Analysis of the Relationship between Fatal Rural Road Crashes and Road Design Elements: Namibian Case Study

by

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Declaration

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Robert Ambunda

………………………………

Date: December 2018

Dedication

This thesis is dedicated to my family and friends, for their unconditional love, support and guidance throughout my academic journey.

Abstract

Traffic safety is a major concern in developing countries. Every year over 1.2 million people are killed in road crashes in the world. The crash fatality rate in Namibia has been reported to be higher than the African continental average of 27, at 31 fatalities per 100 000 population. The study focused on analysing the relationship between fatal road crashes and road design elements for the study period between 2013 to 2016, on the Namibian rural road network.

Road sections with the highest fatal crash rates were identified, to determine the potential relationship between the fatal crash rates (dependent variable) and road design elements (independent variables). Negative Binomial Regression was used to assess the statistical correlation and significance of the impact of the road design elements on the occurrence of fatal crashes on the study sections.

The study established that the radii of the horizontal curves, access control and the 85th percentile operating speed have a significant influence in predicting fatal road crashes on roads with a lane width (LW) greater than 3.5m. The study found that road exposure (road length and volume) has a significant impact crash risk level and prediction on road sections with a lane width equal to or less than 3.5m.

The study found that 40% of the study sections did not comply with the Technical Recommendations for Highways 17 guidelines (TRH 17) on lane widths, while half of the study sections did not comply with the TRH 17 guidelines with regard to the unsurfaced shoulder width. The study also established that 90% of the study sections have an under designed unsurfaced shoulder crossfall.

Surveys were carried out on two road sections with LW_1<3.5m> LW_2 to investigate the causation of fatal crashes. More than ninety percent of the surveyed participants on each study section found the sections to be “unsafe”. Reckless and negligent driving was cited as the main safety issue on both study road sections. The Majority of the surveyed participants admitted that they were aware of the significant impact that road engineering and design has on the safety and operational efficiency of a road. Most of the surveyed participants were of the view that increasing the presence of law enforcement would deter drivers from engaging in unsafe driving behaviour.

Word Count: 375

Keywords: Road Safety, Fatal Crashes, Rural Road Design Elements, Negative Binomial Regression, Survey.

Opsomming

Verkeersveiligheid is 'n groot kommer in ontwikkelende lande. Elke jaar word meer as 1.2 miljoen mense in padongelukke in die wêreld doodgemaak. Die ongeluksterftesyfer in Namibië is na berig word hoër as die Afrika-kontinentale gemiddeld van 27, by 31 sterftes per 100 000 inwoners. Die studie het gefokus op die ontleding van die verhouding tussen noodlottige padongelukke en padontwerp-elemente vir die studieperiode tussen 2013 en 2016 op die Namibiese landelike padnetwerk.

Padafdelings met die hoogste noodlottige ongelukkoerse is geïdentifiseer om die potensiële verhouding tussen die noodlottige ongelukkoerse (afhanklike veranderlike) en padontwerpelemente (onafhanklike veranderlikes) te bepaal. Negatiewe Binomiale Regressie is gebruik om die statistiese korrelasie en betekenis van die impak van die padontwerpelemente op die voorkoms van noodlottige ongelukke op die leergedeeltes te assesseer.

Die studie het vasgestel dat die radius van die horisontale krommes, toegangsbeheer en die 85 persentiel-bedryfspoed 'n beduidende invloed het op die voorspelling van noodlottige padongelukke op paaie met 'n laanwydte (LW) van meer as 3.5m. Die studie het bevind dat padblootstelling (padlengte en volume) 'n beduidende impak-ongeluk risiko vlak en voorspelling op pad afdelings met 'n baan wydte gelyk aan of minder as 3.5m.

Die studie het bevind dat 40% van die leergedeeltes nie voldoen het aan die Tegniese Aanbevelings vir Hoofweë 17-riglyne (TRH 17) op laanwydtes nie, terwyl die helfte van die leergedeeltes nie voldoen het aan die TRH 17 riglyne ten opsigte van die onbeheerde skouer breedte. Die studie het ook vasgestel dat 90% van die leergedeeltes 'n onderontwikkelde skouerkruisval het.

Opmetings is uitgevoer op twee padafdelings met LW_1 <3.5m> LW_2 om die oorsaak van noodlottige ineenstortings te ondersoek. Meer as negentig persent van die respondente in elke leergedeelte het bevind dat die afdelings onveilig is. Roekelose en nalatige bestuur is aangehaal as die hoofveiligheidsprobleem op beide studie-paaie. Die meerderheid van die respondente het erken dat hulle bewus was van die beduidende impak wat padingenieurswese en -ontwerp op die veiligheid en operasionele doeltreffendheid van 'n pad het. Die meeste van die ondervraagde deelnemers was van mening dat die verhoging van die teenwoordigheid van wetstoepassing die bestuurders sou weerhou om onveilige bestuursgedrag aan te gaan.

Woordtelling: 375

Sleutelwoorde: Padveiligheid, noodlottige ongelukke, landelike padontwerpelemente, negatiewe binomiale regressie, opname.

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First and foremost, I would like to thank the Lord for his unremitting and unfaltering love and guidance.

Enormous gratitude goes to my supervisor, Prof. Marion Sinclair, for her valuable support, guidance and mentorship throughout the dissertation. I would like to extend my sincere and heartfelt gratitude to the Department of Civil Engineering, at the University of Stellenbosch, for providing me with the opportunity to carry out my dissertation.

Special thanks go to the Namibia National Road Safety Council, the Namibia Motor Vehicle Accident Fund and the Roads Authority of Namibia for the traffic crash data and road design elements information provided timely.

In addition, I would like to acknowledge the all-round support from my family and friends throughout this incredible journey.

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List of Acronyms

AASHTO	: American Association of State Highway and Transportation Officials
CSRA	: Committee of State Road Authorities (South Africa)
DOT	: Department of Transport
FHWA	: Federal Highway Administration
LAC	: Legal Assistance Centre
MVA	: Motor Vehicle Accident Fund (of Namibia)
NMT	: Non- Motorised Transport
NRCF	: Namibia Road Crash Form
NRSC	: National Road Safety Council (of Namibia)
NSA	: Namibia Statistics Agency
PSL	: Posted Speed Limit
RA	: Roads Authority (of Namibia)
SADC	: Southern Africa Development Community
SANRAL	: South African National Roads Agency SOC Ltd
TRH	: Technical Recommendations for Highways
UN	: United Nations
VKT	: Vehicle Kilometres Travelled
WHO	: World Health Organization

1. Introduction

Traffic safety is a vital aspect of the roadway system and is a major concern in developing countries. This study was aimed at evaluating the potential and significance of the relationship between fatal road crashes and road design elements on Namibia's rural road network. This chapter presents a background on the study, purpose of the study, problem statement and the relevance of the study to the study area. The limitations of the study, the research questions addressed in the study and the structure of the dissertation are also presented in this chapter.

1.1. Background

Namibia has a comprehensive rural road network, linking the different parts of the country and enabling the movement of people and goods. The Namibia National Road Safety Council (2012) reports that over a period of ten years up until 2012, Namibia experienced an increase in motorisation, while road safety deteriorated, resulting in an increase in fatal rural road crashes.

Duivenvoorden (2010) notes that road safety is one of the most significant issues in modern society. The World Health Organisation (2017) reports that every year, about 1.2 million road crash fatalities, and between 20 and 50 million road crash injuries are reported globally. Dehuri (2013) warns that road crashes are forecasted to be the third largest contributor to the global burden of injury and disease by the year 2020, if the current trend continues.

Yingxue (2009) states that according to traffic crash investigations and analysis, some traffic crashes are caused by the unsafe behaviour of drivers such as excessive speed, fatigue driving, overloading and high speeds on down- grades. However, some crashes are caused by road design elements and the road environment in which the road traverses.

This study investigated the potential relationship between fatal road traffic crashes and the road design elements on Namibian rural roads. The WHO (2017) states that the road design influences road crash risk, as it determines how road users perceive their environment. Krug and Sharma (2009) report that traffic crashes are a result of the combination and interaction of interrelated factors comprising the driver, road environment and vehicle.

Krug and Sharma (2009) define the Haddon matrix as a basis for relating the sequence of events in a road crash, to the groups of crash contributing factors. Haddon (1972) notes that there are three factors that contribute to road crashes; human factors, vehicle factors and environmental factors.

The American Association of State Highway and Transportation Officials Highway Safety Manual (AASHTO, 2010) reports that roadway factors alone were found to have caused 3 percent of road crashes, while 34 percent of road crashes were found to be due to a combination of roadway factors and other factors, as shown in Figure 1.1.

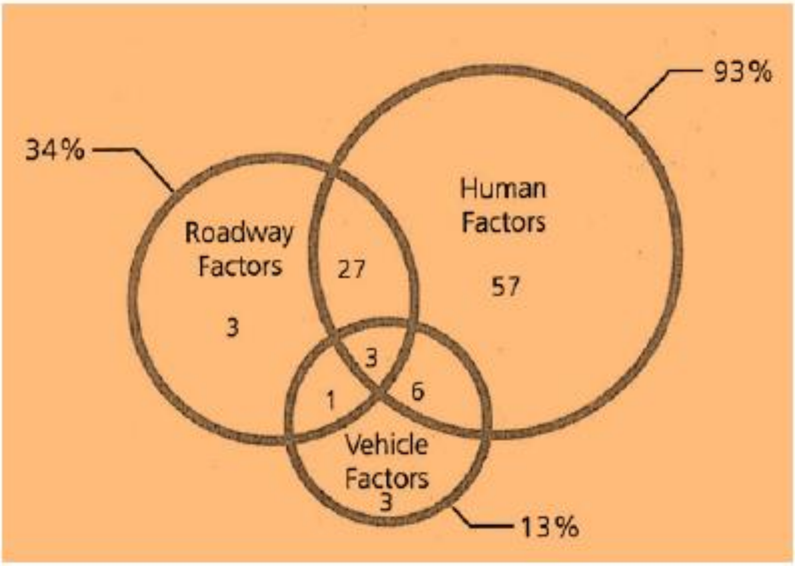

Figure 1.1 Contributing Factors to Vehicular Crashes (AASHTO, 2010)

The United Nations Global Plan for Safer Roads (UN, 2011) reports that road safety and mobility are one of the five pillars of the UN Global Plan for the decade of Action for Road Safety 2011-2020. The pillar highlights the importance of raising the inherent road safety and quality of the roadway system (UN, 2011). The UN (2011) encourages governments to set goals to identify and eliminate hazardous road sections by the year 2020.

1.2. Purpose of the Study

The purpose for the research subject was to study and analyse the relationship between fatal road traffic crashes and the interaction of road design elements on the Namibian rural road network. There is a need to improve the road safety understanding and inform Transportation Engineers in Namibia on the implications of road design elements on fatal road crashes, to allow for the improvement of dangerous rural road sections in the road network.

The study had the following objectives:

1. To map fatal rural road traffic crash data for Namibia.
2. To identify rural road sections with the highest fatal crashes/ km.
3. To develop a methodology that quantitatively assesses the effects of the interaction between the identified road design elements on fatal rural road crash rates.
4. To model the relationship between the road design elements and the fatal crash rates.
5. To assess whether the road design elements comply with the road design standards used in Namibia
6. To study driver behaviour on identified rural roads; and

7. To propose solutions and alternatives to help address the road safety situation in Namibia.

1.3. Problem Statement

The Namibia National Road Safety Council (2012) reports that the Namibian road injury fatality rate is higher than the African continental average by more than 4 fatalities per 100 000 population. The annual road fatality rate of 31 per 100 000 population translates to 600 to 700 fatalities in road crashes every year in Namibia (Namibia Statistics Agency, 2015).

The Namibia Statistics Agency (2015) reports that road traffic crashes are one of the major and increasing causes of deaths in Namibia, despite efforts by the police and campaigns by the Namibia Motor Vehicle Accident (MVA) Fund and partners to reduce the occurrence of fatal road crashes. The precarious road safety situation in Namibia is illustrated in Figure 1.2.

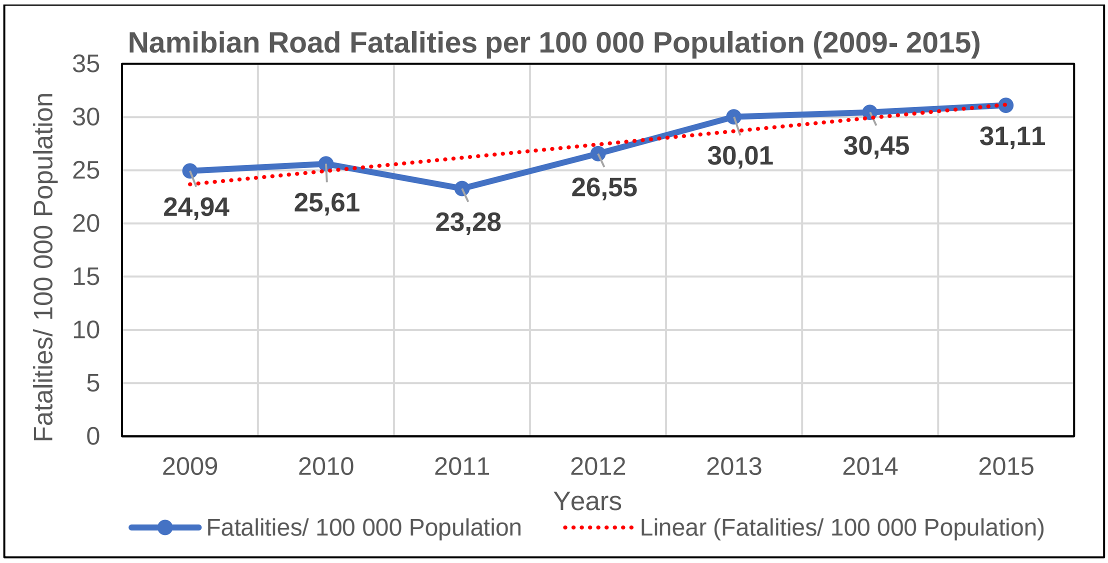

Figure 1.2 Namibia Road Fatalities per 100 000 Population (Namibia Statistics Agency, 2015)

Runji (2003) notes that many aspects of road design are affected by the road environment, which in turn influences the level of road safety provided to the road users. In May 2016, on the topic "Proposals for Enhancing Road Safety in Namibia", the Legal Assistance Centre (2016) (The organisation tasked with protecting human rights in Namibia) wrote:

"*On Friday 12 February 2016, 14 people were killed in a head-on collision involving a truck and a minibus on the road between Ondangwa and Oshivelo in northern Namibia. Responding to the fatal crash on social media, Namibian President Hage Geingob likened Namibian roads to "theatres of horror" and called on everyone to adopt a more "caring attitude" when using transport networks in a public appeal to end the "carnage on our roads". While the President's language is strong, the problem of road safety in Namibia is very real.*" (Legal Assistance Centre, 2016).

Tragically, this fatal rural road crash is just one example of the road safety crisis facing Namibia today. The expansion of the road network and increase in motorisation, negative driver behaviour and negative road design elements, have contributed to the increase in the number of fatal road crashes on the Namibian rural road network.

The study was aimed at assessing the impact of the road design elements on the occurrence of fatal rural road crashes on these road sections and how these could be addressed to reduce the frequency of fatal road crashes.

1.4. Significance and Motivation

This study provides guidance to transportation engineers, road safety authorities, traffic enforcement institutions and emergency services in addressing and deciding on the following issues:

a) Traffic Engineers:

- To identify factors that influence the occurrence and severity of road crashes, to improve roadway design and provide a safer driving environment, and
- To coordinate road crash and injury prevention measures.

b) Road Authorities

- To identify hazardous road sections, to promote safety treatments
- To inform relevant institutions and stakeholders of the nature of road design elements and their impact on traffic crashes; directly influencing road safety, and
- To formulate road safety plans, guidelines and educational campaigns.

c) Traffic Control and Enforcement

- To formulate procedures that deter the violation of road traffic laws and understand the implication of road design traffic crashes, and
- To undertake community education and community awareness programmes to improve safety on the road sections.

d) Emergency Services

- To identify crash hotspots and coordinate road crash emergency response, and
- To allow for adequate measures and planning of routes to traffic crash scenes.

1.5. Limitations

The crash data collected is limited to fatal crash injuries on the rural roads that were identified as hazardous by the principal investigator, by selecting the road segments with the highest number of fatal crash rates on the Namibian rural road network. Fatal road crash data and road design information were collected for a span of 4 years, for the study period between 2013 to 2016.

Road design elements on which data was available on the Road Management System (RMS) of the Roads Authority (RA) of Namibia were selected for the study. The effects of the following road design elements on the frequency of fatal crashes on identified rural roads are addressed:

1. Traffic volume
2. Design, Posted and Operating Speeds
3. Number of lanes
4. Lane Widths
5. Shoulder widths
6. Access Control
7. Horizontal Curvature, and
8. Road Length

Driver attitude towards road safety on the Namibian rural road network was investigated and studied by carrying out surveys on the selected rural roads.

The surveys were intended to investigate the following:

a) Drivers' general perceptions towards road safety and enforcement on the rural roads.
b) Drivers' awareness of the physical road design elements in their driving.
c) Drivers' perceptions on the factors that are contributing to the high fatal crash numbers on the rural roads, and
d) Drivers' views on what can be done to tackle the high fatal crash numbers on the rural roads, in terms of driver behaviour and road design elements.

The results from the surveys assisted in proving causation of fatal traffic crashes, in addition to the potential correlation established through the analysis of the fatal traffic crashes and crash location information.

1.6. Research Questions

The objectives of the study were addressed by answering the following research questions:

1. Is there a relationship between the interaction of selected road design elements and the frequency of fatal crashes on the identified rural roads?
2. How do drivers perceive road design on the selected rural road sections, and how do the selected road design elements impact their behaviour? and,
3. What solutions and measures can be put in place to address the fatal traffic crash rates on the identified rural roads?

The research questions guided the study in exploring the relationship and interaction between road safety and road design elements on rural roads.

1.7. Chapter Overview

Chapter 1 Introduction

This chapter provides the background and purpose of the study and its relevance to the study area. It highlights the problem statement and the motivation and significance to carry out the study. It clearly states the limitations and the research questions addressed by the study.

Chapter 2 Literature Review

This chapter presents the literature that was covered and considered relevant to the study topic. This chapter covers the concept of road safety from global, African and Namibian perspectives. It covers the road design standards used in Namibia and the different road design elements that have a potential impact on fatal road traffic crashes.

Chapter 3 Methodology

This chapter presents an overview of the study design and justifies the importance of the study methodology used for the study subject. The study apparatus and procedures used for identifying hazardous rural roads, studying road user behaviour (survey), carrying out road safety audits and analysis of the relationship between fatal road crashes and road design elements on the study sections are discussed in this section.

Chapter 4 Study Locations

This chapter presents detailed information on the locations of the study segments and the road design information collected on the selected rural road sections.

Chapter 5 Results and Discussions

This chapter presents and discusses the results of the analysis of the potential relationship between the fatal road crashes and the road design information. Furthermore, the results of the road safety audits and the survey carried out on the selected rural roads are discussed in this section.

Chapter 6 Conclusions and Recommendations

This chapter presents conclusions of the dissertation, to consolidate the findings of the study on the potential impact of road design elements on the occurrence of fatal road crashes on the study sections. Future research areas are suggested in this chapter.

2. Literature Review

2.1. Introduction

Addressing road safety issues that relate to the three major traffic safety pillars; humans, vehicles and infrastructure, has been a crucial challenge to traffic engineers. An important aspect of road safety analysis is to locate dangerous road sections, to understand how the relationship between driver behaviour and road design elements affects the safety of all road users. The literature review focuses on road design elements and road user behaviour on two-lane two-way rural roads (singe carriageways).

2.2. Road Safety: Global

Roads are a means for transporting goods and people for most communities. There is a close relationship between mobility and development as 90 percent of transport worldwide is accommodated by road infrastructure. Rural areas that would be isolated are made accessible by roads (Lautrédou, 2007).

Shalom Hakkert and Gitelman (2014) state that motorisation rates in low and middle income countries have rapidly increased over a period of ten years up until 2014. Al-Matawah (2009) notes that roads are used by a great diversity of users. Vehicle fleets are rapidly growing in numbers, while in South- East Asia and some parts of West Africa, the most common form of transport has become motorcycles (Lautrédou, 2007).

Approximately 1.2 million people die on the worlds roads every year (WHO, 2017). Over 3 000 fatalities are recorded daily due to road collisions. Road fatalities in high income countries are projected to decrease by 20 percent by the year 2020, while the projected road fatality trends are expected to rise by 80 percent in low and middle income countries (WHO, 2017). Figure 2.1 shows the distribution of road fatality rates across the world.

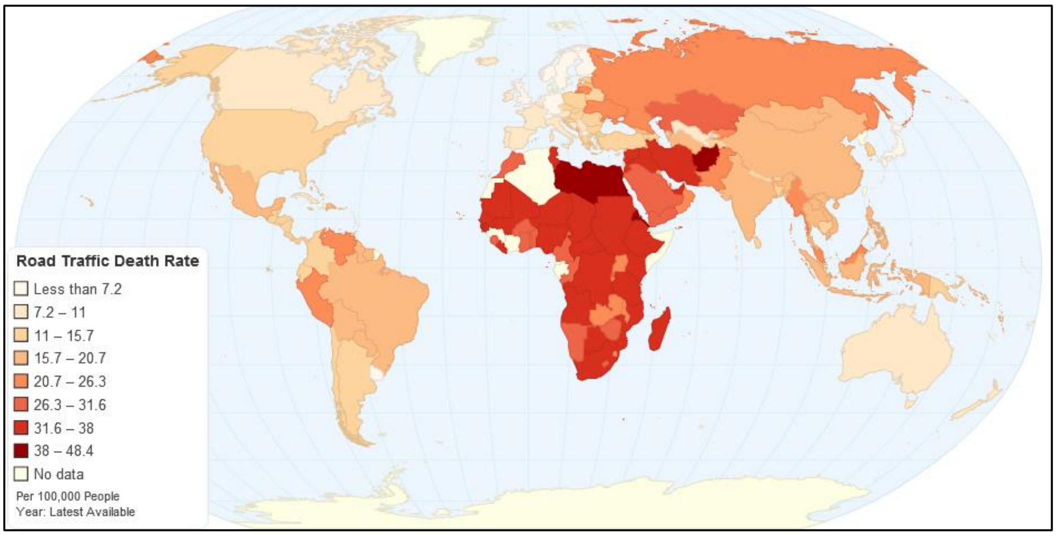

Figure 2.1 Fatal Road Traffic Crash Rates

Butchart and Mikton (2014) state that low and middle income countries have road fatalities of 21.5 and 19.5 per 100 000 population respectively. This is an extremely high number, compared with the 10.3 per 100 000 population in high income countries. Over 90 percent of the road fatalities in the world occur in low and middle income countries, which only have 48 percent of the world's registered vehicles (WHO, 2017). Table 2.1 shows the modelled road traffic fatality rates by world regions and income groups.

Table 2.1 Modelled Road Traffic Injury Fatality Rates (per 100 000 population), [a] *by World Regions and Income Groups* (WHO, 2017)

WHO Region	High income	Middle income	Low Income	Total
African region [b]	-	32.2	32.3	32.2
Region of the Americas	13.4	17.3	-	15.8
South- East Asia Region [c]	-	16.7	16.5	16.6
Eastern Mediterranean Region	28.5	35.8	27.5	32.2
European region	7.9	19.3	12.2	13.4
Western Pacific Region	7.2	16.9	15.6	15.6
Global	10.3	19.5	21.5	18.8

[a] 30-day definition: A traffic injury is one which causes death within 30 days after the crash

[b] No high income countries

[c] No low income countries

2.3. Road Traffic Crash Data

Information on traffic crashes (date of crash, location of crash, number of people involved, number of vehicles involved and weather conditions) is vital in understanding some of the factors involved in a road crash. Detailed road crash data is necessary to identify appropriate measures to prevent and reduce the frequency of road crashes and injury severity (Mohammed, 2013).

Ahmed (2013) mentions that it is critical to monitor road crash injuries in developing a picture of the actual scale of road safety problem in a country. Lautrédou (2007) mentions the importance of giving the police the responsibility to collect all the road crash data, using standard data collection forms, to increase the accuracy and quality of crash data collected. Standard forms make the vital process of data sharing between stakeholders an easy task.

Wegman (2017) notes that huge gaps exist in the coverage and quality of road injury data that countries record and report on. Reliable and accurate data on road fatalities and injuries are important in assessing the scope of the road crash problem, to target preventive measures, and to monitor and evaluate the effectiveness and efficiency of the intervention measures (Butchart and Mikton, 2014).

The WHO (2017) reports that although road fatality rates in many high income countries have steadied or declined in recent years, crash data suggests that the global epidemic of traffic injuries is still increasing in most regions of the world. The WHO (2017) reports that road fatalities are forecasted to be the fifth leading cause of death by 2030, leading to an estimated 2.4 million road fatalities per year if no immediate action is taken, as shown in Table 2.2 and Table 2.3.

Table 2.2 Leading Causes of Death in 2004 (WHO, 2017)

Rank	**Leading cause**	**%**
1	Ischaemic Heart Disease	12.2
2	Cerebrovascular Disease	9.7
3	Lower Respiratory Infections	7.0
4	Chronic obstructive pulmonary disease	5.1
5	Diarrhoeal Diseases	3.6
6	HIV/ AIDS	3.5
7	Tuberculosis	2.5
8	Trachea, bronchus, lung cancers	2.3
9	**Road Traffic injuries**	2.2
10	Premature and low birth weight	2.0

Table 2.3 Projected Leading Causes of Death in 2030 (WHO, 2017)

Rank	**Leading Cause**	**%**
1	Ischaemic Heart Disease	12.2
2	Cerebrovascular Disease	9.7
3	Chronic obstructive pulmonary disease	7.0
4	Lower Respiratory Infections	5.1
5	**Road Traffic injuries**	3.6
6	Trachea, bronchus, lung cancers	3.5
7	Diabetes mellitus	2.5
8	Hypertensive Heart disease	2.3
9	stomach cancer	2.2
10	HIV/ AIDS	2.0

Regular global safety assessments of road safety are needed as most countries have begun to address their road safety problems. These assessments require a standardised methodology and are required to enable countries to compare their road safety situation with other countries and to measure global progress (WHO, 2017).

The WHO (2017) reports that over the past 30 years, countries that have been able to sustainably reverse the rising trend of road fatalities have one thing in common: the political will to address road safety issues. Significant strides in road safety can be made only when policy makers are won over and are aware about the issue of road safety (Pinard, Ellis and Eriksson, 2003). The new position on road safety is outlined as follows:

a) Road crashes are an unavoidable consequence of economic growth, leading to an economic burden to society.
b) Road crash injuries are a man- made issue that are preventable and predictable through targeted measures and rational analysis.
c) Affordable and reliable targeted measures are available for implementation (WHO, 2017).

2.4. Measures to Improve Road Safety

Shinar (2007) states that understanding driver behaviour and driver attitudes in relation to the road environment is key to improving highway safety. It is important that drivers are seen in terms of their capacities, needs and limitations, in the total roadway system context. Improvements to road safety can be done intelligently, by understanding the characteristics of road users, the vehicle and road environment (Shinar, 2007).

Road crashes are often the consequence of a series of root causes, with the vehicle (factor in 5 to 10 percent of crashes), road infrastructure (10 to 20 percent of crashes) and road user behaviour (80 to 90 percent of road crashes) all contributing to the type of crash and injury severity (Lautrédou, 2007).

Mohammed (2013) states that the interaction between road users and the physical road design elements is critical to road safety. The designs of roads and vehicles must make provision for human errors (Shinar, 2007). The Haddon matrix identifies the risk factors pre-crash, during the crash and post-crash, relative to the vehicle and the environment (Krug and Sharma, 2009). Table 2.4 shows the Haddon matrix.

Table 2.4 The Haddon Matrix (Shinar, 2007)

Phase		Human	Vehicles and Equipment	Environment
Pre- crash	Crash Prevention	Information Attitudes Impairment Police Enforcement	Roadworthiness Lighting Braking Handling Speed management	Road design and road layout Speed limit Pedestrian Facilities
Crash	Injury prevention during crash	Use of restraints Impairment	Seat belts Occupant restraints Other safety devices Crash- protective design	Crash- protective roadside objects
Post- crash	Life sustaining	First-aid skill Access to medics	Ease of access Fire risk	Rescue facilities Congestion

Road crash causes usually relate to the road, vehicle and human factors (Deller, 2013). Mollel *et al.* (2011) states that it is vital to develop and evaluate the remedial measures that tackle road crash causes. Lautrédou (2007) recommends the following targeted measures to improve road safety.

Five emergency measures:

- Increasing awareness of the road safety problem, especially amongst policy makers.
- Establishing an effective system for collecting and analysing road crash data.
- Establishing a lead agency responsible for preparing and implementing coordinated intervention measures for road safety.
- Combating the major road safety risk factors (failure to wear seat belts, failure to wear crash helmets, over- speeding and drunk (alcohol) driving) through awareness campaigns, enforcement and traffic penalties.
- Encouraging associations and the private sector to get involved in road safety.

Five long- term measures:

- Improving the overall condition of vehicles using the roadway.
- Incorporating safety measures in all existing and planned roadway facilities.
- Introducing and improving road safety education in schools and assessing and improving the quality of road testing and training programmes.
- Improving emergency response time and the care afforded to traffic crash victims.
- Encouraging international cooperation between countries and road safety agencies.

It is imperative that all parties participate in implementing road safety programmes and measures that aim towards reducing road fatalities, as road safety is a collective responsibility for all stakeholders (Hagenzieker, 2014).

2.5. Road Safety: Africa

Al-Matawah (2009) reports that more road crash fatalities per 100 000 population are recorded in Africa than in any other part of the world. Non-Motorised Transport (NMT) is particularly at greater risk on the roads (Woolley *et al.*, 2002). Although most African countries still do not have road safety policies in place to protect vulnerable road users, others are yet to pass comprehensive laws to combat more general road safety risk factors such as speeding, drunk driving, and a lack of seatbelts and child restraints (Archer *et al.*, 2008). Poor law enforcement measures negatively affect implementation in countries where legal provisions are in place (Legal Assistance Centre, 2016).

The LAC (2016) reports that Africa remains the least motorized of the six world regions, yet it suffers the highest road crash fatality rates. Karlaftis and Golias (2009) mention that despite the African region possessing only 2 percent of the world's vehicle population, it contributes 16 percent to the global road crash fatalities. Nigeria and South Africa have the highest road crash fatality rates, with 33.7 and 31.9 deaths per 100 000 population respectively (Gichaga, 2017). Figure 2.2 shows the various road crash fatalities per 100 000 population across the African region in 2010.

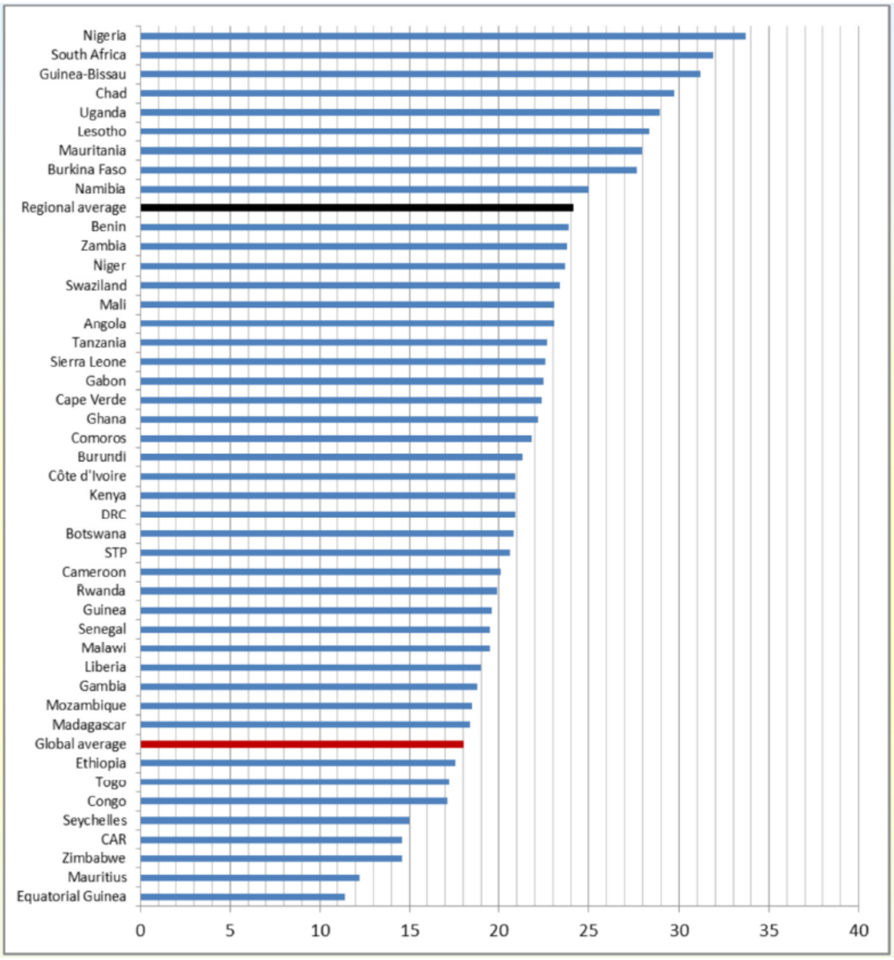

Figure 2.2 Comparative Road Fatality Rates (Fatalities per 100 000 Population) in Africa, 2010 (WHO, 2017)

The economic cost of such high rates of road crash fatalities is significant to the African region, which is home to most of the low income countries in the world (WHO, 2017). Parizel and Phillips (2004) estimate that between one and nine percent of the total GDP is lost due to road crash fatalities, as more than 60 percent of road fatalities are young adults (15 to 44 years) in their productive years. Figure 2.3 illustrates the high fatality rates in most of the low income countries in Africa compared to high and middle income countries.

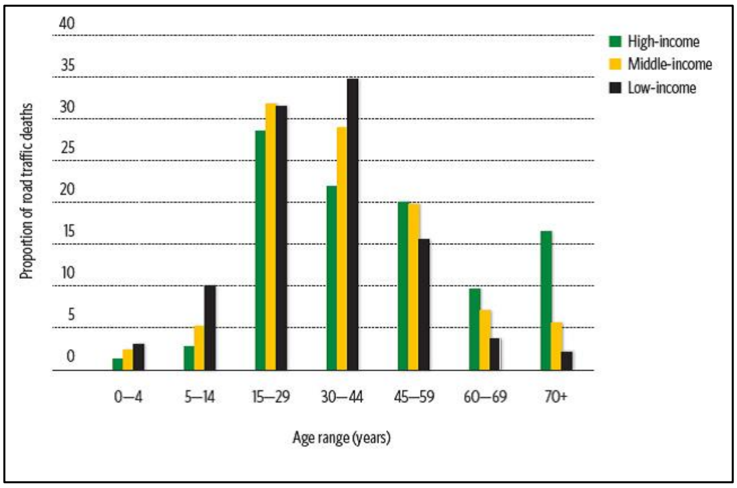

Figure 2.3 Road deaths by age group in 12 African countries, 2013 (WHO, 2017)

Bax *et al.* (2014) state that Improvements in effectual strategic policy initiatives, statutory provisions and traffic law enforcement are imperative if road safety is to be addressed adequately and sustainably. Lack of law enforcement, in particular, frustrates the effectiveness of laws in those countries that do have a comprehensive implementation strategy in place (Alfonsi *et al.*, 2016).

Addressing the road safety crisis effectively and sustainably would allow for resources that would be lost due to road crash fatalities to be invested in the promotion of social and economic initiatives (Legal Assistance Centre, 2016). Gichaga (2017) states that improving road infrastructure and road safety measures would help to reinforce the relationship between mobility and development, particularly in Africa, where close to 90 percent of people and goods are transported by the road.

2.6. Road Safety: Namibia

The United Nations Global Plan for Road Safety (2011) states that road infrastructure is a crucial element for generating economic growth, alleviating poverty, combating inequality and increasing domestic and international competitiveness, hence the need to ensure it is sustainably developed and maintained.

The Namibia National Road Safety Council (2012) reports that in 2012 the road crash fatality rate in Namibia was significantly higher than the African continental average of 26.6 fatalities per 100 000 population, at 31 fatalities per 100 000 population. When compared with the European region's decreasing rate of 9.3 fatalities per 100 000 population, notwithstanding that the European region has experienced an increase in motorisation, it can be concluded that Namibia has a precarious road safety situation (Namibia Statistics Agency, 2015). Figure 2.4 indicates that Namibia is part of the top 25 countries in the world with the highest road crash fatality rates per 100 000 population.

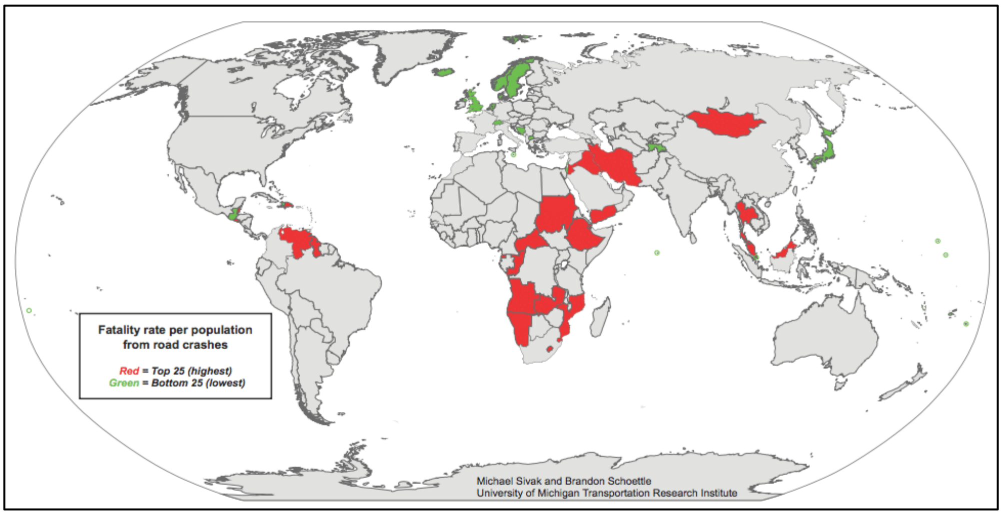

Figure 2.4 Fatality rate per population from road crashes (Legal Assistance Centre, 2016)

Butchart and Mikton (2014) report that the negative impact of road crashes on the economy and society has raised awareness and triggered coordinated global efforts towards combating and substantially reducing the number road crashes and injury severity.

The LAC (2016) notes that the Namibian Road Traffic and Transportation Act (Act 22 of 1999), tasks the police with collecting road crash information. The Roads Authority of Namibia is responsible for the national road network, where it carries out traffic counts to determine the Vehicle Kilometres Travelled (VKT) and provides information on the number and roadworthiness of vehicles registered (Runji, 2003). The National Road Safety Council (NRSC) of Namibia, which was established under the National Road Safety Act (Act 9 of 1972), is tasked with the duty of capturing and processing road crash data (Namibia road crash forms), promoting road safety and disseminating road safety information to all stakeholders (Namibia National Road Safety Council, 2012).

Runji (2003) states that it is vital that the targeted road safety solutions for Namibia recognise the prospective channels available for road safety cooperation and development at regional, national, and international levels.

2.6.1. Namibian Road Safety Statistics

The Namibia National Road Safety Council (2012) reported that during the period from 2002 to 2012, the number of road crashes had risen by an annual average of 5.4 percent. The number of registered vehicles operating on the road of increased by an annual average of 4.7 percent, with an overall annual growth of 5.8 percent in the number of vehicles kilometres travelled (VKT) (Namibia Statistics Agency, 2015).

Namibia had a slightly improving road safety situation as demonstrated by a 5.04 percent decrease in the road injury crash numbers from 2 585 in 2011 to 2 461 in 2012. Slight injuries recorded the sharpest decrease in number from 2 470 to 2 171, representing a 12.1 percent reduction. The number of road user fatalities dropped by 5.9 percent from 406 in 2011 to 382 in 2012. Furthermore, the serious injuries dropped by 12.7 percent, which amounted to a fall from 1 531 in 2011 to 1 336 in 2012, as reported by the Namibia NRSC (2012).

Over the course of ten years, from 2002 to 2012, a general upward trend in road crash severities was picked up in the data, although the was a slight decline in the ratio of road users injured to the number of road crashes (Namibia NRSC, 2012).

Table 2.5 shows trends in the road safety situation on the Namibian roads from 2002 to 2012.

Table 2.5 Variations in Road Safety Conditions for the years 2002- 2012: Road Traffic Indicators and Levels of Exposure Risk (Namibia NRSC, 2012)

Year	Numbers								
	Crashes	Number of vehicles involved	Injury crashes	Fatalities	Serious Injuries	Slight injuries	Registered Vehicles	Vehicle Kilometres Travelled (VKT)	National Population
2002	10 915	17 708	2 125	308	1 245	2 253	180 342	4 722 048 700	1 860 145
2003	10 957	17 838	1 956	278	1 149	1 195	192 321	4 795 168 400	1 891 097
2004	10 262	17 074	1 763	291	896	1 861	204 460	5 089 239 800	1 923 347
2005	11 146	18 257	1 834	252	1 054	1 928	218 140	5 343 794 700	1 956 899
2006	13 396	19 870	1 248	330	560	1 240	232 348	5 747 261 300	1 991 746
2007	13 720	20 247	2 053	252	971	1 801	239 885	5 929 692 400	2 027 870
2008	13 825	21 710	2 279	259	1 335	2 251	213 939	6 409 643 700	2 065 224
2009	15 537	24 433	2 537	278	1 403	2 483	229 806	7 141 761 800	2 103 762
2010	17 387	24 817	2 570	313	1 594	2 499	249 421	7 969 687 101	2 143 411
2011	17 835	25 337	2 585	406	1 531	2 470	269 907	8 085 571 000	2 113 077
2012	17 892	25 189	2 461	382	1 336	2 171	280 583	8 271 980 501	2 155 440

The number of road crashes has increased steadily from year to year. The number and severity of injuries and fatalities resulting from road crashes are more varied. The Namibia National Road Safety Council (2012) notes that there was a decrease in the road safety risk indicators showing the ratio of fatalities per 10 000 people, over the period of 2010 to 2012. Figure 2.5 shows the number of fatalities per 10 000 people.

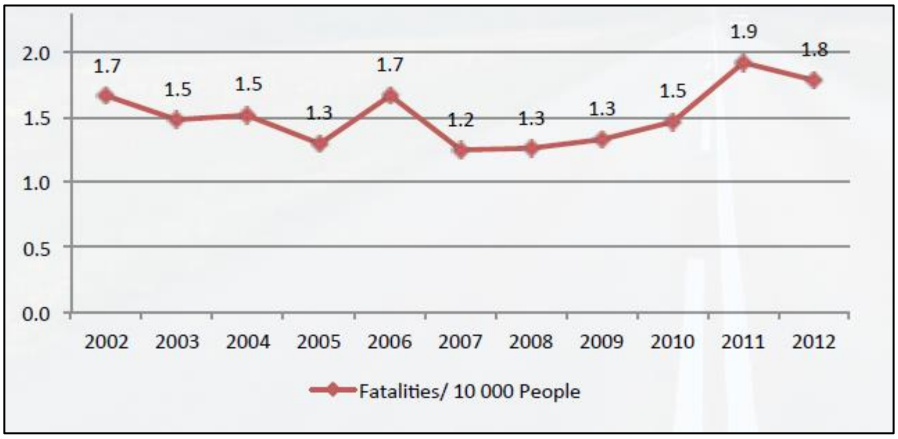

Figure 2.5 Fatalities/ 10000 People, 2002- 2012 (Namibia NRSC, 2012)

The Namibia NRSC (2012) reports that the risk of a road crash fatality has decreased slightly from 19.2 to 17.7 per 100 000 population. Despite variations in fatality rates during the period of 2002 to 2012, the upward trend from 2007 depicted in Figure 2.6 indicates a rise in road crash fatalities. The road crash fatality rate per 10 000 vehicles has reduced to 13.6, as Figure 2.7 indicates.

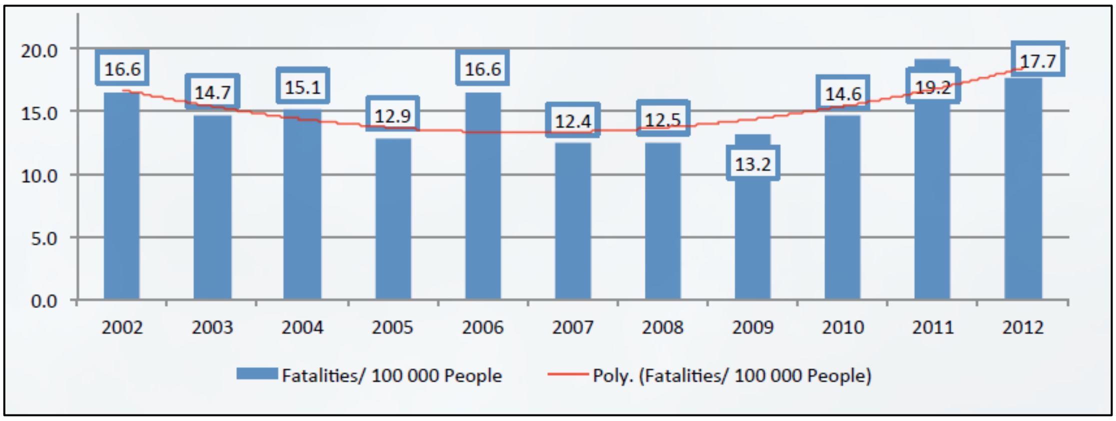

Figure 2.6 Fatalities/ 100 000 Persons, 2002- 2012 (Namibia NRSC, 2012)

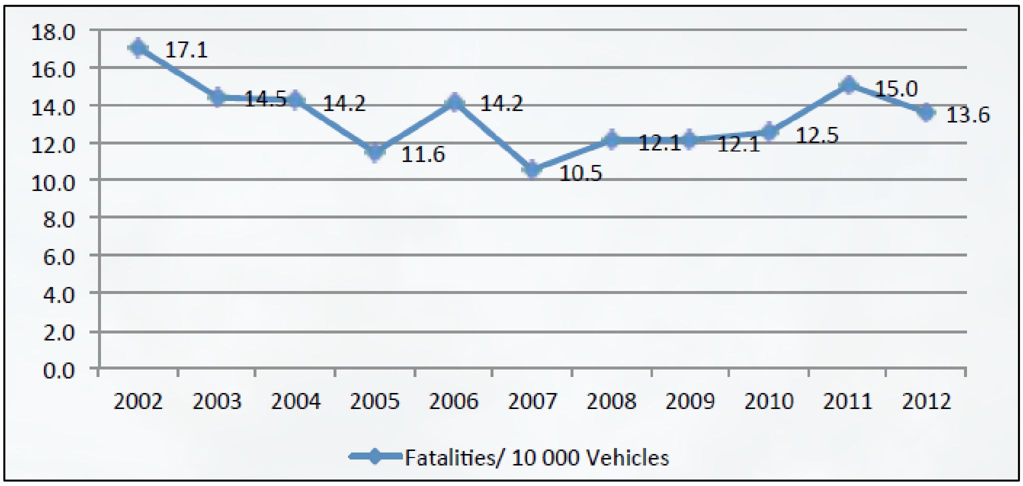

Figure 2.7 Fatalities/ 10 000 Vehicles, 2002- 2012 (Namibia NRSC, 2012)

Figure 2.8 shows the various injury severities sustained by road crash victims during the period 2002 to 2012. During the study period, an average of 8.7 percent (304) of the people involved in crashes were recorded as fatalities, 33.9 percent (1 189) were seriously injured, while 57.4 percent (2 014) sustained slight injuries (Namibia NRSC, 2012).

The highest increase in road fatalities was observed in 2011 with 406 fatalities, compared to 2012, which had 382 road fatalities. A World Health Organization underreporting factor of 1.3 was added to the actual number of fatalities reported, as structures for following up and reporting deaths caused by road crash injuries occurring within 30 days of the road crash were not in place (Namibia NRSC, 2012).

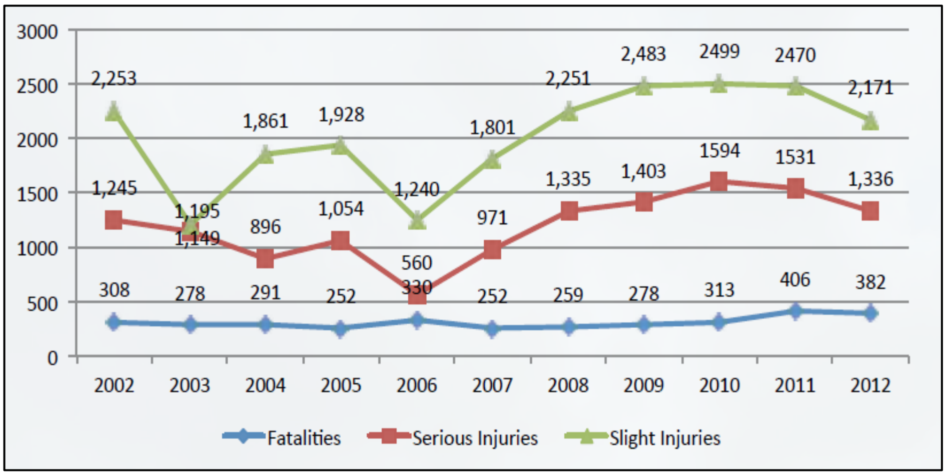

Figure 2.8 Severity of injury resulting from road crashes, 2002- 2012 (Namibia NRSC, 2012)

Table 2.6 shows crash severity information for the top ten rural road crash locations during the study period 2002 to 2012. The highest number of road crash fatalities occurred on the main road between Kalkfeld and D2483, resulting in 29 fatalities, followed by the Karibib-Swakopmund road section with 21 fatalities. The Omaruru-Karibib road had the third highest road fatalities with 7 fatalities. These road sections have high traffic volumes, especially during weekends (Namibia NRSC, 2012).

Table 2.6 Top ten crash locations and crash severity outside towns, 2002-2012 (Namibia NRSC, 2012)

Road No	Between (towns/ city)	Fatalities	Serious Injuries	Slight injury	Injury crashes	Damage only	Injury crashes & damage total	% injury crashes of total
D2414	Kalkfeld and D2483	29	54	49	35	209	244	17%
D2512	D2512- D2804	4	20	24	26	92	118	28%
D2427	D2505- M0063	0	2	6	7	61	68	11%
M0067	Outjo- Ruacana	4	18	11	15	56	71	27%
M0092	Outapi- Ogongo	1	24	34	36	171	207	21%
T0110	Oshivelo- Tsumeb	3	24	26	25	78	103	32%
T0111	Oshivelo- Ondangwa	3	32	49	45	147	192	31%
T0202	Karibib- Swakopmund	21	29	17	25	122	147	20%
T0203	Omaruru- Karibib	7	13	20	17	55	72	31%
T0601	Windhoek- Gobabis	4	24	23	27	127	154	21%

2.7. Proposed Remedies

Wegman (2017) states that road traffic crashes are a significant but preventable cause of death, trauma and economic burden in developing and emerging economies. Al-Matawah (2009) notes that the following two key factors need to be considered to identify the appropriate measures to reduce the frequency of road crashes.

1) The physical, human and road/ traffic environment characteristics of a country; and
2) An accurate and effective traffic crash data collection and analysis system.

Remedial measures implemented should be evaluated to understand their performance on the road section. These evaluations give an indication of the performance of a roadway in terms of the crash numbers and the crash severity on the road section (Al-Matawah, 2009). Road safety improvements and evaluations are mostly based on the 3 Es', namely Education, Enforcement and Engineering, with two additional Es' recommended, being Encouragement and Evaluation (Al-Matawah, 2009).

The Namibia National Road Safety Council (2012) proposed the following remedial measures to prevent and reduce the frequency of road crashes on Namibian roads:

a) The use of public transport should be promoted to reduce the volume of traffic on the national road network. Provisions for road infrastructure for the most vulnerable road users (Pedestrians and Cyclists) should be made in large urban centres by the local authorities.
b) Road safety education for lower primary schools should be made compulsory and extensive awareness should be raised to pedestrian safety and responsibilities through public campaigns.
c) Efforts should be made to construct separate and safe cycling lanes and pedestrian walkways in urban areas and open roads. Drivers should also be sensitised on the presence of these NMTs on such roads.
d) All stakeholders involved in road safety should make an effort to create a platform where vital information can be shared and to develop future research areas arising from the analysis of such information.

2.8. Road Design Standards

The Committee of State Road Authorities (CSRA 1988) defines road design standards as a basic and vital principle used to guide and control the design of roadway facilities. Semar (2003) states that the flexibility in the design standards allows for localised solutions for different functional and operational requirements. The American Association of State Highway and Transportation Officials (AASHTO, 2011) states that the design standards for the geometric design of highways are aimed at providing operational efficiency, comfort, safety and convenience to road users.

Pinard *et al*. (2003) states that the design of a road is linked to key factors that include a country's road network state of development and the functional and performance requirements within the unique characteristics of the road environment. (Mohammed, 2013) mentions that the road geometric design philosophy varies to a certain extent between developing and developed countries.

The road network in the SADC region provides different complex characteristics and functionalities compared to road networks in developed countries (Rose *et al.*, 2014). Design philosophies developed in industrialised countries typically cater for traffic volumes that are high and network requirements with operational efficiencies less suited for SADC (CSRA, 1988).

In the light of the absence of standards designed for the SADC region, the standards designed for industrialised countries are utilised and adopted to the local setting in the SADC region, particularly the AASHTO policy on the Geometric Design of Rural highways (South African National Road Agency Limited, 2003).

Pinard *et al.* (2003) states that design philosophies should meet the specific needs of the road users through the selection of appropriate vertical and horizontal alignments and road widths to provide the following:

1. Minimum levels of safety and comfort for drivers
2. A framework for economic design, and
3. Alignment consistency.

It is important that design standards deliver a roadway with a consistent cross-section and alignment by taking into consideration the traffic characteristics, road conditions, road user behaviour and the road environment (Mollel *et al.*, 2011).

2.8.1. Road Safety Aspects of Road Design Standards

The CSRA (1988) states that the impact that the surrounding environment has on road design, has a huge impact on the level of road safety that is provided to the road users. It is a miscalculation to adopt standards from the industrialised community with the thinking that they will address the road safety issues in developing countries, as these are generally reinforced with effective traffic law enforcement, driver training and public education, which is often not the case in the developing community, particularly in the SADC region (Pinard *et al.*, 2003).

Othman and Thomson (2007) state that the design of a road potentially impacts the economic, physical, cultural and social environments of an area where the road alignment passes through. In the SADC region, practical measures that have to be taken and understood during the design of the road are usually not addressed, resulting in road sections that potentially become unsafe for road users (CSRA, 1988).

2.8.2. Road Design Standards in Namibia

Pinard *et al.* (2003) states there are no existing standards in any SADC country that are based on African studies regarding safety and economic factors. The standards used are rather a reflection of the practice of developed countries with which SADC countries have had ties or those preferred by international consultant in these countries. The CSRA (1988) mentions that most of the road design standards used in SADC are a direct interpretation of international standards, with modifications to compensate for local operational differences and deficiencies, often without the consequences being fully evaluated.

Namibia uses the ***Technical Recommendations for Highways (TRH)*** series of guidelines, which are design practices largely derived from practices in South Africa. The Committee of State Road Authorities (1988) accepted the use of TRH series of guidelines for local roadway design and maintenance. The TRH series give a detailed description of recommended practices for highway engineering which have been localised to address the functional requirements for the South African road traffic environment (CSRA, 1988).

The ***TRH 17 on Geometric Design of Rural Roads*** offer design guidelines that are intended to be used for the geometric design of rural roads (CSRA, 1988). Pinard *et al.* (2003) states that while TRH series of guidelines are used to design roads that traverse through rural settings, for urban areas in South Africa, The Urban Transport Guidelines (UTG) series of guidelines are utilised. The UTG 1, UTG 5 and UTG 7, which all relate to geometric design of different road classes in urban areas, guide transportation engineers when rural roads traverse through urban built up areas, to ensure that road safety is not compromised (Pinard *et al.*, 2003).

2.9. Road Design Elements

2.9.1. Introduction

This section discusses how the road design elements selected for the study are developed in the delivery of an operationally efficient and safe roadway system. The interactive relationship between the road design elements and the impact they have on driver behaviour and road safety is also deliberated in this section. This is key to showing whether appropriate design processes were followed on the existing road sections analysed in the study. The design information provided in this section was used to categorise the road design elements of the study section for analysis in the regression models.

Jaiswal and Bhatore (2016) report that road design elements play a key role in defining the traffic operational efficiency and the safety of any roadway system. Mohammed (2013) mentions that key road design elements such as the number and width of lanes, the presence and width of hard shoulders and the horizontal and vertical alignments all influence traffic safety and operations, even though from a traffic safety point of view, it is difficult to predict with absolute certainty where traffic black spots will develop.

The SANRAL Geometric Design Manual (SANRAL, 2003) notes that road geometric design comprises the following stages:

1. The selection of road design elements;
2. The sizing of road design elements selected, and
3. Linking the road design elements to develop a roadway system.

The road design elements together represent the final design of a roadway, which when built, must satisfactorily establish a transportation road system addressing the needs directly and indirectly related to the movement of people and goods. Importantly, the transportation road system should match the criteria of safe, convenient and affordable, with minimum consequences for the road user (SANRAL, 2003).

2.9.2. Traffic Volume

Garber and Hoel (2009) state that traffic volume studies are carried out to gather data on the number of vehicles and/ or pedestrians that pass a point on a roadway facility during a specified period. Housley (2015) mentions that the traffic volume study period varies from as little as 15 minutes to as long as a year, depending on the expected use of the data.

Vayalamkuzhi and Amirthalingam (2016) state that it is vital that factual data on the traffic volumes which the road will have to accommodate are used in the design of the road infrastructure. Mollel *et al.* (2011) mentions that the usual design control is the design volume, which is the estimated traffic volume at a certain future year.

Mollel *et al.* (2011) reports that the following general measures are used for vehicular traffic on a road:

a) The **Design Volume**, which is the traffic volume expected to use a certain roadway facility during the design period.
b) The **Average Annual Daily Traffic (AADT)**, which is the total traffic volume for the year divided by the days in a year (365 days). For two-lane roads, the bi- directional total traffic is taken; and
c) The **Average Daily Traffic (ADT)**, which is the total volume of traffic during a given study period (full days), greater than one day and less than one year, divided by the number of days in the study period. For two-lane roads, the bi- directional total traffic is taken.

2.9.3. Traffic Speed

Deller (2013) mentions that speed studies are a vital measure for assessing the safety and geometry of a roadway. Housley (2015) reports that when upgrading existing roads, the results of speed studies serve as a foundation for selecting design speeds that are within the acceptable range of a roadways' functional class.

Deller (2013) mentions that though the speed selections made by drivers are based on factors in the road safety system and clues related to the design and operational factors of the road, the speed selections are also influenced by the risk-taking behaviour, driving skills and abilities and risk perceptions of the drivers. Porter *et al.* (2012) state that the speed distributions arising from drivers' speed selections on a road segment are routinely used to justify the posted speed limits on road sections. Since the study focuses on existing road sections, focus will be on the operating speed and posted speed limits.

2.9.3.1. *Design Speed*

Housley (2015) defines design speed as the maximum functional class speed based on the off-peak 85^{th} percentile speed anticipated within the range of the functional class selected. The design speed is used as the basis for designing the appropriate road section geometric elements. Elements directly linked to the design speed include horizontal and vertical alignments, superelevation and sight distances. Other elements such as lane width, shoulder width and road side clearance are indirectly related to design speeds (SANRAL, 2003).

Semar (2003) notes that it is important that the road design standards provided for a design speed to develop the road alignment are consistent with the anticipated speeds on the roadway. A relatively straight road alignment on a flat terrain is likely to generate higher speeds and thus a higher design speed. In contrast, a winding alignment on hilly terrain or amongst dense land use constraints is likely to generate lower traffic speed (AASHTO, 2011).

The SANRAL Geometric Design Manual (SANRAL, 2003) recommends that a constant design speed be adopted to a substantial length of roadway as it maintains consistency. A change in design speed in certain sections can be dictated by variations in the terrain and other physical controls (Semar, 2003). The introduction of a lower or higher design speed should not be effected abruptly, but over sufficient distance to encourage gradual speed change (SANRAL, 2003).

Table 2.7 shows the minimum and recommended design speeds for the different road design classes.

Table 2.7 Design Speeds for Various Road Design Classes (SANRAL, 2003)

Design Class	Carriageway Width (m)	Minimum Design Speeds (km/h)			Recommended Design Speeds (km/h)		
		Flat to Rolling	Rolling to Hilly	Mountainous	Flat to Rolling	Rolling to Hilly	Mountainous
1	2×7.0	120	90	70	120	90	70
2	7.5	100	80	60	110	80	70
3	7.0	100	80	60	110	80	70
4	6.5	80	70	50	100	80	60
5	6.5	70	50	40	80	70	50
6	6.0	70	50	40	80	70	50
7	6.0	60	50	40	70	60	50
8	5.5	50	50	40	60	50	40
9	4.0	50	40	30	50	50	40

2.9.3.2. *Operating Speed*

Sayed (2004) defines the operating speed as the speed at or below which 85 percent of the vehicle population is observed travelling under free-flowing conditions past a study point. When there is a headway of at least four seconds between vehicles, a road user is considered to be operating under free- flowing conditions (Taylor *et al.*, 2000). The posted speed limit does influence the operating speed, together with influence from other road environment factors (Deller, 2013).

Deller (2013) mentions that the operating speed is determined from speeds that drivers select to use to traverse a road section. In the maintenance and upgrading of roadway facilities, the operating speed is vital in determining the appropriate design speed. Vayalamkuzhi and Amirthalingam (2016) affirm that a consistent road design, conforming to the expectations of drivers, leads to fewer driver errors and helps drivers in selecting speeds that are appropriate for the road section.

When there are disparities between the actual speed at which a feature is supposed be traversed safely and what drivers assume to be a safe speed to drive through a feature, road crashes are likely to occur (Deller, 2013). Sayed (2004) notes that the difference between the operating speed and design speed (V85-Vd) serves as a good indicator of the inconsistency in design experienced by drivers at one single element. The Brisbane Department of Transport Management (2009) suggests that operating speeds should also be logged where there are no apparent attempts for overtaking manoeuvres, to assess the safety of these road features.

2.9.3.3. *Posted Speed Limit*

Haglund and Aberg (2002) state that the posted speed limits are determined with the purpose to establish credible speed limits that avoid disparities between a road user's perception of the safe speed setting and an acceptable level of safety for all road users and land users next to the road. Woolley *et al*. (2002) report that there is a significant assumption that the experience and knowledge of drivers are important factors in safely traversing a road section.

Deller (2013) states that when determining an appropriate posted speed limit, several safety criteria and factors are considered, to make sure it is determined within the road safety system context. These factors include the environment in which the road is situated; traffic volume, prevailing speeds and activity; the pavement, the width of the lanes and hard shoulders; horizontal and road vertical alignment and access density (Deller, 2013).

In assessing the road design elements of an existing roadway, Deller (2013) mentions that the crash rate of the road is one of the most vital considerations in reviewing the posted speed limit. Road authorities often change speed limits when the road has already been opened to traffic, with a variety of reasons, ranging from political pressure to changes to adjoining land use being used (Deller, 2013). Archer *et al.* (2008) mention that the changes in the posted speed limit often result in the new posted speed limit not being a reflection of the road's design speed. The inconsistency that arises from the posted speed limit exceeding the design speed of a section can raise liability concerns despite the fact that drivers can safely exceed the design speed (Haglund and Aberg, 2002).

Liu *et al.* (2016) report that drivers tend to exceed the speed limit with the belief that their excess speed will not threaten safety. Deller (2013) notes that authorities tend to avoid the costly exercise of making changes to road infrastructure after a series of crashes; instead they reduce the posted speed limit on the road section, which increases the difference between the new posted speed limit and the design speed of the road.

Gaudry and Vernier (2002) report that disparities between the posted speed limit and the design speed play a crucial role in road crash rates. Deller (2013) mentions that though the average speed generally corresponds with the design speed, the speed variance and road crash rate are lowest when the speed limit is approximately 8-16 km/h lower than the design speed. The risk of a road crash occurring increases when changes are made to the posted speed limit without considering changes to other roadway corridor factors that influence speed choice (Archer *et al.*, 2008).

2.9.4. Terrain

Mohammed (2013) mentions that the topography of the land on which a road user traverses has a significant influence on the horizontal and vertical alignments of the roadway. Semar (2003) states that terrain classifications relate to the general character of a road corridor. Housley (2015) notes that for design purposes, the variations in the topography of an area are categorized by terrain. Housley (2015) defines the dissimilarities in topography as follows:

a) **Level Terrain**: The highway condition where horizontal and vertical sight distances (range of gradient) are usually long and can be constructed without major difficulty or expenses.
b) **Rolling Terrain**: The highway condition where slopes rise above and fall below the grade of the road consistently. Restrictions to the road's vertical and horizontal alignments are occasionally caused by the rolling terrain.
c) **Mountainous Terrain**: The highway condition where the traverse and longitudinal change in the ground's elevation in relation to the roadway are sudden (hilliness and bendiness). To obtain satisfactory horizontal and vertical alignments, side hill excavation and benching are often required.

2.9.5. Vertical and Horizontal Alignment (Road Alignment)

Hanno (2004) defines the road alignment as the combination of vertical and horizontal road geometric elements, therefore providing the road location in the terrain. Mollel *et al.* (2011) states that the alignment design should take care of road safety, comfort, aesthetics, economics and environmental factors.

Hassan and Easa (2003) report that the road crash rate on horizontal curves is significantly higher than the road crash rate on road tangents. Drivers' speed selections are significantly affected by the presence of a horizontal curve on a road section (Easa, 2003). Hanno (2004) states that a poor coordination between the horizontal and vertical alignments leads to poor driver perceptions and driving errors, which consequently compromise the safety of the road.

Krug and Sharma (2009) report that the inconsistent design of a roadway leads to an increase in the drivers' workload and to road sections that do not meet the expectations of the drivers. Hanno (2004) notes that design procedures have stressed the importance of the inclusion of the impact of the combination of horizontal and vertical alignments on road safety. It has been observed that certain combinations of vertical and horizontal alignments lead to an increase in the frequency of road crashes (Hassan and Easa, 2003).

The National Cooperative Highway Research Program (NCHRP) Guide for Addressing Run-Off-Road Collisions (Transportation Research Board of the National Academies, 2003) notes that while vehicles are more likely to leave the roadway along curves, most run-off-road (ROR) crash fatalities on two-lane rural roads are on tangent sections, with 42% of ROR fatal crashes reported on curves and 58% on tangents on all roads. The (TRB, 2003) Reports that the percentage of ROR fatal crashes on curves increases to 50% on two-lane rural roads. The high percentage of fatal crashes occurring on tangent sections on all roads most likely reflects that most road sections are tangents.

Garcia and Abreu (2016) state that a reduction in crash rates occurs with an increase in the horizontal curve radius. Easa (2003) found that a horizontal curve radius greater than 400m and a vertical grade equal to or less than 5% have a significantly low effect on road crashes while a steep increase in speed and road crashes was noted on vertical grades greater than 6%. The ratio between the sag vertical curve and the horizontal curves for combined elements should range between one fifth (1/5) and one tenth (1/10) (Easa, 2003).

Easa *et al.* (2007) observed that drivers significantly reduce their speeds when traversing horizontal curves, with the desire to maintain a satisfactory side road friction. Bella (2014) found that the combination of a crest vertical curve and a horizontal curve causes drivers to reduce their speeds, as they perceive the curves to be sharp, while the combination of a sag curve and a horizontal curve are perceived less sharp by drivers, causing drivers to increase their speeds.

Yingxue (2009) states that traffic engineers should ensure that there are no abrupt changes in the road geometric standards and guarantee consistency in the road alignments and cross-sections. Abrupt changes in the road and inconsistent design standards can defy a driver’s expectation and cause traffic crashes (Mollel *et al.*, 2011). Figure 2.9 shows the different cases of road alignment combination.

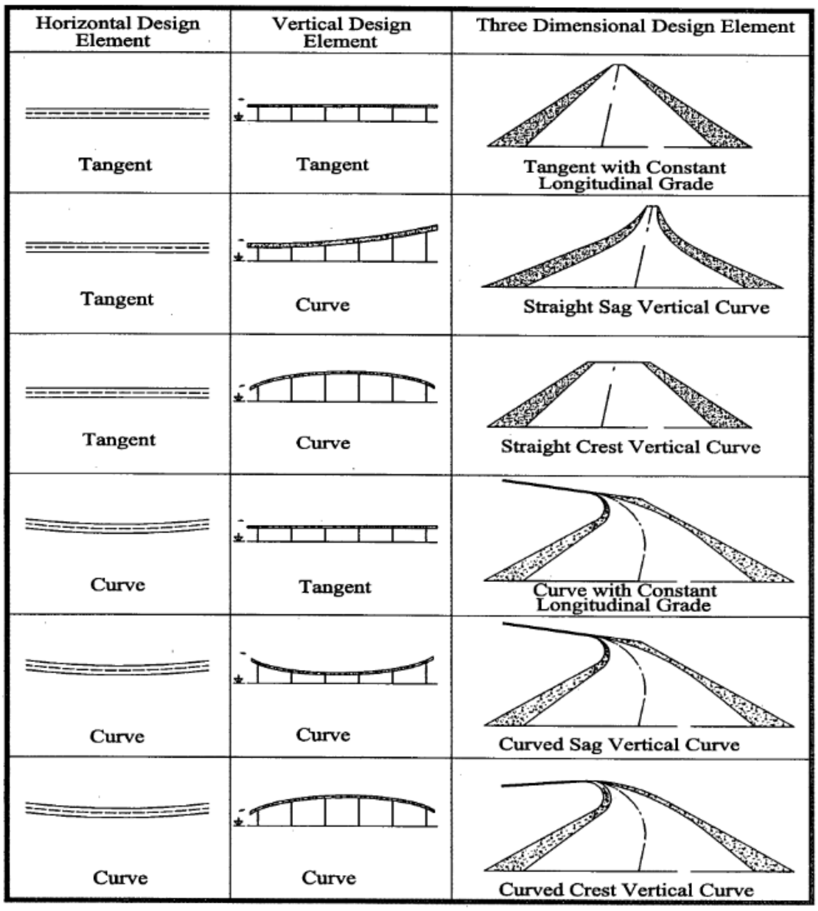

Figure 2.9 Three- Dimensional Combination of Vertical and Horizontal Road Design Elements (Hanno, 2004)

The following sections discuss some facts about horizontal and vertical alignments, to create a better understanding on their capabilities, limitations and effects on road safety.

2.9.5.1. *Sight Distances on Road Alignment*

Hanno (2004) defines sight distance as the distance visible to the driver of the vehicle. Housley (2015) mentions that sight distance plays a vital role in determining the alignment of a road. It is vital that transportation engineers provide sufficient sight distances to ensure that drivers are able to safely control the operation of their vehicles while on the road (Mollel *et al.*, 2011).

The SANRAL Geometric Engineering Manual (SANRAL, 2003) states that two-lane highways should have adequate sight distances to enable drivers to occupy the opposing traffic lane for overtaking manoeuvres without the risk of a road crash. The passing sight distance on two-lane rural highways should be provided for a significant road section length and at regular intervals, to allow for safe overtaking manoeuvres (Mollel *et al.*, 2011). The rate of curvature (K) values for passing Sight Distance can be used to indicate whether overtaking should be permitted during road marking and provision of traffic signs (SANRAL, 2003).

Table 2.8 indicates the passing sight distances and minimum rate of curvature (K) for vertical curves that should be provided to allow for safe overtaking manoeuvres.

Table 2.8 Sight Distances on Level Ground (G=0) and K- Values for Vertical Curves (SANRAL, 2003)

Design Speed (km/h)	Coefficient of Friction (f)	Stopping sight distances (m)	Passing sight distances from formulae (m)	Reduced passing sight distances for design (m)	K-Values to Satisfy stopping sight distances (m / % of g)		K-values to satisfy passing distances sight distances (m/ % of g)
					Crest	Sag	
30	0.40	30	217	75	3	4	50
40	0.38	45	285	125	5	8	86
50	0.35	63	345	175	10	12	126
60	0.33	85	407	225	18	18	176
70	0.31	110	482	275	22	25	246
80	0.30	130	540	315	49	32	310
90	0.30	169	573	340	71	41	387
100	0.29	205	670	375	105	51	475
110	0.28	247	728	399	151	62	561
120	0.28	285	792	425	201	74	664

Gaudry and Vernier (2002) state that traffic engineers should ensure that the stopping sight distance on a roadway is great enough to allow for a vehicle travelling at the design speed to come to a halt without hitting a stationary object in its path. Mollel *et al.* (2011) notes that Equation (2.1) determining the sight distances on the road alignment puts into consideration the distance required to halt a vehicle and the reaction time of the driver.

$$SSD = 0.278 \times t \times V + \left(\frac{V^2}{254\,(f+G)}\right) \qquad (2.1)$$

Where; SSD = Stopping Sight Distance (m).

t = Driver reaction time, generally taken as 2.5 seconds.

V = Vehicle speed (km/h).

F = Coefficient of longitudinal friction.

G = Percentage grade, + for upgrade and - for downgrade (%).

2.9.5.2. *Horizontal Alignment*

Hassan and Easa (2003) mention that the horizontal alignment is made up of the tangent, the circular curve, the transition curve and the superelevation section.

a) Tangent Section

The SANRAL Geometric Design Manual (SANRAL, 2003) defines the tangent section as the straight section of the road that comes before traversing into the curved sections and after leaving the curved sections. These straight sections provide good sight distances for overtaking manoeuvres and for stopping (Mollel *et al.*, 2011). Garcia and Abreu (2016) report that tangent sections have the disadvantage of causing road crashes due to speeding, driver fatigue and headlight glare. The Tanzania Geometric Design Manual (Mollel *et al.*, 2011) recommends the length of straight sections on a road to be equal to or less than 2 kilometres.

b) Transition Curves

The Tanzania Geometric Design Manual (Mollel *et al.*, 2011) notes that transition curves are provided to ensure a smooth transition between tangents. They start at the tangents with a radius equal to infinity, and join the circular curve with radius equal to that of the circular curve (Mollel *et al.*, 2011). The TRH 17 (CSRA, 1988) states that a transitioned lane gives the drivers a natural path that is easy to follow while providing a suitable arrangement for superelevation run-off.

The TRH 17 (CSRA, 1988) recommends the use of transition curves where the associated circular arc is to have a superelevation of 60 percent or more. The TRH 17 (CSRA, 1988) recommends that the transition curve takes the form of a spiral, with a length equal to the length required for the development of superelevation from the point where the crossfall is equal to the normal camber.

The design of transition curves is shown in Figure 2.10 and Figure 2.11 for Reverse and Broken-Back curves respectively.

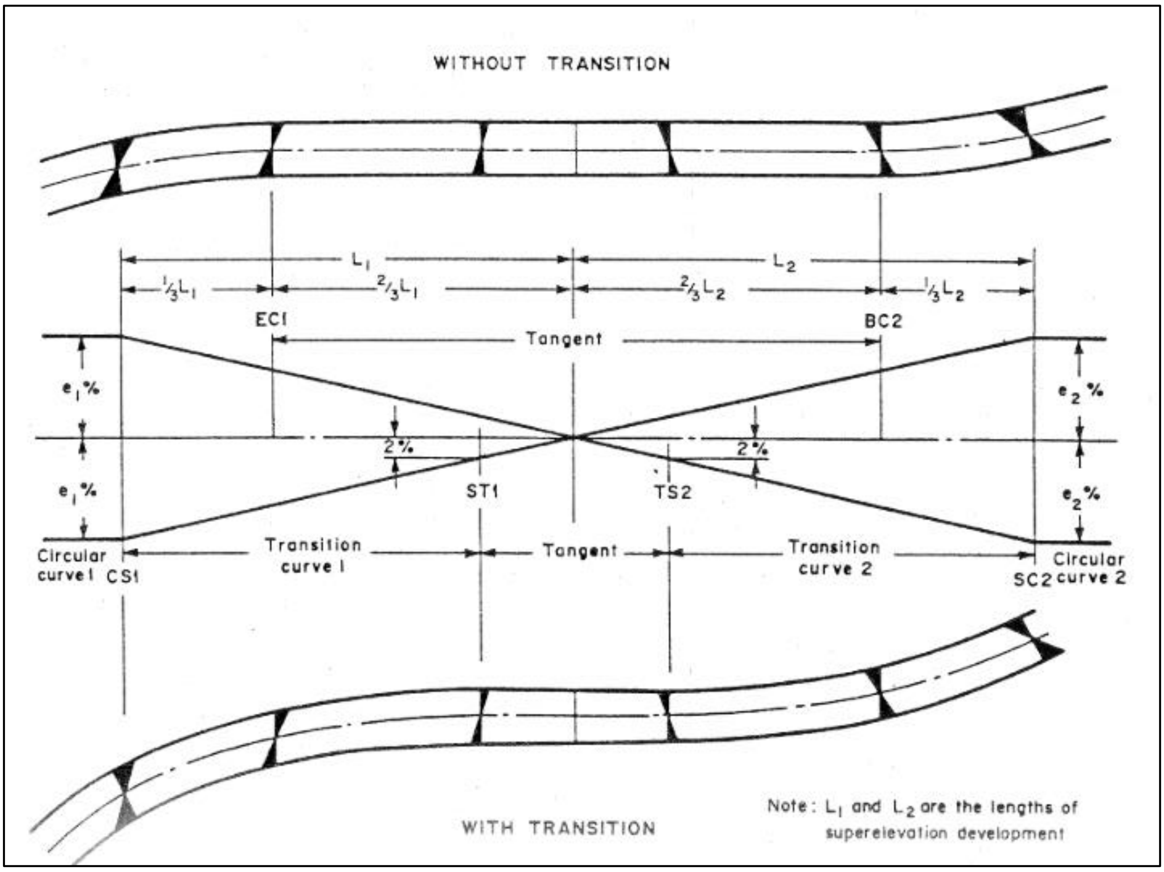

Figure 2.10 Geometric Design of Reverse Curves (CSRA, 1988)

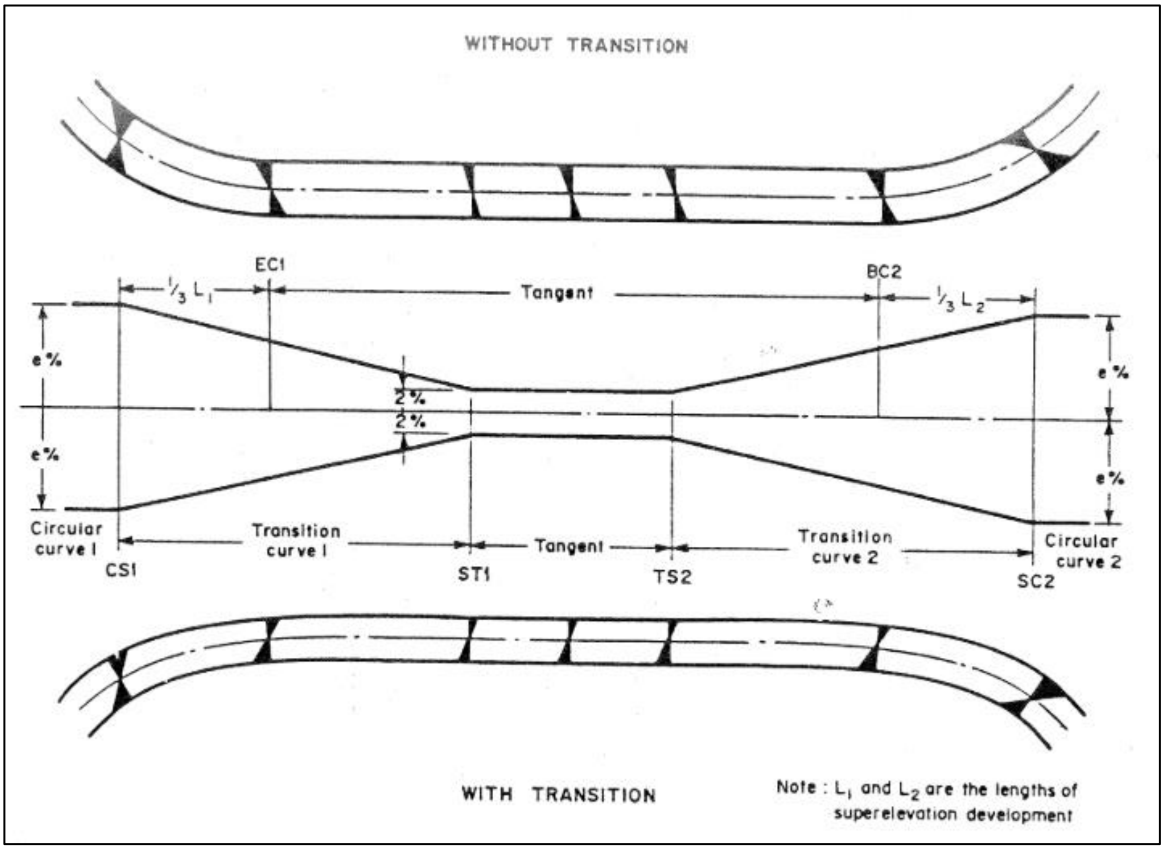

Figure 2.11 Geometric Design of Broken-Back Curves (CSRA, 1988)

c) Circular Curves

Hassan and Easa (2003) note that to facilitate the smooth transition between tangent sections when changing direction, circular curves are used. The Tanzania Geometric Design Manual (Mollel *et al.*, 2011) notes that where the deflection angle is less than 5°, a minimum length of 150m should be used for circular curves. To avoid the kink experience, curves should have a minimum length of 200m. A maximum length of 800m is desirable for a circular curve, with an absolute maximum length of 1 000m, as curves that are too long tend be problematic for overtaking manoeuvres (Mollel *et al.*, 2011). Garber and Hoel (2009) mention that a circular curve comprises various features, as shown in Figure 2.12.

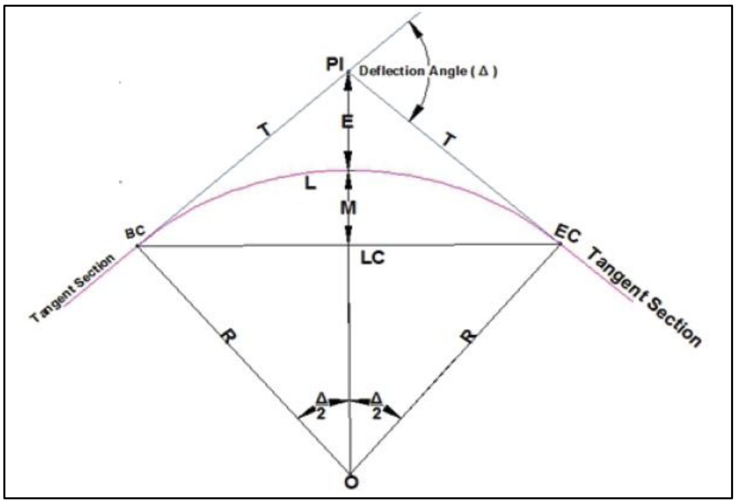

Figure 2.12 Elements of Circular Curve (Garber and Hoel, 2009)

Where; PI = The point where two tangents intersect.

T = The length of the tangent, T = R tan(Δ/2).

Δ = The deflection angle formed by the intersection of the two tangents at the PI.

L = The arc (curve) length between the BC and EC, L = Δ×R 2π/360.

LC = The long chord length between the BC and the EC, LC = 2R sin(Δ/2).

E = The external distance from the PI to the centre of the arc, E = R (sec(Δ/2)-1).

M = The distance from the middle of the arc to the midpoint of the Long Chord (middle ordinate), M = R(1-cos(Δ/2)).

BC = The point where the tangent ends and the curve begins (Point of Curvature), BC = PI – T.

EC = The point where the curve ends, and the tangent starts (Point of Tangency), EC = BC + L.

R = The distance from the centre of the circle (O) to any point on the circumference (Radius).

For road sections with a small deflection angle, the length of the horizontal curve should be long enough to avoid the kink experience. The Technical Recommendations for Highways 17 on the Geometric Design of Rural Roads, developed by the CSRA (1988) suggests a minimum length of 300m, which can be reduced to 150m if space is limited. The TRH 17 (CSRA, 1988) suggests that the minimum length of the curve should be increased by 150m by 30m for each 1° decrease in the deflection angle, for deflection angles less than 5°. Table 2.9 provides information on the minimum horizontal curve radii recommended by the CSRA (1988).

Table 2.9 Minimum Radii of Horizontal Curvature (CSRA, 1988)

Design Speed (km/h)	Radius (m)
50	80
60	110
70	160
80	210
90	270
100	350
110	430
120	530
130	640
140	760

d) Superelevation (e_{max})

Housley (2015) defines superelevation (e_{max}) as the cross slope of the roadway in a horizontal curve, provided to partially offset the centrifugal force on a vehicle as it traverses the curve. Housley (2015) mentions that the allowable rate of superelevation is influenced by multiple factors, including the climate and the type of area (rural/ urban).

The SANRAL Geometric Design Manual (SANRAL, 2003) states that rural road settings typically have a higher e_{max} value, while lower e_{max} values are applied to roads in urban areas due to spatial constraints. In urban settings, the speeds achieved vary between zero and the posted speed limit or higher, depending on the level of congestion, traffic control devices and the local level of traffic law enforcement (SANRAL, 2003).

The SANRAL Geometric Design Manual (SANRAL, 2003) mentions that the range of driver speed selections in rural areas is relatively limited and the distance required for the development of the superelevation is usually available. Pinard *et al.* (2003) mention that the maximum value of superelevation that can be applied is limited by the climatic conditions. Undesirable weather conditions typically require the application of a lower e_{max} value (SANRAL, 2003).

Table 2.10 indicates the rates of superelevation for various road domains (SANRAL, 2003).

Table 2.10 Design Domain for Superelevation (SANRAL, 2003)

Setting	Suggested range for e_{max}
Rural Roads	8% to 10%
High Speed urban roads	6% to 8%
Minor Urban roads	4% to 6%

Drivers generally select their speed when approaching a curve based on the radius of the curve that they perceive and not on the superelevation that is provided on the section. For this reason, it is safer that a consistent value of e_{max} is provided on a road curve, to prevent driver errors that may lead to road crashes (SANRAL, 2003).

2.9.5.3. *Vertical Alignment*

Garber and Hoel (2009) note that the vertical alignment of a roadway is made up of suitable grades (straight sections) that are connected by vertical curves of the appropriate length. Mohammed (2013) mentions that the terrain of the area has a significant impact on the development of a road’s vertical alignment.

a) Road Gradient

Gichaga (2017) notes that the road grade has the properties of length and gradient, representing the height gained or lost in metres divided by a horizontal distance of 100m, expressed as a percentage. The SANRAL Geometric Design manual (SANRAL, 2003) reports that there is a strong statistical correlation between the speed differential between trucks and passenger cars, and the crash rates on road gradients. The SANRAL Geometric Design Manual (SANRAL, 2003) found that crash rates fluctuate between 1 to 5 road crashes per million vehicle kilometres travelled, for a speed reductions of less than 15km/h, while a speed reduction of 30km/h, caused a sharp increase to 21 road crashes per million kilometres travelled. The critical length of grade is typically considered to be the distance over which a 15km/h speed reduction occurs (SANRAL, 2003).

The SANRAL Geometric Design Manual (SANRAL, 2003) states the it is vital that the 85th percentile mass to power ratio is of the order of 185 kg/kW. Figure 13 shows the performance of the 85th percentile of trucks.

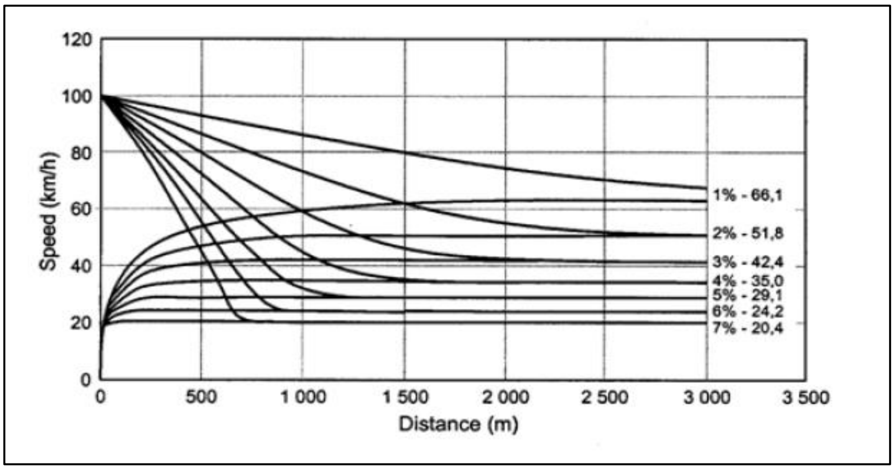

Figure 2.13 Truck Speeds on Grades (SANRAL, 2003)

The SANRAL Geometric Design Manual (SANRAL, 2003) notes that the critical lengths of a grade for a speed reduction of 15 km/h are derived from the 85th percentile truck performance curves shown in Figure 2.11. Housley (2015) warns that for grades that are longer than the critical lengths, it is important that treatment is applied to lessen their impact on traffic performance and road safety.

Table 2.11 shows the various critical lengths required for various gradients.

Table 2.11 Lengths of grade for 15km/h Speed reduction (SANRAL, 2003)

Gradients (%)	Critical Length of Grade (m)
2	550
3	380
4	300
5	240
6	180
7	140
8	100

b) Vertical Curvature

Garber and Hoel (2009) state that vertical curves provide a gradual change from one tangent grade to another, to enable vehicles to run smoothly as they traverse the road section.

The SANRAL Geometric Design Manual (SANRAL, 2003) notes that the vertical curve length can be expressed by Equation (2.2):

$$L = A \times K \tag{2.2}$$

Where; L = Curve length (m)

A = Algebraic difference between the gradients on either side of the curve

K = Rate of change.

Pinard *et al.* (2003) note that vertical curves are typically developed in a parabolic shape. For this reason, the lengths of a vertical curve exhibit the properties of a parabola shape (Housley, 2015).

Figure 2.14 shows the different types of vertical curves and the associated parameters.

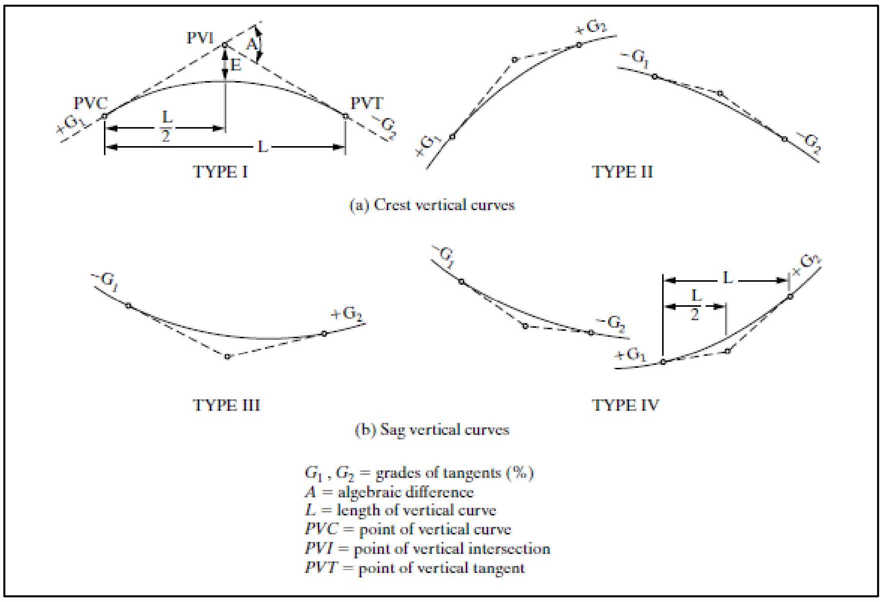

Figure 2.14 Types of Vertical Curves (SANRAL, 2003)

a) Crest and Sag Vertical Curve

Garber and Hoel (2009) state that provision of a minimum Stopping Sight Distance (SSD) is vital, as it is the only criterion that is used for the development of a crest vertical curve on a roadway.

The SANRAL Geometric design Manual (SANRAL, 2003) describes the parameter K as the key factor that determines the shape of the parabolic curve. Adequate sight distance along the length of the road curve is primarily determined by the value of K (SANRAL, 2003).

The SANRAL Geometric Design Manual (SANRAL, 2003) notes that the levels of the different points of a vertical curve are computed using the Equation (2.3):

$$LEV_{x} = LEV_{BVC} + G_1 x + (G_2 - G_1)\, x^2 / 2L_{VC} \qquad (2.3)$$

Where; LEV_x = The level at point x meters from the beginning of vertical curve.

LEV_{BVC} = The level at the beginning of vertical curve.

G_1 = The slope of the first tangent in percentage.

G_2 = The slope of the second tangent in percentage.

x = The distance from the beginning of the vertical curve.

L_{VC} = The length of vertical curve.

2.9.6. Road Classification

The Technical Recommendations for Highways 26 on Road Classification and Access Management (CSRA, 1988) states that the primary purpose of a road network is to serve the need to travel for all modes of transport. The road network should provide a safe and efficient means of moving people and goods.

The basic concept of road classification is illustrated in Figure 2.15, in which the travel desire lines are shown as straight lines connecting the origins and destinations of users. The TRH 26 (CSRA, 1988) notes that the width of the lines relate to the travel desires while the length relate to the travel distances for users. The principles illustrated by Figure 2.15 apply to both rural and urban roads (CSRA, 1988).

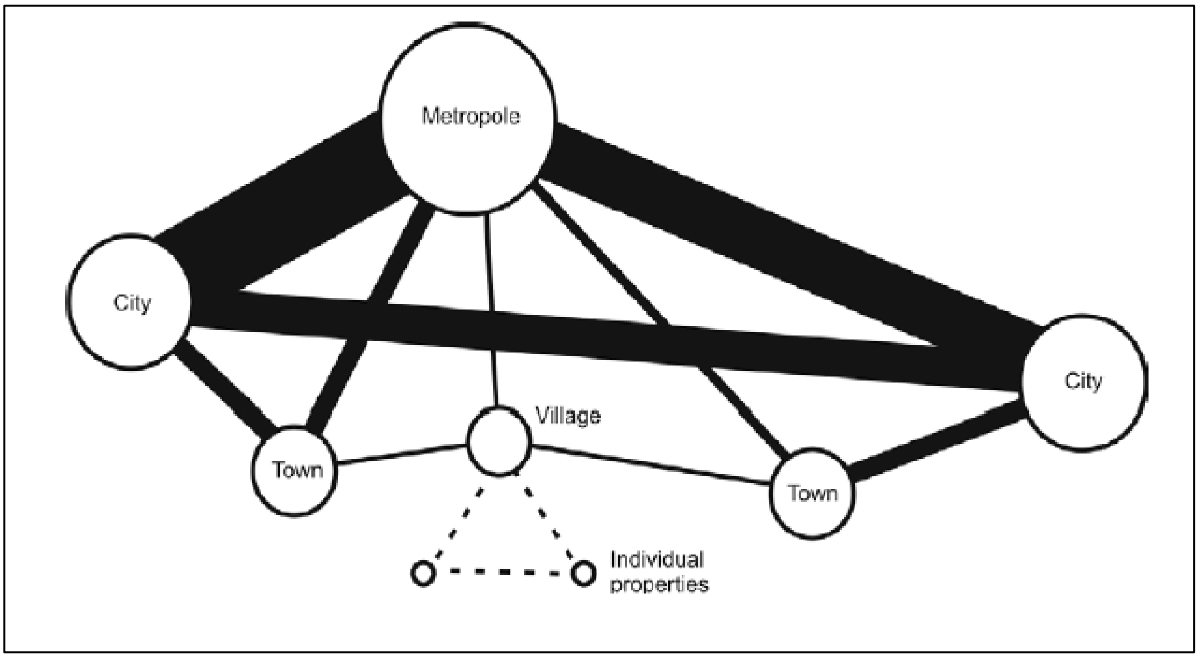

Figure 2.15 Travel Desire Lines (CSRA, 1988)

The Tanzania Geometric Design Manual (Mollel *et al.*, 2011) notes that roads have two basic service functions, which from a road design perspective, are incompatible with each other. These basic traffic service functions are:

1. To provide safe and efficient traffic mobility areas; and
2. To provide safe access to the land and properties adjoining the roads.

Housley (2015) mentions that the design criteria to be used for the development of a road in the national road network are significantly impacted by the intended function of the road. Pinard *et al.* (2003) note that roads that have a major function to provide safe mobility, uniform speeds and uninterrupted traffic flows are usually desirable, while for roads whose main function is to provide access to adjoining land, it is undesirable and unsafe to design for high speeds, as this can lead to hazardous conditions on the road sections. Mollel *et al.* (2011) classify the road network into the following:

1. National roads; and
2. District roads.

2.9.6.1. *National Roads*

National roads include the following roads:

a) **Class A: Trunk roads**

Mollel *et al.* (2011) define trunk roads as national routes linking multiple major international or regional headquarters on a road network.

b) **Class B: Regional roads**

Ambros *et al.* (2016) define secondary national routes as routes linking regional headquarters (trunk roads) to district roads in a road network.

2.9.6.2. *District Roads*

District roads include the following roads:

a) **Class C: Collector roads**

Housley (2015) notes that collector roads serve a dual function of collecting and distributing road traffic and providing access to properties adjoining the routes, thereby, allowing for traffic circulation and providing land access.

b) **Class D: Feeder Roads**

Housley (2015) defines feeder roads as roads within urban areas responsible for linking traffic from residential areas to the central business districts (CBD).

c) **Community Roads**

These are village roads interconnecting multiple or linking traffic between villages (Housley, 2015).

Roads of the highest functional classes (Class A and B) provide a high level of service with high road design speeds for traffic flow (Mollel *et al.*, 2011). Gaudry and Vernier (2002) note that the main function of the highest functional class roads is to provide safe mobility for road users having longer trips. The roads of lower functional classes (Class C, D and E) provide a dual function of feeding the higher class roads and accommodating shorter trips (Mollel *et al.*, 2011).

Table 2.12 shows the range of road geometric design standards applicable road functional classes to ensure satisfactory performance and safety for road users.

Table 2.12 Linkage between Road Design Class and Functional Class (Mollel *et al.*, 2011)

Road Design Class	AADT*(veh/day) in the design year	Foundation Class				
		A	B	C	D	E
DC1	>8000	■	■			
DC2	4500-8000	■	■			
DC3	900-4500	■	■			
DC4	400-900	■ M	■	■		
DC5	200-400		■ M	■		
DC6	50-200			■	■	
DC7	20-50			■	■	■
DC8	<20				■	■

■ Applies to roads in flat to rolling terrain

M: Minimum standard for the appropriate functional class

Table 2.13 shows the various cross-sectional dimensions for each standardised design class.

Table 2.13 Cross Section Dimension of the Road Design Classes (Mollel *et al.*, 2011)

Design Class	Surface	Road Reserve Width (m)	Roadway Width (m)	Carriage way			Shoulder Width (m)	Median Width (m)
				Width (m)	Lane width (m)	No. of lanes		
DC1	Paved	60	28-31	2 x7.0	3.5	≥ 4	2 x 2.5 [a]	9 – 12
DC2		60	11.5	7.5	3.70	2	2 x 2.0	-
DC3		60	11.0	7.0	3.5	2	2 x 2.0	-
DC4		60	9.5	6.5	3.25	2	2 x 1.5	-
DC5		60	8.5	6.5	3.25	2	2 x 1.0	-
DC6	Gravel or Paved	40	8.0	6.0	3.0	2	2 x 1.0	
DC7	Gravel	30	7.5	5.5	2.75	2	2 x 1.0	
DC8	Earth or Gravel	20	6.0	4.0	4.0	1	2 x 1.0	

[a] Inner Shoulders of 2× 0.9 metres are included in the median width

2.9.7. Access Control

Mollel *et al.* (2011) state that access control is a key factor in road safety and maintaining efficiency on major roads. Hochstein *et al.* (2007) mention that roads without access control are equally important in serving neighbouring facilities of the road. Garber and Hoel (2009) notes that the following three levels of access control are relevant.

1. Full Access: Access to selected roads only by providing crossing at- grade facilities.
2. Partial Access: Access provided to public roads with through traffic being given preference.

3. Unrestricted Access: Local traffic is given preference with the adjoining areas being served through direct road access connections.

Alsubeai (2017) reports that given the extent of traffic conflicts in the operation of access points on a roadway, the intersections experience an inconsistent number of fatal road crashes. Thompson (2017) found that in areas with high commercial development, divided roads with higher posted speed limits are associated with higher crash rates. Hochstein *et al.* (2007) found that right- angle collisions accounted for the majority of road crashes at rural roadway intersection, with stop control.

The SANRAL Geometric Design Manual (SANRAL, 2003) mentions that the function of a road determines the level of access control to be exercised on it. Table 2.14 provides the general guidelines for the level of access control in relation to the functional road classifications.

Table 2.14 Level of Access Control in relation to the Road Functional Class (Mollel *et al.*, 2011)

Functional Class	Level of Access Control	
	Desirable	**Reduced**
A: Trunk Roads	Full	Partial
B: Regional Roads	Full or Partial	Partial
C: Collector Roads	Partial	Partial or Unrestricted
D: Feeder Roads	Partial or Unrestricted	Unrestricted
E: Community Roads	Unrestricted	Unrestricted

2.9.8. Road and Lane Width

Housley (2015) defines the highway lane as a portion of the roadway used for a single line of vehicles. Mollel *et al*. (2011) state that the road should be wide enough to sufficiently carry the traffic safely and efficiently. Deller (2013) mentions that factors such as the traffic volume, types of vehicles to be accommodated and traffic speed are vital in selecting the appropriate lane width.

The Tanzania Geometric Design Manual (Mollel *et al.*, 2011) recommends the use of lanes of width 3.75m on roads where high traffic volumes and high traffic speeds are experienced. The narrowest lane width for national roads is typically 3.25m, which gives a clear space of about 0.35m on either side of a 2.5m wide vehicle. The widest lane recommended for a district road is 3.25m, having a total road width of 9.5m, and the narrowest lane width recommended is 2.75m, having a total road width of 7.5m (Mollel *et al.*, 2011). Table 2.13 provides guidelines by the Tanzania Geometric Design Manual (Mollel *et al.*, 2011) with regard to the lane widths on a roadway.

Liu *et al.* (2016) report that lane widths have a significant impact on driver speed selections, with the average driving speed increasing from 60.0km/h on the narrowest road lane to a speed of 88.1km/h on the widest road lane. Liu *et al.* (2016) note that lane widths have a greater impact on driver behaviour than the width of the road shoulder, with regard to lateral lane deviations and speed variations.

Othman *et al.* (2009) found that roadways with a width of less than 5.8m have lower fatal road crashes compared with roadways with a width greater than 5.8m. Zegeer *et al.* (1981) found that the presence of narrow lanes significantly impacts the fatal road crashes and injury severity. With an increase in the lane width from 2.7m to 3.1m, the road crash rate decreased from 1.5 to 1.1 road crashes per million vehicle kilometres travelled. The road crash rate decreased further to 0.9 road crashes per million vehicles kilometres travelled on lane widths between 3.4m to 3,7m (Zegeer *et al.*, 1981).

Mollel *et al.* (2011) mention that on paved roads, the lane width excludes the edge line markings as they are considered as part of the shoulder as illustrated in Figure 13.

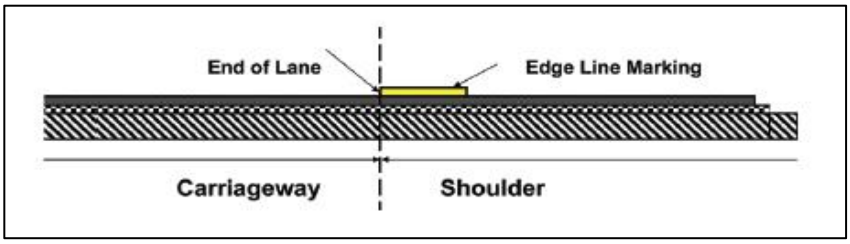

Figure 2.16 Edge line, End of Lane (Mollel et al., 2011)

2.9.9. Shoulders

SANRAL Geometric Design Manual (SANRAL, 2003) defines a roadway shoulder as that part of the roadway adjacent to traffic lanes, that provides lateral support to the road structure, is used as refuge for stopped/ disabled vehicles and can also be used by emergency vehicles on the roadway. Abele and Møller (2011) note that road shoulders are frequently used by other forms of transport, particularly Non-Motorised Transport (NMT).

Abele and Møller (2011) report that driver speed selections are lower on roadways with unsurfaced shoulders due to visual cues (colour difference between the surfaced roadway and the unsurfaced shoulder) that indicate a narrower driving lane, compared to conditions where a hard shoulder is present. Zegeer *et al.* (1981) report that there is a lack of correlation between shoulder width and road crashes on two lane rural roads, where traffic volume conditions of AADT below 2 000 vehicles exist. Wide shoulders (1.2m to 1.4m) on roadways where traffic volume conditions of AADT between 3 000 to 5 000 vehicles exist, positively impact roadway safety (Zegeer *et al.*, 1981).

The SANRAL Geometric Design Manual (SANRAL, 2003) states that the widest outer shoulder width of 3.0m is typically used in road traffic conditions that demand a dual-carriageway. The SANRAL Geometric Design Manual (SANRAL, 2003) recommends that an inner shoulder width of 1.0m be used in such situations to satisfy the following shoulder requirements:

1. Protect the integrity of the road pavement layers;
2. Avoid vehicle drop offs at the road lane edge; and
3. Provide space for roadway markings.

Table 2.15 shows the shoulder widths for use on undivided two- lane rural roads.

Table 2.15 Shoulder Widths for Undivided Rural Roads (SANRAL, 2003)

Design Speed (km/h)	Design hour volume (veh/h)		
	<250	250- 450	>450
	Width of shoulder (m)		
50	1.0	-	-
60	1.5	1.5	-
70	1.5	2.5	-
80	2.5	2.5	2.5
90	2.5	2.5	3.0
100	2.5	2.5	3.0
110	-	3.0	3.0
120	-	3.0	3.0
130	-	-	3.0

Note: *Shoulder widths are not quoted for unlikely combinations of speed and volume*

The SANRAL Geometric Design Manual (SANRAL, 2003) states that it is important that paved shoulder widths of between 1.5 and 2.5 metres are avoided, as their presence may cause drivers to move onto them to allow overtaking vehicles to pass. These widths cannot accommodate a moving vehicle and such manoeuvres can easily lead to a road crash (SANRAL, 2003).

The SANRAL Geometric Design Manual (SANRAL, 2003) reports that the use of rumble strips (raised or grooved) on paved road shoulders, providing an audible warning to drivers in addition to edge markings, has proved to be an effective method in reducing run-off incidents, resulting in a 20 percent reduction in run off crashes on rural roads.

2.10. Relationship Between Road Design Elements

Mohammed (2013) states that speed is a significant measure in road safety as it is indicative of the risk of a road user being involved in a road crash and has a significant impact on the severity of the road crash. Deller (2013) reports that speed reductions owing to changes to the road geometric elements positively impact the safety of a road section.

Karlaftis and Golias (2002) report that the road lane and shoulder widths play a key role in the speed selections made by drivers using a road section. Garcia and Abreu (2016) report that roads with narrower lanes and shoulder widths, cause drivers to select slower driving speeds, compared to roads with wider lanes.

Deller (2013) mentions that road sections with significant disparities between the posted speed limit and the design speed have higher road crash frequencies. Deller (2013) reports that the traffic speed variance and frequency of road crashes is lowest when the posted speed limit is approximately 8-16 km/h lower than the design speed of the road.

Hassan and Easa (2003) note that the consistency of the road alignment, operation speed and driver workload are important interrelated factors in ensuring that drivers make appropriate speed selections. Čičković (2016) reports that the lack of road geometry consistency leads to disparities between driver expectations and the safe manoeuvres required to traverse the road section safely. These disparities lead to an increase in road crash rates (Deller, 2013).

Mohammed (2013) agrees that a relationship between road geometric consistency and road traffic safety exists. Jaiswal and Bhatore (2016) affirm that studies on the relationship between highway safety in terms of road crash frequency and road design variables, such as horizontal and vertical alignments, access density, lane and shoulder width, number of lanes and speed characteristics, are important in assessing the safety of a roadway facility.

Table 2.16 shows the direct relationship between road design variables, related to the occurrence of fatal crashes, as indicated by Deller (2013), Garcia and Abreu (2016), Mohammed (2013) and Karlaftis and Golias (2002).

Table 2.16 Relationship Between the Road Design Elements

		Design Variables							
		Traffic Volumes	**Speed (Operational, Design & posted)**	**No. of lanes**	**Lane widths**	**Shoulder width**	**Access Control**	**Horizontal Curvature**	**Vertical Curvature**
Design Variables	**Traffic Volumes**		■	■	■				
	Speed (Operational, Design & posted)	■		■	■	■	■	■	■
	No. of lanes	■	■		■				
	Lane widths	■	■	■		■		■	
	Shoulder width		■		■			■	
	Access Density	■	■					■	
	Horizontal Curvature	■	■	■	■				■
	Vertical Curvature	■	■	■	■			■	

■ *Represents a direct relationship between road design elements*

2.11. Key Conclusions from Literature Studies

The studies used in the literature review show clearly that a strong relationship exists between road design elements and the occurrence of road crashes on roadway sections. The studies by Mohammed (2013), Karlaftis and Golias (2002), Hassan and Easa (2003), Abele and Møller (2011) and Garcia and Abreu (2016) established the following key conclusions on ***two-lane two-way rural roads (single carriageways)***:

a) A consistent road alignment reduces the probability of road crashes considerably as drivers know what to expect and when to expect it.

b) A strong statistical relationship exists between the road crash rate and the posted speed limit on a road section. Rural road sections with posted speed limits of 100km/h or higher experience high crash rates and injury severity.

c) The lane and shoulders widths significantly impact the speed selection of drivers. Narrower lane and shoulder widths result in drivers selecting lower speeds to traverse the road section, while wider lane and shoulder widths have the reverse effect.

d) The radii and length of horizontal curves influence the frequency of crashes occurring on curves. As the radii decrease, the number of road crashes generally increase. Curves with a radius of less than 350m are considered hazardous for drivers on road sections with design speeds of 120km/h.

e) High vertical down-grades on roads lead to a higher incidence of road crash rates.

f) Rural roads with high access density pose a high risk to road users, as the speeds on rural roads are typically much higher than those on roads in an urban environment.

These conclusions provide an insight into how sound engineering practices and design guidelines are vital in developing road sections that satisfactorily ensure the safety of all road users.

3. Methodology

3.1. Introduction

The main goal of the study was to evaluate and model the working relationship between road design elements for identified hazardous road sections and fatal crash data and to establish the impact of road design elements on fatal crash rates on these sections.

The following objectives were used as a guideline for developing the study design presented in this section:

1. To identify road sections with the highest fatal crashes/ km on the Namibian rural road network,
2. To study and analyse the relationship between rural roads design elements and fatal crashes, and
3. To study drivers' perceptions of road safety on the rural roads.

The study design was used to determine how to collect and analyse the quantitative and qualitative data for the modelling of the relationship between the road design elements and road traffic crashes.

3.2. Research Design

The nature and purpose of the research determines the research context, topic and method to be applied on the study, to achieve the study objectives. Literature relevant to the study subject helped to outline the scientific research problem with regard to rural road design elements and fatal road crashes.

Information provided by the literature review aided in developing the study methodology. Data collected from the MVA, the NRSC, the RA and from survey results was analysed using Negative Binomial Regression (NBR) and descriptive statistical methods, in the statistical package Statistica. The analysis was done to explore and understand the relationship between road design elements, fatal traffic crashes on rural roads and driver behaviour on the study road sections.

The study design is illustrated in Figure 3.1.

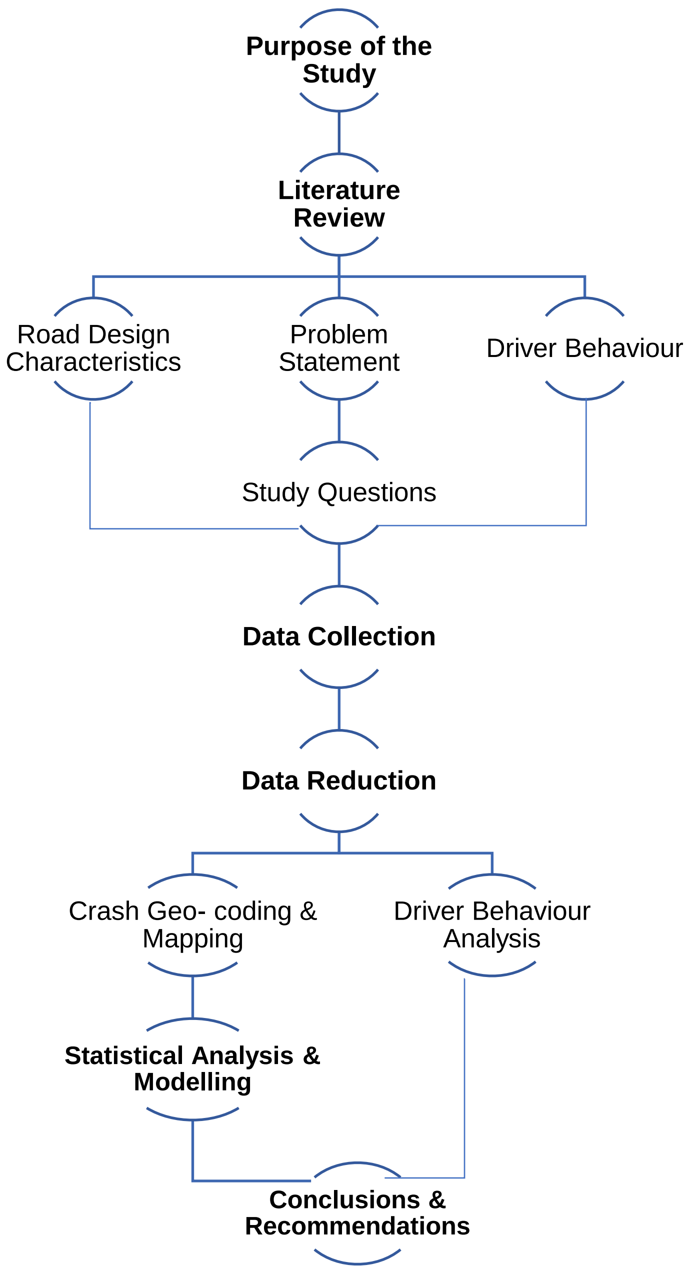

Figure 3.1 Study Design

3.3. Data Collection

Driver perceptions about contributing factors in fatal crashes on the rural roads were studied. These perceptions assisted in informing the cause of fatal crashes on rural roads by explaining how drivers perceived certain road design elements and how these perceptions contributed to their behaviour on the rural roads. Information on the road design variables shown in Table 3.1 was collected for analysis to determine the potential impact of the road design characteristics on fatal crashes on the Namibian rural road network.

3.3.1. Post-Crash Data Analysis Method

Existing crash and maintenance databases were used to help assess and identify potential correlations between road design elements and fatal crashes (Post-Crash Data Analysis method). The following steps were undertaken in the study:

1. Collect traffic crash data from the NRSC and MVA,
2. Geo-code and map the fatal traffic crashes on rural roads,
3. Collect road design element information from the RA of Namibia, and
4. Analyse and identify correlations between road design elements and fatal traffic crashes

It was important to establish whether any improvements had been made on the selected rural roads with regard to changes in the geometry of the road design elements or changes in road class during the analysis period of 2013 to 2016. The rural roads on which improvements were made were not considered to prevent inconsistencies arising in the data, as a result of improvements in road safety that may have/ may have not occurred owing to the measures implemented.

3.3.1.1. *Road Design Elements and Characteristics*

Table 3.1 defines the different road design elements studied and describes their effect on road safety. The road characteristics information provided by the RA of Namibia significantly influenced the selection of the road design elements. Road design variables with adequate information provided by the RA of Namibia were selected for the NBR analysis carried out in Section 5.3.

Table 3.1 Road Design Elements and Descriptions

Element	Units	Description	Effect on Safety
Road Variables			
Traffic Volume	Veh/ Hour	The number of motor vehicles (MVs) crossing the study section per hour. It will be instrumental in determining the AADT	Traffic volume influences road safety through MVs interactions. As traffic volume increases, MV crashes increase and crash severity declines, while opposite occurs when traffic volume decreases (Duivenvoorden, 2010).
Design Speed, Posted Speed Limit and Operating Speed	Km/hour	Design Speed: Tool used to determine the geometric features of a road during road design stage Posted Speed: Regulated speed that the road users should adhere to when traversing a road section Operating Speed: Speed at which motor vehicles generally operate on a certain road	Speed is an important factor in road safety. It does not only affect crash severity but is also related to the risk of being involved in a crash. A 5% increase in average driving speed leads approximately to a 20% increase in fatal crashes, Similarly, a reduction of 20% in fatal crashes follows a 5% reduction in average driving

			speed (Abele and Møller, 2011).
Number of lanes	Count	Roadway segment (carriageway) that is designated for use by a single line of vehicles, to control and guide drivers and reduce traffic conflicts	Drivers tend to make risky manoeuvres on two- lane rural roads when compared to multi-lane roads due to less overtaking opportunities. 35% to 50% of road fatalities are caused by overtaking manoeuvres (Yang *et al.*, 2017).
Lane width	(m)	The width of the road section along which Drivers traverse.	Drivers tend to speed on roads with greater lane widths as compared to those that are narrow. This influences the severity of the crashes experienced on these roads. There is a 28% decrease in crashes due to increased lane width from 2.75m to 3.65m (Zegeer, Deen and Mayes, 1981).
Shoulder width	(m)	The width of the roadway adjacent to the traffic lanes	Provides refuge for stopped or disabled vehicles, for travel by emergency vehicles to avoid endangering other traffic. Crash rates due to run- offs decrease with increase in shoulder width (Liu, Wang and Fu, 2016).
Access Density	Intersections/ km	The number of access points provided to the main carriageway	This influences the capacity of the road and the operational speeds. Few access points result in less points of potential conflicts, this is opposite as the access points increase (Alsubeai, 2017).
Horizontal Curvature	Degree	Facilitate smooth transition when there is a change of direction.	The radius of the curve influences the speed at which motor vehicles traverse the curve. As the horizontal curvature radius decreases, the more prone the section is to crashes as opposed to sections with a higher horizontal curve radius (Hanno, 2004).
Section Length [a]	(m)	The length of the road section traversed by motor vehicles	As the length of a road section increases, drivers tend to speed and make riskier manoeuvres. The opposite happens when shorter section lengths are involved (Ahmed, 2013).

[a] The road length (km) of the study sections was used to determine the fatal crash rates and the level of exposure (Volume × Length) on the selected road sections.

The interactive relationship and impact that the selected variables mentioned in Table 3.1 have on the design and safe performance of the road sections was investigated.

3.3.1.2. *Driver Behaviour and Perceptions*

Drivers' attitudes towards road safety on the Namibian rural road network were investigated by carrying out surveys on the selected rural roads. The survey was imperative in investigating driver perceptions on self-evident road alignment designs and the impact of road design variables on driver behaviour and crash risk levels.

The surveys were intended to investigate the following:

a) General perceptions towards road safety and enforcement on rural roads.
b) Drivers' awareness of the physical road design elements while driving.
c) Drivers' perceptions of the factors that contribute to the high fatal crash rates on rural roads, and
d) Drivers' views on what can be done to tackle the high fatal crash rates on rural roads, in terms of driver behaviour and road design elements.

The results from the surveys assisted in proving causation of fatal traffic crashes, in addition to the potential correlations proven through the analysis of the fatal traffic crashes and road design information.

3.4. Research Methods

The following research techniques were used in the collection of research data on the parameters mentioned in Section 3.3, in order to meet the objectives of the study.

a) **Data Sourcing**: Road traffic data, fatal traffic crash data and road design element information for the period 2013 to 2016 were obtained from multiple institutions.

   Road traffic flow data and road design element information were obtained from the Roads Authority (RA) of Namibia, through their pavement management system. The RA is the institution responsible for collecting traffic count data on the different routes around the country. Fatal traffic crash data was sourced from the National Road Safety Council (NRSC) and the Motor Vehicle Accident (MVA) Fund. These institutions are responsible for formulating and coordinating road safety campaigns. Information from drivers using the rural roads was collected by carrying out surveys.

b) **Site Selection:** After geo-coding and mapping of the fatal rural road crashes that occurred during the study period of 2013 to 2016, the ten rural road sections with the highest number of fatal crashes per km were chosen for the study. As all the selected study sections are single carriageways, a minimum of 5kms from the built-up areas was considered as a rural section for the road under consideration.

c) **On- site data collection**: Information on lane and shoulder widths for study sections T0112, T1002 and T0111, as indicated in Table 3.2, had to be measured on-site. Horizontal curvature information on all the road sections in the study had to be collected using the Google Earth (GE) application, with the measuring instrumentation provided in the Google Earth application.

3.5. Research Instruments

The following instruments were used to collect and analyse the research data:

a) **Surveys**: A survey guide was developed and carried out on a sample of road users using the road sections under study. A non-probability sampling method (Volunteer Sampling) was employed in the survey. Locations with similar road design element characteristics and fatal crash patterns were grouped together for sampling. Equation 3.1 was used to determine the sample size for each grouping of study locations, at 95 percent confidence level.

$$n \geq \frac{N}{1+Ne^2} \qquad (3.1)$$

Where; *N* = Annual Average Daily Volume (AADT), and

e = standard error (5 percent) (Gogtay, 2010)

For statistical significance, the highest number of surveys possible was carried out, with a minimum of 150 participants from each location. The surveys were aimed at building an understanding of the attitude of the drivers towards the theme of road safety through their opinions and responses.

b) **QGIS**: This is a Geographical Information System tool that is used for mapping. QGIS was used to show the number of fatal road crashes occurring across Namibia and identifying hotspots characterized by clusters of fatal crashes per road length during study period of 2013 to 2016. The fatal road crash data collected from the MVA and the NRSC were provided as a text file. The fatal crash data were geo-coded and mapped using QGIS.

c) **Statistica**: This statistical package was used in the analysis of the fatal crash data, road design element information and survey information collected to study the potential relationship between fatal crashes and the road design elements that play a crucial role in road safety.

3.6. Data Analysis

Using the research techniques and instruments mentioned in Sections 3.4 and 3.5 respectively, data on road design elements in Table 3.1 and driver behaviour and attitudes on the selected rural roads were collected and reduced for analysis.

3.6.1. Identification of High Fatal Crash Rural Roads

Rural roads with the highest traffic fatalities per km were identified through the following methods for study:

3.6.1.1. *Fatal Crash Rates*

Road traffic crash rate (CR) is one way to control results (Wegman, 2017). It considers the length of a roadway section and the traffic volume, to allow a direct comparison of different roadway sections, with respect to traffic safety. Othman and Thomson (2007) note that the crash rate is presented as crashes per million vehicle kilometres (CVKm), as shown by Equation (3.2).

$$CR = \frac{Crashes \times 10^6}{AADT \times 365 \times T \times L} \text{ Crashes per } 10^6 \text{ vehicle kilometres} \qquad (3.2)$$

Where;	CR	= Crash Rate
	AADT	= Average Annual Daily Traffic
	L	= Length of investigated section (km)
	T	= Length of investigation period (years), and
	365	= Number of days/ year.

After determining CR, descriptive statistical methods and Negative Binomial Regression were used to analyse the processed data.

3.6.1.2. *Fatal Crashes/ Road Length*

Gaudry and Vernier (2002) note that for road sections that demonstrate variations in road standard performance, assessing the lengths that present a long- term steady estimation of fatal crash risk, essentially reduces the impact of year on year variability.

The number of fatal traffic crashes on road networks over a three-year data period for sections of at least 5kms provide an acceptable estimate of risk as stated by Joanne (2013). Sections less than 5kms tend to show greater year on year variability in crash numbers, in addition to being more likely to change risk rating from one period to the other when compared over time. These differences were significant up to section lengths of 10kms for motorways and dual carriageways (Joanne, 2013).

For a road section to be considered as a rural road section for purposes of road crash modelling, an average minimum threshold of 5kms on single carriageways from an urban environment is recommended as a starting point for a rural road crash risk level assessment (Joanne, 2013).

After identifying the fatal road crashes from the crash data collected from the NRSC and the MVA, QGIS was used to map the selected crashes on the Namibian rural road network. The fatal crash map was used to select crash hot spots by identifying cluster zones on the crash map characterized by the number of fatal crashes per km.

The fatal crash frequency method was used to rank the road sections by the number of fatal crashes occurring per km. Crash numbers and traffic flow data were assigned to each section for the study period of 2013 to 2016 to give a robust estimate of risk. Joanne (2013) states that the assessment period can be extended where fatal crash numbers are below the threshold of 20 fatal crashes over the period of analysis. Where it is not possible to aggregate short sections, care must be taken when interpreting the results.

Joanne (2013) notes that the general relationship between crash numbers and design elements is strong when compared over time. When the number of fatal crashes falls below 20, the variation in the frequency of crashes can become large over a three-year assessment period, per road section.

Where crash numbers are low, the following options are available:

a) Increase route length
b) Using all- injury crash data in addition to fatal and serious crashes
c) Increase the time period over which crash rates are calculated (Joanne, 2013).

a) Fatal Rural Road Crashes (2013- 2016)

The map provided in Figure 3.2 shows the fatal traffic crashes for the years 2013 to 2016 on the rural sections of the Namibians road network.

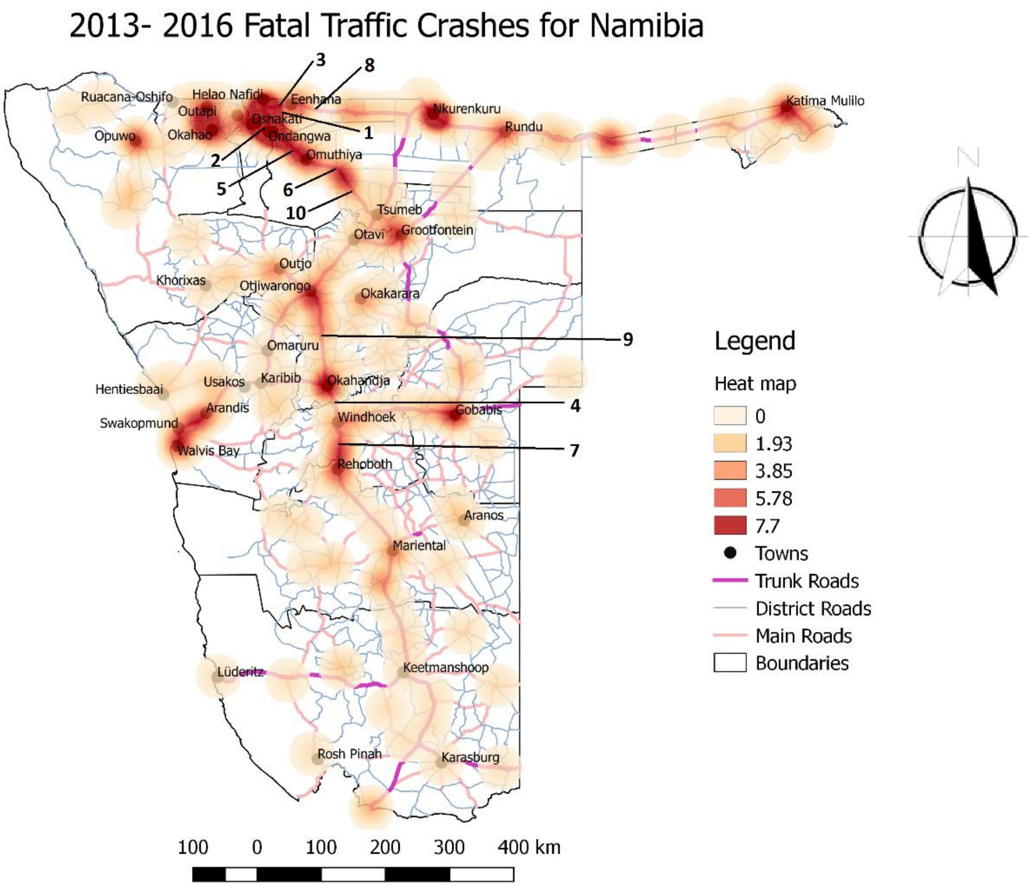

Figure 3.2 Fatal Road Crashes (Rural Roads) for 2013- 2016

The heatmap provides a visual summary of the rural roads experiencing high fatal crash numbers on the Namibian rural road network. These roads are summarized in Table 3.2.

Table 3.2 shows the ten worst rural roads in terms of fatal crashes for the period 2013 to 2016 on the Namibian road network. The selected road sections are shown in order of the crash density (FC/km) on the sections.

Table 3.2 Top 10 Fatal Crash Locations for 2013 to 2016

No	Section	Road Name	Road Type [a]	Road Length (km) [b]	No. Fatal Crashes (4 years)	*Fatal Crashes/ Km*	AADT	Fatal Crash Rates (CKm) [c]
1	Ondangwa- Onhuno	T0112	Single	35,80	30	0,84	2 585	0,22
2	Ondangwa- Oshakati	M0092	Single	24,80	20	0,81	9 399	0,06
3	Onhuno- Eenhana	T1002	Single	36,61	26	0,71	1 699	0,29
4	Windhoek- Okahandja	T0106	Single	64,42	39	0,61	14 005	0,03
5	Omuthiya- Onethindi	T0111_1	Single	92,26	53	0,57	1 435	0,27
6	Oshivelo- Omuthiya	T0111_2	Single	61,82	33	0,53	3 019	0,12
7	Windhoek- Rehoboth	T0105	Single	73,58	34	0,46	4 483	0,07
8	Eenhana- Okongo	T1002	Single	99,75	39	0,39	1 248	0,21
9	Otjiwarongo- Okahandja	T0107	Single	164,60	62	0,38	1 973	0,13
10	Tsumeb- Oshivelo	T0110	Single	84,95	29	0,34	991	0,24

[a] Road type is either a single carriageway or multiple carriageway.

[b] A minimum threshold of 5kms for single carriageways was recommended as starting points in assessing crash numbers for rural road sections.

[c] Fatal crash rates are represented in crashes per million vehicle kilometres travelled.

3.6.2. Development of Crash Model

3.6.2.1. *Crash Model*

The study explored the potential effects of road design elements on fatal traffic crashes. The primary objective of the study was to create models that test the significance of the effect that road design elements have on fatal traffic crashes on Namibian rural roads.

Data on fatal road crashes were retrieved from the NRSC and the MVA for the study period from 2013 to 2016. A typical road crash record includes the date of the crash, time, location of the crash, vehicles involved, gender and cause of the crash.

The road design data shown in Table 3.1 from the RA's Pavement Management System (PMS), was linked to the fatal crash data collected from the NRSC and the MVA for the identified road sections using Negative Binomial Regression. This was done to study the potential correlation between the interaction of various road design elements and fatal crashes on the road study sections.

Othman and Thomson (2007) state that comparing the absolute number of fatal crashes is misleading, due to the different comparative conditions on the road sections. It is understood that the length of a section and the traffic volume on that section have an impact on traffic crashes (road user exposure), therefore it is essential that they are considered in comparative traffic crash studies (Othman and Thomson, 2007).

The use of multiple linear regression in road crash modelling suffers from repeated practical inconsistencies and logical limitations due to the random nature and occurrence of fatal crashes. Several studies have overcome these shortcomings by using Poisson Regression models, which is a good alternative for events that occur independently and randomly over time (Vayalamkuzhi and Amirthalingam, 2016; Deublein *et al.*, 2013).

The restriction with Poisson Regression models is that they assume that the variance and mean of the dependant variable are equal. This condition, when violated, invalidates the t-test parameter estimates (Gaudry and Vernier, 2002). Gaudry and Vernier (2002) state that *Negative Binomial Regression (NBR)* (Equation 3.3) overcomes this limitation by allowing for the variance of the dependant variable to be different from the mean, therefore NBR is instrumental in analysing the safety of roadways, through road crash modelling.

$$\ln\mu = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \qquad (3.3)$$

Where the predictor variables $x_1, x_2, \ldots, x_p$ are given for the analysis, and the population regression coefficients $\beta_1, \beta_2, \ldots, \beta_p$ are to be estimated for the Negative Binomial Regression model.

3.6.2.2. *Crash Model Confidence*

The calculated probability value (P) indicated the confidence in the model results. The relationship between the dependent and independent (predictor) variables was considered significant if the probability value (P) was equal to 0 up to 5 percent difference from zero. The strength of the relationship between dependant and predictor variables was indicated by the correlation coefficient R^2. However, the statistical significance of this association was not indicated by the correlation coefficient (Othman and Thomson, 2007).

3.6.3. Road Audit

A road assessment was carried out to examine whether the road design variable information used in the study for the period 2013 to 2016 complied with the ***Technical Recommendations for Highways 17 (TRH 17) on the Geometric Design of Rural Roads*** used for road alignment designs in Namibia.

3.6.4. Analysis of the Surveys

Descriptive statistics methods were used to analyse and illustrate the results from the driver surveys on driver behaviour and attitudes and their understanding of the relationship between road design elements and fatal crashes on the Namibian rural road network.

3.7. Limitations

The study was limited to the Namibian rural road network, the design elements of these roads and Namibian drivers' perceptions and observations.

3.8. Ethics

At the University of Stellenbosch, ethical considerations are guided by the Policy for Responsible Research Conduct at Stellenbosch University. The main guiding values are:

a) Transparency;
b) Mutual respect
c) Scholarship (scientific and academic professionalism); and
d) Responsibility (Stellenbosch University, 2013).

All participants were informed of the study objectives as well as the potential benefits of the study towards society, before signing the consent form.

Institutional ethics approval was obtained prior to the carrying out of the surveys.

4. Study Locations

4.1. Introduction

The rural road segments with the highest number of fatal crashes per km, were selected for analysis in the study. Road design information for the road sections was vital in establishing the significance of the potential relationship between the road design elements and the fatal road crashes.

Table 4.1 shows the fatal crash information for the ten locations identified for the study. The highest number of fatal crashes occurred on the T0107 road section, with 62 fatal crashes, while M0092 had the lowest number of fatal crashes, with 20 fatal crashes during the study period from 2013 to 2016.

Table 4.1 show the road sections with the highest fatal crash rates on the Namibian rural road network. Segment T0112 experienced the highest number of fatal crashes/ km with 0.84 FC/km compared to segment T0110 that experienced the lowest number of fatal crashes/ km with 0.34 FC/km. Section T1002 has the highest crash rate as determined using Equation 3.2 of 0.29 crashes per million vehicle kilometres, while section T0106 has the lowest crash rate of 0.03 crashes per million vehicle kilometres travelled. Road sections M0092, T0106 and T0105 with the highest AADT of 9 399, 14 005 and 4 483 vehicles respectively, experienced the lowest fatal crash rates (CR < 0.12 CKm), as indicated by Table 4.1. Duivenvoorden (2010) explains that roads with high AADT experience lower driver speed selections and low fatal crash rates, contrary to high driver speed selections and fatal crash rates on roads with low AADT.

Table 4.1 Fatal Crashes Information on the Ten Road Study Sections (2013- 2016)

No	Road Segment	Road Length (km)	No. Fatal Crashes	AADT	Fatal Crashes/ Km	Crash Rates [a]
1	T0112	35,80	30	2 585	0,84	0,22
2	M0092	24,80	20	9 399	0,81	0,06
3	T1002_1	36,61	26	1 699	0,71	0,29
4	T0106	64,42	39	14 005	0,61	0,03
5	T0111_1	92,26	53	1 435	0,57	0,27
6	T0111_2	61,82	33	3 019	0,53	0,12
7	T0105	73,58	34	4 483	0,46	0,07
8	T1002_2	99,75	39	1 248	0,39	0,21
9	T0107	164,60	62	1 973	0,38	0,13
10	T0110	84,95	29	991	0,34	0,24

[a] Crash Rates represent the number of crashes per million vehicle kilometres travelled

The following sub-sections discuss the road design information provided by the Roads Authority of Namibia, on the study road sections identified in Table 4.1.

4.2. T0112 (Ondangwa-Onhuno)

Road section T0112 is 35.8km long with a bi-directional AADT of 2 585 vehicles. The section has 15 horizontal curves (HC) and has two access points over the length of the study section. Figure 4.1 shows the location of the study section.

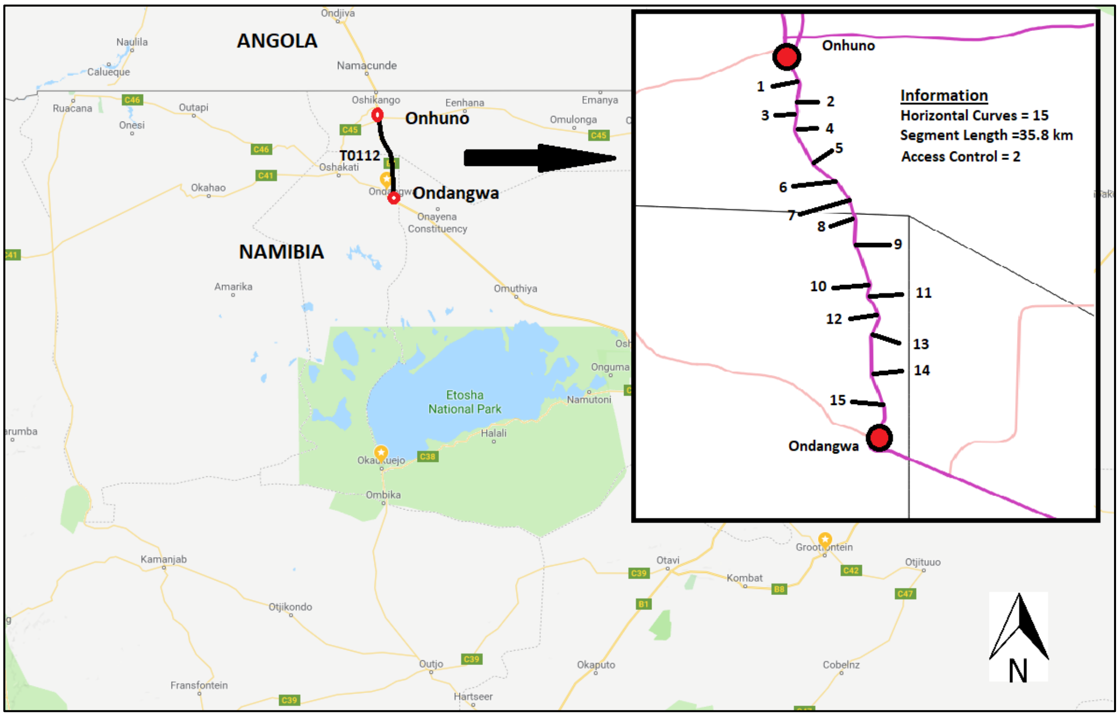

Figure 4.1 Road Segment T0112 Horizontal Alignment

Table 4.2 shows the radii of the 15 Horizontal Curves (HC) on study section T0112. The largest radius on this section is 1 126m on HC 15, while the smallest radius is 240m on HC 7.

Table 4.2 Horizontal Curves on Road Segment T0112

Number of HC	Radius (m)
1	613.00
2	940.00
3	714.00
4	490.00
5	770.00
6	890.00
7	240.00
8	670.00
9	800.00
10	911.00
11	385.00
12	470.00
13	975.00
14	1 000.00

15	1 126.00

Figure 4.2 shows the cross-section design of road segment T0112. The segment is a single carriageway surfaced with bitumen with lane widths of 3.20m. The Forward Ground Shoulder (GSF) has a width of 1.30m and Backward Ground Shoulder (GSB) of width of 1.33m. The road segment does not have surfaced hard shoulders. The lanes have a crossfall of 3% while the ground shoulders have a crossfall of 3.3%. The road section has a mixture of channelising, dividing and no overtaking (No crossing) road markings along its length.

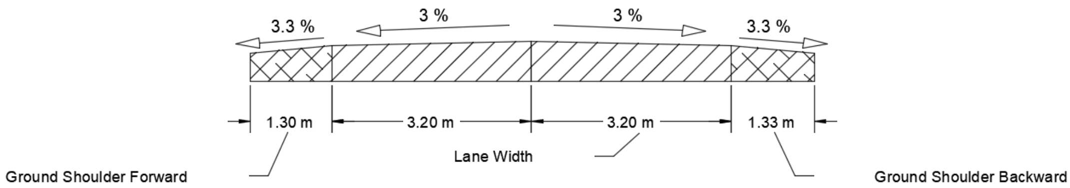

Figure 4.2 Cross Section for Road Segment T0112

Figure 4.3 shows the elevation profile for the road section T0112, from Ondangwa to Onhuno. The segment has a minimum elevation of 1 095m and a maximum elevation of 1 112m, with an average elevation of 1 102m along the road section. Maximum and minimum slopes of 4.5% and -6.4% were recorded along the study segment, with an average positive slope of 0.9% and average negative slope of -1.0%.

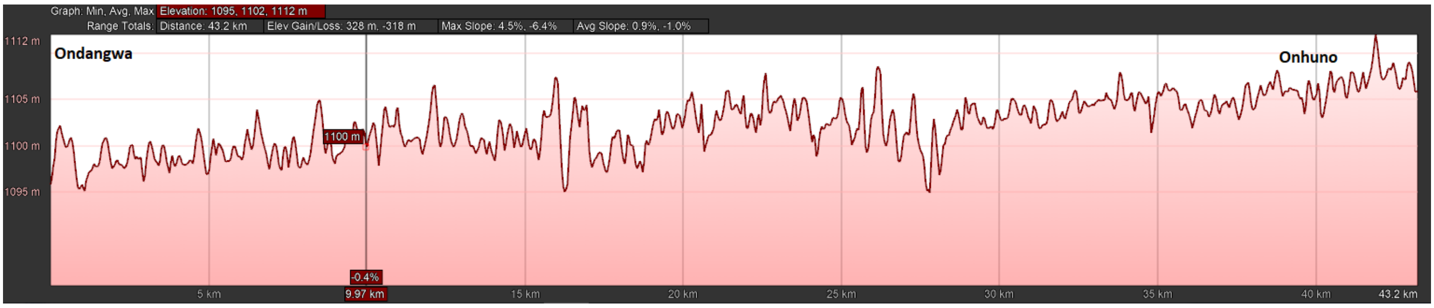

Figure 4.3 Elevation Profile for Road Section T0112

4.3. M0092 (Ondangwa-Oshakati)

Road section M0092 has a length of 24.8km, with a bi-directional AADT of 9 399 vehicles. The horizontal alignment has 13 horizontal curves (HC) and 4 access control points over the length of the study section. The location of the study segment is shown in Figure 4.4.

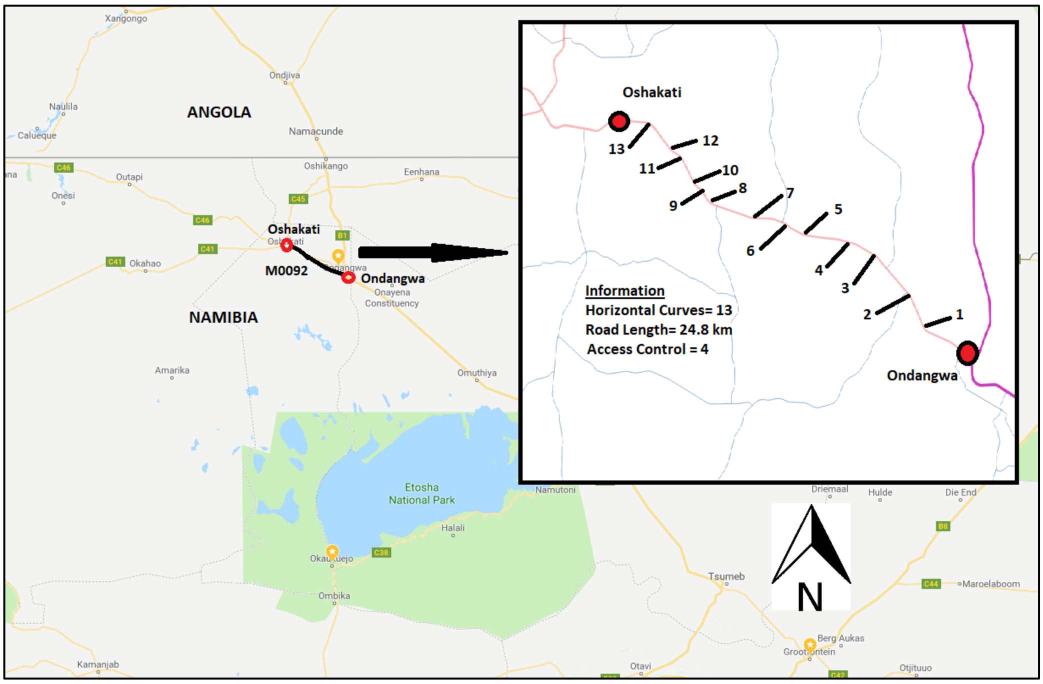

Figure 4.4 Road Segment M0092 Horizontal Alignment

The radii of the 13 Horizontal Curves (HC) on the study section M0092 are shown in Table 4.3. HC 3 has the largest radius on the study section, with 900m, while the smallest radius of 370m is on HC 13.

Table 4.3 Horizontal Curves on Road Segment M0092

Number of HC	Radius (m)
1	745.00
2	700.00
3	900.00
4	800.00
5	500.00
6	650.00
7	770.00
8	630.00
9	670.00
10	555.00
11	640.00
12	385.00
13	370.00

Figure 4.5 shows the cross-section design of M0092. The road section is a single carriageway with a bitumen surface and no paved hard shoulders. A Forward Ground Shoulder (GSF) and a Backward Ground Shoulder (GSB) are available on the road section, with widths of 1.00m and 1.01m respectively. The surfaced lanes have a crossfall of 2.9%, while the GSF and GSB have crossfalls

of 3.1% and 3.2% respectively. The study section has channelising lines, Dividing lines and no overtaking (No crossings) road markings along its length.

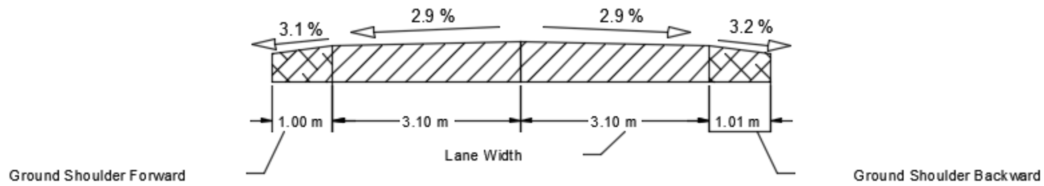

Figure 4.5 Cross Section for Road Segment M0092

The elevation profile for study section M0092, from Ondangwa to Oshakati is shown in Figure 4.6. A minimum elevation of 1 095m and a maximum elevation of 1 107m was recorded on the study section, with an average elevation of 1 100m along the road length. Minimum and maximum slopes of 4.9% and -5.2% were recorded on the road section, with an average positive slope of 1.3% and an average negative slope of -1.2% over the road section's length.

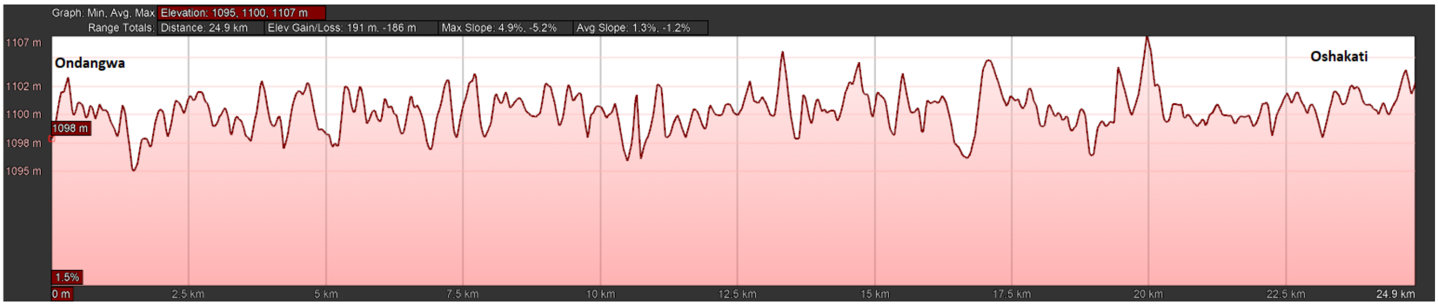

Figure 4.6 Elevation Profile for Road Segment M0092

4.4. T1002_1 (Onhuno-Eenhana)

The road section T1002 between Onhuno and Eenhana has a length of 36.61km, with a bi-directional AADT of 1 699 vehicles. The section has 17 horizontal curves and five access points along the road length. The location of this section is shown in Figure 4.7.

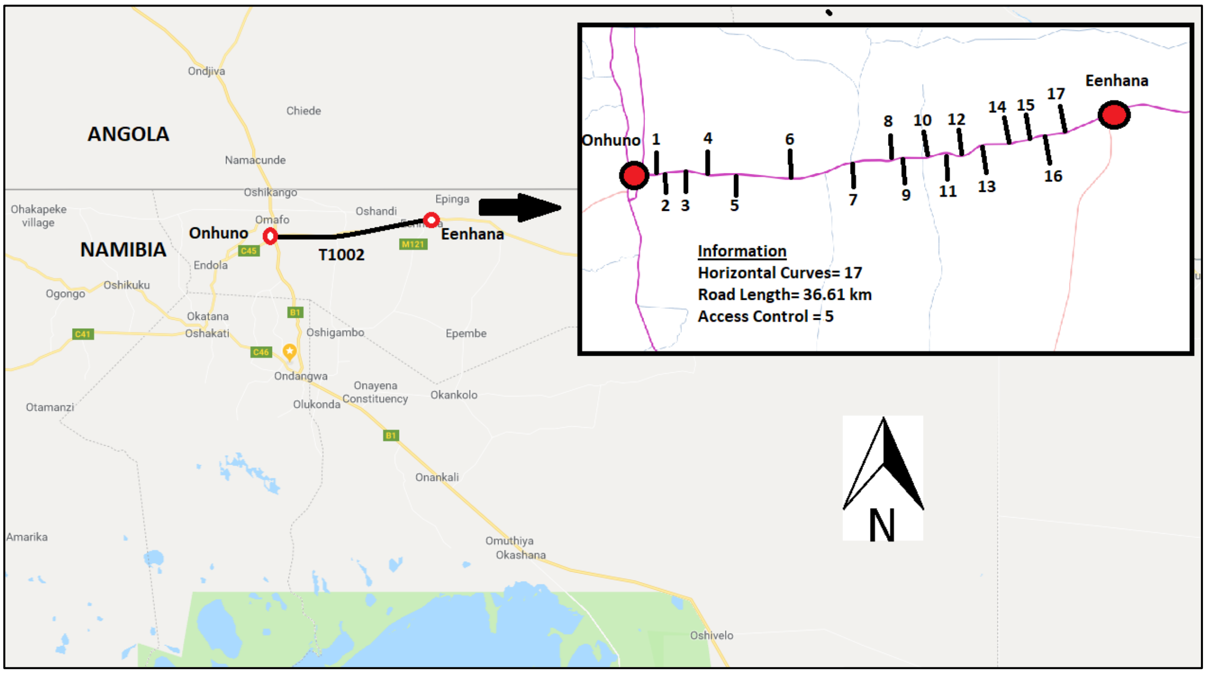

Figure 4.7 Road Segment T1002 Horizontal Alignment

Table 4.4 shows the radii of the 17 Horizontal Curves on the road section T1002. The largest radius of 3 000m is on HC 8, while HC 13 and HC 16 have the smallest radii on the road section (900m).

Table 4.4 Horizontal Curves on Road Segment T1002

Number of HC	Radius (m)
1	1 500.00
2	1 200.00
3	1 600.00
4	1 670.00
5	1 700.00
6	1 800.00
7	1 300.00
8	3 000.00
9	1 527.00
10	1 398.00
11	2 176.00
12	1 826.00
13	900.00
14	1 001.00
15	1 231.00
16	900.00
17	1 500.00

The cross-section for road section T1002 is shown in Figure 4.8. The segment is a single carriageway paved with bitumen. The section has lanes of 3.40m width. The section has a GSF and an SSF width of 1.02m and 0.10m respectively. The GSB and SSB have widths of 1.05m and 0.11m respectively. The lanes on the road have a crossfall of 2.4%, while the ground shoulders have a crossfall of 2.6%. The road section has a combination of channelising, dividing and no overtaking (No crossing) road markings along its length.

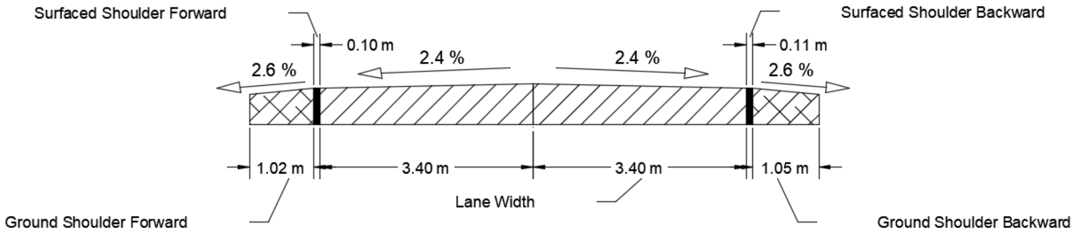

Figure 4.8 Cross Section for Road Segment T1002

Figure 4.9 shows the elevation profile of road section T1002 from Onhuno and Eenhana. The road section has a minimum and a maximum elevation of 1 102m and 1 119m respectively. An average elevation of 1 111m was recorded on the section. The section has a maximum slope of 4.2% and a minimum slope of -2.7%. An average positive slope of 0.7% was recorded with an average negative slope of -0.7%.

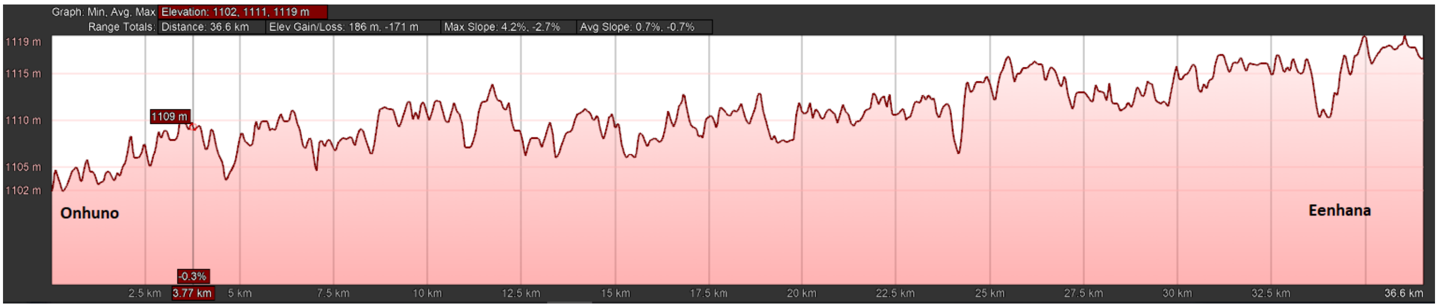

Figure 4.9 Elevation Profile for Road Segment T1002

4.5. T0106 (Windhoek-Okahandja)

Road section T0106 between Windhoek and Okahandja has a length of 64.42km, with a bi-directional AADT of 14 005 vehicles. The section has 23 horizontal curves and four access points along the road length. The location of this section is shown in Figure 4.10.

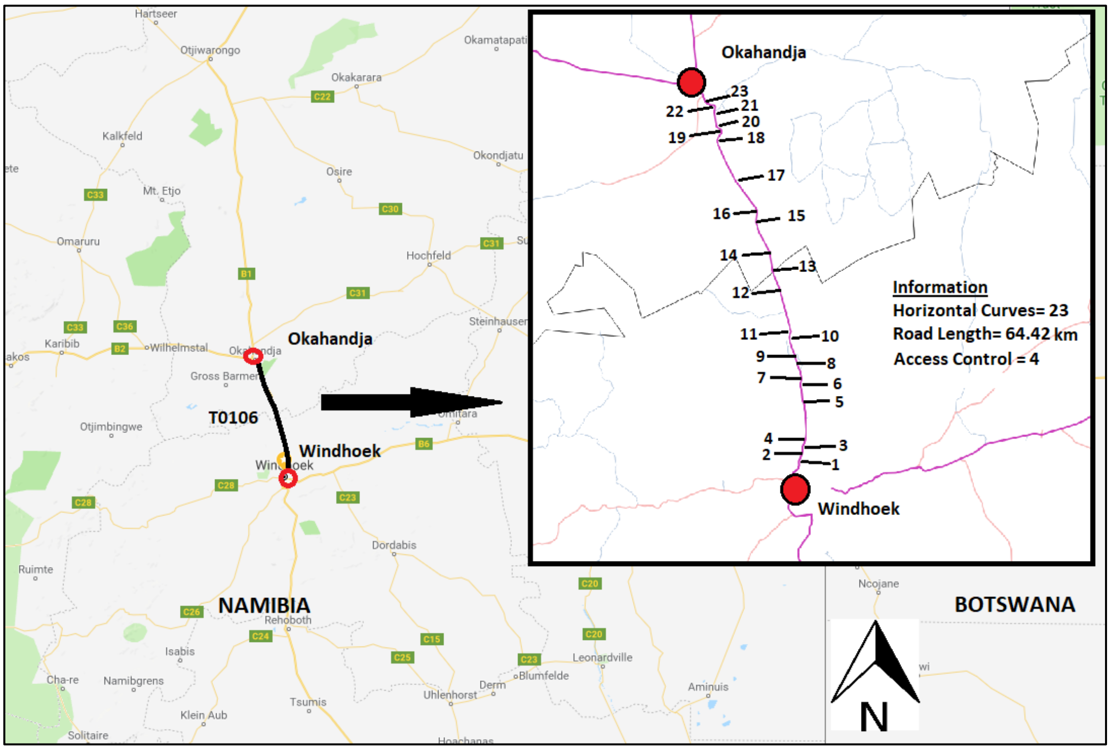

Figure 4.10 Road Segment T0106 Horizontal Alignment

The radii of the 23 Horizontal Curves (HC) on the study section are shown in Table 4.5. The largest radius of 2 100m was recorded on HC 12, while the smallest radius of 300m was recorded on HC 5.

Table 4.5 Horizontal Curves on Road Segment T0106

Number of HC	Radius (m)
1	1 653.00
2	1 500.00
3	1 102.00
4	650.00
5	300.00
6	1 242.00
7	1 130.00
8	1 500.00
9	1 400.00
10	680.00
11	350.00
12	2 100.00
13	1 300.00
14	1 070.00
15	1 200.00
16	1 239.00
17	1 180.00
18	1 300.00
19	1 040.00

20	681.00
21	844.00
22	670.00
23	600.00

Figure 4.11 shows the cross-section profile for road section T0106. The segment is a single carriageway surfaced with bitumen, with lanes of 3.80m in width. The section has a GSF and SSF width of 1.70m and 0.15m respectively. A GSB and SSB width of 1.78m and 0.12m respectively, are provided on the section. A lane cross fall of 2.2%, with GSF and GSB cross slopes of 2.4% and 2.5% respectively, are used on the section. The road section has a combination of channelising, dividing and no overtaking (No crossing) road markings.

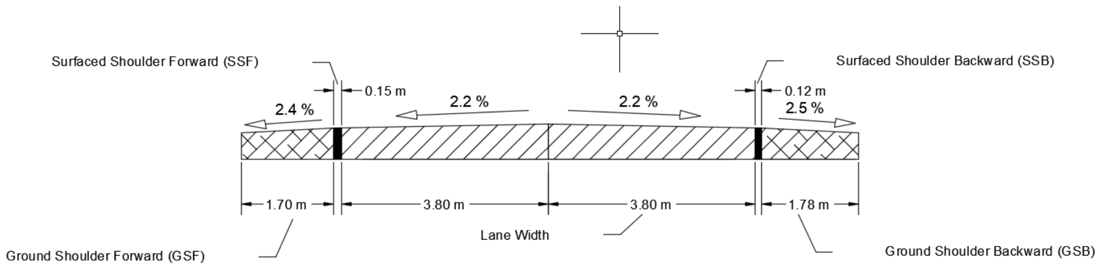

Figure 4.11 Cross Section for Road Segment T0106

Figure 4.12 shows the layout of road section T0106, connecting the towns of Windhoek and Okahandja.

Figure 4.12 Road Section T0106

Figure 4.13 shows the elevation profile of road section T0106, between Windhoek and Okahandja. The road section has a minimum and a maximum elevation of 1 308m and 1 651m respectively. The section has an average elevation of 1 425m. The road section has a maximum slope of 13.7% and a minimum slope of -16.4%. The study section has an average positive slope of 1.5% and an average negative slope of -1.4%.

Figure 4.13 Elevation Profile for Road Segment T0106

4.6. T0111_1 (Omuthiya-Onethindi)

T0111_1 road section between Onethindi and Omuthiya has a length of 92.26km, with a bi-directional AADT of 1435 vehicles. The road section has one horizontal curve with a radius of 1 400m and five access points along the road length. The location of this section is shown in Figure 4.14.

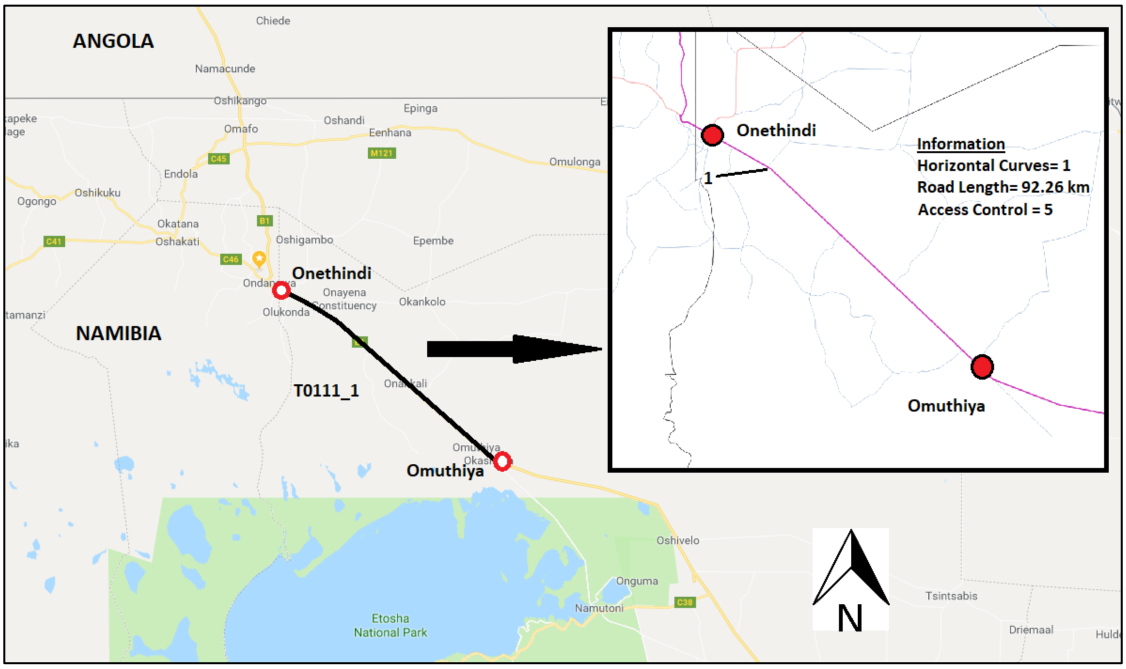

Figure 4.14 Road Segment T0111_1 Horizontal Alignment

Table 4.6 shows the radius of the Horizontal Curve on road section T0111_1.

Table 4.6 Horizontal Curves on Road Segment T0111_1

Number of HC	Radius (m)
1	1 400.00

The cross-section profile for road section T0111_1 is shown in Figure 4.15. The segment is a single carriageway surfaced with bitumen, with lane widths of 3.50m. The GSF and GSB have widths of

2.43m. A lane crossfall of 2.3% and a ground shoulder crossfall of 2.5% are provided on the section. The road section has a combination of channelising, dividing and no overtaking (No crossing) road markings.

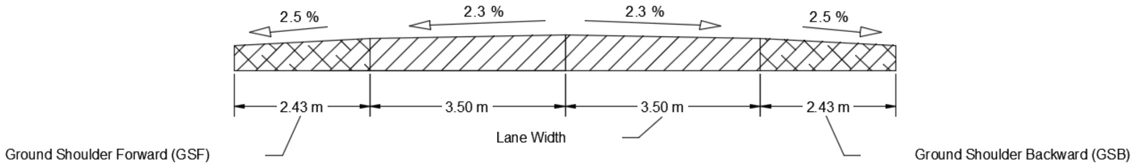

Figure 4.15 Cross Section for Road Segment T0111_1

The elevation profile of the road section T0111_1 is shown in Figure 4.16. The road section has a minimum and a maximum elevation of 1 095m and 1 109m respectively. The section has an average elevation of 1101m along the length of the road. The section has a maximum slope of 1.4% and a minimum slope of -2.5%, with an average positive slope of 0.4% and an average negative slope of -0.4%.

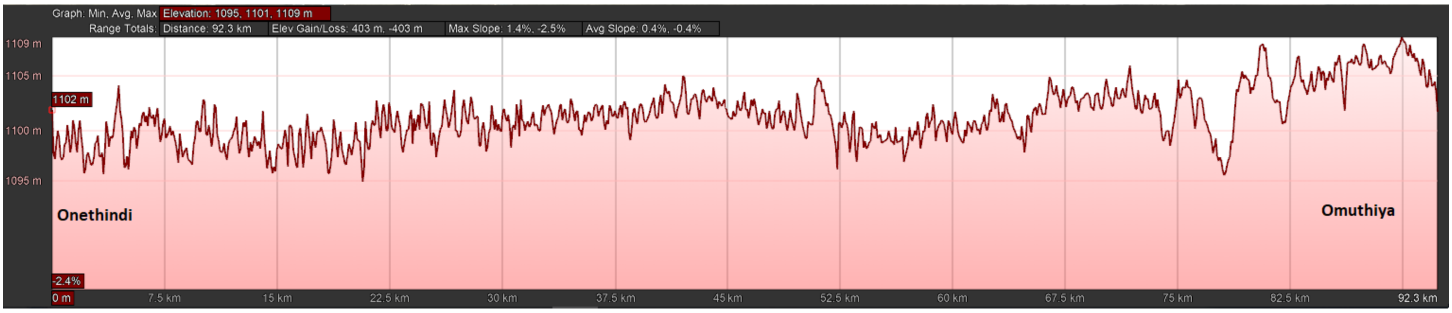

Figure 4.16 Elevation Profile for Road Segment T0111_1

4.7. T0111_2 (Oshivelo-Omuthiya)

The road section between Oshivelo and Omuthiya has a length of 61.82km, with a bi-directional AADT of 3 019 vehicles. The road section has 5 horizontal curves (HC) and three access points along the road section. The location of this section is shown in Figure 4.17.

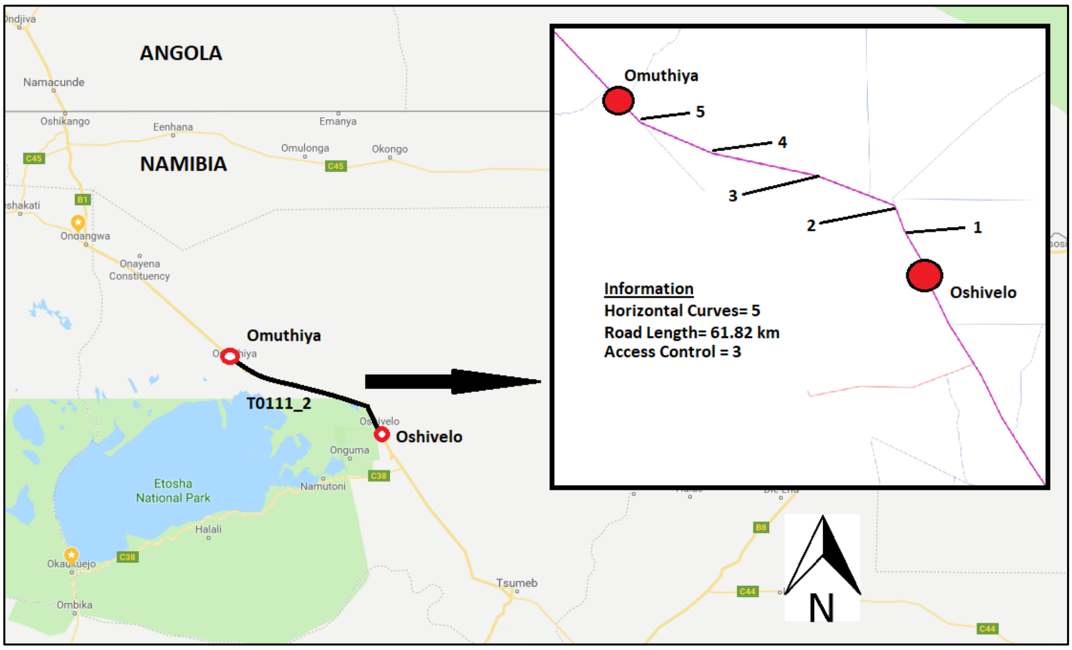

Figure 4.17 Road Segment T0111_2 Horizontal Alignment

Table 4.7 shows the radii of the 5 horizontal curves (HC) on road section T0111_2. The largest radius on the study section is 3 900m on HC 1, while the smallest radius is 600m on HC 2.

Table 4.7 Horizontal Curves on Road Segment T0111_2

Number of HC	Radius (m)
1	3 900.00
2	600.00
3	3 500.00
4	3 800.00
5	3 700.00

Figure 4.18 shows the cross-section profile for the road section T0111_2. The road section is a single carriageway surfaced with bitumen, with lane widths of 3.55m. The section has GSF and SSF widths of 2.45m and 0.10m respectively. GSB and SSB widths of 2.44m and 0.11m respectively are provided on the section. A lane crossfall of 2.2% and a ground shoulder crossfall of 2.4% are used on the section. The road section has a combination of channelising, dividing and no overtaking (No crossing) road markings.

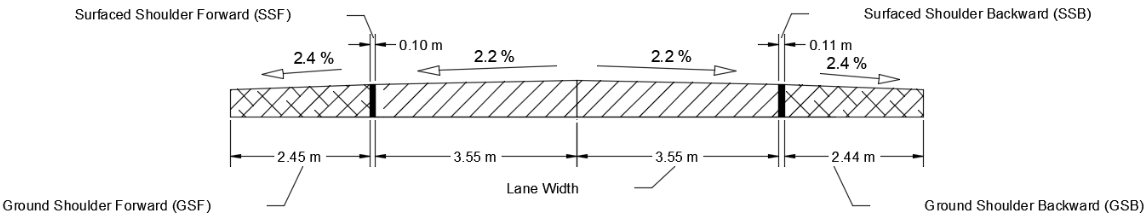

Figure 4.18 Cross Section for Road Segment T0111_2

Figure 4.19 shows the elevation profile of the study section T0111_2. The road section has a minimum and a maximum elevation of 1 092m and 1 120m respectively. The section has an average elevation of 1 106m along the road length. The section has a maximum slope of 2.9% and a minimum slope of -2.1% with an average positive slope of 0.5% and an average negative slope of -0.5%.

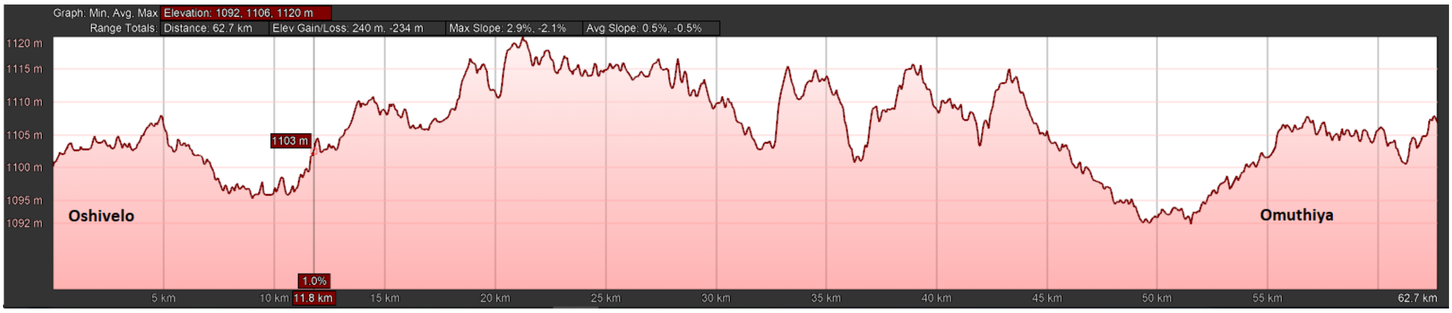

Figure 4.19 Elevation Profile for Road Segment T0111_2

4.8. T0105 (Windhoek-Rehoboth)

The road section T0105 between Windhoek and Rehoboth has a length of 73.58km, with a bi-directional AADT of 4 483 vehicles. The road section has 12 horizontal curves and eight access points along the road length. Figure 4.20 shows the location of this road section.

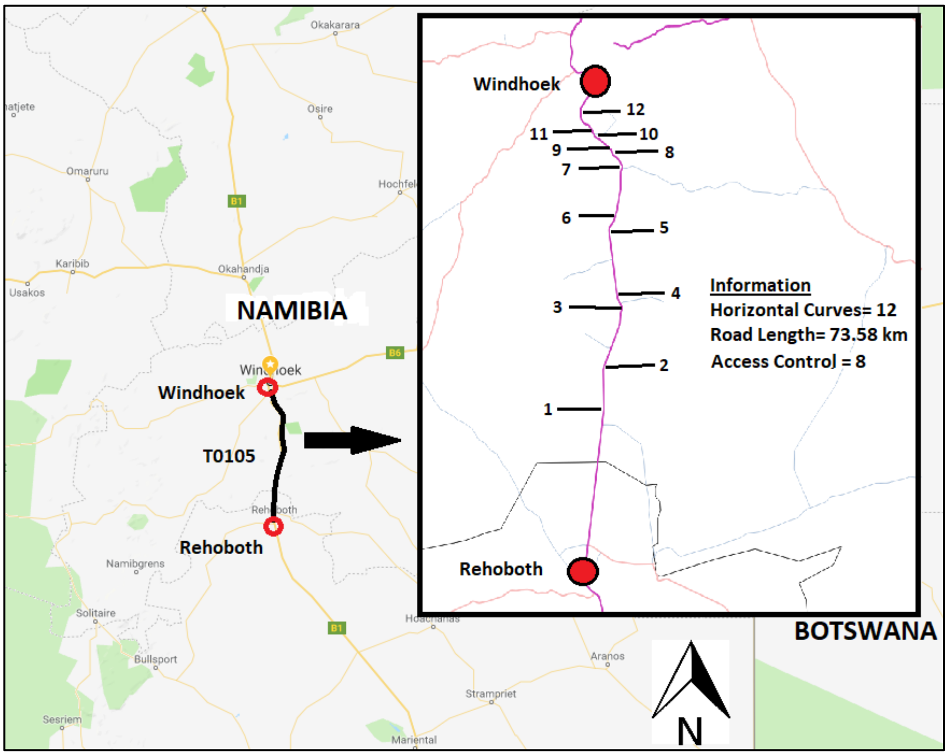

Figure 4.20 Road Segment T0105 Horizontal Alignment

Table 4.8 shows the radii of the 12 horizontal curves (HC) on the road section T0105. The largest radius on the study section is 5 000m on HC 1, while the smallest radius is 500m on HC 12.

Table 4.8 Horizontal Curves on Road Segment T0105

Number of HC	Radius (m)
1	2 678.00
2	1 800.00
3	2 300.00
4	5 000.00
5	800.00
6	1 500.00
7	760.00
8	1 600.00
9	830.00
10	1 300.00
11	3 500.00
12	500.00

Figure 4.21 shows the cross-section profile for the road section T0105. The section is a single carriageway surfaced with bitumen, with lanes of 3.70m width. The section has GSF and SSF widths of 1.92m and 0.20m respectively. GSB and SSB widths of 1.88m and 0.25m respectively are provided on the section. A lane crossfall of 2.3% and GSF and GSB crossfalls of 2.5% and 2.6% respectively, are provided on the road section. The road section has a combination of channelising, dividing and no overtaking (No crossing) road markings.

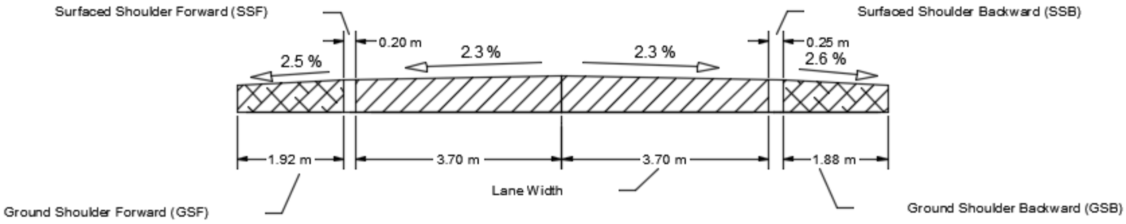

Figure 4.21 Cross Section for Road Segment T0105

Figure 4.22 shows the layout of road section T0105, connecting the towns of Windhoek and Rehoboth.

Figure 4.22 Road Section T0105

The elevation profile of the road section T0105 between Windhoek and Rehoboth is shown in Figure 4.23. The section has a minimum and a maximum elevation of 1 414m and 1 954m respectively, with an average elevation of 1 678m along the road length. The section has a maximum slope of 17.0% and a minimum slope of -16.2%, with an average positive slope of 2.5% and an average negative slope of -1.8%.

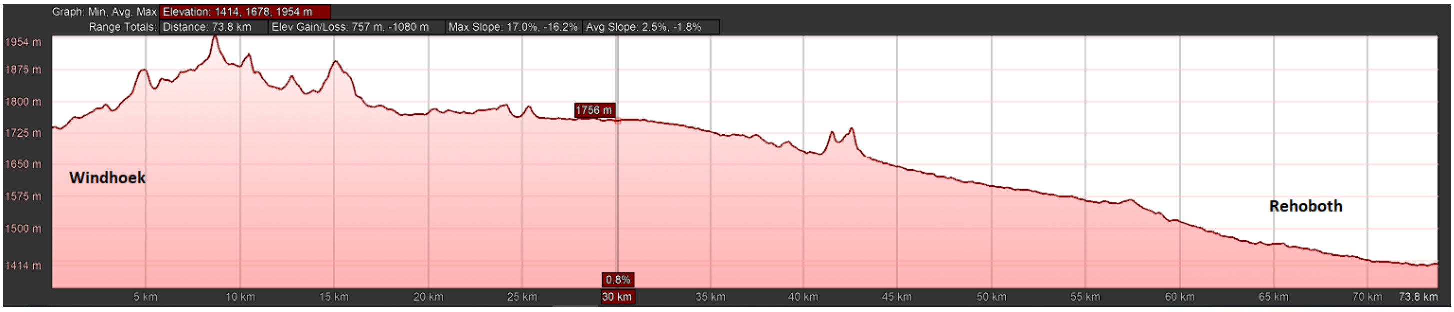

Figure 4.23 Elevation Profile for Road Segment T0105

4.9. T1002_2 (Eenhana-Okongo)

The road section T1002 between Eenhana and Okongo has a length of 99.75km, with a bi-directional AADT of 1248 vehicles. The road segment has 8 horizontal curves (HC) and ten access points along the road length. Figure 4.24 shows the location of this road section.

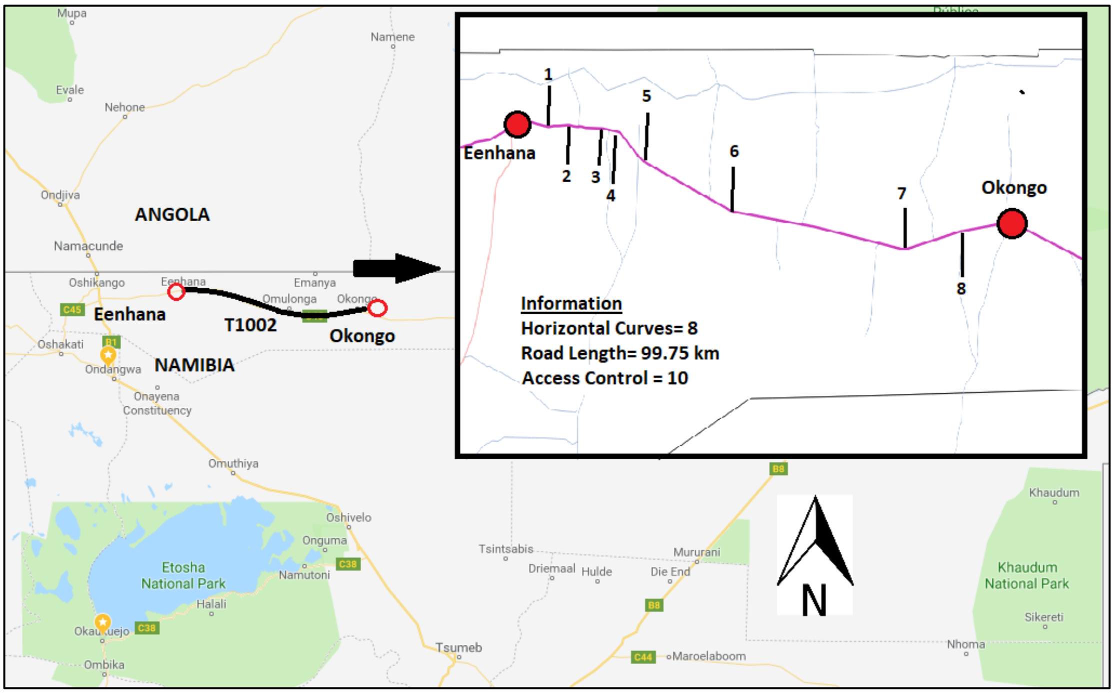

Figure 4.24 Road Segment T1002 Horizontal Alignment

Table 4.9 shows the radii of the 8 horizontal curves (HC) on the study section. The largest radius of 2 100m is on HC 8, while the smallest radius of 400m is on HC 4.

Table 4.9 Horizontal Curves on Road Segment T1002

Number of HC	Radius (m)
1	1 300.00
2	1 000.00
3	1 200.00
4	400.00
5	1 700.00
6	1 400.00
7	1 550.00
8	2 100.00

Figure 4.25 shows the cross-section profile for the road section T1002. The segment is a single carriage way surfaced with bitumen, with lanes of 3.55m in width. The section has GSF and SSF widths of 0.70m and 0.55m respectively. GSB and SSB widths of 0.67m and 0.56 m respectively are provided on the road section. The road section had a lane crossfall of 2.2% and a ground shoulder crossfall of 4%. A combination of channelising, dividing and no overtaking (No crossing) road markings are used along the length of road section.

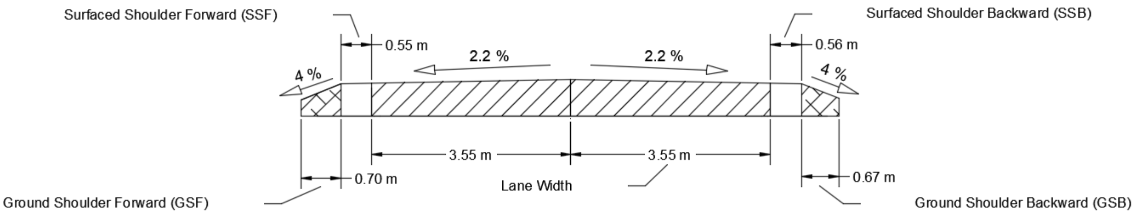

Figure 4.25 Cross Section for Road Segment T1002

The elevation profile of the road section T1002 between Eenhana and Okongo is shown in Figure 4.26. The section has a minimum and a maximum elevation of 1 114 m and 1 157m respectively, with an average elevation of 1 141m along the length of the road section. The section has a maximum slope of 2.1% and a minimum slope of -2.1%, with an average positive slope of 0.3% and an average negative slope of -0.3%.

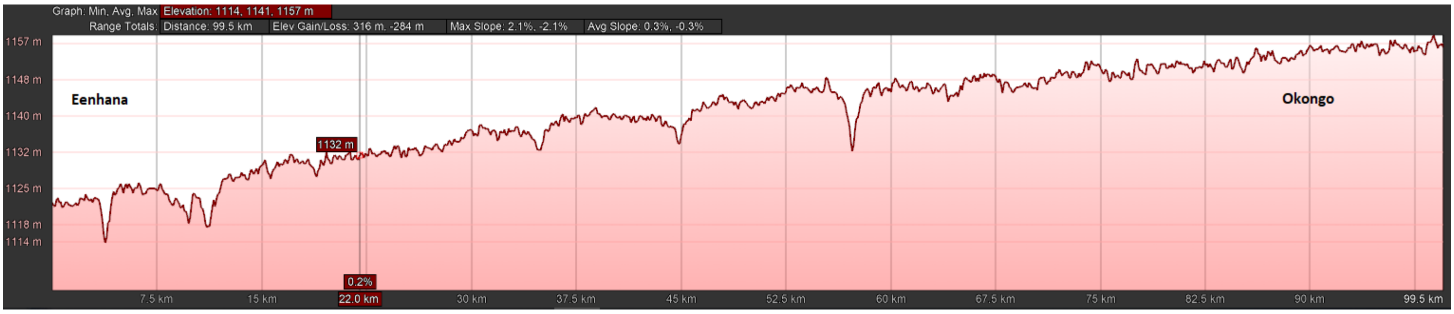

Figure 4.26 Elevation Profile for Road Segment T1002

4.10. T0107 (Otjiwarongo-Okahandja)

The road section T0107 between Otjiwarongo and Okahandja has a length of 164.60km, with a bi-directional AADT of 1 973 vehicles. The road section has 13 horizontal curves (HC) and ten access points along the road length. Figure 4.27 shows the location of this road section.

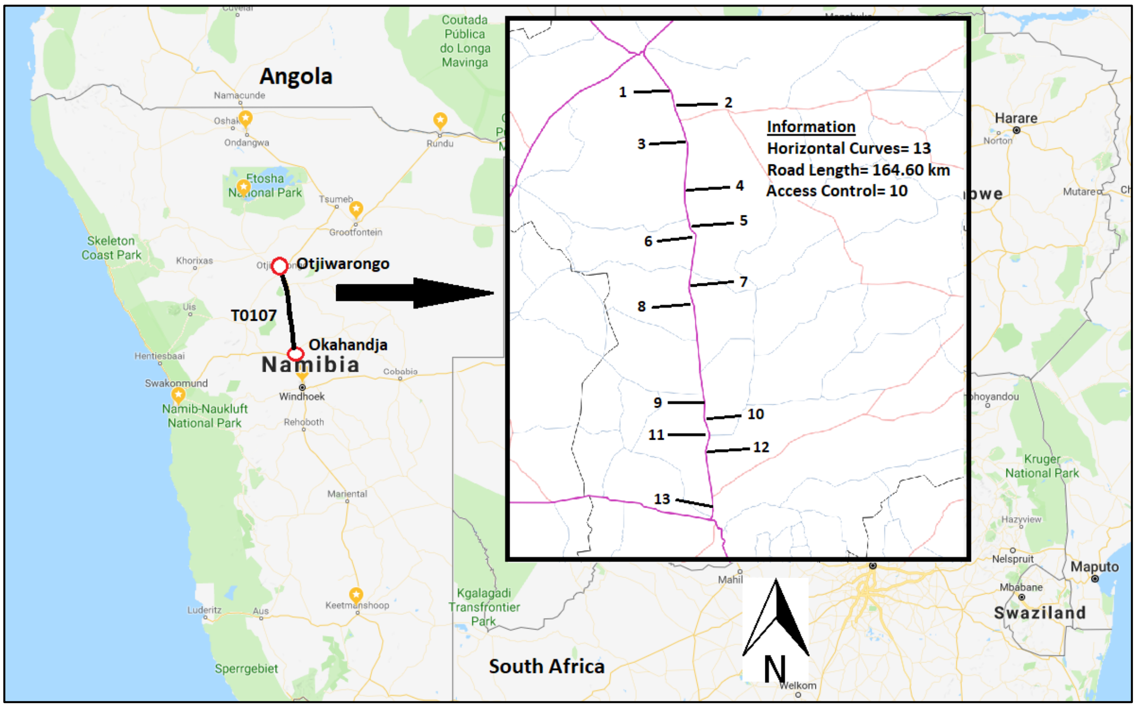

Figure 4.27 Road Segment T0107 Horizontal Alignment

Table 4.10 shows the radii of horizontal curves (HC) on the road section. The largest radius of 3 500m is on HC 4, while the smallest radius of 770m is on HC 6.

Table 4.10 Horizontal Curves on Road Segment T0107

Number of HC	Radius (m)
1	1 850.00
2	1 710.00
3	2 900.00
4	3 500.00
5	1 717.00
6	770.00
7	1 126.00
8	1 920.00
9	2 300.00
10	3 000.00
11	1 400.00
12	780.00
13	2 200.00

Figure 4.28 shows the cross-sectional profile for the road section T0107. The segment is a single carriageway surfaced with bitumen, with lanes of 3.30m in width. The section has GSF and GSB widths of 2.50m and 2.55m respectively, with no surfaced shoulders. The road has a lane crossfall of 2.3% and a ground shoulder crossfall of 2.5%. A combination of channelising, dividing and no overtaking (No crossing) road markings are used on the road section.

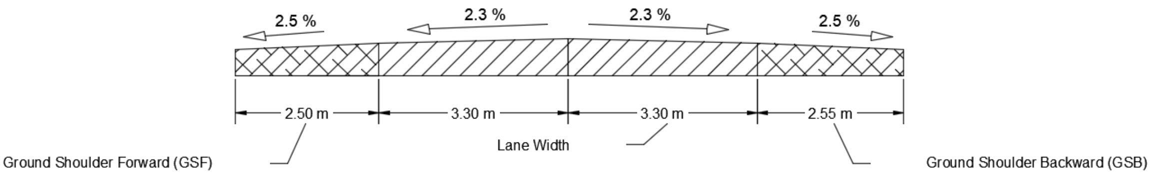

Figure 4.28 Cross Section for Road Segment T0107

Figure 4.29 shows the layout of road section T0107, connecting the towns of Otjiwarongo and Okahandja. The survey was carried out on drivers using this study section, for study sections with lane widths equal to or less than 3.50m.

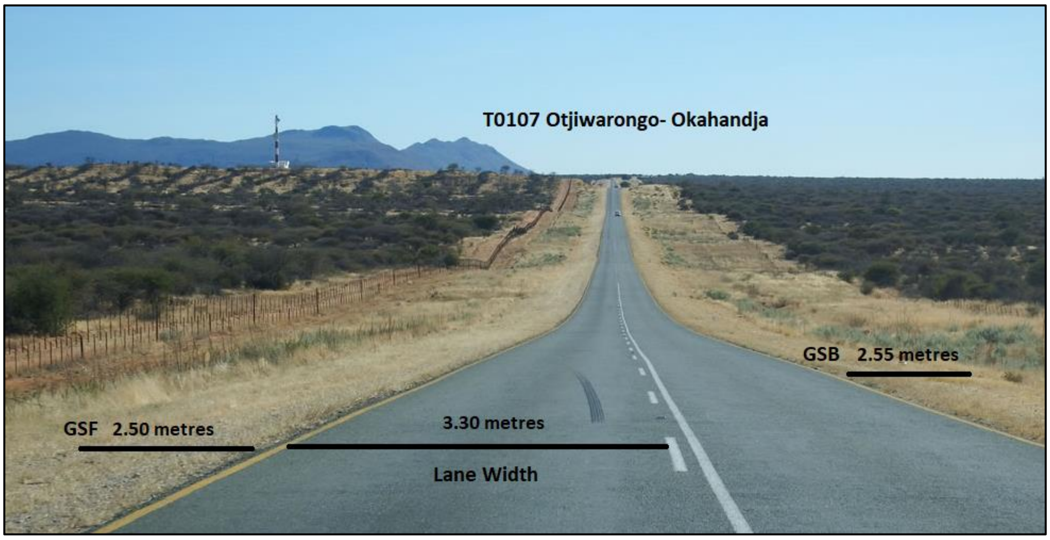

Figure 4.29 Road Section T0107

The elevation profile of the road section T0107 is shown in Figure 4.30. The section has a minimum and a maximum elevation of 1 395m and 1 636m respectively, with an average elevation of 1 485m along the length of the road. The section has a maximum slope of 8.6% and a minimum slope of -5.4%, with an average positive slope of 0.6% and an average negative slope of -0.6%.

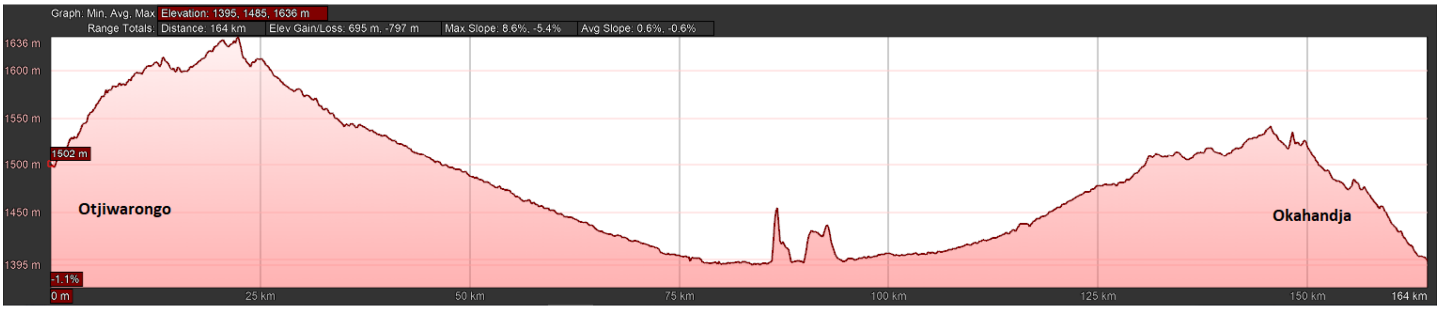

Figure 4.30 Elevation Profile for Road Segment T0107

4.11. T0110 (Tsumeb-Oshivelo)

The road section T0110 between Tsumeb and Oshivelo has a length of 84.95km, with a bi-directional AADT of 991 vehicles. The section has 6 Horizontal Curves (HC) and six access points along the road length. Figure 4.31 shows the location of this road section.

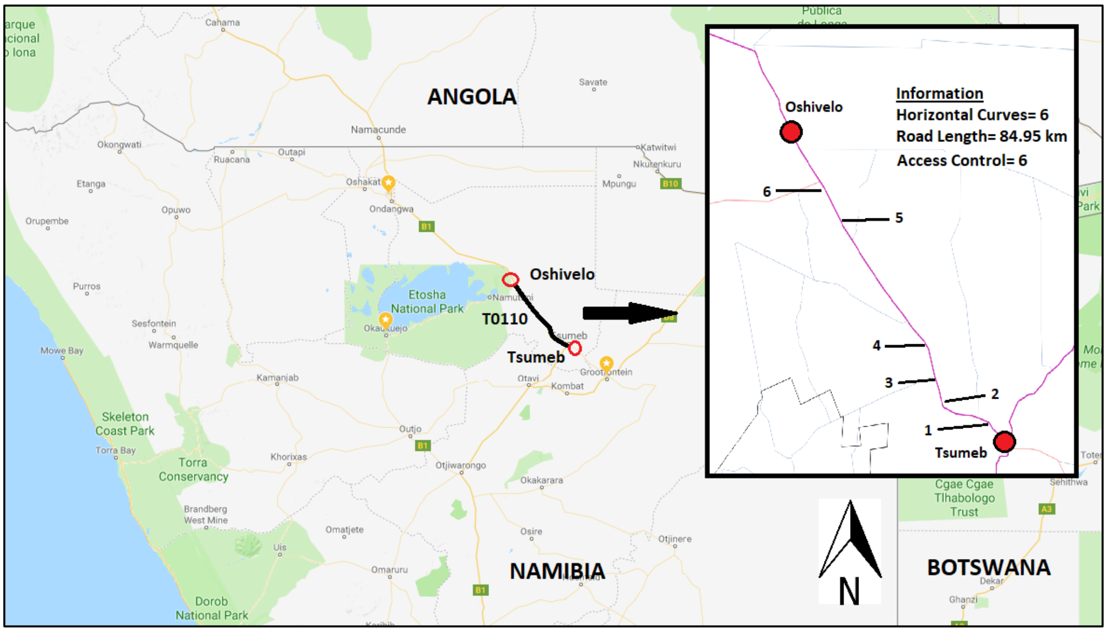

Figure 4.31 Road Segment T0110 Horizontal Alignment

Table 4.11 shows the radii of the 6 Horizontal Curves (HC) on the road section. HC 5 has the largest radius with 5 550m, while HC 2has the smallest radius on the section with 900m.

Table 4.11 Horizontal Curves on Road Segment T0110

Number of HC	Radius (m)
1	2 200.00
2	900.00
3	1 300.00
4	1 850.00
5	5 550.00
6	2 385.00

The cross-section profile for the road section T0110 is shown in Figure 4.32. The segment is a single carriageway surfaced with bitumen, with lanes of 3.70m in width. The section has GSF and GSB widths of 2.01m and 2.00m respectively, with no surfaced shoulders. The road section has a lane crossfall of 2.2% and a ground shoulder crossfall of 2.5% are provided. A combination of channelising, dividing and no overtaking (No crossing) road markings are used on the road section.

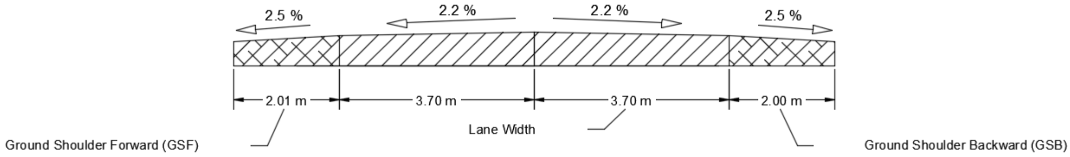

Figure 4.32 Cross Section for Road Segment T0110

Figure 4.33 shows the layout of road section T0110, connecting the towns of Tsumeb and Oshivelo. The study survey was carried out on participants using this study section, for roads with lane widths greater than 3.50m.

Figure 4.33 Road Section T0110

The elevation profile of the road section T0110 between Tsumeb and Oshivelo is shown in Figure 4.34. The section has a minimum and maximum elevation of 1 114m and 1 273m respectively, with an average elevation of 1 173m along the road length. The section has a maximum slope of 2.5% and a minimum slope of -3.3%, with an average positive slope of 0.3% and an average negative slope of -0.4%.

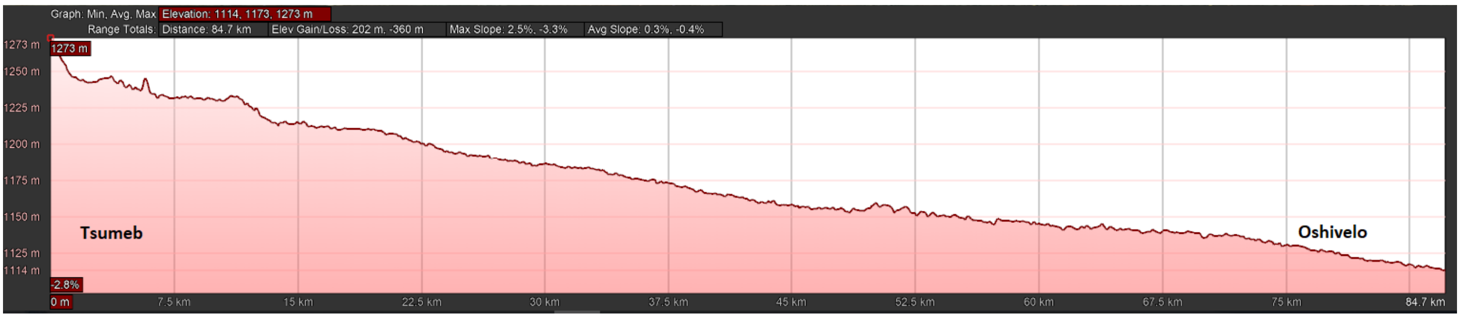

Figure 4.34 Elevation Profile for Road Segment T0110

4.12. Summary of Study Locations Design and Speed Information

Table 4.12 and Table 4.13 provide a summary of the road design information from the Roads Authority of Namibia and those determined from Google Earth (Horizontal and Vertical Alignment information) for the study sections. All the study sections are single carriageways surfaced with bitumen, with a posted speed limit of 120 km/h.

Table 4.12 shows that road section T0107 has the longest road length (164.60km) and the highest recorded 85th percentile speed (120.30km/h), while the lowest 85th percentile speed (62.52km/h) was recorded on section M0092, with the shortest road length (24.80km) and a high number of horizontal curves with small radii. Deller (2013) states that driver speed selections at horizontal curves are determined by the radius of the curves, with shorter length radii having lower speed selections, compared to curves with larger radii. Road section T0111_1 has the largest horizontal curvature radius average (3100m).

Turner (2005) states that the crash risk level is higher on horizontal curves with radius of 350m and below. Horizontal curve 7 (240m) on T0112 and horizontal curves 5 (300m) and 11 (350m) on T0106 have curve radii equal to and below the critical radius of 350m. These curves are most likely to pose a significant threat to road users on these study sections.

Road section T0106 has the widest lane widths (3.80m), in contrast to road section M0092, with the narrowest lane widths (3.10m). Othman and Thomson (2007) state that traffic speeds tend to be slower on narrow lane widths in contrast to higher speed selections on wider lane widths. The lower speed selections (62.52km/h) on section M0092, can be ascribed to the narrow lane widths and short horizontal curve radii on the road section.

Road section T1002_2 has the narrowest ground shoulder widths (0.67m), while road section T0107 has the widest ground shoulder width (2.55m). Section T0106 has the highest number of horizontal curves (23) along the road length, while section T0111_1 has the lowest number of horizontal curves (1). The highest number of access control points (10) is provided along the lengths of sections T1002_2 and T0107, compared to the lowest number of access control points (2), on section T0112.

Table 4.12 Road Design Information for the Top Ten Fatal Crash Rural Road Sections (2013- 2016)

No	Road	RL (km) [a]	PSL (km/h) [b]	85th Percentile Traffic Speeds (km/h) [c]	AADT (Bi-Direction)	PT [d]	Lanes	Lane Widths (m)	GSF (m) [e]	GSB (m) [f]	SSF (m) [g]	SSB (m) [h]	No. of HC [i]	HC Avg. Radius (m)	AC [j]
1	T0112	35,80	120	105,88	2 585	B	2	3,20	1,30	1,33	0,00	0,00	19	749,26	2
2	M0092	24,80	120	62,52	9 399	B	2	3,10	1,00	1,01	0,00	0,00	13	639,62	4
3	T1002_1	36,61	120	108,33	1 699	B	2	3,40	1,02	1,05	0,10	0,11	17	1542,88	5
4	T0106	64,42	120	106,34	14 005	B	2	3,80	1,70	1,78	0,15	0,12	23	1075,26	4
5	T0111_1	92,26	120	109,05	1 435	B	2	3,50	2,43	2,43	0,00	0,00	1	1400,00	5
6	T0111_2	61,82	120	104,40	3 019	B	2	3,55	2,45	2,44	0,10	0,11	5	3100,00	3
7	T0105	73,58	120	104,74	4 483	B	2	3,70	1,92	1,88	0,20	0,25	12	1880,67	8
8	T1002_2	99,75	120	103,85	1 248	B	2	3,55	0,70	0,67	0,55	0,56	8	1331,25	10
9	T0107	164,60	120	120,30	1 973	B	2	3,30	2,50	2,55	0,00	0,00	13	1936,38	10
10	T0110	84,95	120	115,69	991	B	2	3,70	2,01	2,00	0,00	0,00	6	2364,17	6

[a] RL represents the length of the road section in km

[b] PSL represents the Posted Speed Limit of the road section under study in km/h

[c] 85th percentile speed represents the speed that 85 percent of the vehicles do not exceed on the study section

[d] PT represents the type of pavement on the road section under study. B represents Bitumen while G represents Gravel

[e] GSF represents the width of the Forward Ground (Unsurfaced) Shoulder

[f] GSB represents the width of the Backward Ground (Unsurfaced) Shoulder

[g] SSF represents the width of the Forward Surfaced Shoulder

[h] SSB represents the width of the Backward Surfaced Shoulder

[i] HC represents the number of Horizontal curves on the road study section

[j] AC represents the number of access points on the road section under study.

Table 4.13 provides information on the elevation profile and the cross-sectional grades of the road sections in the study. Road section T0105 has the highest average elevation (1 678m), with the highest average positive (2.5%) and lowest average negative (1.8%) slopes. The lowest average elevation (1 100m) is on road section M0092. Road section T0112 has the steepest lane cross fall (3%), while road sections T0106, T0111_2 and T0110 have the lowest lane cross fall (2.2%). Road section T1002_2 has the steepest ground shoulder crossfall (4%), in contrast to road sections T0106 and T0111_2, with the lowest ground shoulder crossfall (2.4%).

Table 4.13 Elevation Profile and Cross- Section Grade Information for Top Ten Fatal Crash Rural Sections (2013- 2016)

No	Road Name	Average Elevation (m)	Average (+) Slope (%)	Average (–) Slope (%)	Lane Cross-Slope (%)	GSF Cross-Slope (%)	GSB Cross-Slope (%)
1	T0112	1102	0.9	1.0	3	3.3	3.3
2	M0092	1100	1.3	1.2	2.9	3.1	3.2
3	T1002_1	1111	0.7	0.7	2.4	2.6	2.6
4	T0106	1425	1.5	1.4	2.2	2.4	2.5
5	T0111_1	1101	0.4	0.4	2.3	2.5	2.5
6	T0111_2	1106	0.5	0.5	2.2	2.4	2.4
7	T0105	1678	2.5	1.8	2.3	2.5	2.6
8	T1002_2	1141	0.3	0.3	2.2	4	4
9	T0107	1485	0.6	0.6	2.3	2.5	2.5
10	T0110	1173	0.3	0.4	2.2	2.5	2.5

5. Results and Discussions

5.1. Introduction

This chapter provides the results and discussions on the relationship between road design elements and fatal crashes on the identified hazardous rural road sections in Table 4.1. A road audit was carried out to assess whether the road design characteristics on the study road sections comply with the road design standards and guidelines used in Namibia. Negative Binomial Regression was then used to develop models for the analysis of the relationship between the road design characteristics and the fatal crashes that occurred on the rural road sections during the study period 2013 to 2016. Ben-Bassat and Shinar (2011) note that road design elements have a significant impact on drivers' perception of road safety and behaviour on the road sections. A survey was carried out to study and understand driver perceptions and general opinions on road safety with regard to the impact of the road design elements on their behaviour, while traversing the rural road study sections.

5.2. Road Audit

5.2.1. Introduction

Road design standards provide guidelines to Transportation Engineers to develop road elements that deliver an operationally efficient, safe and convenient roadway for all road users. Road design elements are interrelated and significantly impact driver behaviour and road safety. It is thus important to examine whether the appropriate road design standards and guidelines were used on the study road sections.

5.2.2. Road Design Assessment

This section provides a verification of whether the road design characteristics provided by the Roads Authority of Namibia on the rural road sections analysed in the study comply with the road design standards used in Namibia, namely the ***Technical Recommendations for Highways 17 (TRH 17) on the Geometric Design of Rural Roads***, accepted by the Committee of State Road Authorities (1988). It is important to acknowledge that some of the roads were designed for traffic conditions that have been far exceeded by current traffic conditions. This assessment will assist traffic authorities to recognise the roads that need targeted measures, to enable them to deal with the current traffic conditions.

5.2.2.1. *Lane Widths and Shoulder Widths*

Housley (2015) defines a road lane as a portion of the roadway used by vehicles to traverse a road section. The study sections are undivided single carriageways, carrying traffic between major Namibian towns. Nine of the ten study road sections are Class A functional roads (trunk roads), with M0092 being a Class B functional road (Regional road) as shown in Section 2.6.6. Table 5.1 shows the cross-sectional width characteristics of the study sections, in comparison to the Technical Recommendations for Highways 17 (CSRA, 1988) guidelines on cross-sectional road widths.

Table 5.1 Cross- Sectional Width Characteristics Audit on the Study Sections

No.	Sections Name	AADT[a]	DC[b]	FC[c]	Existing		TRH 17	
					LW (m) [d]	GSW (m) [e]	LW (m)	GSW (m)
1	**T0112** (Ondangwa- Onhuno)	2585	DC3	A	**3.20**	**1.33**	3.50	2.00
2	**M0092** (Ondangwa- Oshakati)	9399	DC1	B	**3.10**	**1.01**	3.50	2.50
3	**T1002_1** (Onhuno- Eenhana)	1699	DC3	A	3.40	**1.05**	3.50	2.00
4	**T0106** (Windhoek- Okahandja)	14005	DC1	A	**3.80**	**1.78**	3.50	2.50
5	**T0111_1** (Omuthiya- Onethindi)	1435	DC3	A	3.50	2.43	3.50	2.00
6	**T0111_2** (Oshivelo- Omuthiya)	3019	DC3	A	3.55	2.45	3.50	2.00
7	**T0105** (Windhoek- Rehoboth)	4483	DC2	A	3.70	1.92	3.70	2.00
8	**T1002_2** (Eenhana- Okongo)	1248	DC3	A	3.55	**0.70**	3.50	2.00
9	**T0107** (Otjiwarongo- Okahandja)	1973	DC3	A	**3.30**	2.55	3.50	2.00
10	**T0110** (Tsumeb- Oshivelo)	991	DC3	A	3.70	2.01	3.50	2.00

[a] AADT represent the Annual Average Daily Traffic on the roads
[b] DC represent the deign class on the roads
[c] FC represents the functional class of the roads
[d] LW represents the lane widths
[e] GSW represents the ground shoulder widths

The study sections have surfaced shoulder widths between **0.0m** and **0.55m** as shown in Table 4.12. The TRH 17 (CSRA, 1988) recommends surfaced shoulder widths of **1.0m** to **3.0m** on undivided rural roads, with the greatest width of 3.0m used in traffic situations that demand a dual carriageway. The TRH 17 (CSRA, 1988) also recommends a minimum ground shoulder width of 2.0m and a maximum ground shoulder width **3.0m**, on rural roads where traffic volumes are high.

Rural roads T0112, M0092 and T0107 in Table 4.12, have lane widths that are under designed to deal with the traffic conditions on the road sections. The road sections have lane widths well below 3.50m recommended by the TRH 17 (CSRA, 1988). It is important that lanes are wide enough to adequately carry road traffic safely. Rural road T0106 has lane widths that are over designed. The road section has a lane width of 3.80m, compared to the 3.50m recommended by the TRH 17 (CSRA, 1988). Deller (2013) states that over design can lead to reckless driving and an increase in traffic speeds on the road sections.

Rural roads T0112, T1002_1 and T1002_2, and rural roads M0092 and T0106 have ground shoulder widths significantly less than the ground shoulder widths recommended by the TRH 17 (CSRA, 1988), as shown in Table. Rural roads T0112,T1002_1 and T1002_2 have GSWs of 1.33m, 1.05m and 0.70m, compared to the TRH 17 (CSRA, 1988) recommendation of 2.0m. The SANRAL Geometric Design Manual (SANRAL, 2003) states that it is important that sufficient shoulder width is provided to the adjacent traffic lanes, for lateral support to the road structure, to provide refuge to disabled vehicles and for use by emergency vehicles.

5.2.2.2. *Camber*

The CSRA (1988) defines the camber as two slopes directed away from the high point of the centre of a two-lane two-way road towards the shoulder on both sides. The camber facilitates drainage on the road surface. The TRH 17 (CSRA, 1988) recommends a 2-3% camber slope. Slopes greater than 3% cause operational problems, as they invariably cause the undue wear of vehicle components. Table 5.2 shows the cross- sectional grades characteristics for the study sections, in comparison to the recommended grades by the TRH 17 (CSRA, 1988).

Table 5.2 Cross- Sectional Grade Characteristics Audit on the Study Sections

No.	Sections Name	DC	FC	Existing		TRH 17	
				Lane Grade (%)	GS [a] Grade (%)	Lane Grade (%)	GS Grade (%)
1	**T0112** (Ondangwa-Onhuno)	DC3	A	3.0	**3.3**	2-3	4
2	**M0092** (Ondangwa-Oshakati)	DC1	B	2.9	**3.2**	2-3	4
3	**T1002_1** (Onhuno-Eenhana)	DC3	A	2.4	**2.6**	2-3	4
4	**T0106** (Windhoek-Okahandja)	DC1	A	2.2	**2.5**	2-3	4
5	**T0111_1** (Omuthiya-Onethindi)	DC3	A	2.3	**2.5**	2-3	4
6	**T0111_2** (Oshivelo-Omuthiya)	DC3	A	2.2	**2.4**	2-3	4
7	**T0105** (Windhoek-Rehoboth)	DC2	A	2.3	**2.6**	2-3	4
8	**T1002_2** (Eenhana-Okongo)	DC3	A	2.2	4	2-3	4
9	**T0107** (Otjiwarongo-Okahandja)	DC3	A	2.3	**2.5**	2-3	4
10	**T0110** (Tsumeb- Oshivelo)	DC3	A	2.2	**2.5**	2-3	4

[a] GS represents the ground shoulder (unsurfaced shoulder)

All rural roads shown in Table 5.2 have lane grades within the 2-3% grades recommended by the TRH 17 (CSRA, 1988). Lane grades facilitate drainage off the road surface. A crossfall of 4% is recommended by the TRH 17 (CSRA, 1988) for unsurfaced shoulders. Only rural road T1002_2 has a crossfall of 4%, as recommended by the TRH 17 (CSRA, 1988). Nine of the ten rural roads have cross falls ranging from 2.4% to 3.3%, which are below the TRH 17 (CSRA, 1988) recommendations for unsurfaced road shoulders. The CSRA (1988) states that it is vital that the appropriate crossfall is provided on the unsurfaced shoulders, to ensure that the surfaced road and the rougher surface have the same rate of flow.

5.2.2.3. *Horizontal Curvature (HC)*

The consistency of the road design greatly determines the comfort, ease and safety with which vehicles traverse a road section. Using appropriate horizontal curve radii, related to the design speed of the road, allows for a suitable side friction for a vehicle to traverse the horizontal curve safely and without discomfort. Using Table 2.9 that provides the minimum radii for horizontal curves according to their design speeds, Table 5.3 provides an assessment on whether the HC radii of the road study sections comply with TRH 17 (CSRA, 1988) guidelines on the radii of horizontal curves.

Table 5.3 Horizontal Curvature Radius Audit on the Study Sections

No.	**Sections Name**	**FC**	**Design Speed (km/h**	Existing		TRH 17
				No	Curve Radii (m)	Min. Curve Radii (m)
1	**T0112** (Ondangwa- Onhuno)	A	120	1	613	530
				2	940	
				3	714	
				4	**490**	
				5	770	
				6	890	
				7	**240**	
				8	670	
				9	800	
				10	911	
				11	**385**	
				12	**470**	
				13	975	
				14	1000	
				15	1126	
2	**M0092** (Ondangwa- Oshakati)	B	120	1	745	530
				2	700	
				3	900	
				4	800	
				5	**500**	
				6	650	
				7	770	
				8	630	
				9	670	
				10	555	
				11	640	
				12	385	
				13	370	
3	**T1002_1** (Onhuno- Eenhana)	A	120	1	1500	530
				2	1200	
				3	1600	
				4	1670	

				5	1700	
				6	1800	
				7	1300	
				8	3000	
				9	1527	
				10	1398	
				11	2176	
				12	1826	
				13	900	
				14	1001	
				15	1231	
				16	900	
				17	1500	
4	**T0106** (Windhoek-Okahandja)	A	120	1	1653	530
				2	1500	
				3	1102	
				4	650	
				5	**300**	
				6	1242	
				7	1130	
				8	1500	
				9	1400	
				10	680	
				11	**350**	
				12	2100	
				13	1300	
				14	1070	
				15	1200	
				16	1239	
				17	1180	
				18	1300	
				19	1040	
				20	681	
				21	844	
				22	670	
				23	600	
5	**T0111_1** (Omuthiya-Onethindi)	A	120	1	1400	530
6	**T0111_2** (Oshivelo-Omuthiya)	A	120	1	3900	530
				2	600	
				3	3500	
				4	3800	
				5	3700	
7	**T0105** (Windhoek- Rehoboth)	A	120	1	2678	530
				2	1800	
				3	2300	
				4	5000	
				5	800	
				6	1500	
				7	760	
				8	1600	
				9	830	
				10	1300	
				11	3500	
				12	**500**	

8	**T1002_2** (Eenhana- Okongo)	A	120	1	1300	530
				2	1000	
				3	1200	
				4	**400**	
				5	1700	
				6	1400	
				7	1550	
				8	2100	
9	**T0107** (Otjiwarongo-Okahandja)	A	120	1	1850	530
				2	1710	
				3	2900	
				4	3500	
				5	1717	
				6	770	
				7	1126	
				8	1920	
				9	2300	
				10	3000	
				11	1400	
				12	780	
				13	2200	
10	**T0110** (Tsumeb- Oshivelo)	A	120	1	2200	530
				2	900	
				3	1300	
				4	1850	
				5	5550	
				6	2385	

The horizontal curve radii on all ten study sections were assessed whether they comply with Technical Recommendations for Highways 17 (CSRA, 1988) guidelines on radii of horizontal curves. It is important to acknowledge the influence of topography and built environment on the road alignment, including the radius and alignment of the horizontal curves.

Turner (2005) states that the risk of a road crash on a horizontal curve increases with a reduction in the radius of the curve, with horizontal curve radius considered ***critical at radius less than 350m***. Similarly, as the horizontal curve level of curvature was increased, the crash risk level reduced. Figure 5.1 illustrates the relative risk of a road crash on horizontal curves of different radii.

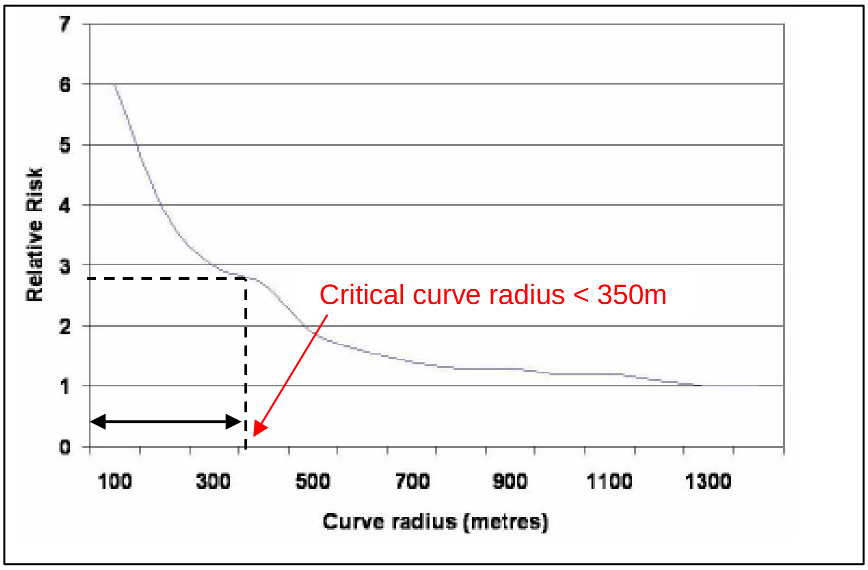

Figure 5.1 Relative Crash Risk for different Horizontal Curve Radii (Turner, 2005)

The radii on the horizontal curves on study road sections T1002_1, T0111_1, T0111_2, T0107 and T0110 complied with the TRH 17 (CSRA, 1988) guidelines on HC radii. For road section T0112, Horizontal curve 4, 7, 11 and 12 with radii of 490m, 240m, 385m and 470m respectively, do not comply with the TRH 17 (CSRA, 1988) recommendation of a minimum HC radius of 530m. On road section T0112, HC 7 has a high crash risk level in comparison to the crash risk levels on the rest of the HCs on the section, as it has a radius (240m) below the critical curve radius of 350m. On section M0092, HC 5 with a radius of 500m did not comply with TRH 17 (CSRA, 1988) recommendation of a minimum radius of 530m.

On section T0106, HC 5 and HC 11 with radius of 300m and 350m respectively, did not comply with the TRH 17 (CSRA, 1988) recommendation of a minimum curve radius of 530m. HC 5 (300m) and HC 11 (350m) have a higher crash risk level compared with the rest of the curves on T0106, as they have radii equal to and below the critical curve radius of 350m respectively. On section T0105, one of the twelve HCs, namely HC 5 with a radius of 500m did not comply with the TRH 17 (CSRA, 1988) with regard to the minimum curve radius (530m). On road section T1002_2, HC 4 with a curve radius of 400m did not comply with the minimum curve radius (530m) recommended by the TRH 17 (CSRA, 1988).

5.3. Relationship between Fatal Crashes and the Road Design Elements

5.3.1. Introduction

This section shows the results of the ***Negative Binomial Regression Models*** developed, on the potential relationship between fatal crashes and the various interactions between road design elements on the study road sections, during the study period of 2013 to 2016. The study sections were grouped with the guidance of Table 2.13, according to the ***Lane Width (LW)*** on the study sections. The design elements on the road sections in the different design classes were used as independent variables in the regression models.

5.3.2. Lane Width Classification of Road Study Section

The road study sections were classified into two study groups, according to the following criteria:

1. Criteria 1: Lane Width > 3.50m
2. Criteria 2: Lane Width ≤ 3.50m

The study groups classified according to LW criterion are shown in Table 5.4.

Table 5.4 Classification of Road Sections according to Lane Widths

Classification	No	Section Name	AADT	LW (m)	Number of Fatal Crashes [a]	Fatal Crash rate
Criteria 1: LW> 3.5m	1	***T0106*** (Windhoek- Okahandja)	14005	3.80	39	0.03
	2	***T0111_2*** (Oshivelo- Omuthiya)	3019	3.55	33	0.12
	3	***T0105*** (Windhoek- Rehoboth)	4483	3.70	34	0.07
	4	***T1002_2*** (Eenhana- Okongo)	1248	3.55	39	0.21
	5	***T0110*** (Tsumeb- Oshivelo)	991	3.70	29	0.24
Criteria 2: LW≤ 3.5m	6	***T0112*** (Ondangwa- Onhuno)	2585	3.20	30	0.22
	7	***M0092*** (Ondangwa- Oshakati)	9399	3.10	20	0.06
	8	***T1002_1*** (Onhuno- Eenhana)	1699	3.40	26	0.29
	9	***T0111_1*** (Omuthiya- Onethindi)	1435	3.50	53	0.27
	10	***T0107*** (Otjiwarongo- Okahandja)	1973	3.30	62	0.13

[a] Fatal Crash rates represent the number of fatal crashes per million vehicle kilometres travelled

The road sections in Table 5.4 were split into sub-sections with the guidance of the RA of Namibia as shown in Table 5.5 and Table 5.17. The split was done to avoid the limitations in NBR analysis caused by having less study cases than the selected road design variables. Fatal crashes per km on road sections shown in Table 5.5 and Table 5.17 were used as dependant variables in the NBR analysis as AADT information was not available on the RA of Namibia's Road Management System (RMS) to determine the CKm for the individual sections. AADT was only provided for the combined section, which was not a good representative of the origins and destinations of the road users on the road sections (road user exposure).

5.3.3. Criteria 1 (LW> 3.5m): Road Sections Analysis and Discussions

This section provides the analysis and discussion of the potential relationships found between fatal crashes and road design elements, on road study sections with lane widths greater than 3.50m. The five Criteria 1 roads shown in Table 5.4 were divided into 22 sections with the guidance of the RA of Namibia, to prevent having less study section cases than the selected road variables in the NBR analysis. Table 5.5 provides information on the 22 cases for the Criteria 1 roads. The Horizontal curve radius for the study sections are provided in Section 4.

Table 5.5 Variable Information on Criteria 1 (LW> 3.5m) Roads Sub-Sections

Road Sections	No.	Length	FC/km [a]	LW [b]	HCNUMB [c]	GSW [d]	OPSPEED [e]	AC [f]
T0106	1	19	0.47	3,71	3	1,81	115,63	0
	2	14	0.71	3,61	7	1,61	117,12	2
	3	14,42	0.55	3,8	5	1,75	113,23	1
	4	17	0.71	3,5	8	1,55	119,43	1
T0111_2	5	17,5	0.46	3,71	2	1,71	113,98	0
	6	13,82	0.72	3,63	1	1,58	117,11	1
	7	16,5	0.36	3,7	2	1,89	109,34	1
	8	14	0.64	3,75	0	1,62	116,76	1
T0105	9	20,5	0.49	3,65	6	1,57	116,78	4
	10	16,58	0.36	3,75	2	1,88	109,03	1
	11	14,5	0.48	3,7	3	1,8	109,45	1
	12	22	0.50	3,6	1	1,53	117,34	2
T1002_2	13	14,4	0.35	3,7	5	1,9	106,23	1
	14	17,5	0.51	3,65	1	1,62	115,98	4
	15	16,6	0.36	3,7	0	1,84	109,79	1
	16	15,5	0.45	3,65	0	1,79	111,01	2
	17	20	0.40	3,65	1	1,66	112,66	1
	18	15,75	0.25	3,75	1	1,91	104,23	1
T110	19	21,2	0.42	3,7	3	1,66	116,34	4
	20	26	0.19	3,55	1	1,85	108,88	1
	21	20,95	0.38	3,7	1	1,7	112,55	0
	22	16,8	0.42	3,65	1	1,74	110,56	1

[a] FC/ km represents the number of fatal crashes per km on the study section
[b] LW represents the lane width
[c] HCNUM represents the number of horizontal curves on the section
[d] GSW represents the Ground Shoulder Width
[e] OPSPEED represents the 85th percentile speed on the study section
[f] AC represents the access control (number of access points per road length) on the study section

Table 5.6 provides information on the continuous variables on the study sections used in the Negative Binomial Regression analysis for Criteria 1 road sections.

Table 5.6 Continuous Variables Information on Criteria 1 Road Sections

Continuous Variable Information: Criteria 1						
		N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Dependent Variable	**FC/ km**	22	0.19	0.72	0.46373	0.13987
Covariate	**Road Length**	22	13.82	26.00	17.5236	3.13337
	LW	22	3.55	3.80	3.6732	0.06896
	HCNUM	22	0.00	8.00	2.4545	2.32434
	GSW	22	1.53	1.91	1.7259	0.12366
	OPSPEED	22	102.85	119.43	112.8832	4.09503
	HCRAD	22	300	5500	1622.8520	1142.9820
	AC	22	0.00	4.00	1.4091	1.18159

In Table 5.6, *N* represents the number of study cases for each variable and *HCRAD* represents the radius of the horizontal curves on the study sections. The road segments analysed in this section are all single carriageways surfaced with bitumen, with a posted speed limit of 120 km/h. The number of lanes and the posted speed limit was therefore not tested on the relationship between fatal crashes (***FC/km***) and the interaction between the selected road design elements in the Negative Binomial Regression analysis. The NBR models identified five statistically significant relationships between fatal crashes (FC/km) and road design elements on Criteria one road sections.

5.3.3.1. *Relationship 1 (Fatal Crashes and All Design Elements)*

Table 5.7 shows that a statistically significant relationship exists between fatal crashes and the interaction of all selected road design elements listed in Table 5.6. The regression model linking fatal crashes to the road design elements has a probability value of 0.000, which is significantly less than the alpha value of 0.05 (5%). The adjusted R^2 for the test model suggests that 95% of the variance in fatal crashes is accounted for by the road design elements.

Table 5.7 Criteria 1 Model Significance Test for Relationship 1

Dependant Variable	**Whole Model R**									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS [a] Residual	MS [b] Residual	F	P value
FC/ km	0.9833	0.9669	0.9504	86.8491	7	12.4070	2.9691	0.2121	58.5014	***0.000***

[a] SS Residual represents the error of sums of squares
[b] MS Residual represents the error of means of squares

The parameter estimates for the predictor variables in the test model are shown in Table 5.8. The test model indicates that the 85th percentile speed (OPSPEED) and lane width (LW) significantly predict the fatal crashes in comparison to the rest of the road design elements. The 85th percentile speed has a probability value of 0.000, which is significantly less than the set alpha value of 0.05 (5%). The parameter B indicates that for every one unit increase in the 85th percentile speed, there is an increase of 0.350 in the fatal crashes log counts. The lane width (LW) parameter has a probability value of 0.039, which is less than the alpha value of 0.05 (%). For every one unit increase in the lane width, parameter B indicates that there is a decrease of 3.208 in the fatal crashes log count.

Table 5.8 Criteria 1 Parameter Estimates and Effects for Relationship 1

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition Std. Error of Estimate: 0.4607										
	Df [a]	B	Std. Err [b] B	F	t	p value	-95% CL [c]	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	-13.827	12.2942	0.8050	-0.8972	0.261	-37.923	10.269			
OPSPEED	1	0.350	0.0610	20.8954	4.5712	***0.000***	0.230	0.469	0.6926	0.3676	1.0176
Length	1	-0.054	0.0329	1.7213	-1.3120	0.100	-0.119	0.010	-0.0820	-0.2160	0.0520
AC	1	-0.108	0.0893	0.9220	-0.9602	0.229	-0.283	0.068	-0.0735	-0.2377	0.0907
LW	1	-3.208	1.5534	2.7148	-1.6477	***0.039***	-6.253	-0.164	-0.1070	-0.2463	0.0323
HCNUM	1	0.055	0.1215	0.1309	0.3618	0.650	-0.183	0.293	0.0621	-0.3059	0.4300
GSW	1	-2.115	2.3956	0.4960	-0.7043	0.377	-6.810	2.580	-0.1265	-0.5116	0.2587
HCRAD	1	-0.002	0.0014	0.8082	-0.8990	0.260	-0.004	0.001	-0.1436	-0.4864	0.1991

[a] Df represents the degree of freedom of the variables
[b] Std. Error represents the standard error for coefficient B
[c] CL represents the Confidence Limit

5.3.3.2. *Relationship 2 (Fatal Crashes, Lane Widths and Ground Shoulder Widths)*

The relationship between the fatal crashes and the combination of lane widths (***LW***) and ground shoulder widths (***GSW***) on the study sections is shown in Table 5.9. The model linking fatal crashes with the lane widths and ground shoulder widths was statistically significant, as the p value= 0.000 significantly less than the set alpha value of 5% (0.05) for the F test performed. the adjusted R^2 for the model suggests that 84.1% of the variance in fatal crashes is accounted for by the predictors in the model.

Table 5.9 Criteria 1 Model Significance Test for Relationship 2

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.9250	0.8557	0.8405	76.8646	2	38.4323	12.9535	0.6818	56.3716	***0.000***

Table 5.10 shows the parameter estimates for the predictor variables and their effects in the model. GSW was a statistically significant predictor in the model, with a probability (p) value of 0.000, that is less than the alpha value of 5%. The GSW parameter B suggests that for every one unit increase in GSW, there is a 15.4229 decrease in the log count of fatal crashes. This indicates that despite the lane width on the study section, the GSW significantly impacts the number of fatal crashes that occur on the road.

Table 5.10 Criteria 1 Parameter Estimates and Effects for Relationship 2

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition Std. Error of Estimate: 0.8257										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	35.2015	9.8582	12.7504	3.5708	***0.0020***	14.5680	55.8350			
LW	1	-0.1835	2.9581	0.0026	-0.0620	0.9511	-6.3749	6.0079	-0.0061	-0.2126	0.2003
GSW	1	-15.4229	1.6497	87.4009	-9.3488	***0.0000***	-18.8757	-11.9700	-0.9221	-1.1287	-0.7157

5.3.3.3. *Relationship 3 (Fatal Crashes, Lane Widths, Horizontal Curve Radius and 85th Percentile Speed)*

There exists a statistically significant relationship between fatal crashes and road design elements, namely lane widths, horizontal curvature radius and the 85th percentile speed, as indicated by a probability value of 0.000, in Table 5.11. The adjusted R^2 of the model suggests that 95.3% of the variance in the fatal crashes is accounted for by the predictors in the model.

Table 5.11 Criteria 1 Model Significance Test for Relationship 3

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.9797	0.9699	0.9532	86.2128	3	28.7376	3.6053	0.2003	143.4753	***0.000***

The parameter estimates for fatal crashes are indicated in Table 5.12. The horizontal curvature radius, lane width and 85th percentile speed are statistically significant in predicting fatal crashes, as they have probability values of 0.007, 0.025 and 0.000 respectively, that are less than the test models' alpha value of 0.05 (5%). The horizontal curvature radius and lane width have negative B parameters, indicating that for every one unit increase in either predictor, there would be a 0.003

and 3.254 decrease in fatal crash log counts respectively. The parameter B for the 85th percentile speed, indicates that for every one unit increase in the predictor, there is a 0.341 log count increase in fatal crashes.

Table 5.12 Criteria 1 Parameter Estimates and Effects for Relationship 3

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition Std. Error of Estimate: 0.4475										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	-15.679	11.7459	1.7819	-1.3349	0.1986	-36.503	5.144			
HCRAD	1	-0.003	0.0012	6.0014	-2.4498	***0.007***	-0.006	-0.001	0.997	0.995	0.999
LW	1	-3.254	1.4566	4.0841	-2.0209	***0.025***	-6.109	-0.399	0.039	0.002	0.671
OPSPEED	1	0.341	0.0553	31.0182	5.5694	***0.000***	0.232	0.448	1.406	1.261	1.567

5.3.3.4. *Relationship 4 (Fatal Crashes, Horizontal Curve Radius and Number of Horizontal Curves)*

Table 5.13 shows that a statistically significant relationship exists between fatal crashes and the combination of the radius of the horizontal curves and the number of horizontal curves on a study section. The test model has a probability value of 0.000, which is significantly less than the alpha value of the model, set at 0.05 (%). The adjusted R^2 value indicates that 85.3% of the variance in the fatal crashes is accounted for the test model.

Table 5.13 Criteria 1 Model Significance Test for Relationship 4

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.9309	0.8666	0.8526	77.8378	2	38.9189	11.9804	0.6305	61.7222	***0.000***

Table 5.14 indicates that the number of horizontal curves and the radius of the curves are significant in predicting fatal crashes, with probability values of 0.0300 and 0.012 respectively, that are less than the alpha value of 0.05 (5%). The parameter B for the number of horizontal curves indicates that for every one unit increase in the number of horizontal curves, there is an increase of 0.2955 in the log counts of fatal crashes. The parameter B for the horizontal curvature radius indicates the opposite. For every one unit increase in the radius of the horizontal curve, there exists a decrease of 0.0071 in the fatal crashes log count.

Table 5.14 Criteria 1 Parameter Estimates and Effects for Relationship 4

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition Std. Error of Estimate: 0.7941										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	12.6005	2.5534	24.3519	4.9348	***0.0000***	7.950	17.251			
HCNUM	1	0.2955	0.1468	4.0523	2.0130	***0.0300***	0.028	0.563	1.344	1.029	1.756
HCRAD	1	-0.0071	0.0019	14.4670	-3.8036	***0.0012***	-0.011	-0.004	0.993	0.989	0.996

5.3.3.5. *Relationship 5 (Fatal Crashes, Access Control and Length)*

Table 5.15 that a statistically significant relationship exists between fatal crashes and the combination of the road length and access control on the study sections. The probability value of 0.0024 indicates the model's significance, as it is less than the alpha value of 0.05 (%). The adjusted R^2 value of the model suggests that 41.5% of the variance in fatal crashes is accounted for by the predictors in the model.

Table 5.15 Criteria 1 Model Significance Test for Relationship 5

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.6858	0.4703	0.4146	42.2457	2	21.1229	47.5725	2.5038	8.4363	***0.0024***

The parameter estimates for the predictors in the test model are shown in Table 5.16. Access Control (AC) is significantly predicting fatal crashes on the study sections, as it has a probability value of 0.0006, that is less than the alpha value of 0.05 (5%). This indicates that despite the length of the road section, the access control is key to the safety of the road section. The parameter B for the AC suggests that for every one unit increase in the AC, there is a 0.9993 increase in the log count of fatal crashes.

Table 5.16 Criteria 1 Parameter Estimates and Effects for Relationship 5

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition Std. Error of Estimate: 1.5267										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	5.3056	2.0158	6.9277	2.6320	***0.0164***	1.0866	9.5247			
AC	1	0.9993	0.2442	16.7477	4.0924	***0.0006***	0.4882	1.5103	0.6833	0.3338	1.0328
Length	1	0.0345	0.1102	0.0981	0.3133	0.7575	-0.1961	0.2652	0.0523	-0.2972	0.4018

5.3.4. Criteria 2 (LW≤ 3.5m): Road Sections Analysis and Discussions

The analysis and discussions of the potential relationships found between fatal crashes (FC/ km) and road design elements on road sections with lane widths equal to or less than 3.50m, are provided in this section. Criteria 2 roads were divided into 21 sections with the guidance of the RA of Namibia for the NBR analysis. Table 5.17 shows variable information on the 21 sections. Information on HC radius is provided in Section 4.

Table 5.17 Variable Information on Criteria 2 Roads Sub- Sections

Road Section	No	Length	FC/ km [a]	LW [b]	HCNUM [c]	GSW [d]	OPSPEED [e]	AC [f]
T0112	1	14,2	1,76	3,15	8	1,12	105,88	2
	2	9	1,33	3,5	3	1,32	102,44	0
	3	12,6	1,03	3,45	4	1,31	101,23	0
M0092	4	14,8	0,81	3,2	9	0,95	62,52	3
	5	10	0,80	3,45	5	1,08	59,33	1
T1002_1	6	12	0,67	3,41	5	1,05	108,33	1
	7	11,61	0,60	3,4	4	1,11	101,22	1
	8	13	0,85	3,23	8	0,97	106,23	3
T0111_1	9	15	0,53	3,5	0	2,43	101,21	1
	10	19,5	0,51	3,25	0	2,3	105,53	2
	11	14,26	0,77	3,23	0	2,29	106,55	2
	12	21	0,48	3,29	0	2,31	108,33	0
	13	22,5	0,62	3,15	1	2,25	109,05	0
T0107	14	15,5	0,39	3,45	2	2,41	104,56	0
	15	20,1	0,45	3,29	0	2,25	106,1	2
	16	16,5	0,42	3,35	2	2,47	104,3	1
	17	17,6	0,34	3,4	1	2,45	105,44	0
	18	21,2	0,42	3,29	3	2,3	115,69	2
	19	17,8	0,39	3,25	1	2,44	103,34	1
	20	22,9	0,31	3,3	0	2,39	101,23	0
	21	33	0,33	3,2	4	2,2	110,12	4

[a] FC/ km represents the number of fatal per km on the study sections
[b] LW represents the lane widths on the study sections
[c] HCNUM represents the number of horizontal curves on the study sections
[d] GSW represents the Ground Shoulder Width
[e] OPSPEED represents the 85th percentile on the study sections
[f] AC represents the access control (number of access points per road length) on the study sections

Table 5.18 provides information on the continuous variables used in the NBR analysis for Criteria 2 road sections.

Table 5.18 Continuous Variables Information on Criteria 2 Road Sections

Continuous Variable Information: Criteria 2						
		N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Dependent Variable	**FC/ km**	21	0.31	1.76	0.65762	0.36069
Covariate	**Road Length**	21	9.00	33.00	16.8605	5.47837
	LW	21	3.15	3.50	3.3210	0.11247
	HCNUM	21	0.00	9.00	2.8571	2.86855
	GSW	21	0.95	2.47	1.8762	0.62220
	OPSPEED	21	59.33	125.69	103.3367	13.85766
	HCRAD	21	240.00	3500.00	1222.22	721.5126
	AC	21	0	4.00	1.1905	1.20909

In Table 5.18, *N* represents the number of study cases for the selected variables and *HCRAD* represents the radius of the horizontal curves on the study sections. The study sections are single rural carriageways surfaced with bitumen, with a posted speed limit of 120 km/h. Therefore, the number of lanes and the posted limit were not part of the NBR analysis, as they are consistent with all the road sections. The NBR models identified four statistically significant relationships between fatal crashes (FC/km) and road design elements on Criteria two road sections.

5.3.4.1. *Relationship 1 (Fatal Crashes and All Design Elements)*

Table 5.19 indicates that a statistically significant relationship exists between fatal crashes on roads with lane widths less than 3.50m and the road design elements of the study sections. The test model has a probability value of 0.0012, which is significantly less than the models' alpha value of 0.05 (5%). The adjusted R^2 indicates that 68.7% of the variance in fatal crashes is accounted for by the model.

Table 5.19 Criteria 2 Model Significance Test for Relationship 1

Dependant Variable	**Whole Model R**									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS [a] Residual	MS [b] Residual	F	P value
FC/ km	0.8925	0.7965	0.6869	102.7123	7	14.6732	26.2401	2.0185	7.2695	***0.0012***

[a] SS Residual represents the error of sums of squares
[b] MS Residual represents the error of means of squares

One of the road design elements, namely the lane width, has a significant impact on predicting the fatal crashes in the test model, as indicated in Table 5.20. The lane width (LW) has a probability value of 0.001, which is significantly less the models' alpha value of 0.05 (5%). The parameter B for the lane width suggests that for every one unit increase in the lane width, there is a 17.961 decrease in the long count of fatal crashes.

Table 5.20 Criteria 2 Parameter Estimates and Effects for Relationship 1

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.4207										
	Df [a]	B	Std. Err [b] B	F	t	p value	-95% CL [c]	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	69.698	15.5828	20.0056	4.4727	***0.001***	36.0335	103.3626			
LW	1	-17.961	4.0553	19.6164	-4.4290	***0.001***	-26.7221	-9.2002	-0.7955	-1.1836	-0.4075
HCRAD	1	-0.001	0.0008	1.4607	-1.2086	0.248	-0.0028	0.0008	-0.2162	-0.6027	0.1703
GSW	1	-1.048	1.3830	0.5738	-0.7575	0.462	-4.0353	1.9401	-0.2567	-0.9888	0.4754
Length	1	-0.017	0.1000	0.0298	-0.1726	0.866	-0.2333	0.1988	-0.0372	-0.5033	0.4289
HCNUM	1	0.163	0.3413	0.2267	0.4761	0.642	-0.5749	0.8999	0.1836	-0.6494	1.0166
OPSPEED	1	0.017	0.0277	0.3608	0.6006	0.558	-0.0432	0.0765	0.0911	-0.2366	0.4189
AC	1	-0.124	0.4104	0.0918	-0.3029	0.7667	-1.0108	0.7622	-0.0592	-0.4813	0.3629

[a] Df represents the Degrees of freedom of the variables
[b] Std. Error represents the Standard Error for coefficient B
[c] CL represents the Confidence Limit

5.3.4.2. *Relationship 2 (Fatal Crashes, Lane Width, Horizontal Curves Radius and Ground Shoulder Width)*

A statistically significant relationship exists between fatal crashes and the combination of road design elements, namely the lane width (LW), the radius of the horizontal curves (HCRAD) and the ground shoulder width (GSW), as indicated by the probability value of 0.000, which is significantly less the models' alpha value of 0.05 (5%). The models' adjusted R^2 suggests that 75.2% of the variance in fatal crashes is accounted for by the predictors, as indicated by Table 5.21.

Table 5.21 Criteria 2 Model Significance Test for Relationship 2

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.8881	0.7888	0.7515	101.7121	3	33.9040	27.2403	1.6024	21.1587	***0.000***

Table 5.22 indicates that the lane width (LW) and ground shoulder width (GSW) are significant in predicting the fatal crashes in the model, with probability values of 0.000 and 0.007 respectively. The parameter B for lane width suggests that for every one unit increase in the lane width, there is an 18.3834 decrease in the log count of fatal crashes. For ground shoulder width (GSW), the parameter B indicates that for every one unit increase in GSW, there is a 1.4680 decrease in the log count of fatal crashes.

Table 5.22 Criteria 2 Parameter Estimates and Effects for Relationship 2

Effect	**Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.2658**										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	73.3688	8.5763	73.1849	8.5548	***0.000***	55.2743	91.4632			
LW	1	-18.3834	2.5814	50.7126	-7.1212	***0.000***	-23.8299	-12.9370	-0.8142	-1.0555	-0.5730
HCRAD	1	-0.0007	0.0006	1.5615	-1.2496	0.228	-0.0019	0.0005	-0.1490	-0.4007	0.1026
GSW	1	-1.4680	0.4761	9.5039	-3.0828	***0.007***	-2.4727	-0.4633	-0.3597	-0.6059	-0.1135

5.3.4.3. *Relationship 3 (Fatal Crashes, Access Control and Road Length)*

Table 5.23 indicates that a statistically significant relationship exists between fatal crashes (FC) and the combination of the roads access control (AC) and length, on the study sections with lane widths less than 3.50m. The test model has a probability value of 0.033, which is less than the alpha value of 0.05 (5%). The predictors in the model account for 19.8% of the variance in the fatal crashes, as indicated by the adjusted R^2, in Table 5.23.

Table 5.23 Criteria 2 Model Significance Test for Relationship 3

Dependant Variable	**Whole Model R**									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.5271	0.2778	0.1976	35.8242	2	17.9121	93.1282	5.1738	3.4621	***0.033***

Access control has a significant influence in predicting the fatal crashes, as indicated by the probability value of 0.011, in Table 5.24. The parameter B of access control indicates that for every one unit increase in the access control, there is a 1.0277 increase in the fatal crashes log count. The length of the study section did not have an influence on the fatal crashes in the test model, as indicated by the probability value of 0.600, which is greater than the alpha value of 0.05 (5%).

Table 5.24 Criteria 2 Parameter Estimates and Effects for Relationship 3

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2.2746										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	7.0326	1.6432	18.3157	4.2797	***0.000***	3.5802	10.4849			
AC	1	1.0277	0.4386	5.4899	2.3431	***0.011***	0.1062	1.9492	0.4894	0.0506	0.9281
Length	1	0.0470	0.0968	0.2352	0.4850	0.600	-0.1564	0.2503	0.1013	-0.3375	0.5401

5.3.4.4. *Relationship 4 (Fatal Crashes, Number of Horizontal Curves and Road Length)*

Table 5.25 indicates that a statistically significant relationship exists between the fatal crashes (FC) and road design elements, namely the road length and number of horizontal curves (HCNUM) on a study section. The probability value of 0.017, is less than the alpha value of 0.05 (5%) set for the model. The adjusted R^2 suggests that 24.8% of the variance in fatal crashes is accounted for by the predictors in the model.

Table 5.25 Criteria 2 Model Significance Test for Relationship 4

Dependant Variable	Whole Model R									
	Multiple R	Multiple R^2	Adjusted R^2	SS Model	df	MS Model	SS Residual	MS Residual	F	P value
FC/ km	0.5681	0.3227	0.2475	41.6141	2	20.8071	87.3383	4.8521	4.2882	***0.017***

Table 5.26 indicates that the road length and the number of horizontal curves have a significant effect on predicting the fatal crashes, with probability values of 0.024 and 0.004 respectively. The parameter B value for the length suggests that for every one unit increase in length, there is a 0.1999 increase in fatal crashes log count, while the parameter B value for the number of horizontal curves (HCNUM) suggests that for every one unit increase in the number of horizontal curves, there is a 0.4863 increase in the fatal crashes log count.

Table 5.26 Criteria 2 Parameter Estimates and Effects for Relationship 4

Effect	Parameter Estimates for FC/ km Sigma- restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2.2028										
	Df	B	Std. Err B	F	t	p value	-95% CL	+95% CL	Beta (β)	-95% CL	+95% CL
Intercept	1	4.2881	1.7833	4.9562	2.2263	***0.016***	0.2414	8.3347			
Length	1	0.1999	0.0888	4.3429	2.0840	***0.024***	-0.0016	0.4014	0.4313	-0.0035	0.8660
HCNUM	1	0.4863	0.1696	7.0471	2.6546	***0.004***	0.1014	0.8711	0.5494	0.1146	0.9841

5.4. Analysis of Surveys and Discussions

Relationships between road fatal crashes and the interaction of rural road design elements on the study sections were developed in Section 5.3. Bella (2013) states the importance of analysing the impact of the physical road environment on driver behaviour and safety perceptions. It is vital that Transport Engineers establish and study how the self-evident road design is perceived by road users and how it co-impacts the level of crash risk, together with the interactive relationships between road design elements.

A survey was undertaken to assess and study the general perceptions of drivers regarding road safety, primarily their awareness of the physical road design elements while using the road sections. The survey was also aimed at studying driver opinions on what they deemed as contributing factors to high fatal crash rates on the selected rural roads. The survey guide used in the survey has been provided in Addendum B.

The report section presents the results of the surveys under the following sections:

a) General perceptions and opinions regarding road safety on rural roads, and
b) Driver awareness of physical road design elements while driving.

Study sections were grouped for the survey, according to the width of the lanes on the study sections. Two road sections were used for the survey and the responses from the drivers on these roads were considered as a representation of the views of all the users using the represented study sections. The following criteria were used to group the study sections for the survey.

1. Criteria 1: Lane Width > 3.50m
2. Criteria 2: Lane Width ≤ 3.50m

Table 5.27 shows the grouping of the study sections according to the lane width criteria provided. The road section ***T0110 (Tsumeb-Oshivelo)*** represented the roads under Criteria 1, while the road section ***T0107 (Otjiwarongo-Okahandja)*** represented the roads under Criteria 2.

Table 5.27 Lane Width Classification of the Study Sections for the Survey

Classification	No	Section Name	AADT	LW (m)	Fatal Crashes	No. of Participants
Criteria 1	1	***T0106*** (Windhoek-Okahandja)	14005	3.80	39	-
	2	***T0111_2*** (Oshivelo-Omuthiya)	3019	3.55	33	-
	3	***T0105*** (Windhoek-Rehoboth)	4483	3.70	34	-
	4	***T1002_2*** (Eenhana- Okongo)	1248	3.55	39	-
	5	***T0110* (Tsumeb- Oshivelo)**	**991**	**3.70**	**29**	**178**
Criteria 2	6	***T0112*** (Ondangwa- Onhuno)	2585	3.20	30	-
	7	***M0092*** (Ondangwa-Oshakati)	9399	3.10	20	-
	8	***T1002_1*** (Onhuno-Eenhana)	1699	3.40	26	-
	9	***T0111_1*** (Omuthiya-Onethindi)	1435	3.50	53	-
	10	***T0107* (Otjiwarongo-Okahandja)**	**1973**	**3.30**	**62**	**155**

5.4.1. General Perceptions and Opinions Regarding Road Safety on Rural Roads

Survey Responses:

1. How often do you use this road section and for what purpose?

Figure 5.2 shows that 88% of the participants on the T0107 road cited that they "always" use the road section as they travel long distances and commute to work, compared to 91% on the T0110 road that use the road section for the same purposes. 11% of the participants on the T0107 section use the road "sometimes", to travel for leisure activities (Lodges and game farms), compared with 5% of the participants on the T0110 section that use the road for similar purposes. 1% of the survey participants on the T0107 section mentioned that they "rarely" used the road section, compared with 4% of the participants on the T0110 section.

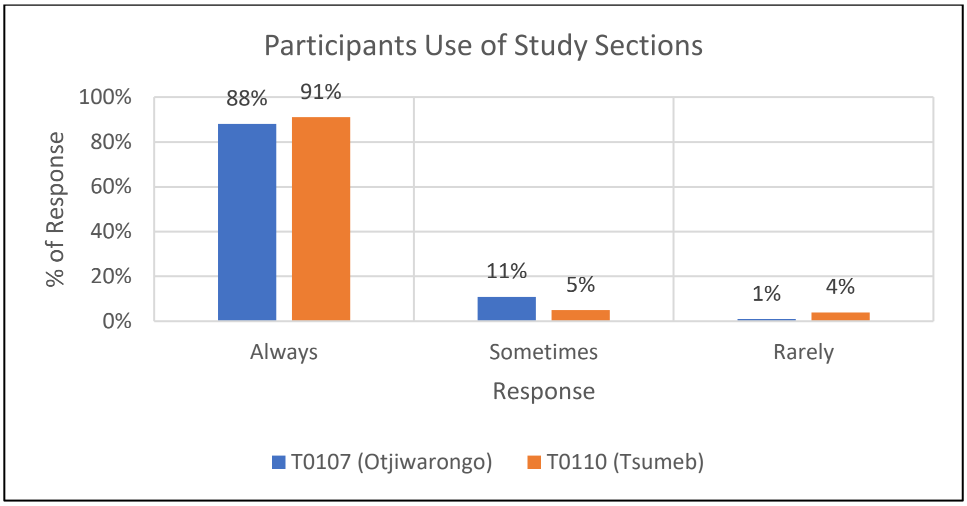

Figure 5.2 Survey Participants Use of the Road Sections

2. In your opinion, is this road section safe/ unsafe? Why?

Figure 5.3 indicates that 96% of the participants on T0107 described the section as “unsafe”, while 4% of the participants traversing the study section described it as “safe”. 95% of the participants on the section T0110 described the section as “unsafe”, while 5% of the participants found the study section to be “safe” for travelling. On T0107, 87% of the participants cited “reckless and negligent driving” as a major cause for concern, 11% of the participants mentioned “road unworthy vehicles”, while 2% of the drivers mentioned dangerous pavement conditions (“pavement rutting and cracks”). On study section T0110, 70% of the drivers mentioned “reckless and negligent driving” as the major reason why they felt the study section was not safe, 19% of the drivers cited poor road conditions (“pavement cracks”) and design (“long- straight road sections causing driver fatigue”), while 11% of the drivers mentioned the poor condition of vehicles on the road section. Statistical analysis shows that the study road sections have the highest number of fatal crashes per km travelled on the Namibian rural road network, as indicated in Table 4.1, confirming the perception of majority of the drivers’, that the road sections are “unsafe”.

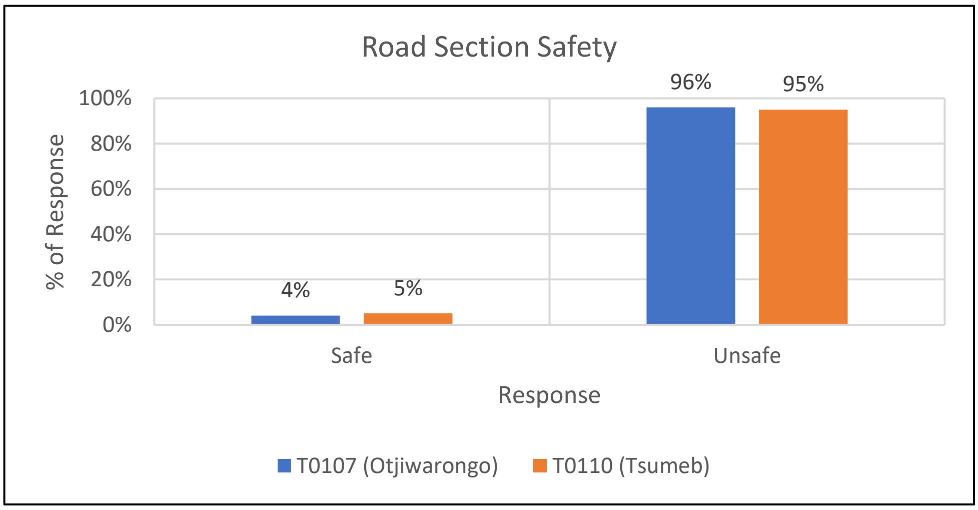

Figure 5.3 Survey Participants Views on Road Sections Safety

3. What do you feel constitutes a major safety problem on this road?

87% of the drivers on T0107 cited "reckless and negligent driving" as a major safety concern on the study section, as "drivers are ignorant of the traffic rules and are not considerate of other road users". 11% of the drivers mentioned that "road unworthy vehicles pose a safety threat to all road users". 2% of the respondents mentioned that "pavement rutting and cracks" contribute to the poor road conditions on the section, which consequently leads to safety issues on the road. On section T0110, 70% of the drivers cited "reckless and negligent driving" as a major safety issue on the section. 11% of the drivers mentioned that "pavement cracks and long straight sections contribute to driver fatigue and safety hazards" on the section, while 19% of the respondents cited poor vehicle conditions as a safety issue on the study section. Figure 5.4 illustrates the safety issues on the study sections.

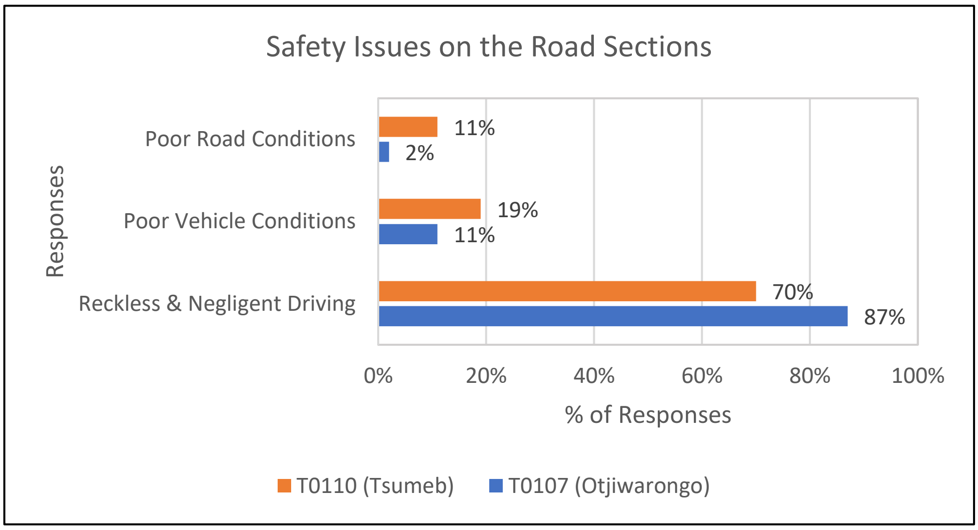

Figure 5.4 Road Sections Safety Issues

4. What risky behaviour have you observed being made by other drivers on this road?

On study section T0107, 45% of the respondents mentioned that "distracted drivers not paying attention to the road environment posed the highest safety threat, as they make unexpected turns and movements". 41% of the respondents mentioned speeding as a significant safety issue, while 14% of the respondents cited "reckless overtaking" as one of the key safety issues observed on the section. On study section T0110, 47% of the participants typically mentioned that "distracted drivers are a common scene on the road, usually committing driver errors that can potentially be fatal". 46% of the participants mentioned that speeding on the study section was very prevalent on the road. Drivers mentioned that "the posted speed limits are largely ignored" on the road section. Reckless overtaking was mentioned as one of the observed risky manoeuvres on T0110 by 7% of the participants. The risky road behaviour perceptions of respondents on the two road sections are illustrated in Figure 5.5.

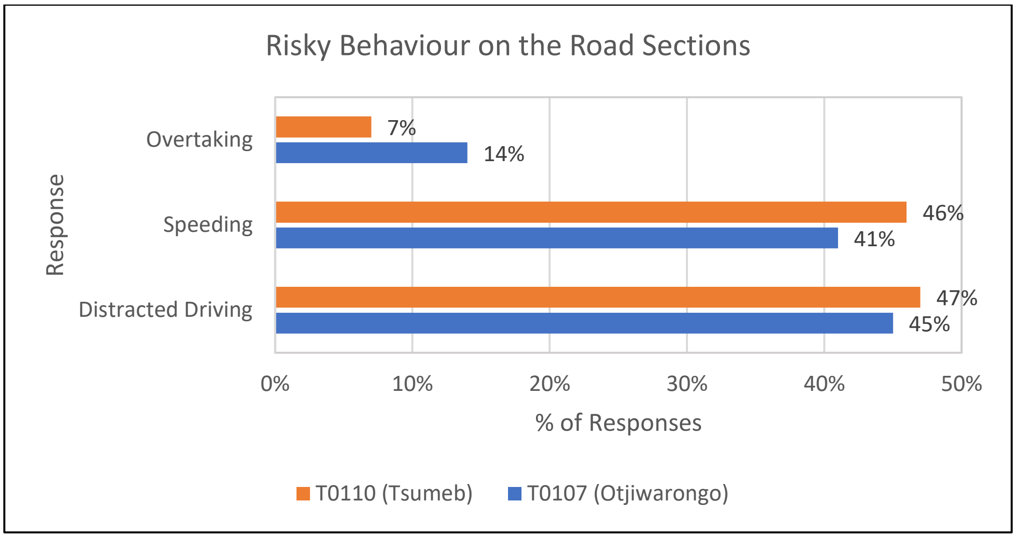

Figure 5.5 Risky Road Behaviour Observed by Survey Participants

5.4.2. Driver Awareness of Physical Road Design Elements while Driving

Survey Responses:

1. What impact does the number of lanes on the road have on your driving?

Figure 5.6 shows that the number of lanes available on a road section has a high impact on 71% of the participants on T0107, compared to 78% on T0110 road section. Participants typically cited that they "tend to take more risks on single carriageways, compared to multi- lane roads, through speeding and reckless overtaking, due to limited manoeuvring space". 23% and 19% of the respondents on T0107 and T0110 respectively, mentioned that the number of lanes has a "moderate" impact on their driving behaviour. 6% of the participants on T0107 mentioned that the number of lanes has a low impact on their driving behaviour, compared to 3% of the participants on T0110.

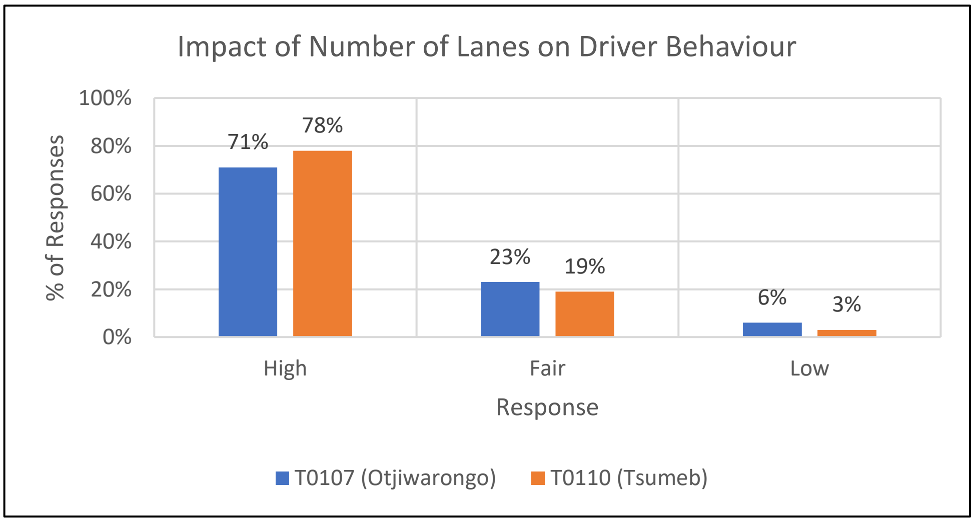

Figure 5.6 Impact of Number of Lanes on Survey Participants Driving Behaviour

2. How do narrow lane widths impact your driving behaviour, compared to wider lane widths?

89% of the respondents on T0107 cited that lane widths have a high impact on their driving behaviour, compared to 82% of the participants on T0110. The participants mentioned that they "drive slower, cautiously and are very alert on narrow lanes, as the driving errors are more likely to be fatal". The statistical analysis showed that driver speed selections (112.9km/h) are higher on road sections with lane widths greater than 3.50m (wider lanes), in comparison with speed selections (103.3km/h) on roads with lane widths equal to or less than 3.50m (narrow lanes). 9% and 15% of the respondents on T0107 and T0110 respectively cited that lane widths have a fair impact on their driving behaviour, while 2% and 3% of the participants on T0107 and T0110 respectively stated that lane widths have a low impact on their driving behaviour, as illustrated in Figure 5.7.

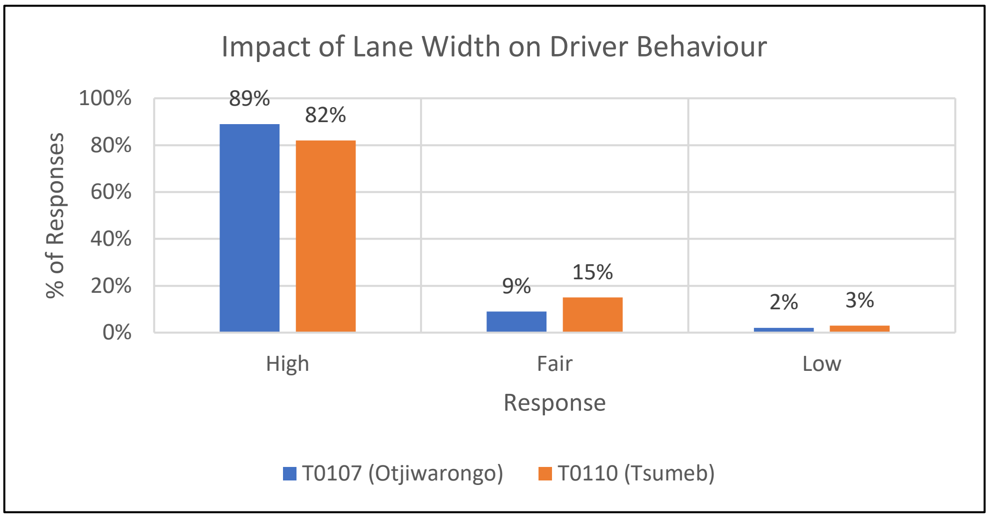

Figure 5.7 Impact of Lane Widths on Survey Participants Driving Behaviour

3. How is your driving behaviour impacted by the presence of a paved hard shoulder, compared to the absence of a paved hard shoulder?

Figure 5.8 illustrates that the presence of a paved high shoulder has a high impact on 83% and 76% of the participants on T0107 and T0110 respectively. Participants mentioned that the presence of a paved hard shoulder "allows for a driver to safely get off the road due to emergencies and allows for overtaking manoeuvres to safely take place". 14% and 19% of the respondents on T0107 and T0110 respectively cited that the presence/ absence of a paved hard shoulder has a fair impact on their driving behaviour, with a low impact cited by 3% and 5% of the participants on T0107 and T0110 respectively.

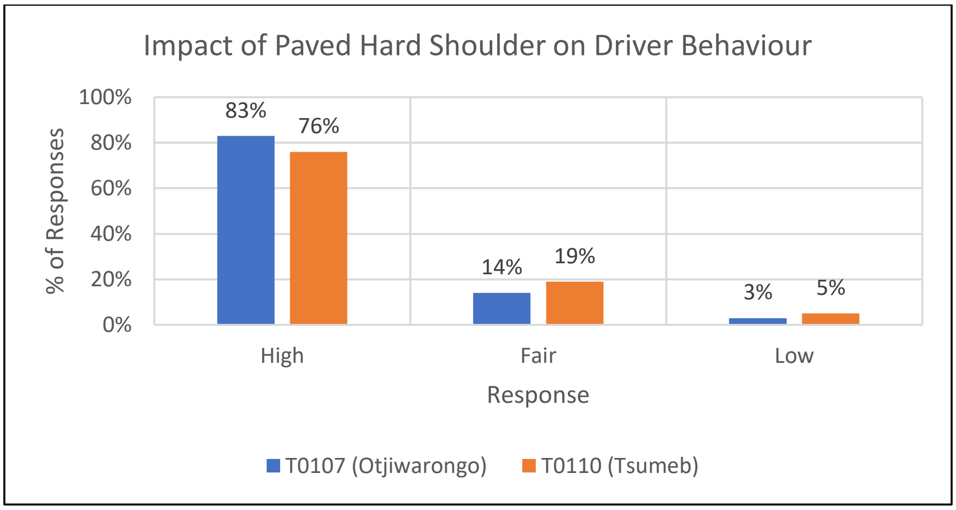

Figure 5.8 Impact of Paved Hard Shoulder on Survey Participants Driving Behaviour

4. How does the presence of a wider hard shoulder (paved) affect your driving behaviour, compared to a narrow hard shoulder (paved)?

85% and 81% of the participants on T0107 and T0110 believed that a wider hard shoulder has a high impact on their driving behaviour. One participant mentioned that "a wider hard shoulder allows them to give adequate space to overtaking vehicles and increases their chances of avoiding head on and side swipe collisions, as they have more space to manoeuvre". 6% and 14% of the participants on road sections T0107 and T0110 respectively, mentioned that the width of a hard shoulder has a fair impact on their driving behaviour, while 9% and 5% of participants on sections T0107 and T0110, mentioned that the width of the hard shoulder has a low impact on their driving behaviour, as illustrated in Figure 5.9. The statistical analysis found that pavements with a greater width (including the paved shoulder width), lead to drivers selecting higher speeds, due to a sense of safety and space to correct driving errors, compared with lower speed selections on narrower pavement widths. The study found that roads with greater widths had higher correlations between fatal crashes and road design elements, compared with lower correlations on roads with narrower widths.

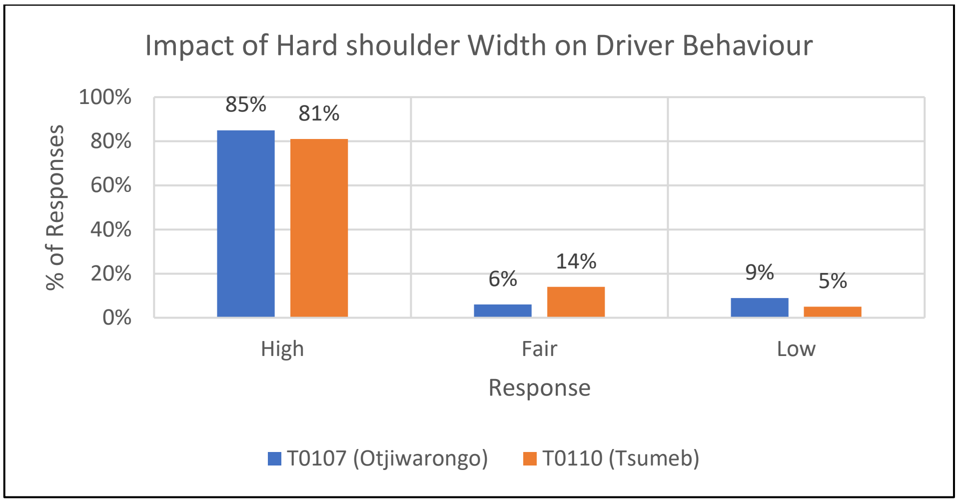

Figure 5.9 Impact of Hard Shoulder Width on Survey Participants Driving Behaviour

5. What influence does the Posted Speed Limit (PSL) have on your driving behaviour?

Figure 5.10 shows that 52% of the participants on T0107 responded that the PSL has a high impact on their driving, compared to 40% of the participants that cited a “low” impact, mentioning that “low traffic enforcement presence on the section” is the reason why the PSL has a low impact on their driving behaviour. 8% of the participants mentioned that the PSL has a fair impact on their driving behaviour. On T0110, 49% of the participants cited that the PSL has a high impact on their driving behaviour compared with 47% of the participants that stated that PSL has a low impact. 4% of the participants stated that the PSL has a low impact on their driving behaviour. Figure C.2 and Figure C.9 in Addendum C show that the traffic control on the study sections is almost non- existent, explaining the significantly high “low impact” response that the PSL has on the drivers using the study road sections.

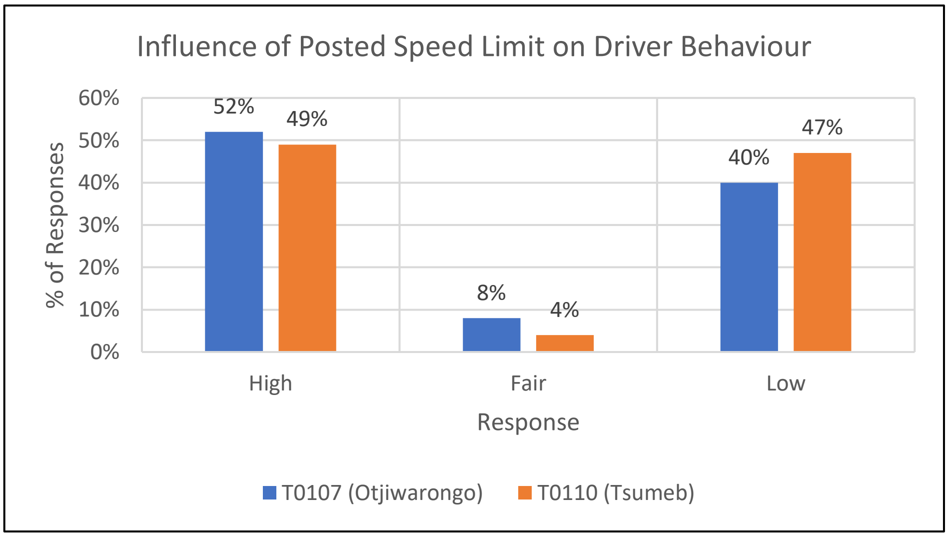

Figure 5.10 Influence of Posted Speed Limit on Survey Participants Driving Behaviour

6. How does the volume of MVs on the road section impact your driving behaviour?

83% and 76% of the drivers on T0107 and T0110 respectively, stated that traffic volume has a high impact on how they behave on the roads. One driver mentioned that “high traffic volumes cause one to overtake more often so as to reduce the travel time”, consequently leading to reckless driving and overtaking. In contrast, 7% and 3% of participants on T0107 and T0110 respectively responded that traffic volume has a low impact on their driving behaviour, as they “use alternative routes to avoid increasing the travel time”. 10% and 21% of the drivers responded that traffic volume has a fair impact on their driving behaviour, as illustrated by Figure 5.11.

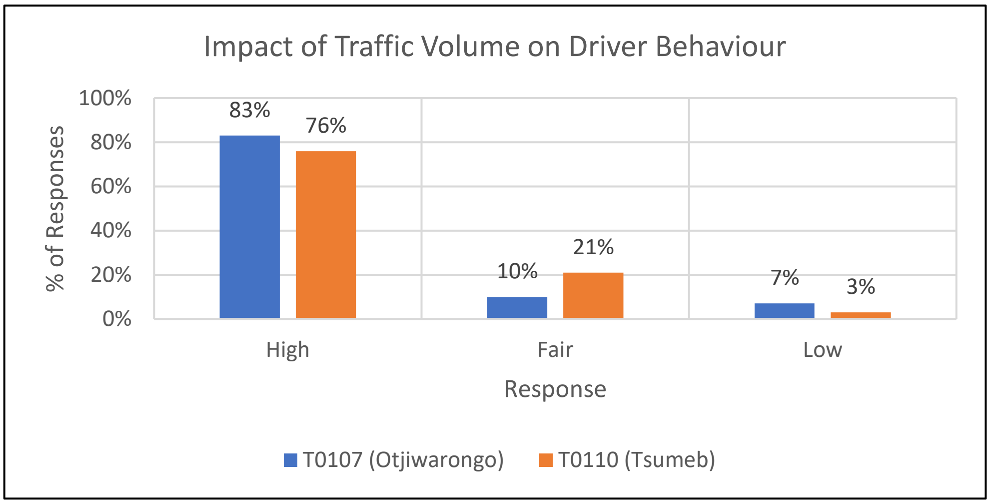

Figure 5.11 Impact of Traffic Volume on Survey Participants Driving Behaviour

7. How does the presence of a Horizontal Curve (Road bends that allow for change of direction) impact your driving?

The presence of a horizontal curve on the study sections has a high impact on 94% and 89% of the drivers on T0107 and T0110 respectively. One driver mentioned that they are “more cautious and reduce their speed considerably, when navigating a horizontal curve”. The statistical analysis in the models developed, showed that the radius of the horizontal curves has a significant influence on the safety of drivers traversing the study sections. 6% and 11% of the drivers on T0107 and T0110 responded that the presence of a horizontal curve has a fair impact on how they drive, as Figure 5.12 illustrates.

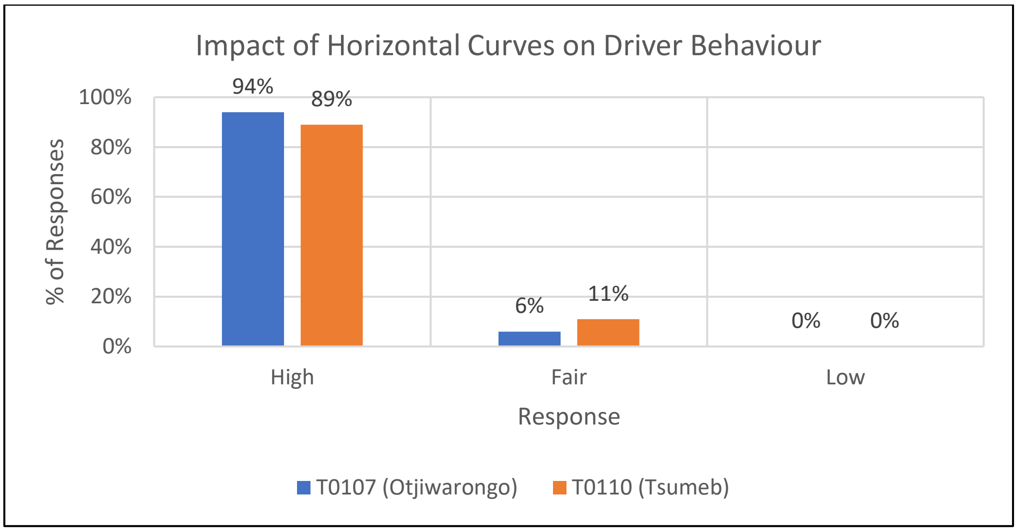

Figure 5.12 Impact of Horizontal Curves on Survey Participants Driving Behaviour

8. What impact does road engineering and design have on your driving behaviour?

Eighty three percent (83%) and ninety percent (90%) of the drivers on T0107 and T110 respectively, acknowledged that road engineering and design has a major impact on their driving and safety. The drivers mentioned that "it affects how safely, timeously and comfortably they can traverse the study sections". In contrast, 2% of participants on both study sections responded that road engineering and design has a low impact on their driving. 15% and 8% of the participants on T0107 and T0110 respectively responded that road engineering and design has a moderate impact on their driving behaviour, as illustrated in Figure 5.13.

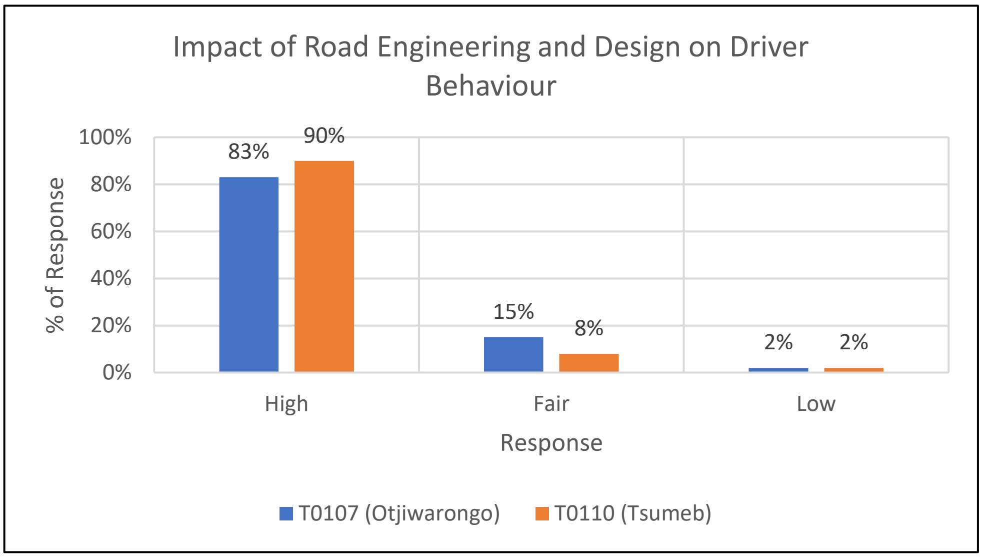

Figure 5.13 Impact of Road Engineering and Design on Survey Participants Driving Behaviour

9. In your opinion, to improve road safety, what road safety measures should the traffic authorities focus on?

Seventy five percent (75%) and fifty two percent (52%) of the participants on T0107 and T0110 respectively, cited traffic enforcement as a measure that would greatly improve road safety. Drivers on the study sections mentioned that "increasing the presence of traffic law enforcement on the road would deter drivers from violating the traffic rules". 21% and 33% of the drivers on T0107 and T0110 respectively were of the view that "increasing traffic penalties will dissuade drivers from engaging in risky and potentially fatal driving behaviour". 4% and 15% of the respondents on T0107 and T0110 respectively, mentioned that "more road safety campaigns and an increase in public discourse on road safety will lead to a reduction in fatal crashes". Figure 5.14 illustrates the safety measures suggested by the participants.

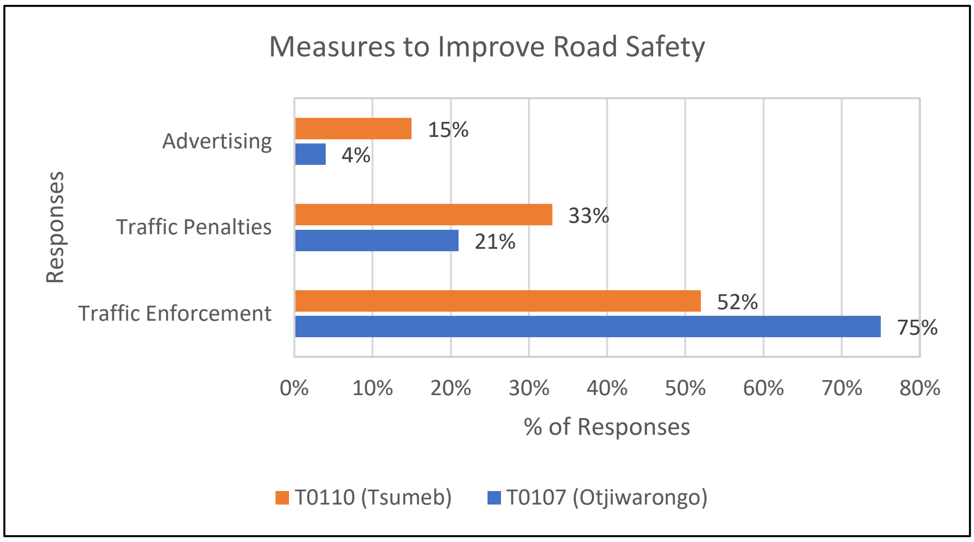

Figure 5.14 Measures to Improve Road Sections Safety

6. Conclusions and Recommendations

6.1. Introduction

The focus of the study was to develop and understanding of the potential relationship between road design elements shown in Table 3.1 and the occurrence of fatal crashes on the identified study sections in Table 4.1. The study developed Negative Binomial Regression (NBR) models to identify multiple relationships between fatal crashes and a combination of rural road design elements on the Namibian rural road network. In addition, with the use of a survey, an understanding of drivers' perception of road safety and awareness of the physical road design elements on the study section was developed. The road audit performed found that a significant number of road design elements on the study sections did not comply with the ***Technical Recommendations for Highways 17 on the Geometric Design of Rural Roads*** Standards (CSRA, 1988) used in Namibia.

6.2. Road Design Audit

Road information on cross sectional and horizontal curve design was provided by the Roads Authority of Namibia and assessed against the Technical Recommendations for Highways 17 (CSRA, 1988) design guidelines used for road design in Namibia. It was important to assess the compliance of the road sections with the highest number of fatal crashes per km, with the TRH 17 Geometric Design of Rural Roads Standards (CSRA, 1988) used to develop the roads. The study found that two fifths of the study sections do not meet the TRH design requirements with respect to lane widths, while half of the road sections do not comply with the TRH 17 (CSRA, 1988) design requirements for unsurfaced shoulder widths. None of the study road sections comply with the TRH 17 (CSRA, 1988) surfaced shoulder design requirements for their design classes, while ninety percent of the road sections do not meet the TRH 17 (CSRA, 1988) design requirements for unsurfaced shoulder cross fall.

The ground shoulder widths on rural roads T1002_1 and T1002_2 are under designed and consequently do not satisfy the TRH 17 (CSRA, 1988) recommendations. The lane width on rural road T0107 is less than the lane width recommended by the TRH 17 (CSRA, 1988). The lane width and ground shoulder widths on rural road T0112 do not satisfy the TRH 17 (CSRA, 1988) recommendations, as they are under designed for the Design Classes of the two roads.

Two rural roads, namely M0092 and T0106, did not satisfy any of the TRH 17 (CSRA, 1988) recommendations regarding lane, ground shoulder and median widths. Section M0092 has lane and ground shoulder widths that are under designed for the roads' Design Class. Road section T0106 has an over designed lane width and an under designed ground shoulder width that do not satisfy the recommended widths by the TRH 17 (CSRA, 1988). The TRH 17 on the Geometric Design of Rural Roads (CSRA, 1988) recommends that roads M0092 and T0106 employ the use of a median, due to the high traffic volumes experienced on the two roads.

Rural road study section T1002_2, is the only road that satisfied the TRH 17 (CSRA, 1988) design requirements on unsurfaced road shoulder cross falls, having a cross fall of 4% on the unsurfaced road shoulder. Nine of the ten study sections have cross falls ranging from 2.4% to 3.3%, which are below the TRH 17 (CSRA, 1988) recommendation of 4%. All the study sections used in the study satisfied the 2-3% lane grade, recommended by the TRH 17 (CSRA, 1988). The study sections have lane grades ranging from 2.2% to 3%, as recommended by the TRH 17 (CSRA, 1988).

The radii of the Horizontal Curves on road sections T1002_1, T0111_1, T0111_2, T0107 and T0110 complied with the minimum curve radii (530m) recommended by the TRH 17 (CSRA, 1988), with horizontal curve radii's ranging from 600m to 5550m. HC 7 on road section T0112 (240m) and HC 5 (300m) and HC 11 (350m) on T0106 have curve radii equal to and less than the critical curve radius (350m) respectively. These horizontal curves have a higher crash risk level compared with the crash risk level on other study horizontal curves.

HC 4 and HC 12 on section T0112, HC 5 on M0092, HC 11 on T0106, HC 5 on T0105 and HC 4 on road section T1002_2, did not comply with the minimum curve radius (530m) recommended by the TRH 17 (CSRA, 1988), despite having radius above the critical radius (350m). Horizontal curves that do not comply with the required design standards pose a safety threat to road users, due to the potential inaccurate perceptions of the road elements by road users, leading to inappropriate driver speed selections and manoeuvres on the road sections.

6.3. Relationship between Fatal Crashes and Road Design Elements

The road safety investigation identified rural road section with the highest fatal crashes per km, using Post-Crash analysis approaches. Fatal crash information on the 365 fatal crashes recorded on the ten road sections for the period from 2013 to 2016, and maintenance databases for these sections over the same period, were used to find potential correlations between fatal crashes and the road design elements on the ten identified study sections.

The study locations were divided into two groups, using lane width as the criterion for the grouping. Road sections with a lane width of less than or equal to 3.5m were separated from road section with lane width greater than 3.5m, for the statistical analysis. Using Statistica, Negative Binomial Regression (NBR) models identifying significant correlations between fatal crashes and road design elements were developed in the study. The Negative Binomial Regression technique was used in evaluating the influence of road elements and parameters on the occurrence of fatal crashes. The results of the analysis were considered significant if the correlation coefficient R^2 was significant at alpha level of 0.05 (5%).

For ***Criteria 1***, road sections with lane widths greater than 3.5m, the Negative Binomial Regression models found five statistically significant relationships between fatal crashes and a combination of several road design elements on the study section. A statistically significant relationship (p value=

0.000) was found to exist between the fatal crashes, and a combination all the road design elements (the 85th percentile speed, road length, the access control, lane width, the number of horizontal curves, the horizontal curve radius and the ground shoulder width), with 95% of the variance in fatal crashes accounted for by the model. The ***85th percentile speed*** (p value= 0.000) and the ***lane width*** (p value= 0.039) parameters were found to significantly predict fatal crashes in the NBR statistical model.

Fatal crashes (FC/km) and a combination of lane widths and ground shoulder widths on the study sections had a statistically significant relationship (p value= 0.000), with the ***ground shoulder width*** (p value= 0.000) parameter significantly predicting fatal crashes. More than eighty percent (84.1%) of the variance in the fatal crashes was accounted for by the statistically significant model.

A statistically significant relationship between fatal crashes, and a combination of ***horizontal curve radii, lane widths*** and the ***85th percentile speed***, exists on study sections with a lane width greater than 3.50m. The three predictor variables were found to significantly predict fatal crashes on the study sections, indicated by their p values of 0.007, 0.025 and 0.000 respectively. The regression model had a probability value of 0.000, significant at a 95% confidence level, while accounting for more than ninety percent (95.3%) of the variance in fatal crashes on the study sections.

The combination of the ***number of horizontal curves*** (p value= 0.030) and the ***radius of the horizontal curves*** (p value= 0.001) on the study section, was found to significantly influence the occurrence of fatal crashes. The regression model accounted for more than eighty percent (85.3%) of the variance in the fatal crashes, with a probability value of 0.000, significant at alpha level 0.05 (5%).

The relationship between fatal crashes, access control and the length of the road was found to be statistically significant, as indicated by the models 'probability value of 0.0024, significant at alpha level 0.05 (5%). The ***access control*** (p value= 0.001) parameter was found to significantly predict fatal crashes on the study sections. In contrast, the road length parameter had a p value (0.758) greater than the alpha value of 0.05 (5%) set for the NBR model. The correlation coefficient R^2 suggested that less than fifty percent (41.5%) of the variance in fatal crashes was accounted for by the model.

For ***Criteria 2***, road sections with lane widths less than or equal to 3.5m, the Negative Binomial Regression models identified four statistically significant relationships between a combination of various road design elements and the occurrence of fatal crashes on the study sections. The regression analysis found that a statistically significant relationship (p value= 0.0012) existed between the fatal crashes and all the road design elements (the 85th percentile speed, road length, the access control, lane width, the number of horizontal curves, the horizontal curve radius and the ground shoulder width), on the study sections with lane widths less or equal to 3.50m, with the ***lane***

width parameter significantly predicting (p value= 0.001) fatal crashes. The statistical model accounted for slightly more than two thirds (68.7%) of the variance in fatal crashes on the study section.

The analysis found a statistically significant (p value= 0.000) correlation between fatal crashes, lane width, ground shoulder width and the horizontal curvature radius. The statistical NBR model accounted for three quarters (75.2%) of the variance in fatal crashes at a 95% confidence level. The ***lane width*** (p value= 0.000) and ***ground shoulder width*** (p value= 0.007) were found to significantly predict fatal crashes in the statistical model.

Fatal crashes, access control and the road length exists, had a statistically significant (p value= 0.033) relationship, significant at a 95% confidence level. The model had a very low correlation coefficient, with the predictors accounting for less than twenty percent (19.8%) of the variance in fatal crashes on the study sections. The **access control** parameter was found to significantly predict (p value= 0.011) fatal crashes in the NBR statistical model, at 0.05 (5%) alpha level.

The NBR analysis found that the combination of the road ***length*** (p value= 0.024) and the ***number of horizontal curves*** (p value= 0.004) significantly predicted fatal crashes on study sections with lane widths less or equal to 3.50m. The statistically significant model (p value= 0.017) accounted for less than a quarter (24.8%) of the variance in the fatal crashes, at a 95% confidence level.

The road length had statistical significance in predicting fatal crashes on roads where the lane width was equal to or less than 3.50m, while no statistically significant relationship was found for the road length, on study sections with lane widths greater than 3.50m. The radius of the horizontal curves and the 85th percentile speed were statistically significant in predicting fatal crashes on the study sections with lane widths greater than 3.50m.

Access control was found to have a high statistical impact on roads with lane widths greater than 3.50m, which have a high 85th percentile operational speed of 112.9 km/h, in comparison to the low statistical impact it has on roads with lane widths equal to or less than 3.50m, which have 85th percentile operational speeds of 103.3km/h. The case studies in Section 2.8 also affirm that access control has a high impact on fatal crashes on roads with high operational. The lane width, access control, number of horizontal curves and ground shoulder widths were found to have statistically significant relationships with fatal crashes, at different levels, on all the study sections.

All the study sections had posted speed limits of 120km/m and had the highest fatal crashes rates on the Namibian rural road network. Road sections with higher posted speed limits on the Namibian rural road network pose a higher safety risk in comparison to roads with lower posted speed limits. High correlations between the road design elements were found on study sections with lane widths greater than 3.50m, in contrast to low correlations found on study sections with lane widths equal to or less than 3.50m. Therefore, strong statistical relationships between fatal crashes and road design elements exists on roads with lane widths greater than 3.50m.

6.4. Survey

The survey on drivers' perceptions on road safety and awareness of the road design elements while driving, was imperative in establishing the causation of fatal crashes and developing an understanding of the impact of the physical road environment on driver behaviour on Namibian rural roads. Using the lane width as the main criteria in choosing the survey locations, surveys were carried out on two representative study locations, namely T0110 (Tsumeb-Oshivelo), with lane widths greater than 3.50m and T0107 (Otjiwarongo-Okahandja), with lane widths less than or equal to 3.50m. A combined total of 333 drivers participated in the survey, with 178 surveyed on the T0110 road section and 155 surveyed on the T0107 road section.

6.4.1. General Perceptions and Opinions regarding Road Safety on Namibian Rural Roads

More than eighty five percent of the participants on road sections T0107 and T0110 cited that they "always" use the road sections on a regular basis. This is compared to less than fifteen percent of the participants on each study section who use the road sections "sometimes" or "rarely". The road safety of the study sections was generally considered hazardous. A significantly high number of the participants stated that the study sections are "unsafe" for road users, representing more than ninety percent of all the participants on each study section. This assessment was affirmed by the analysis, with the study road sections having the highest fatal crashes per km, on the Namibian rural road network.

When asked about the most common safety issues on the road sections, more than eighty five percent (87%) and almost three quarters (70%) of the passengers on T0107 and T0110 respectively, cited reckless and negligent driving as a major road safety issue on the study sections. The passengers mentioned that "most drivers violate traffic rules willingly and are inconsiderate of other road users". Pavement cracks and rutting were cited as a safety issue by less than five percent (2%) of the respondents on T0110, while slightly more than ten percent (11%) of respondents on T0107 mentioned that "pavement cracks and long straight sections" contributed to poor road conditions and driver fatigue on the study section.

On road sections T0110 and T0107, less than half of the respondents (47% and 45% respectively) mentioned that "distracted drivers are a dangerous feature on the roads". Slightly more than forty percent (41%) and slightly more than forty five percent (46%) of participants on sections T0107 and T0110 respectively, cited speeding as a notable road safety risk factor on the study sections, as the posted speed limits are "largely ignored" on the roads.

6.4.2. Driver Awareness of Physical Road Design Elements while Driving

Slightly less than three quarters (71%) of participants on T0107 and slightly more than three quarters (78%) of participants on T0110 stated that the number of lanes available on the roads have a "high" impact on their driving. The respondents mentioned that due to limited manoeuvring space on single carriage ways, they tend to speed and overtake more to reduce travelling time on the study sections, in contrast, less than ten percent (6% and 3% respectively) of the respondents stated that the number of lanes had a low impact on their driving behaviour. More than eighty percent of the participants on T0107 (89%) and T0110 (82%) mentioned that the width of the lanes available on the roads has a "high" impact on driver behaviour, with less than five percent (2% and 3% respectively) stating otherwise. The Negative Binomial Regression models found a statistically significant correlation between the lane widths and the occurrence of fatal crashes on the study sections. Study sections with greater lane widths experienced higher 85th percentile speeds, compared with the lower driver speed selections on roads with narrow lane widths.

The majority of the respondents on T0107 (83%) and T0110 (76%) mentioned that the presence of a paved hard shoulder has a high impact on how safely they can traverse the study sections, with more than eighty percent (85% and 81%) of the respondents on T0107 and T0110 respectively, stating that wider paved hard shoulder significantly impact their driving behaviour. The study showed that narrow roads (including paved shoulder width) caused drivers to choose lower speeds and to exhibit safe driving behaviour, compared with higher speed selections on wider roads, which give drivers a sense of security and safety while traversing the road sections. The study also found that drivers tend to use the hard shoulders during overtaking manoeuvres. The hard shoulders are not intended for such a purpose and this contributes to the safety issues on the study sections.

Slightly more than half (52%) and slightly less than half (49%) of the participant on T0107 and T0110 respectively, cited that the posted speed limit highly influences their driving behaviour on the roads, in contrast, forty percent (40%) and forty seven percent (47%) of the participants on T0107 and T0110 respectively, stating that the posted speed limit has a "low" impact on their driving. The low presence of law enforcement on the study sections, was cited as the reason for the low impact and non- compliance of the drivers to the posted speed limit.

The majority of the participants on study sections T0107 and T0110, with eighty three percent and seventy six percent respectively, stated that traffic volumes on the road sections has a "high" impact on how they traverse the roads. The respondents mentioned that they tend to overtake more often when the traffic volumes are high, to try and reduce the travelling time on the road. This leads to reckless driving behaviour, that is potentially dangerous and fatal to all road users.

Most of the participants on T0107 (94%) and T0110 (89%) stated that the presence of horizontal curves on the study sections greatly influenced their driving behaviour. The participants mentioned that they are “more cautious” and “significantly reduce driving speeds” when traversing a horizontal curves on the road. Majority of the participants on T0107 and T0110, acknowledged that road engineering and design highly influences the safety and convenience of using the study sections.

To tackle the precarious road safety situation on the study sections, three quarters (75%) of the respondents on T0107 suggested that an increase in the presence of law enforcement on the study section would deter drivers from violating the traffic rules, and/ or engaging in risky driving behaviour that potentially endanger all road users, in comparison, slightly more than half (52%) on T0110 suggested that the presence of more law enforcement would reduce the possibility of drivers violating traffic rules. In contrast, less than a quarter (21%) of the participants on T0107 stated that penalties for violating traffic rules should be increased, with a third of the respondents on T0110 echoing similar sentiments. An increase in publicity and advertising on road safety was suggested by less than five percent (4%) and fifteen percent of respondents on T0107 and T0110 respectively. Respondents firmly mentioned that more public discourse on road safety would encourage policy makers to favourably look at road safety policies, resulting in protection for all road users.

6.5. Limitations

Observations on the study locations could not be carried out, due to the resources required to traverse the study sections and the long distances between the study locations.

6.6. Recommendations

A strong statistical relationship between fatal crashes and road design elements exists on roads with lane widths greater than 3.5m. The roads have a higher 85th percentile speed in comparison to the road sections with lane widths equal to or less than 3.5m. Road safety programmes to sensitise drivers on these sections (LW> 3.5m) on the dangers of speeding and reckless driving, combined with a greater presence of law enforcement would potentially result in the reduction of crash rates on the sections.

The road audit has shown that half of the study sections have a ground shoulder width less than the recommended width by the TRH 17 (CSRA, 1988), with ninety percent of the study sections not having the required cross fall on the unsurfaced shoulders. 100% (10/10) of the study sections do not have the required surfaced shoulder width for their design classes, therefore, increasing the chances of drivers falling off the edge of the road surface. The traffic authorities are encouraged to carry out quality checks on existing and future roads, to address and deliver measures that address the short comings of the road design elements on the study sections.

Educational programmes on the importance of safe and undistracted driving should be promoted, to reduce the number of fatal crashes on the study sections. The traffic authorities tasked with road safety on Namibian rural roads should develop traffic safety campaigns and marketing programmes aimed at changing the reckless and negligent driving behaviour on the study road sections.

Promotion of the use of road public transport on the study sections and other public transportation modes should be encouraged, as the study showed that the majority of the vehicles involved in fatal crashes were light passenger vehicles. This will lead to a reduction in the number of vehicles traversing the study sections, and to a reduction in the number of passenger vehicles involved in fatal crashes.

6.7. Future Research

Future research on the influence of road design elements on the safety of urban roads and a study on the driver- pedestrian interaction in the urban road environment, are recommended.

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A. Addendum A (Tables)

Survey Results

Table A.1 Otjiwarongo Survey Point Results

Otjiwarongo Survey Point: 155 Participants			
Questions	Response	Total	Total (%)
General Perceptions and Opinions towards road safety on Namibian Rural Roads			
1. How often do you use this road section and for what purpose	Always	136	88
	Sometimes	17	11
	Rarely	2	1
2. In your opinion, is this road section safe/ unsafe? Why?	Safe	6	4
	Unsafe	149	96
3. What do you feel constitutes a major safety problem on this road	Reckless & Negligent Driving	135	87
	Poor Vehicle Conditions	17	11
	Poor Road Conditions	3	2
4. What risky manoeuvres have you observed being made by other drivers on this road?	Distracted Driving	70	45
	Speeding	64	41
	Overtaking	21	14
Driver Awareness of Physical road Design elements in their Driving			
1. What impact does the number of lanes on the road have on your driving behaviour?	High	110	71
	Fair	36	23
	Low	9	6
2. How do narrow lane widths impact your driving behaviour, compared to wider lane widths?	High	138	89
	Fair	14	9
	Low	3	2
3. How is your driving behaviour impacted by the presence of a paved hard- shoulder, compared to the absence of a paved hard- shoulder?	High	129	83
	Fair	22	14
	Low	4	3
4. How does the presence of a wider hard- shoulder (paved) affect your driving behaviour, compared to the presence of a narrow hard- shoulder (paved)?	High	132	85
	Fair	9	6
	Low	14	9
5. What influence does the Posted Speed Limit (PSL) have on your driving behaviour?	High	81	52
	Fair	12	8
	Low	62	40
6. How does the volume of MV's on this road section impact your driving behaviour?	High	129	83
	Fair	15	10
	Low	11	7
7. How does the presence of a horizontal curve impact your driving?	High	146	94
	Fair	9	6

	Low	0	0
8. What impact does road engineering and design have on your driving behaviour?	High	129	83
	Fair	23	15
	Low	3	2
9. In your Opinion, to improve road safety, what safety measures should Authorities focus on?	Traffic Enforcement	117	75
	Traffic Penalties	32	21
	Advertising	6	4

Table A.2 Tsumeb Survey Point Results

Tsumeb Survey Point: 178 Participants			
Questions	Response	Total	Total (%)
General Perceptions and Opinions towards road safety on Namibian Rural Roads			
1. How often do you use this road section and for what purpose	Always	162	91
	Sometimes	9	5
	Rarely	7	4
2. In your opinion, is this road section safe/ unsafe? Why?	Safe	9	5
	Unsafe	169	95
3. What do you feel constitutes a major safety problem on this road	Reckless & Negligent Driving	125	70
	Poor Vehicle Conditions	34	19
	Poor Road Conditions	19	11
4. What risky manoeuvres have you observed being made by other drivers on this road?	Distracted Driving	84	47
	Speeding	82	46
	Overtaking	12	7
Driver Awareness of Physical road Design elements in their Driving			
1. What impact does the number of lanes on the road have on your driving behaviour?	High	139	78
	Fair	34	19
	Low	5	3
2. How do narrow lane widths impact your driving behaviour, compared to wider lane widths?	High	146	82
	Fair	27	15
	Low	5	3
3. How is your driving behaviour impacted by the presence of a paved hard-shoulder, compared to the absence of a paved hard- shoulder?	High	135	76
	Fair	34	19
	Low	9	5
4. How does the presence of a wider hard- shoulder (paved) affect your driving behaviour, compared to the presence of a narrow hard- shoulder (paved)?	High	144	81
	Fair	25	14
	Low	9	5
5. What influence does the Posted Speed Limit (PSL) have on your driving behaviour?	High	87	49
	Fair	7	4
	Low	84	47
6. How does the volume of MV's on this road section impact your driving behaviour?	High	135	76
	Fair	38	31
	Low	5	3
7. How does the presence of a horizontal curve impact your driving?	High	159	89
	Fair	19	11

	Low	0	0
8. What impact does road engineering and design have on your driving behaviour?	High	160	90
	Fair	14	8
	Low	4	2
9. In your Opinion, to improve road safety, what safety measures should Authorities focus on?	Traffic Enforcement	93	52
	Traffic Penalties	59	33
	Advertising	26	15

B. Addendum B (Other Documents)

Survey Guide

The final version of the survey guide used in the study is provided below:

Driver Personal Information
Driver Experience:
Other Information
Date:
Road Section:

Please respond to the following questions

Driver Behaviour and Perceptions on the Road

1. Do you Drive?
2. How often do you use this road section and for what purpose?
3. In your opinion is the road section safe/ unsafe? Why?
4. What do you feel constitutes a major safety problem on this road?
5. What risky manoeuvres have you observed being made by other drivers on this road?

Road Design Elements

1. What impact does the ***number of lanes*** on the road have on your driving behaviour?
2. How do ***narrow lane widths*** impact your driving behaviour, compared to ***wider lane widths***?
3. How is your driving behaviour impacted by the ***presence*** of a hard shoulder, compared to the ***absence*** of a hard shoulder on this road?
4. How does the presence of a ***wider hard shoulder*** affect your driving behaviour, compared to the presence of a ***narrow hard shoulder***?
5. What influence does the ***posted speed limit*** have on your driving behaviour?
6. How does the ***volume*** of MVs on this road section impact your driving behaviour?
7. How does the presence of a ***horizontal curve*** (Road bends that allow for change of direction) impact your driving?
8. What impact does road engineering and design have on your driving behaviour?
9. In your opinion, to improve road safety, what safety measures should the Authorities focus on?

C. Addendum C (Additional Information)

Road Fatal Crash Data

a) Introduction

This section provides an analysis and discussion of the national fatal crash data on the Namibian rural road network, in comparison to the identified hazardous rural road study sections, during the study period of 2013 to 2016. The study sections were grouped according to the lane widths on the road sections. The fatal crash data for the study road sections was compared to the National rural road crash data, for road sections complying with the same lane width criteria. The following criteria was used to group the road sections:

1. Criteria 1: Lane width (LW) > 3.50m
2. Criteria 2: Lane width (LW) ≤ 3.50m

Table C.1 shows the grouping of the study road sections, according the lane widths on the study sections.

Table C.1 Rural Road Study Sections Grouping by Lane Widths

Classification	No	Section Name	AADT	LW (m)	Number of fatal crashes [a]	Fatal Crash Rate
Criteria 1	1	***T0106*** (Windhoek- Okahandja)	14005	3.80	39	0.03
	2	***T0111_2*** (Oshivelo- Omuthiya)	3019	3.55	33	0.12
	3	***T0105*** (Windhoek- Rehoboth)	4483	3.70	34	0.07
	4	***T1002_2*** (Eenhana- Okongo)	1248	3.55	39	0.21
	5	***T0110*** (Tsumeb- Oshivelo)	991	3.70	29	0.24
Criteria 2	6	***T0112*** (Ondangwa- Onhuno)	2585	3.20	30	0.22
	7	***M0092*** (Ondangwa- Oshakati)	9399	3.10	20	0.06
	8	***T1002_1*** (Onhuno- Eenhana)	1699	3.40	26	0.29
	9	***T0111_1*** (Omuthiya- Onethindi)	1435	3.50	53	0.27
	10	***T0107*** (Otjiwarongo- Okahandja)	1973	3.30	62	0.13

[a] Fatal crash rates represent the number of fatal crashes per 10^6 vehicle kilometres travelled

b) Criteria 1 Fatal Crash Data

The study sections meeting Criteria 1, with lane widths greater than 3.5m, had a total of ***174 fatal crashes*** during the study period of 2013 to 2016. The fatal crashes on road sections with lane widths greater than 3.5m represented ***47.7%*** of all the fatal crashes on the study sections.

1. Criteria 1 Terrain Distribution of Fatal Rural Road Crashes (2013- 2016)

Figure C.1 shows the distribution of fatal crashes between the different types of terrains during the study period of 2013 to 2016, comparing National and study road sections with lane widths greater than 3.50m. Close to two thirds (65%) of the fatal crashes on National roads with LW greater than

3.50m occurred on flat terrain, compared with slightly more than two thirds (68%) of the fatal crashes on the study sections that occurred on flat terrain. Slightly more than one third (35%) of the fatal crashes on the National sections occurred on sloped terrain, compared with slightly less than one third (32%) of the fatal crashes on the study sections that occurred on sloped terrain.

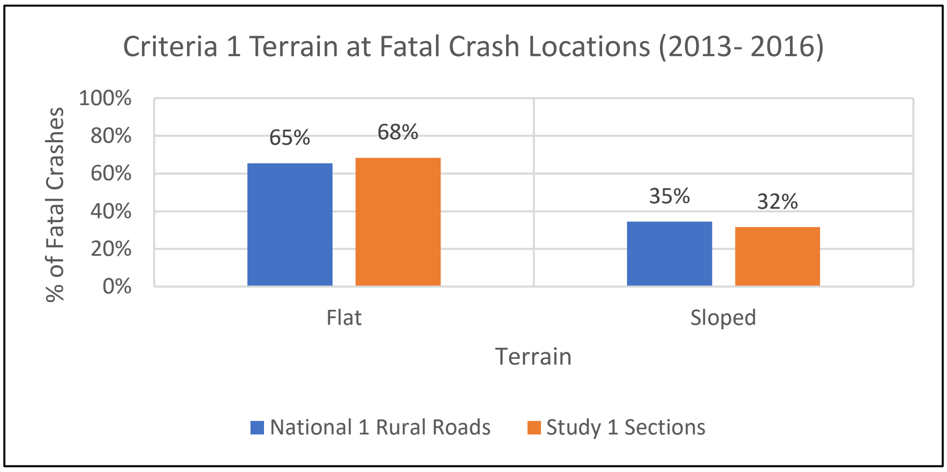

Figure C.1 Criteria 1 Terrain at the Fatal Crash Location (2013- 2016)

2. Criteria 1 Traffic Control at the Fatal Crash Locations (2013- 2016)

Figure C.2 shows the level of traffic control on the National and study rural road sections, with lane widths greater than 3.5m, on which fatal crashes occurred during the study period 2013 to 2016. Majority of the fatal crashes on both the national and study sections occurred on uncontrolled road sections, representing 99% of fatal road crashes Nationally and on the study road sections. Fatal crashes on controlled rural road sections represented 1% of all fatal crashes Nationally and on study road sections with lane widths greater than 3.50m. The study survey participants mentioned that the lack of traffic control on the study sections caused majority of the drivers to violate the traffic laws. Figure C.2 confirms the lack of traffic control cited by the survey participants on the study road sections.

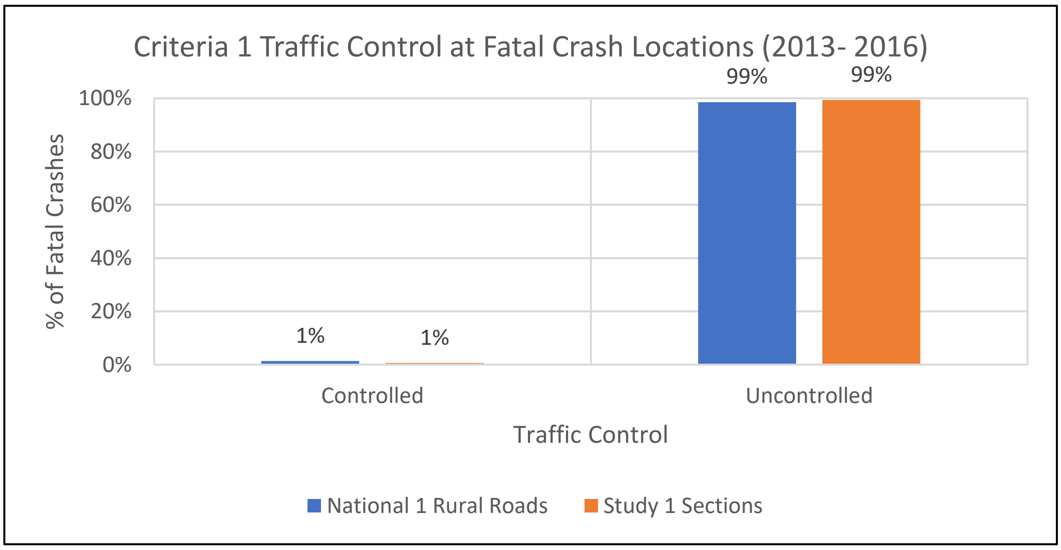

Figure C.2 Criteria 1 Level of Traffic Control at the Fatal Crash Locations (2013- 2016)

3. Criteria 1 Road Marking Type at Fatal Crash Locations (2013- 2016)

The road markings on the National and study road sections on which fatal crashes occurred during the study period of 2013 to 2016, are shown in Figure C.3. The highest number of fatal crashes on the National and study road sections occurred on roads with a dividing line, representing slightly less than three quarters (74% and 73% respectively) of all fatal crashes. The lowest number of fatal crashes on the National and study road sections occurred on roads with Channelising lines, representing 2% and 4% of all the fatal crashes respectively. No fatal crashes occurred on painted islands, on roads with lane widths greater than 3.50m.

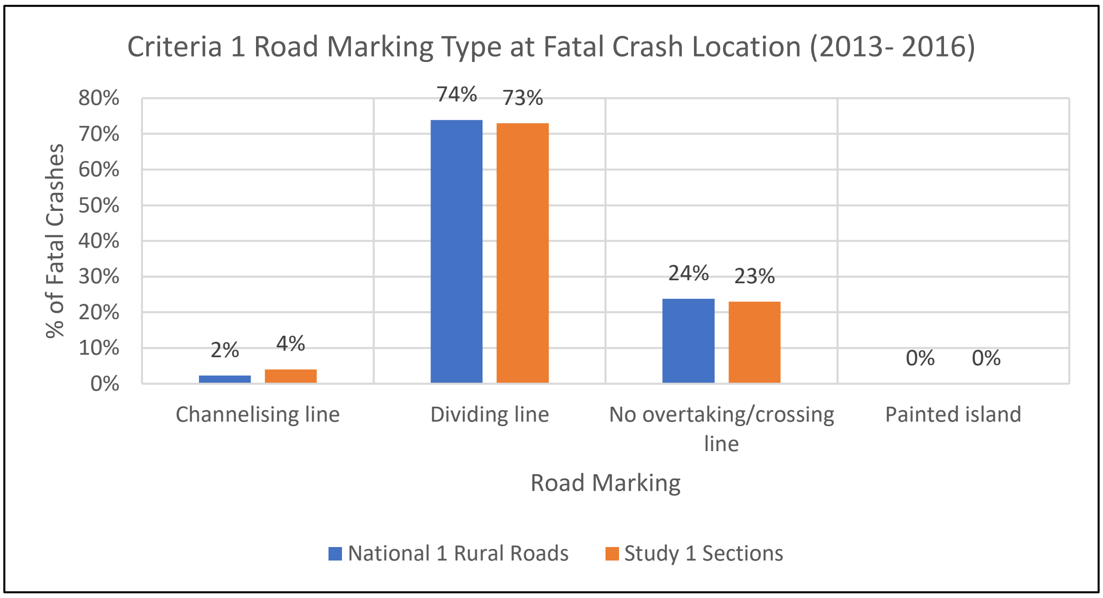

Figure C.3 Criteria 1 Road Markings at the Fatal Crash Locations (2013- 2016)

4. Criteria 1 Vehicle Numbers and Types Involved in fatal Crashes (2013- 2016)

Figure C.4 shows the number and types of vehicles involved in fatal crashes during the study period of 2013 to 2016, on National and study rural road sections. Nationally, a total of 950 vehicles were involved in fatal crashes on road with lane widths greater than 3.5m, representing 48.4% of the total vehicle population involved in rural road fatal crashes. On the study road sections, 249 vehicles were involved in fatal crashes on roads with lane widths greater than 3.5m, representing 47.2% of the total vehicle population involved in fatal crashes. Majority of the vehicles involved in fatal crashes Nationally and on study road sections were light passenger vehicles, representing 80% and 83% of the total vehicles involved in fatal crashes respectively. It is assumed that majority of the traffic on the road sections was light passenger vehicles during the study period of 2013 to 2016, indicating the reluctancy of road users in using public transport. Heavy vehicles involved in fatal crashes Nationally and on the study road section accounted for 20% and 17% of the total vehicle population involved in fatal crashes respectively.

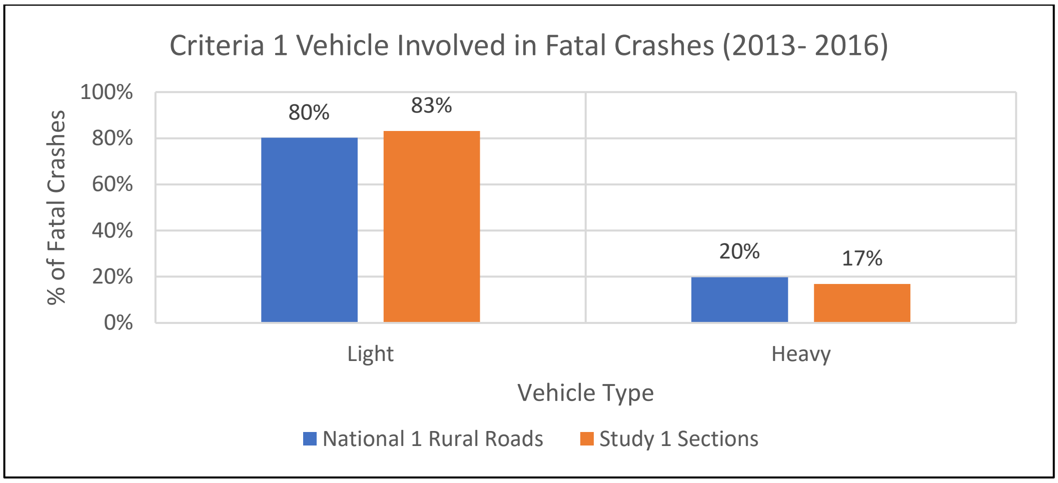

Figure C.4 Criteria 1 Vehicles Involved in fatal Crashes (2013- 2016)

5. Criteria 1 Weather Conditions at Time of Fatal Crash (2013- 2016)

Figure C.5 shows the weather conditions at the fatal crash locations Nationally and on the study road sections, during the study period of 2013 to 2016. The highest number of fatal crashes Nationally and on study road sections, occurred while the weather conditions were considered "clear" by the reporting authority, representing 70% and 74% of all fatal crashes respectively. The lowest number of fatal crashes Nationally occurred in "mist/fog" weather conditions, representing 2% of all fatal crashes, compared to the lowest number of fatal crashes on the study road sections, reported to have occurred in "unknown" weather conditions, representing 5% of all fatal crashes. No fatal crashes were recorded in "mist/fog" weather conditions on the study road sections.

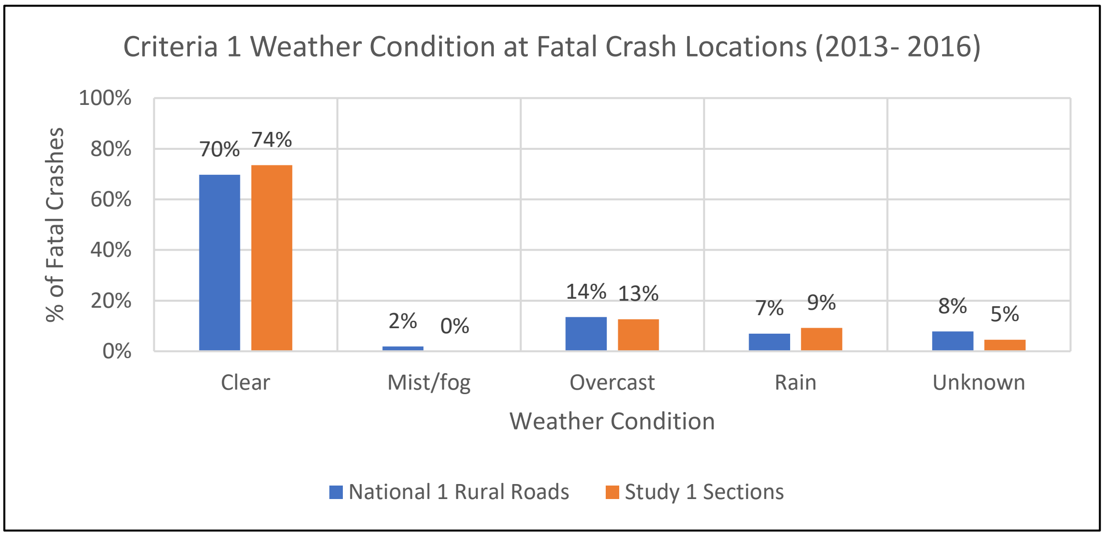

Figure C.5 Criteria 1 Weather Conditions at the Fatal Crash Locations (2013- 2016)

6. Criteria 1 Lighting Conditions at Time of Fatal Crash (2013- 2016)

The lighting conditions at the fatal crash locations Nationally and on study road sections with lane widths greater than 3.50m, during the study period of 2013 to 2016, are shown in Figure C.6. The highest number of fatal crashes Nationally occurred during "daylight" conditions, representing slightly less than half (49%) of all fatal crashes, compared with the highest number of fatal crashes on the study sections that occurred in "daylight" conditions, representing more than half (55%) of all the fatal crashes. The lowest number of fatal crashes Nationally and on study road sections occurred during the night, in "street lighting" conditions, representing 1% of all fatal crashes in each analysis.

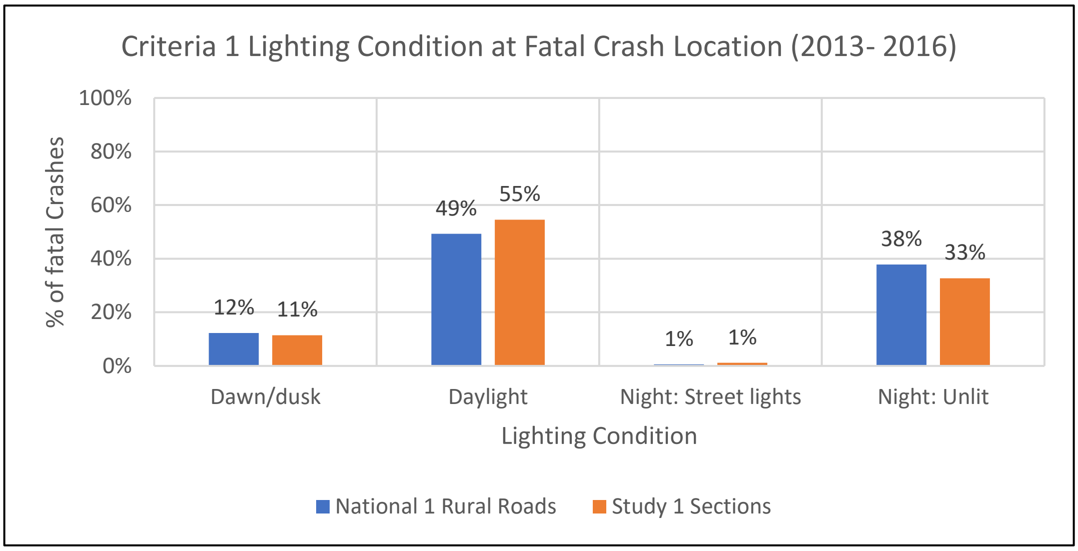

Figure C.6 Criteria 1 Lighting Conditions at the Fatal Crash Locations (2013- 2016)

7. Criteria 1 Visibility Conditions at Time of Fatal Crash (2013- 2016)

Figure C.7 shows the different visibility conditions at the fatal crash locations Nationally and on study road sections, during the study period of 2013 to 2016. The highest number of fatal crashes Nationally and on study road sections, occurred while the visibility conditions were considered "clear", representing 60% and 74% of all fatal crashes respectively. The lowest number of fatal crashes Nationally and on study road sections occurred in visibility conditions reported as "dusty", representing 4% and 5% of all fatal crashes respectively.

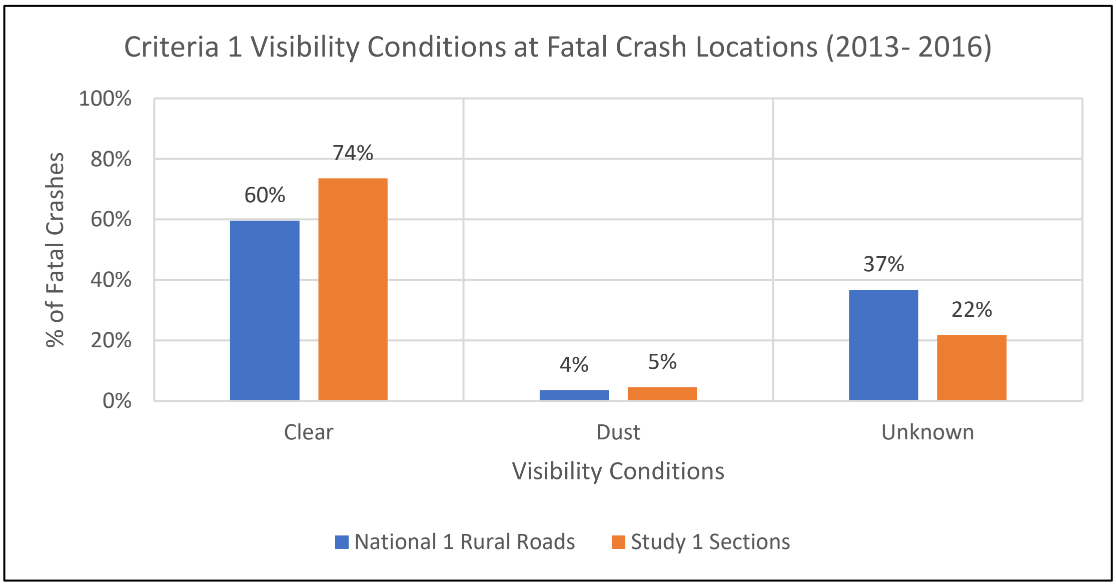

Figure C.7 Criteria 1 Visibility Conditions at the Fatal Crash Locations (2013- 2016)

c) Criteria 2 Fatal Crash Data

The study sections with lane widths equal to or less than 3.5m, therefore meeting Criteria 2, had a total of ***191 fatal crashes,*** representing 52.3% of all fatal crashes on the study sections, during the study period of 2013 to 2016.

1. Criteria 2 Terrain Distribution of Fatal Rural Road Crashes (2013- 2016)

Figure C.8 shows the terrain of the fatal crash locations Nationally and on study sections with a lane width equal to or less than 3.5m, during the study period of 2013 to 2016. The highest number of fatal crashes Nationally and on study road sections occurred on flat terrain, representing 83% and 81% of all fatal crashes respectively. Fatal crashes Nationally and on the study road sections, represented less than a fifth (17% and 19% respectively) of all the fatal crashes in each analysis.

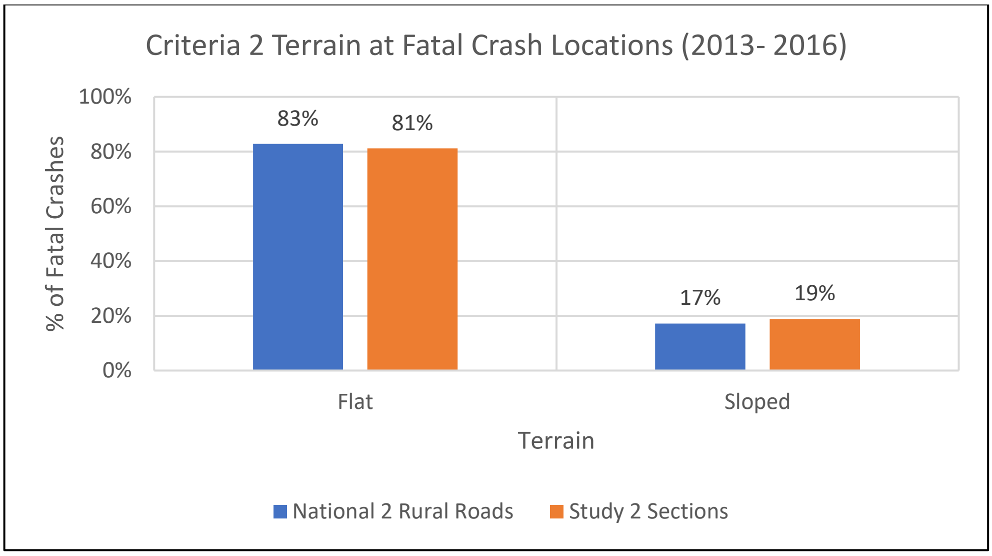

Figure C.8 Criteria 2 Terrain at the Fatal Crash Locations (2013- 2016)

2. Criteria 2 Traffic Control at the Fatal Crash Locations (2013- 2016)

Figure C.9 indicates the level of traffic control at the fatal crash locations, with lane width equal to or less than 3.5m, during the study period of 2013 to 2016. Majority of the fatal crashes Nationally and on study road sections occurred on uncontrolled roads, representing 95% and 93% of all the fatal crashes respectively, compared to fatal crashes that occurred on controlled road sections, representing 5% and 7% respectively. The level of traffic control on the study sections was significantly low. The “low level of traffic control” was cited as one of the reasons why road users frequently violate traffic laws on the study road sections.

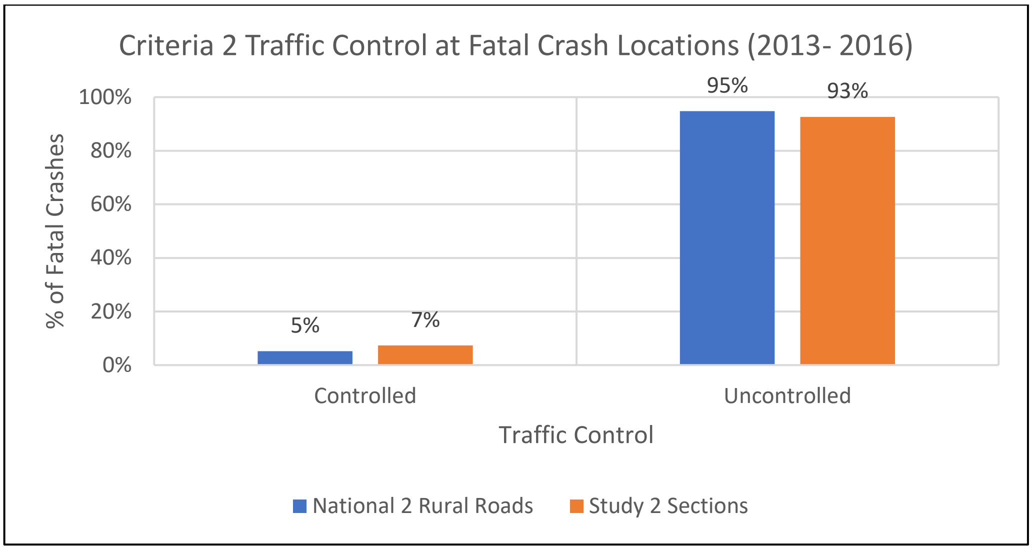

Figure C.9 Criteria 2 Level of Traffic Control at the Fatal Crash Locations (2013- 2016)

3. *Criteria 2 Road Marking Type at Fatal Crash Locations (2013- 2016)*

The road markings at the fatal crash locations Nationally and on study road sections, during the study period of 2013 to 2016, are shown in Figure C.10. Nationally, the highest number of fatal crashes occurred on roads with a dividing line, representing slightly more than half (54%) of all the fatal crashes, compared with slightly more than three quarters (78%) of the fatal crashes that occurred on the study road sections. The lowest number of fatal crashes Nationally and on the study road sections, occurred on road sections with Channelising lines, representing 2% and 7% of all fatal crashes respectively. No fatal crashes were recorded on painted islands in the fatal road crash analysis.

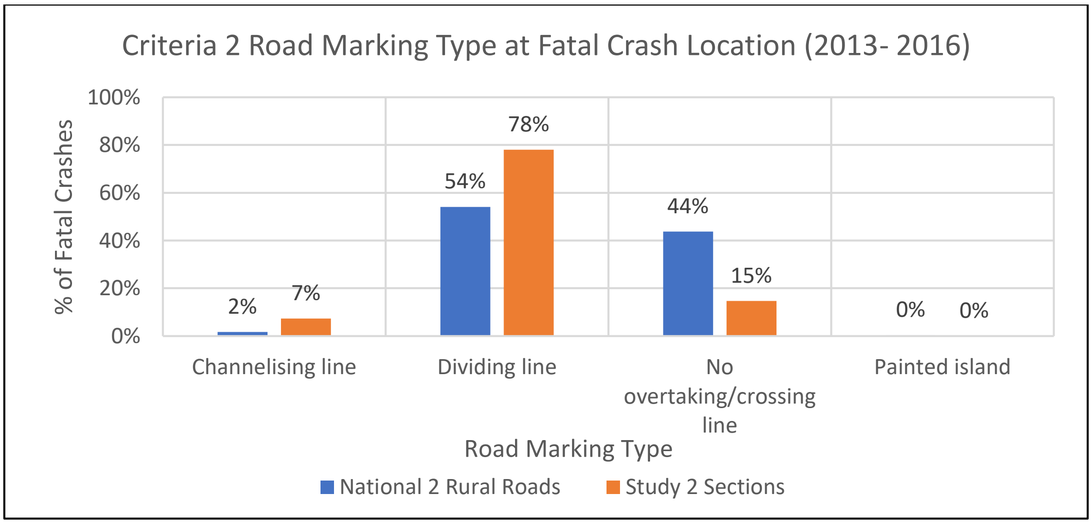

Figure C.10 Criteria 2 Road Markings at the Fatal Crash Locations (2013- 2016)

4. *Criteria 2 Vehicle Numbers and Types Involved in fatal Crashes (2013- 2016)*

Figure C.11 shows the number and types of vehicles involved in fatal crashes, during the study period of 2013 to 2016. 1013 vehicles were involved in fatal crashes Nationally, on roads with lane widths equal to or less than 3.5m, representing 51.6% of the total vehicle population involved in rural road fatal crashes. On Criteria 2 rural road study sections, 278 vehicles were involved in fatal crashes, representing 52.8% of all the vehicles involved in fatal crashes on the study sections. Majority of the vehicles involved in fatal crashes Nationally and on the study road sections were light passenger vehicles, representing 92% and 85% of all vehicles involved in fatal crashes respectively, compared to heavy vehicles that accounted for 8% and 15% of all vehicles involved in fatal crashes respectively. This gave an indication of the publics reluctancy to make use of public transport modes available on the road sections.

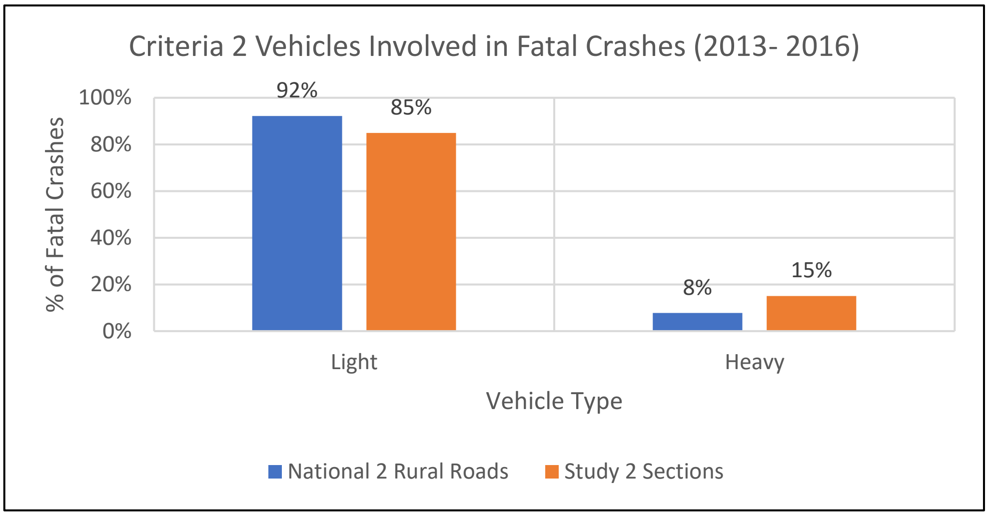

Figure C.11 Criteria 2 Vehicles Involved in fatal Crashes (2013- 2016)

5. Criteria 2 Weather Conditions at Time of Fatal Crash (2013- 2016)

Figure C.12 shows the weather conditions at the fatal crash locations, during the study period of 2013 to 2016. Nationally, the highest number of fatal crashes occurred while the weather conditions were considered “clear”, representing 83% of all fatal crashes. Compared with the study sections, the highest number of fatal crashes also occurred in “clear” weather conditions, representing 73% of all fatal crashes. The lowest number of fatal crashes Nationally, occurred during weather conditions reported as “mist/ fog”, while on the study road sections, the lowest number of fatal crashes occurred in “unknown” weather conditions.

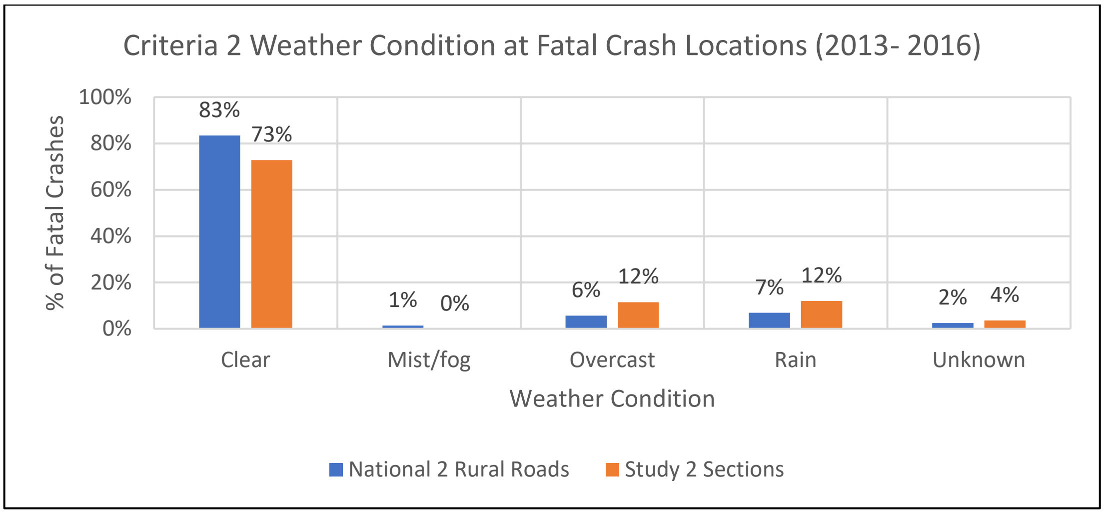

Figure C.12 Criteria 2 Weather Conditions at the Fatal Crash Locations (2013- 2016)

6. *Criteria 2 Lighting Conditions at Time of Fatal Crash (2013- 2016)*

The lighting conditions at the rural road fatal crash locations, during the study period of 2013 to 2016, are shown in Figure C.13. Majority of the fatal crashes Nationally and on the rural road study sections occurred in "daylight" conditions, representing 62% and 54% of all fatal crashes respectively. The lowest number of fatal crashes Nationally and on the study road sections occurred in the night, in "street lighting" conditions, representing 2% of all fatal crashes in each analysis.

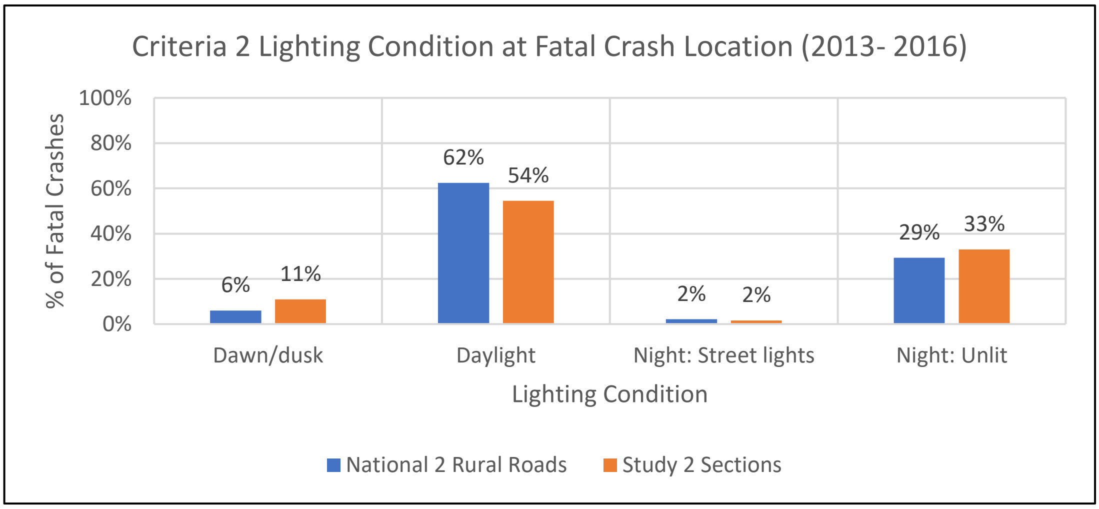

Figure C.13 Criteria 2 Lighting Conditions at the Fatal Crash Locations (2013- 2016)

7. *Criteria 2 Visibility Conditions at Time of Fatal Crash (2013- 2016)*

Figure C.14 shows the visibility conditions at the fatal crash locations, during the study period of 2013 to 2016. Nationally, majority of the fatal crashes occurred during visibility conditions considered as "clear", representing 75% of all fatal crashes, compared with 69% of all fatal crashes on the rural road study sections. The lowest number of fatal crashes Nationally and on the rural road study section occurred in "dusty" visibility conditions, representing 4% and 1% of all fatal crashes respectively.

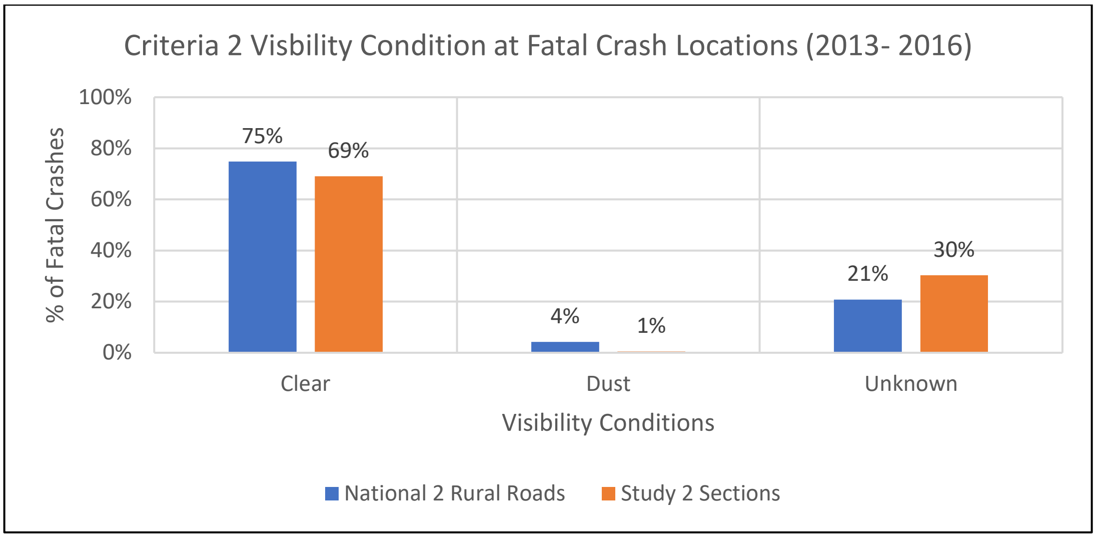

Figure C.14 Criteria 2 Visibility Conditions at the Fatal Crash Locations (2013- 2016)