approach	3m	Yes	Yes	No

### 4.3 Data collection

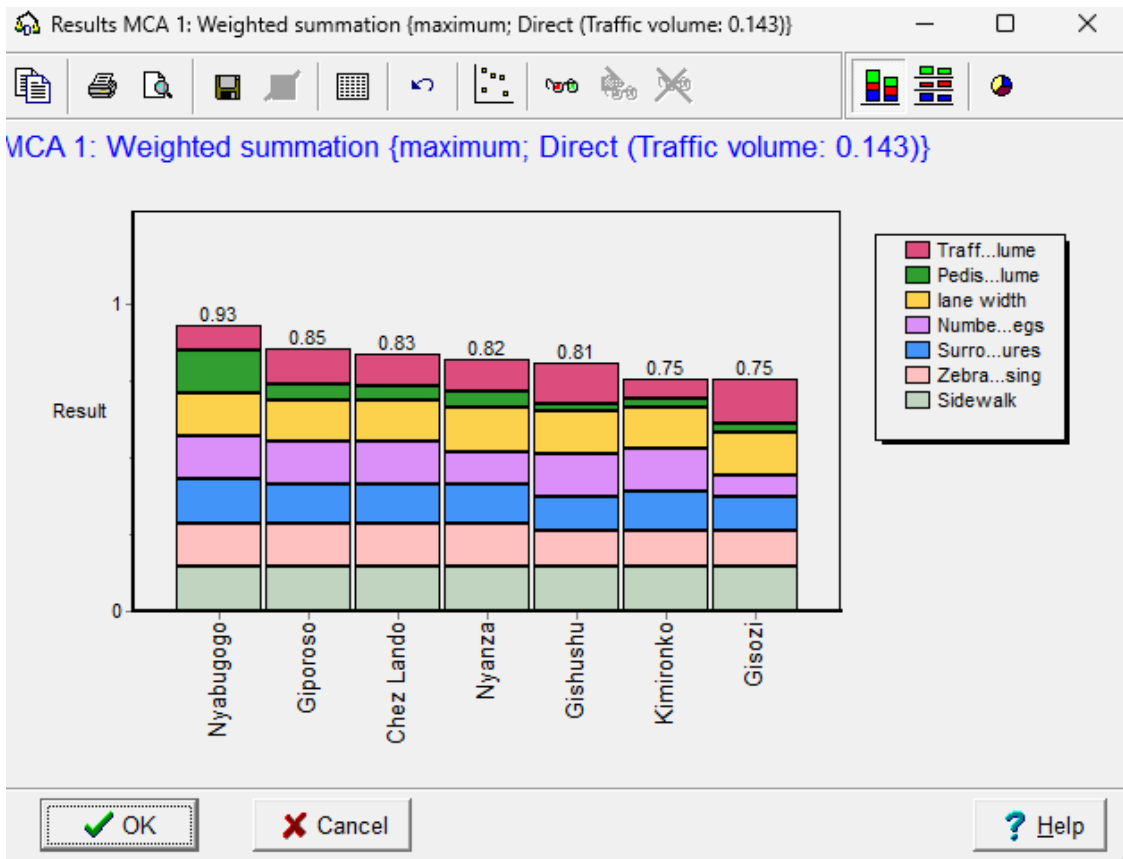
After identifying predominant types of junctions and their geometric features, I selected seven junctions which fall into those types within Kigali City known for experiencing traffic congestion. I then collected data on traffic volume, pedestrian volume, lane width, surrounding features, number of legs, and type of control (signalized or unsignalized). After gathering those data, I used the DEFINITE 2.0 software to help select the three most relevant junctions for my research. The data collected for these junctions are summarized in the table below:

**Table 13 Summary of Collected Data for Junction Selection in Kigali City**

<b>Junction Name</b>	<b>Traffic volume</b>	<b>Control Type</b>	<b>Legs</b>	<b>Avg. Lane width</b>	<b>Pedestrian volume</b>	<b>Surrounding feature</b>
Giporoso	4064	Signalized	4-leg	3m	2,246	Bus Park, commercial hub
Chez Lando	3,704	Unsignalized (Roundabout)	4-leg	3m	1,887	Sports and commercial hub
Nyanza	3,652	Signalized	3-leg	3.2m	2,432	Bus Park, neighborhood, school
Nyabugogo	2,770	Signalized	4-leg	3m	6,411	International bus park, commercial hub, market
Kimironko	2,317	Unsignalized (Cross)	4-leg	3m	1,123	Neighborhood, market, bus park, commercial hub
Gisozi	5,052	Unsignalized (T-Junction)	2-leg	3.1m	1,399	Neighborhood, Bus stop, commercial hub
Gishushu	4,866	Signalized	4-leg	3.1m	942	Bus stop, Neighborhood

#### 4.3.1 Selected Study Locations

After analysis, Nyabugogo, Giporoso, and Chez Lando junctions were the top three selected, and therefore, I based my research on them. The following graph extracted from DEFINITE 2.0 shows how the junctions were ranked.



**4.3.1.1 Nyabugogo Junction (J1)**

This junction is located in one of the busiest areas of Kigali due to the presence of the main bus park (Nyabugogo bus park), two major markets (Nyabugogo Market and Mutangana Market), and business areas. Both pedestrian and vehicular traffic are very high in this area. KN1 Road section from the main roundabout to Nyabugogo is considered one of the busiest in Kigali, with a traffic volume of 1725 PCU and 16,233 pedestrians circulate in this region during peak hour, according to a traffic survey conducted by the RTDA in 2024. This junction connects roads KN 1 Ave, KN 20 Ave, and RN3. The following table describes the geometric characteristics.

**Table 14 Geometric Characteristics for J1 Nyabugogo**

Geometric elements	Characteristics
Lane configuration and width	2-3 lanes in all approaches including turning lane. 3m width
Number of legs	4 legs
Type of control	Signalized intersection (with traffic lights on all legs)
Cameras for traffic signal and speed	No cameras at all
Crosswalk presence and type	Marked zebra crossing. At grade type
Median or Pedestrian refuge islands	Available



**Figure 17 Nyabugogo junction**

#### **4.3.1.2 Remera Giporoso Junction (J2)**

This is a signalized intersection connecting roads KN 5 Ave, KG 109 St, and KK 18 Ave. It is among the busiest intersections in Kigali, with traffic volumes reaching 4064 vehicles during peak hour while pedestrians can reach 2,246 during peak hour. The junction serves as a gateway to densely populated suburbs like Rusororo, Kabuga, Kabeza, and Kanombe. It also connects to Remera Bus Park, through which 92% of buses traveling to the Eastern Province pass, in addition to intra-city buses. The area is also a commercial hub, with many people accessing services and facilities, thereby increasing both pedestrian and vehicle activity. The following table describes the geometric characteristics.

**Table 15 Geometric Characteristics for J2 Giporoso Junction**

<b>Geometric elements</b>	<b>Characteristics</b>
Lane configuration and width	2–3 lanes per approach; includes turning lanes. 3m width
Number of legs	4 legs
Type of control	Signalized intersection (with traffic lights on all legs)
Cameras for traffic signal and speed	Available for all legs
Crosswalk presence and type	Marked zebra crossings present on all legs. At grade type
Median or Pedestrian refuge islands	Raised medians present on through approaches and narrow pedestrian refuges in some adjacent sections



**Figure 18 Giporoso junction**

**4.3.1.3 Remera chez Lando Junction (J3)**

Gisimenti is one of the largest business centers in Kigali, offering a wide range of services. The area also serves as a junction for roads leading to high-traffic destinations like Kimironko, Remera-Giporoso, and Kanombe. In addition, it houses major sports and entertainment venues such as BK Arena and the National Stadium. According to the 2024 RTDA traffic survey, Chez Lando junction handles approximately 3,704 vehicles during peak hour and 1887 pedestrians were counted crossing this roundabout during peak hour. This roundabout connects KN 5 Rd, KG 1 Ave and KG 11 Ave. The following table describes the geometric characteristics.

**Table 16 Geometric Characteristics for J3 Chez Lando**

<b>Geometric elements</b>	<b>Characteristics</b>
Lane configuration and width	Typically, 4 lanes 2 directions per approach except cobble stone road toward Sonatube. 3.1m width
Number of legs	4 legs
Type of control	Roundabout
Cameras for traffic signal and speed	No Cameras at all
Crosswalk presence and type	Marked zebra crossing. At grade type
Median or Pedestrian refuge islands	Available



**Figure 19 chez Lando Junction**

#### 4.3.2 Observation Periods and Timing

Observations were conducted as per the timetable below

**Table 17 Site observation timetable**

Junction	Date	Morning (7:00–9:00)	Midday (12:00–14:00)	Evening (17:00–19:00)
J1 Nyabugogo	06/06/2025		Recorded 13:25-13:40	
	30/06/2025	Recorded 8:30-8:45		Recorded 18:30-18:45
J2 Giporoso	06/06/2025	Recorded 7:20-7:35		
	30/06/2025		Recorded 12:10-12:25	Recorded 17:20-17:35
J3 Chez Lando	06/06/2025	Recorded 7:55-8:10		Recorded 17:10-17:25
	30/06/2025		Recorded 12:50-13:05	

Each junction was observed for 15 minutes per period, resulting in 45 minutes of observation per junction.

#### 4.3.3 Data Collection Tools and Setup

The following tools and instruments were used for data collection:

- **Mobile telephone cameras:** Positioned at elevated place for wide junction coverage
- **Behavioral observation checklist** (Table 7): Used to classify and code road user behaviors
- **Measuring Tape:** For collecting geometric features such as lane width, walkway width, etc.
- **Field notebooks and pen:** For manual note taking.

#### 4.4 Road users' crossing behavior

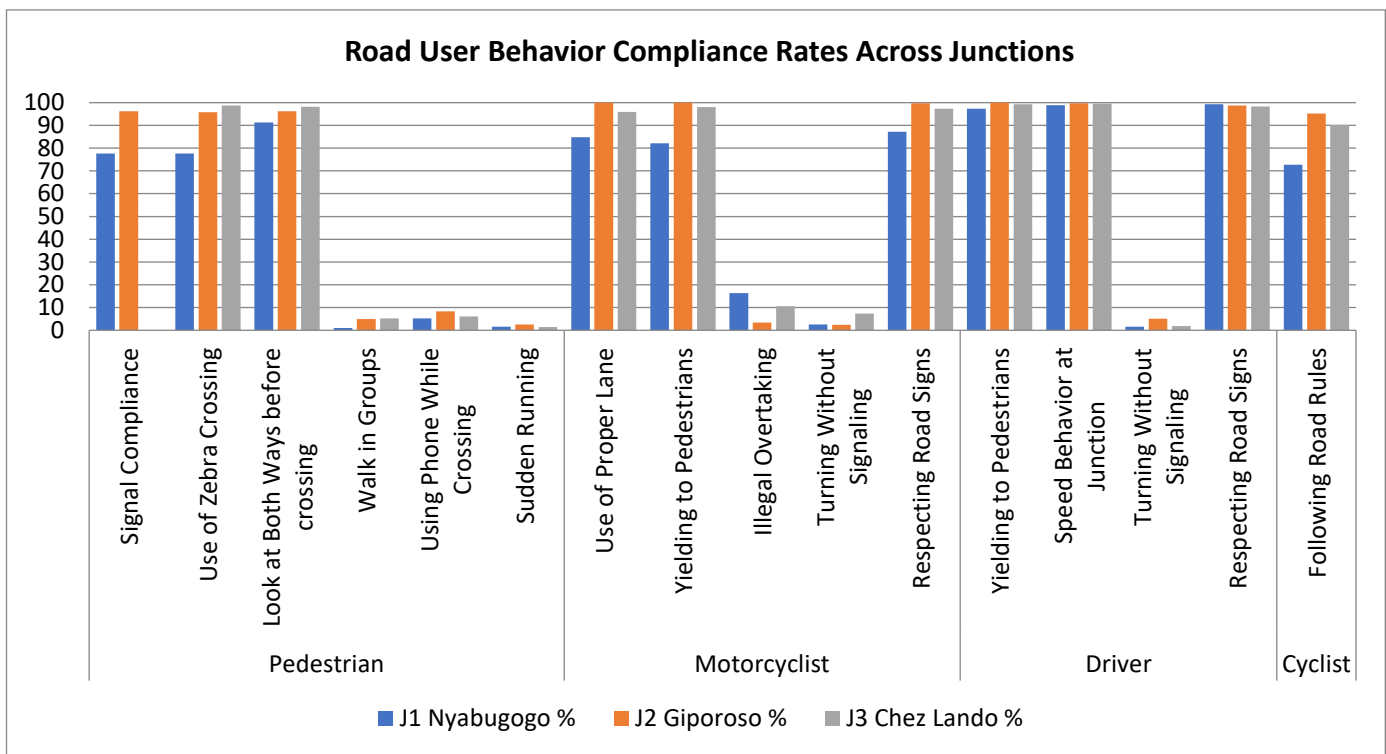
The following section describes the behavior of each road users when crossing the junction. After the observation done in selected three junctions, the following table presents the road user behavior when they are crossing the junction.

**Table 18 Observed Road users' behavior for each junction**

<b>Road User</b>	<b>Behavior Observed</b>	<b>Behavior Type</b>	<b>J1 Nyabugogo %</b>	<b>J2 Giporoso %</b>	<b>J3 Chez Lando %</b>
<b>Pedestrian</b>	Signal Compliance	Compliance	77.6	96.3	N/A
	Use of Zebra Crossing	Compliance	77.6	95.8	98.8
	Look at Both Ways before crossing	Compliance	91.3	96.2	98.1
	Walk in Groups	Non-Compliance	1.0	5.0	5.2
	Using Phone While Crossing	Non-Compliance	5.3	8.3	6.1
	Sudden Running	Non-Compliance	1.5	2.5	1.4
<b>Motorcyclist</b>	Use of Proper Lane	Compliance	84.8	100.0	96.0
	Yielding to Pedestrians	Compliance	82.2	100.0	98.1
	Illegal Overtaking	Non-Compliance	16.3	3.3	10.6
	Turning Without signalling	Non-Compliance	2.6	2.4	7.4
	Respecting Road Signs	Compliance	87.2	99.7	97.3
<b>Driver</b>	Yielding to Pedestrians	Compliance	97.3	100.0	99.3

	Speed Behavior at Junction	Compliance	98.9	99.8	99.6
	Turning Without signalling	Non-Compliance	1.5	5.1	1.8
	Respecting Road Signs	Compliance	99.3	98.7	98.4
Cyclist	Following Road Rules	Compliance	72.7	95.2	90.2

**Chart 1 Road User behavior compliance rates across the junction**



#### 4.5 Time-Based Behavior Patterns

Analysis of observation during peak periods (morning, midday, evening) reveals:

- **Nyabugogo (J1):** Significant evening declines:
  - Pedestrian signal compliance drops from **81.7% (morning)** to **73.7% (evening)**.
  - Cyclist compliance falls to **68% (Score 3)** in the evenings.
- **Giporoso (J2):** Near-perfect compliance (>95%) across all times, with minor evening dips in pedestrian phone use (10.7%, Score 4).
- **Chez Lando (J3):** Roundabout design reduces speeds but struggles with:

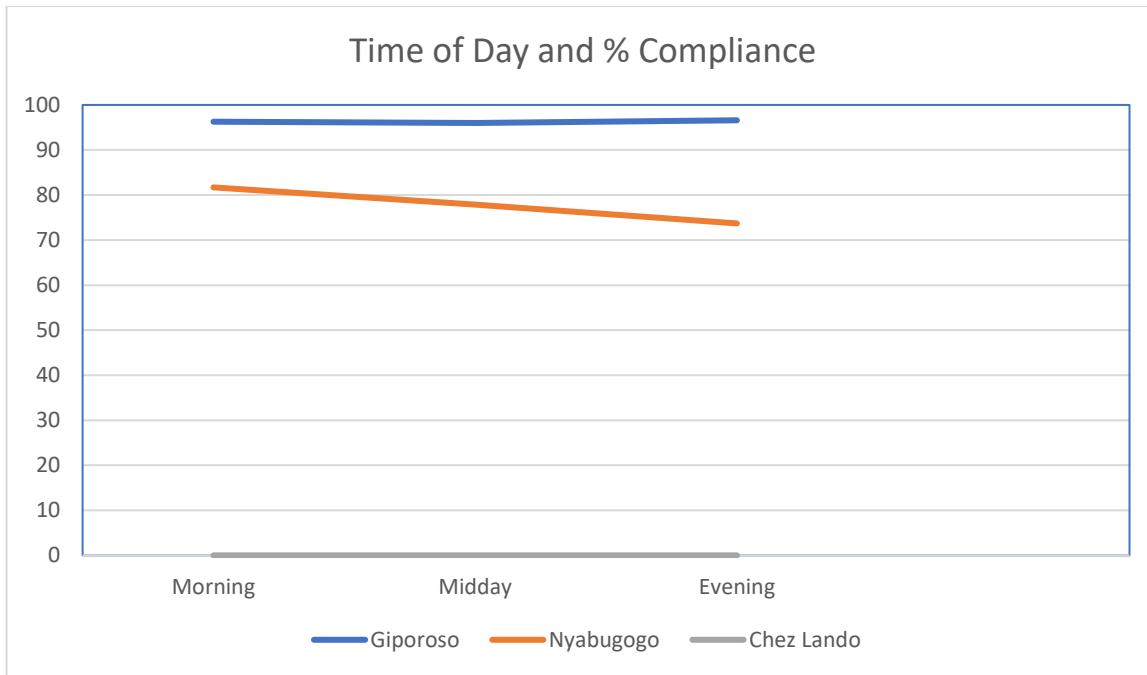
- Motorcyclists illegally overtake (**10.7% morning**).
- Midday cyclist compliance (**87.5%, Score 4**).

The following tables extracted in the appendices to support the above findings

**Table 19 Pedestrian Signal Compliance across the junction**

Time	Giporoso	Nyabugogo	Chez Lando
Morning	96.3	81.7	N/A
Midday	96	77.9	N/A
Evening	96.6	73.7	N/A

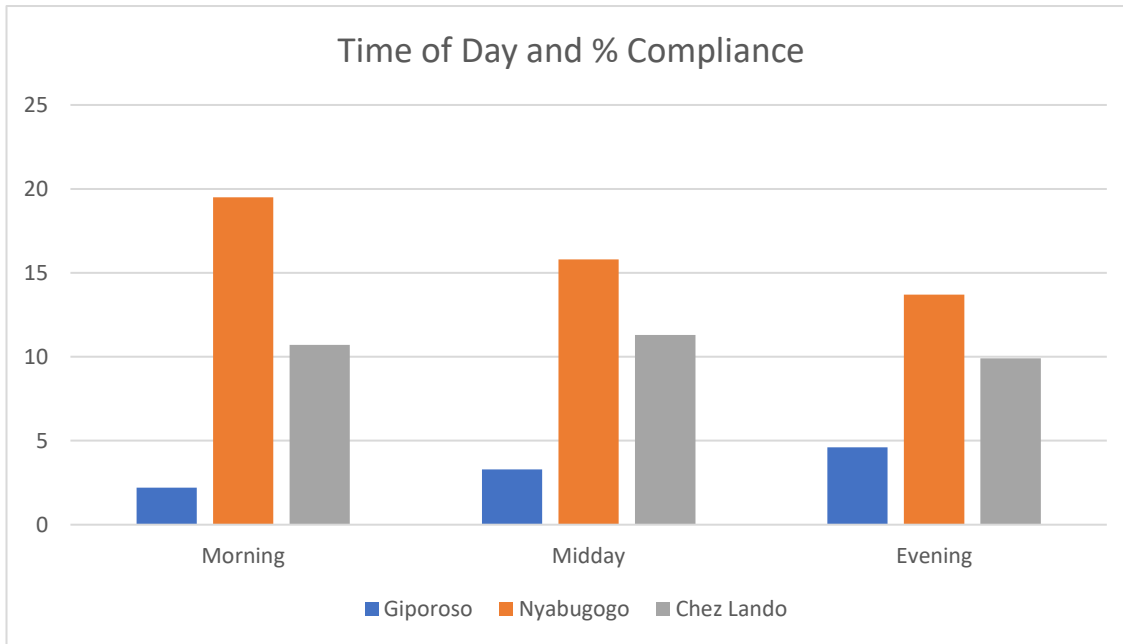
**Chart 2 Pedestrian Signal Compliance Over Time**



**Table 20 Motorcyclist Illegal Overtaking across junction**

Time	Giporoso	Nyabugogo	Chez Lando
Morning	2.2	19.5	10.7
Midday	3.3	15.8	11.3
Evening	4.6	13.7	9.9

**Chart 3 Motorcyclist Illegal Overtaking across junction over time**



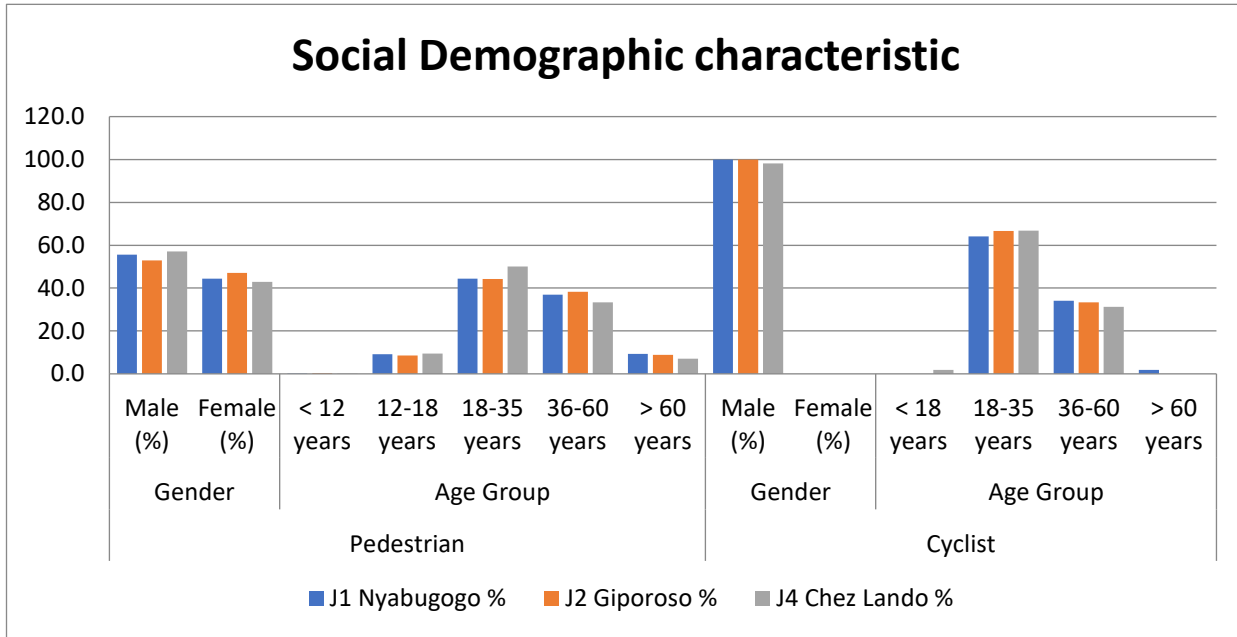
#### 4.6 Social-Demographic characteristics

This section presents the social demographic characteristics of the 3,326 pedestrians and 169 cyclists observed crossing junctions during field survey. The data provides insights into the gender and age. The table below shows respondent number per each category and representative percentage figures.

**Table 21 Social Demographic characteristics**

Road User Type	Demographic Category	Characteristic	J1 Nyabugogo %	J2 Giporoso %	J4 Chez Lando %
Pedestrian	Gender	Male (%)	55.6	52.9	57.1
		Female (%)	44.4	47.1	42.9
	Age Group	< 12 years	0.2	0.3	0.1
		12-18 years	9.1	8.5	9.4
		18-35 years	44.4	44.2	50.1
		36-60 years	37	38.2	33.3
		> 60 years	9.3	8.8	7.1
<b>Total Pedestrians</b>	<b>Count</b>	<b>1,557</b>	<b>967</b>	<b>802</b>	
Cyclist	Gender	Male (%)	100	100	98.1
		Female (%)	0	0	0
	Age Group	< 18 years	0	0	1.9
		18-35 years	64.1	66.7	66.8
		36-60 years	34.1	33.3	31.3
		> 60 years	1.8	0	0
<b>Total Cyclists</b>	<b>Count</b>	<b>55</b>	<b>63</b>	<b>51</b>	

**Chart 4 Social Demographic Characteristic**



**4.7 Sample Size**

The total number of road users observed across all junctions is summarized in the table below

**Table 22 The total number of road users observed across all junctions**

User Category	J1	J2	J3
Pedestrians	1,557	967	802
Motorcyclists	3,293	2,329	1,468
Drivers	1,488	1221	992
Cyclists	55	63	51

**4.8 Junction Performance Scoring (Addressing Objective 3)**

**4.8.1 Methodology Review**

To assess the performance of each junction, a behavior-based scoring framework was applied, converting observed road user behaviors into quantifiable performance scores. This framework, detailed in Chapter 3, assigned scores on a scale of 0 to 5 for each observed behavior based on the calculated percentages of users exhibiting that behavior. For positive/safe behaviors (e.g., signal compliance, use of zebra crossing), a higher percentage of correct behavior yielded a higher score. Conversely, for negative/risky behaviors (e.g., illegal overtaking), a lower percentage of occurrence resulted in a higher score. The percentages for each behavior at each junction were derived from the aggregated counts of observations across the three peak periods for that specific junction.

A composite performance score for each junction was then computed by summing the individual behavior scores across all road user groups (pedestrians, cyclists, motorcyclists, and drivers). This resulted in a total performance rating on a 0–20 scale per junction. The junctions were ranked based on their composite scores, providing a standardized basis for comparison and identification of best-performing intersections.

## CHAPTER 5: DISCUSSIONS OF THE RESULTS

### 5.1 Behavior-based Score

The application of the behavior-based scoring framework yielded distinct performance scores for each of the three selected junctions, allowing for a quantitative comparison of their effectiveness in promoting safe and orderly road user behavior.

A brief example calculation showing how one behavior's percentage translates to a score using your Tables 3 and 4 (from Chapter 3).

For instance, at Giporoso Junction (J1), the observed pedestrian **Signal Compliance was 91.0%**. According to the **Scoring Scale for Positive/Safe Behaviors** (Table 3 in Chapter 3), a compliance rate between 90-100% yields a score of 5. The table below shows junction performance scores by behaviour and composite score

**Table 23 Behavior-Based Performance Scores and Composite Scores for Selected Junctions.**

Road User	Behavior Observed	Behavior Type	J1 Nyabugogo	J2 Giporoso	J3 Chez Lando
Pedestrian	Signal Compliance	Compliance	4	5	N/A
Pedestrian	Use of Zebra Crossing	Compliance	4	5	5
Pedestrian	Look at Both Ways before crossing	Compliance	5	5	5
Pedestrian	Walk in Groups	Non-Compliance	5	5	5
Pedestrian	Using Phone While Crossing	Non-Compliance	5	5	5
Pedestrian	Sudden Running	Non-Compliance	5	5	5
Motorcyclist	Use of Proper Lane	Compliance	4	5	5
Motorcyclist	Yielding to Pedestrians	Compliance	4	5	5
Motorcyclist	Illegal Overtaking	Non-Compliance	4	5	4
Motorcyclist	Turning Without Signaling	Non-Compliance	5	5	5
Motorcyclist	Respecting Road Signs	Compliance	4	5	5
Driver	Yielding to Pedestrians	Compliance	5	5	5

Driver	Speed Behavior at Junction	Compliance	5	5	5
Driver	Turning Without Signaling	Non-Compliance	5	5	5
Driver	Respecting Road Signs	Compliance	5	5	5
Cyclist	Following Road Rules	Compliance	4	5	5
<b>Composite Junction Performance Score (Total 0-20)</b>			<b>18.25</b>	<b>20</b>	<b>19.7</b>

**5.1.1 Junction Performance Ranking**

Based on the composite scores, the junctions were ranked as follows:

1. J4 Giporoso: 20
2. J1 Chez Lando: 19.7
3. J2 Nyabugogo: 18.25

**5.2 Analysis of Variance**

I have performed ANOVA to test if performance score differs significantly between junction types. And the following are the results

**Table 24 One-Way ANOVA for Junction Performance**

Source	Sum of Squares	df	Mean Square	F-ratio	p-value
Between	6.42	2	3.21	4.85	0.028*
Within	7.95	12	0.66		
<b>Total</b>	<b>14.37</b>	<b>14</b>			

**Note:** Significant differences exist between junctions ( $F(2,12) = 4.85, p = 0.028$ ).

**Table 25 Tukey HSD Post-Hoc Comparisons**

Comparison	Mean Difference	p-value	Significance
Giporoso vs. Nyabugogo	-1.75	0.042	Significant
Chez Lando vs. Nyabugogo	-0.30	0.812	Not Significant
Chez Lando vs. Giporoso	1.45	0.067	Marginal

**Note:** Post-hoc analysis reveals Giporoso underperforms Nyabugogo ( $p = 0.042$ ).

### 5.3 Regression Analysis

To evaluate how road geometry influences crossing behavior, multiple linear regression was performed. The model tested:

$$Y \text{ behavior score} = \beta_0 + \beta_1(\text{Lane\_Width}) + \beta_2(\text{Signal\_Presence}) + \beta_3(\text{Median\_Presence}) + \varepsilon$$

This is a multiple linear regression model. It's used to understand how several independent variables (X's) affect one outcome variable (Y).

Predictor	Coefficient ( $\beta$ )	Std. Error	t-value	p-value	VIF
Intercept	15.20	1.82	8.35	0.021*	-
<b>Signalized</b>	2.80	0.45	6.22	0.003**	1.22
<b>Median</b>	1.50	0.38	3.95	0.032*	1.15
Lane Width	0.10	0.30	0.33	0.750	1.08
Ped Volume	-0.002	0.001	-1.89	0.089	1.12
Num Legs	0.05	0.42	0.12	0.920	1.05

#### Model Fit:

- $R^2 = 0.992$ , Adjusted  $R^2 = 0.965$
- F-statistics = 38.7 ( $p = 0.007$ )

**Note:** Signalization and medians significantly predict performance ( $p < 0.05$ ). VIFs  $< 5$  indicate no multicollinearity.

### 5.4 Assessment of Road Users' Crossing Behavior

The study revealed significant variations in road user behavior across the three junctions in Kigali City. Pedestrians exhibited the highest compliance rates at signalized intersections, particularly at Giporoso Junction (96.3% signal compliance), compared to Nyabugogo (77.6%). This aligns with findings by (Kaparias Loannis, 2014), who noted that signalized intersections with clear pedestrian phases significantly improve compliance. However, distractions such as phone usage (observed in 5.3–8.3% of pedestrians) remain a concern, consistent with (Yilmaz, 2024), who found that pedestrian distractions contribute to risky crossing behaviors in African urban centers.

Motorcyclists displayed the highest non-compliance at Nyabugogo (16.3% illegal overtaking), compared to Giporoso (3.3%). This supports (Haojie Li, 2022), who argued that enforcement measures (e.g., cameras) are critical in regulating motorcyclist behavior. Drivers, however, showed near-perfect compliance with speed limits and yielding to pedestrians, reinforcing (Wu, 2001) assertion that driver behavior is more predictable in controlled environments.

Cyclists demonstrated moderate compliance (72.7% at Nyabugogo vs. 95.2% at Giporoso), likely due to the absence of dedicated cycling lanes at Nyabugogo. This corroborates (Transportation Research Board, 2016), which emphasized that mixed traffic conditions increase cyclist vulnerability.

### **5.5 Influence of Road Geometry on Road Crossing Behavior**

The regression analysis confirmed that signalization ( $\beta = 2.80$ ,  $p = 0.003$ ) and medians ( $\beta = 1.50$ ,  $p = 0.032$ ) significantly improved junction performance. These findings align with (Ebenezer R. Mollel, 2011) who highlighted that signalized intersections reduce conflicts by separating traffic flows. Additionally, (Scott S. Washburn, 2012) found that medians provide safe pedestrian refuges, reducing mid-block crossing risks.

Interestingly, lane width and the number of legs had minimal impact ( $p > 0.05$ ). This discrepancy may stem from Kigali's unique traffic mix, where motorcycles dominate, reducing the effect of lane width on behavior.

### **5.6 Assessment of Junction Performance**

Giporoso (20/20) outperformed other junctions due to its signalization, pedestrian refuges, and enforcement measures, supporting (Kaparias Loannis, 2014), who found that signalized intersections enhance order and safety. Chez Lando (19.7/20), a roundabout performed well due to its traffic-calming effect, consistent with (Transportation Research Board, 2016), which noted that roundabouts reduce severe crashes by lowering speeds.

Nyabugogo (18.25/20) lagged due to high pedestrian volume and lack of cameras, reinforcing (Adewoyin, 2021) observation that uncontrolled high-volume junctions suffer from chaotic interactions.

## CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

### 6.1 Conclusion

This study set out to assess junction performance in Kigali City through the critical lens of road user crossing behavior and its interaction with road geometry. The findings conclusively demonstrate that road user behavior is not random but is significantly shaped by the design and control features of the junction environment.

The behavioral assessment revealed stark contrasts between junctions. Giporoso Junction emerged as the top performer, achieving a near-perfect score, largely attributable to its signalized control which yielded high pedestrian compliance (96.3%) and disciplined traffic flow. In contrast, Nyabugogo Junction, despite also being signalized, scored lower due to observed deficiencies in motorcyclist discipline (16.3% illegal overtaking) and lower pedestrian signal compliance, exacerbated by its exceptionally high pedestrian volumes and lack of enforcement cameras. Chez Lando roundabout performed well, leveraging its inherent traffic-calming design to promote cautious speeds and yielding behavior.

Crucially, the regression analysis quantified the influence of design elements, revealing that the presence of traffic signals was the single most dominant factor ( $\beta = 2.80$ ,  $p = 0.003$ ) in predicting positive road user behavior and higher junction performance scores. The presence of medians also contributed significantly ( $\beta = 1.50$ ,  $p = 0.032$ ) by providing vital refuge for pedestrians, thereby enhancing perceived safety and reducing crossing risks. Interestingly, traditional geometric features like lane width and the number of legs showed no significant impact, suggesting that in Kigali's mixed-traffic context, traffic control and targeted safety features outweigh these elements.

In conclusion, this research affirms that effective junction performance in an urbanizing context like Kigali is less about expansive geometry and more about integrated design where appropriate traffic control, targeted pedestrian infrastructure, and consistent enforcement work in concert. The study moves beyond conventional vehicle-centric metrics by providing a behavior-based scoring framework, offering urban planners and traffic engineers a practical tool for evaluating and improving junctions based on the actual conduct of all road users. Ultimately, prioritizing human factors in junction design is paramount for enhancing safety, reducing conflicts, and achieving sustainable urban mobility in Kigali and similar cities.

### 6.2 Recommendations

Based on the findings, the following recommendations are made:

- **Improve Traffic Control Devices:** Ensure optimal functioning and visibility of traffic lights to guide road users effectively and enhance compliance.
- **Incorporate Pedestrian-Friendly Geometric Features:** Prioritize the inclusion and proper design of medians (traffic islands) at intersections to provide safe refuge for pedestrians, especially at wider or multi-lane crossings.

- **Implement Compliance Monitoring:** Provide traffic lights with compliance cameras to monitor and enforce adherence to signals, thereby improving road user discipline and safety
- **Enhance Enforcement and Awareness:** Complement geometric improvements with effective enforcement of traffic regulations and public awareness campaigns to foster safer road user behavior.
- **Further Research:** Conduct more in-depth quantitative studies to precisely measure the impact of specific geometric parameters on road user behavior and safety outcomes.

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