UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

EVALUATION OF SAFETY BENEFITS OF THE ROAD CROSS SECTION UPGRADING ON THE OKAHANDJA KARIBIB ROAD IN NAMIBIA

Minor Dissertation 60 credits

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ABSTRACT

Globally, road fatalities have reached pandemic proportions. The Decade of Action for Road Safety of the United Nations has the aim to reduce road fatalities (UN, 2017, page 23). This dissertation investigates the Global and Namibian road safety status. The global road fatality rate is 17.7 deaths per 100 000 population, and the Africa continent has 26.6 deaths per 100 000 population (WHO, 2015, page 6). Namibia, in 2016, had around 34 deaths per 100 000 population (MVA, 2016, page 5). Namibia, with a small population of 2,2 million people (Census, 2011), is part of the Decade of Action. The crashes in Namibia are reviewed to determine if there are any trends on where and when they occur. The three most frequent crashes in Namibia are roll-over crashes, at 29% of all crashes, collisions at 28% of all crashes, with head-on crashes the most fatal and pedestrian crashes, which account for 22% of all crashes (MVA, 2016, page 5) International reports on mitigation measures for these three types of crashes were reviewed.

The trunk road network of Namibia forms the major transport corridor network that connects the major cities and neighbouring countries. Trunk roads are generally 7.0m wide bitumen surfaced roads with 2.0m gravel shoulders. The Okahandja to Karibib road was upgraded with wider lanes, surfaced shoulders and six passing lane sections. The upgrading was completed in 2012 and this dissertation evaluated the road safety improvements due to the geometrical upgrading of the road, by comparing the road with an adjacent section that has not been upgraded. The National Road Safety Council provided crash data of Namibia from 2007 to 2016. Before construction, roll-over crashes were the most frequent fatal crash type. In the post-construction period no fatal roll-over crashes occurred. The number of collisions has not substantially decreased, but there is a decline in the severity of the crashes.

The study concluded that Namibia has a high road fatality rate in comparison with the global road fatalities. The road upgrading of the Karibib Okahandja road did improve the road safety of the road, but the road fatalities are still high compared with international fatality rates.

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All opinions and results in this study are solely those of the author.

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I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledge, is my own. This dissertation has been submitted to the Turnitin module (or equivalent similarity and originality checking software) and I confirm that my supervisor has seen my report and concerns revealed by such have been resolved with my supervisor.

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1 Introduction

1.1 Motivation for the Research

Globally, there is a focus on road safety. The Decade of Action 2011 to 2020 (WHO, 2015, page xi) has identified five action pillars to improve road safety. The pillars are road safety management, safer roads and mobility, safer vehicles, safer road users and post-crash response. The World Health Organization (WHO, 2015, page 6) has raised the concern that Africa has the highest fatality rate in the world and that the trend is escalating in most African countries (WHO, 2015, page 6). The Decade of Action for Road Safety of the United Nations (WHO, 2015, page 56) and the Sustainable Development Goals for 2030 (UN, 2017, page 23) have specified a reduction in road fatalities. The Sustainable Development Goal, number 3, is to reduce road crash fatalities by 50%, which will be a challenge since the number of vehicles is increasing (UN, 2017, page 23).

The Government of Namibia has embraced the Decade of Action and the goal to provide safe roads. The country has the best roads in Africa (Schwab, 2018, page 373). In 2006 Namibia was ranked the eighth, most risky country in Africa, with a fatality rate of 16.6 fatalities per 100 000 population (NRSC, 2009, page 15). The study of Peden et al. (2013, page 2) used the calibrated WHO 2010 data, which ranked Nigeria as the deadliest with 34 deaths per 100 000 population and ranked Namibia above the Africa Region Average, with 25 deaths per 100 000 population. Unfortunately, in a study by Shivak and Schoettle (2014, page 3), Namibia ranked as the country with the highest crash fatality in the world. According to the study, Namibia has 45 fatalities per 100 000 population per year.

The Motor Crash Fund reported that the road fatality rate was 34.6 deaths per 100 000 population (MVA, 2016, page 9). The National Development Plan of the Namibian Government announced the desired road safety aim for 2021 is to reduce the crash fatalities to 16 per 100 000 population (NDP5, 2017, page 40). The Namibian Road Safety Strategy and Action Plan (NRSC, 2009, page 2) reported that the road fatalities for 2006 was 16.6 deaths per 100 000 and set the goal to reduce road fatalities by 30% by 2015. This, unfortunately, did not happen as the road fatalities have increased since 2006.

1.2 Case Study

Namibia is located on the western side of Africa bordering against Botswana on the east and the Atlantic Ocean on the west. South Africa is the southern neighbouring country and Angola the northern neighbour. The capital of Namibia is Windhoek. Namibia has thirteen regions, and the area of the country is 824 166km^2. Namibia has a population of 2.2 million people with 54% living in urban areas (Census, 2011, page 74).

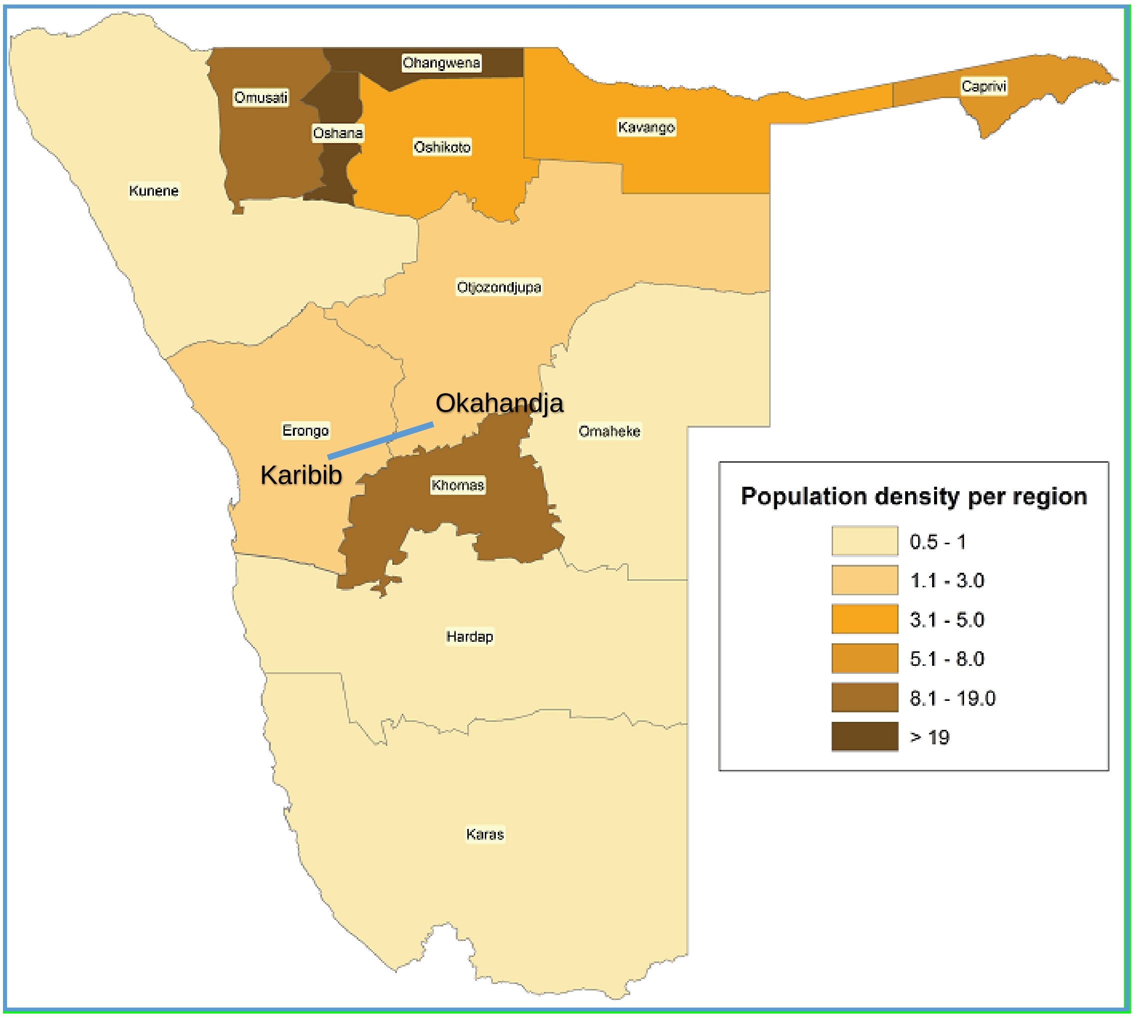

Figure 1 : Regions and Human Population Distribution in Namibia

Source: Housing Census, 2011: Map 2.3.1 pg32

The vision of Namibia is to become a logistic hub for the region (The Logistic Master Plan, 2015), which includes the upgrading of the trunk roads to improve the road safety of the transport corridors.

The Okahandja to Karibib Road, Trunk Road 07/01, was upgraded between 2008 and 2012. The road is located in the Erongo and Otjozondjupa regions. The upgrading consisted of the rehabilitation of the pavement structure, widening of the lanes and provision of 2.5m wide surfaced shoulders, as well as adding six passing lane sections. The upgrading of the adjacent road sections, namely Karibib to Omaruru, and Karibib to Swakopmund, are currently being designed.

The motivation for the research is to evaluate the road safety situation in Namibia to understand the reasons for the high crash rates, despite the good road network, and identify the possible measures that can improve the situation. The study will specifically investigate the Okahandja Karibib Road regarding road safety impact.

1.3 Aim of the Research

The aim of this study is to determine, from literature, the potential or expected road safety improvements for the project road. The study will then analyse the available traffic crash data to determine the road safety on the road. The outcome of the analysis will be compared with the literature results.

Previous studies have been conducted to quantify the safety gain of various road upgrades, especially overseas, but also in Africa. The literature study will identify such studies and review the findings. The data from these studies will be used to predict the improvement of the road upgrading conducted on the Okahandja to Karibib corridor.

The study will then analyse the crash data from the National Road Safety Council (NRSC). The analysis will compare the studied road section with the adjacent road sections. The study will also compare crashes before and after the road upgrading, as well as compare the predicted traffic safety improvement with the actual traffic crash data to see if the trend is similar.

1.4 Research Questions

The Research will focus on answering the following questions:

1. How do the road safety statistics of Namibia compare with international best practice?
2. What are the most frequent crash types on Namibian roads and which measures to mitigate them, are identified in the literature?
3. Are the fatality rates on the Okahandja Karibib Road high compared to Namibian and international practices?
4. Have infrastructure measures, such as road widening and the provision of passing lanes, reduced the road safety risk?

1.5 Scope and Limitations

The Scope of the study was a literature study and a review of the NRSC data.

The NRSC data was used as it is and limited corrections to the data were made. An exercise to add road numbers, based on the destinations, was conducted.

1.6 Methodology

The study commenced with the development and preparation of the Proposal document. The motivation, aim and research questions where defined in this stage.

The second stage was the research. The research consisted of literature study as well as an analysis of the traffic crash data. The literature study reviewed existing literature with the focus on International Road Safety Practices and Namibian Road Safety Practice including the Karibib Okahandja road.

The traffic crash dataset of the National Road Safety Council was obtained for the years' 2008 to 2016. The analysis looked at the various aspects such as time, location, road surface and regions. Tables and graphs were prepared to present the findings of the analyses.

The study was concluded with the writing and preparation of this Dissertation Report.

1.7 Content of the Report

Chapter 2 provides a brief overview on global road safety and the current status according to the WHO, as well as a short overview of road safety in Africa. The report then proceeds to look at road safety in Namibia as a country and the status of road safety in the regions of Namibia.

Chapter 3 describes the type of crashes that occur on Namibian roads. The three crashes that occur most frequently are roll-over accidents, collisions between vehicles and crashes involving pedestrians. The study looked at possible reasons and international practices to mitigate these crashes.

Chapter 4 of the report looks at crashes on the trunk road network of Namibia. The Okahandja Karibib Road was upgraded to higher geometrical standards than the adjacent trunk roads. The study compares the crash-data to investigate the safety benefits of the higher geometrical standards.

The report concludes in Chapter 5 with a final summary and conclusion of the research questions that were formulated in the previous section.

2 Road Safety

Road safety can and has been measured in various ways. Road safety is, generally, measured as the reduction in the risk of fatalities, due to road crashes. The term “crashes” is preferred since “accident” implies that there was no real cause and the term “crashes” does not imply any judgement of the incident cause (Matthews, 2011, page 221). “In the Highway Safety Manual (HSM), a crash is defined as a set of events that result in injury or property damage, due to the collision of at least one motorised vehicle” HSM (2010: page 3-3). The NRSC also include crashes by bicycles or animal-drawn vehicles. “Crashes are rare and random events.” HSM (2010, page 3-5). Table 1 provides an easy overview of the various indexes and role of each index.

Table 1 : *Road Safety Indexes and Perspective*

Road safety index	Appropriate role/perspective
Fatalities per population	Public health
Fatalities per driver	Driver education/licensing
Fatalities per vehicle	Vehicle manufacturing/regulation
Fatalities per distance driven	Traffic/roadway engineering
Fatalities per trip	Urban planning

Source: Sivak 1996 from Sivak and Schoettle,2014: pg1

Fatalities per population is frequently used when comparing countries. The Global Status Report mainly uses fatality per population as the road safety index. The fatalities per population can assist on a national level to compare road fatalities with other causes of death, such as the study by Sivak and Schoettle where they compared cancer, heart disease and cerebrovascular disease with road fatalities in 183 countries. Globally these four causes result in 844 deaths per 100 000 population. Central Africa and the former Soviet Union have the highest death rates while America, Middle East and Southeast Asia have low fatality rates per 100 000 population. Road crashes globally, contribute 18 fatalities per 100 000 population with the highest rate in Namibia with 45 fatalities per 100 000 population and the Maldives the lowest with two fatalities per 100 000 population (Sivak and Schoettle, 2014, page i). The Road Safety Index of fatalities per population does not provide guidance as to which road or which road characteristics are safe or where safety issues are located. The fatalities per distance travelled allows for the comparison of roads in engineering terms. Namibia has long distance of 200km between towns with 46 400km of roads, while the Maldives is an island with only 88km of surfaced roads (RA webpage).

The Road Safety status, according to the various indexes and for a selection of countries, are presented in Table 2. Australia has double the number of fatalities when compared to the United Kingdom in relation to the number of drivers but similar fatality rate in relation to vehicle numbers.

Table 2 : *Road Safety Index for Selection of Countries*

Road Safety Index	United States	United Kingdom	Australia	Angola	South-Africa	Botswana	Namibia
Fatalities per 100 000 population	10.6	2.9	5.4	26.9	25.1	23.6	23.9
Fatalities per 10 000 drivers	1.61	0.48	0.81		3.90		22.04
Fatalities per 10 000 Vehicles	1.3	0.5	0.7	99.2	13.4	9.2	21.4
Fatalities per billion vehicle kilometers		3.50	5.02				183.67

Source: WHO, 2015, pages 81, 85, 99, 187, 226, 246 and 248, NHTSA 2013, National Statistics UK 2015, Statistics of USA, Steinhardt et al. 2012,

2.1 Global Overview

The Global Status Report on road safety (WHO, 2015, page xii) reviewed road fatalities of 180 member-states for the period 2000 to 2013 and the results are graphically shown in Figure 2. The review found that Africa has the highest road traffic fatalities in the world with 26.6 fatalities per 100 000 population per year. The Global Fatality rate is 17.7 per 100 000 population. Taking into account that Africa has the lowest level of motorisation in the world, this fatality rate shows the high road safety risk in Africa. Figure 2 shows the fatality rates for the continents in the world, with only America and Europe below the Global rate.

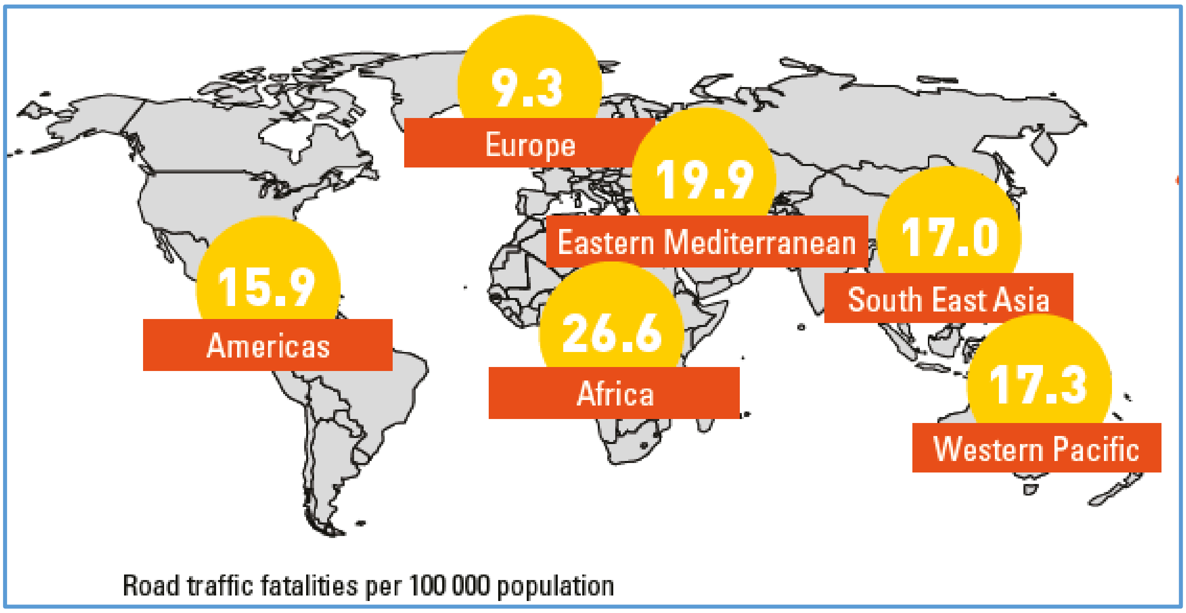

Figure 2 : Global Fatality Rates in *2013 per* 100 000 population

Source: WHO, 2015, Infographics, Road Traffic Injuries: The Facts

The fatality rate for Africa increased from 24.1 per 100 000 population in 2010 to 26.6 per 100 000 population in 2013. Most of the deaths on Africa's roads are vulnerable road users where pedestrians account for 37% of the fatalities and cyclist and motorbike riders account for 15% of the fatalities. Nigeria and South Africa in 2010 had the highest fatality rates at 34 and 32 fatalities per 100 000 population. Namibia in 2010 was ranked 9 with 25 fatalities per 100 000 population, just above the regional average of 24 fatalities per 100 000 population (Peden, Kobusingve and Monono, 2013, page 1).

2.2 Overview of Road Safety in Namibia

In Namibia, the National Road Safety Council (NRSC) has the statutory obligation for road safety. The Government also founded the Motor Vehicle Accident (MVA) Fund in 1991 with the purpose to compensate people injured in crashes or the relatives of fatal crash victims.

The MVA published a Road Crashes and Claims Report in 2016 on the crash trends from 2012 to 2015. The crash trend showed a linear yearly increase of nearly 200 crashes per year as the crashes increased from 3760 in 2012 to 4 309 in 2015. In 2016 a slight decrease was reported resulting in 4 134 crashes overall. The fatal crashes increased from 492 fatal crashes in 2011 to 731 fatal crashes in 2016. The MVA report indicated that in 2011 the crash rate was 23.8 per 100,000 population and this has steadily increased to 34.6 per 100,000 population in 2016. (MVA, 2016, page 11 and 25)

The World Health Organization (WHO) compared countries based on crashes per population in the Global Status Report on Road Safety, 2015. The report includes road safety data sheets for most countries. The Namibian Road Safety sheet is based on 2012 data from the NRSC and reports 308 road fatalities. The WHO estimated the road fatalities to be 551 since the WHO fatality rates included fatalities within a 30-day period after the crash. The published values are, therefore, based on local information, but corrected for this standardised definition of a road fatality. The reported fatality rate per 100 000 population is 23.9, which is in line with the MVA data (WHO, 2015, page 187).

A study by Amweelo (2016, page 110) found a similar rising trend in road crashes and fatalities. The high traffic crash rate is more concerning since "Namibia, generally, has an excellent designed and well-maintained road network and very low traffic densities". Amweelo (2016, page 107) presented even higher fatality rates than the WHO report. For a full comparison see Tables 3 and 4.

Table 3 : *Road Crash Fatalities in Namibia from 2010 to 2016*

Year	Fatalities (Data from NRSC)	Fatalities (MVA, 2016)	Fatalities (Amveelo, 2016)	Fatalities (WHO, 2015)
2010	295		539	
2011	305	492	482	
2012	297	598	561	551
2013	308	656	633	
2014	307	685	676	
2015	342	718	705	
2016	332	731		

Table 4 : *Fatality Rates per 100 000 population in Namibia from 2010 to 2016*

Year	Fatalities per 100 000 population (Data from NRSC)	Fatalities per 100 000 population (MVA, 2016)	Fatalities per 100 000 population (Amveelo, 2016)	Fatalities per 100 000 population (WHO, 2015)
2010			25.61	
2011	12.20	23.80	23.28	
2012	11.00	26.55	26.55	23.90
2013	10.60	29.96	29.96	
2014	9.70	31.99	31.99	
2015	10.10	33.22	33.36	
2016	9.00	34.60		

The difference in the absolute number of fatalities and fatality rates may be attributed to the NRSC recording only fatalities immediately with the crash, while the MVA records fatalities within 30 days of the crash. The MVA (2016, page 5) reported that 22% of the fatalities are seriously injured persons that died in hospitals. Most of the fatalities are confirmed on the crash scene with 63% in 2015 and 69% in 2017. The remainder of the fatalities occur en-route to the hospitals, or are not specified. Comparing the number of fatalities in the NRSC data with the MVA's number of fatalities on the crash scene, there is 30% of unaccounted fatalities in the NRSC data. The number of serious and slightly injured persons in the NRSC data was 55% of MVA's number of injury claims. An in-depth study of the discrepancies between these two sources is beyond the scope of this dissertation.

Sivak and Schoettle, (2014, page 1) studied fatal road crashes in 193 countries in comparison with other health-related fatalities. The study, which was based on WHO 2008 data, ranked Namibia with the highest fatality rate from road crashes in the study. Sivak and Schoettle (2014, page 6) reported that Namibia has 45 fatalities per 100 000 population. The report does not provide the actual number of fatalities and the rate of 45 per 100 000 population seems incorrect if compared with the other sources, listed in Table 4.

The NRSC was established in 1996 as a statutory body under the National Road Safety Act, Act 9 of 1972. One of the objectives of the NRSC is the collection and dissemination of road safety information (NRSC webpage). The NRSC provided historical crash data from 2000 to 2016. The number of recorded crashes substantially increased from 2000 to 2007, partly due to improved reporting of crashes. Most crashes in Namibia are single vehicles crashes, which have doubled from 6 600 in 2007 to 12 200 in 2015, an increase of 8% per year (with a minor reduction in 2016). Crashes involving two vehicles increased from 5 800 in 2007 to 8 600 in 2016, an increase of 4.5 % per annum.

The Gross Domestic Product (GDP) is the monetary value of a country's economic activity. The Namibian GDP since 2009 increased from USD$ 6 billion (N$77.9 billion) to USD 8.4 billion (N$109.7 billion) in 2016. The GDP graph shows that there is a correlation between economic activity and traffic crashes. This correlation exists due to the correlation of traffic volumes and economic activity.

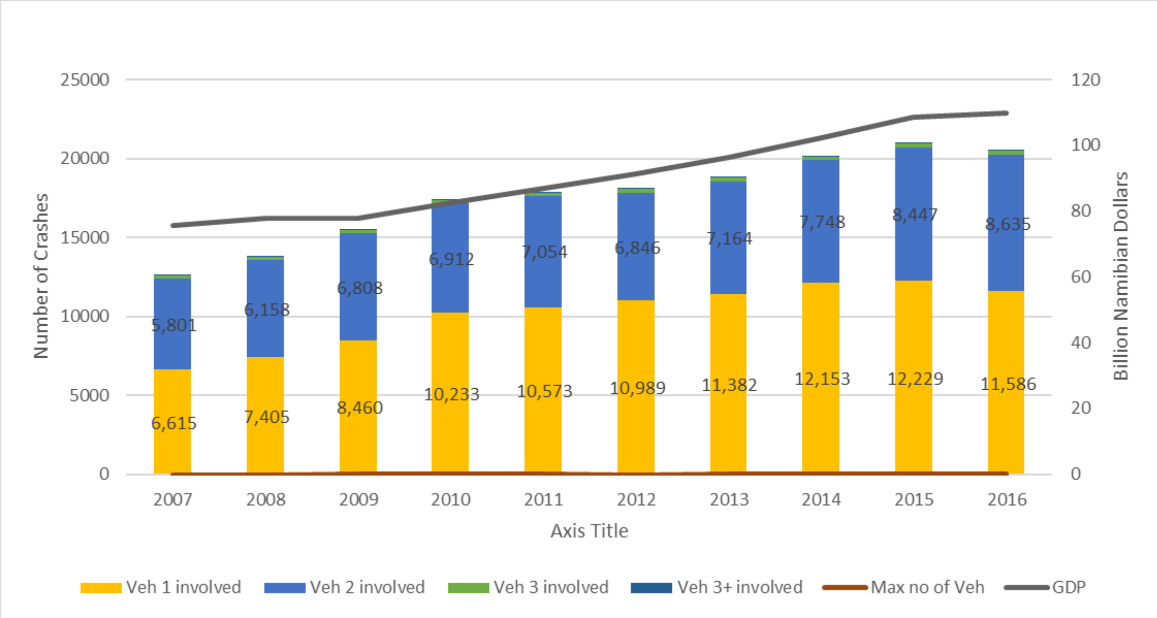

Figure 3 : Number of Crashes in NRSC dataset and GDP Curve

Source: NRSC dataset

The NRSC data showed that there were around 250 fatal crashes in Namibia per annum from 2010 to 2016, except for 2013 with a high of 340 fatal crashes. Crashes with one fatality are dominant. Crashes with two fatalities are around 20 to 30 per annum and crashes with three or more fatalities are generally low. However, there are substantial fluctuations as in 2013 there were 90 crashes with more than three fatalities, while in 2012 there were only four. This study determined that 80% of fatal or serious crashes involve a single vehicle with crashes involving three or more vehicles occurring only on rare occasions.

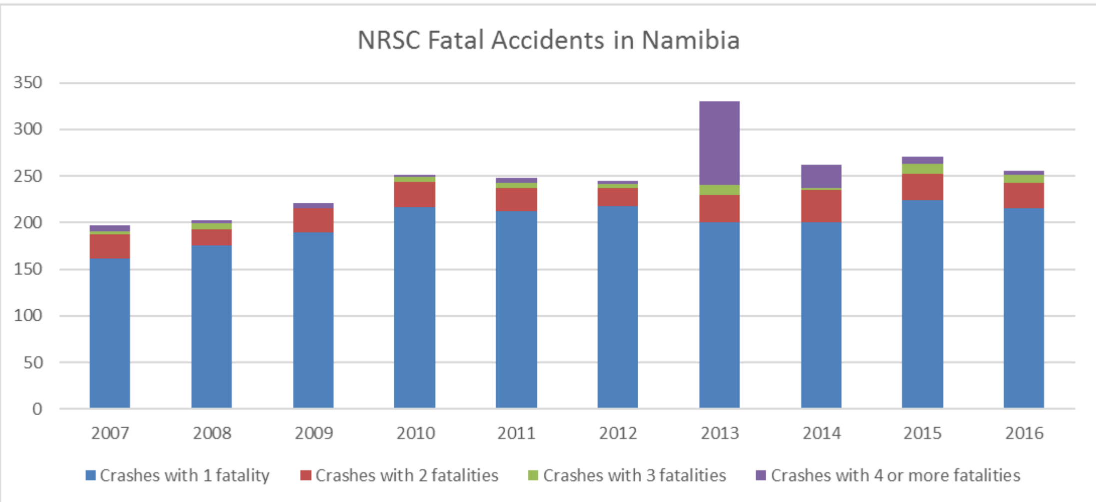

Figure 4 : NRSC Fatal Crashes in Namibia 2007 to 2016

Source: NRSC dataset

Road crash fatalities have been statistically studied to determine trends since 1949 when a Mr. Smeed developed a statistical correlation between road crash fatalities, number of registered vehicles and population (Smeed, 1949, page 7). The resultant formula that he derived was.

Smeed Formula	$D = 0.0000993\ N^{0.3377} P^{0.7323}$	*Formula 1*

With D the number of fatalities, N the number of vehicles and P the population.

The statistical correlation between the three variables is shown in Figure 5.

1949] SMEED—*Some Statistical Aspects of Road Safety Research* 7

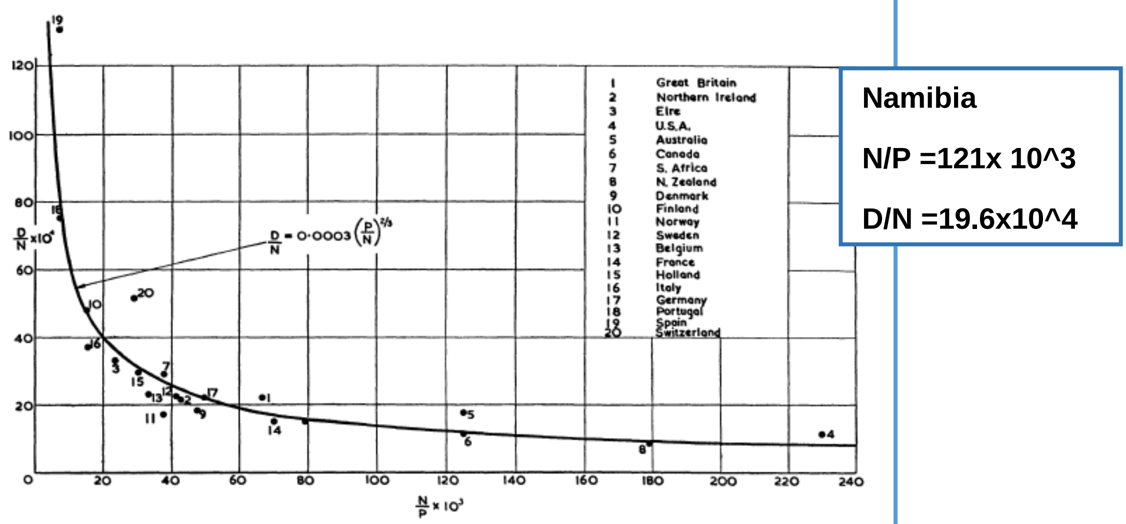

FIG. 1A

Relation between Number of Deaths per 10,000 Registered Motor Vehicles and Number of Vehicles per 1,000 Population for 1938

Figure 5 : Smeed's Relation between fatalities, population and vehicles

Source Smeed, Some Statistical Aspects of Road Safety Research, 1949, page 7

To determine if Namibia has exceptionally high crash rates the Smeed Formula was applied on the current data. Namibia has a population of 2.30 million people with 257 000 registered vehicles. The Smeed relationship predicted 304 fatalities per year and Namibia has some 550 fatalities per year, thus, some 60% more than the formula calculates. Namibia in 2016 is located in nearly the same position on the graph as Australia in 1938.

Data for thirty-six African countries from the Global Status report on Road Safety was used to determine the current relationship between fatalities, vehicle numbers and population. The two extremes are Guinea and Libya. Guinea in West Africa has a population of 11.74 million people with only 33 943 vehicles and 3211 fatalities. Guinea has 28 vehicles per

10 000 population and they have 946 fatalities per 10 000 vehicles. On the other extreme is Libya in North Africa with a population of 6.2 million and 3.55 million vehicles and 4 554 road crash fatalities. Libya has 5 730 vehicles to 10 000 population and 12.8 fatalities per 10 000 vehicles. The other African countries lie between these two extremes, as shown in Figure 6.

The Smeed Formula was applied to the data and the predicted fatalities for a vehicle to population ratio above 2 000, the values converge. Below 2 000 vehicles per 10 000 population in the Smeed Formula under-estimated the current number of fatalities per 10 000 vehicles. The change in the fatalities per vehicle may be due to the higher speed of vehicles and the increased risk of fatalities during a crash. The trend lines of WHO data and the Smeed prediction is also shown in Figure 6.

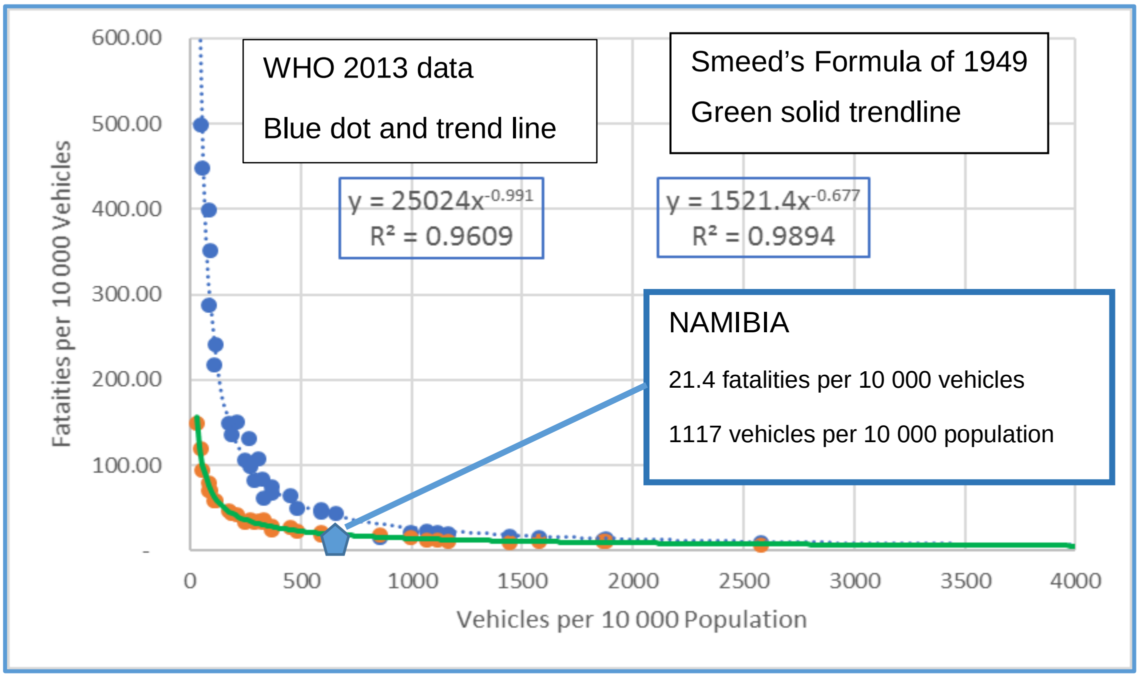

Figure 6 : The relation between fatalities, population and vehicles in Africa 2013

The trend line for African countries predicts 23.8 fatalities per 10 000 vehicles for Namibia. Namibia in 2013 had 21.4 fatalities per 10 000 vehicles, which is 10% fewer fatalities than the Africa Trend.

Although the actual fatality rate for Namibia differs from source to source, the reported fatality rates remain alarmingly high. The Namibian Road Safety Strategy and Action Plan of 2009 used the fatality rate of 16.6 per 100 000 population, based on a 2006 benchmark. The

Strategy aimed to reduce road fatalities by 30% by 2015 and to reduce the fatalities per 100 000 population to 8.3 by 2030. The National Development Plan Five announced that the Namibian Government goal for road safety is to reduce the crash fatalities, by 2021, to 16 per 100 000 population (NDP5, 2017, page 40).

2.3 The Economic Impact of Road Crashes

Road crashes, worldwide have a significant impact on the economy. However, the methods to calculate the road crash cost and to obtain reliable data is difficult across the globe (Dahdah and McMahon, 2008, page 4; Labuschagne, 2016, page 50; De Beer, 2004, page 3). The economic impact of road crashes in African countries are estimated to be between 0.8% and 9% of their GDP (Peden et al., 2013, page 1; WHO, 2015, page 77 to 258). GDP is the market value of the country's economic activity.

The method to determine road crash costs varies per country and obtaining appropriate and reliable data is difficult in most countries. The loss of productivity and the cost of pain, grief and lost quality of life contribute 61% of road cost of any severity and 92% for fatal accidents (Labuschagne, 2016, page 16 and 38). The value of productivity and quality of life is related to the GDP per capita value. The economic value of these intangible elements is based on proxy values, which lead to large variations (Labuschagne, 2016, page 16).

The cost of crashes can be determined with two methods, namely the Human-Capital method or the Willingness-to-Pay method. The Human-Capital method determines the economic impact of a road crash. The Willingness-to-Pay method estimates the amount an individual is willing to pay to reduce the risk of a fatality. The Human-Capital method results in a lower valuation of the crash cost than the Willingness-to-Pay values (Dahdah and McMahon, 2008, page 4)

Willingness to Pay Method

The Willingness-to-Pay method is the preferred method although the surveys to determine the value is difficult. The Willingness-to-Pay rule of thumb is that the economic cost of Value of Statistical Life is 71 times the GDP per Capita. Serious injuries mean value is 17 times the GDP per Capita. (Dahdah and McMahom 2008, page 7).

For Namibia, with a GDP per Capita of US$ 5 780 and 551 fatalities, the cost of fatalities is US$ 226 million. The cost of fatal crashes contributes 42.4% to the total road crash cost (Labuschangne, 2016, page 36). The total road crash cost thus amounts to US$ 533.3 million or 6.4% of GDP.

The Human Capital Method

The Human-Capital crash cost consists of three major components, namely human casualty cost, incident cost and vehicle damage cost. The human casualty cost includes the medical and funeral costs, loss of quality of life, loss of future productivity, as well as workplace re-occupation costs. Vehicle damage cost includes the repair or replacement cost of the vehicle as well as towing cost, loss or damage cost of cargo and goods, assessor and vehicle rental cost. Incident costs are costs related to the incident which are not related to the vehicle or persons. Incident costs include cost by government organizations such as the police, infrastructure damage cost, clean-up costs and legal and administrative costs. Delay time costs to the traffic are also seen as incident costs. The cost components in South Africa consist of 69.3% human casualty cost, 14.9% vehicle damage cost and 15.9% incident costs. (Labuschagne 2016, page 36).

Road Crashes in World based on WHO data

The road crash cost to the economy, as a % of GDP, has only been reported for 75 of the 180 countries (WHO, 2015, page 77 to 258). This information was used to determine a global correlation between road crash cost per incident and GDP per capita, as shown in Figure 7. The best fitting trend was a linear formula as given in Formula 2. The values are highly variable with R^2=0.3775.

Road Crash Cost Formula

Total Crash Cost = (0.0035 * GDP per Capita + 110.7) * GDP per Capita * Number of fatalities

Formula 2

The countries with the highest cost per Capita GDP is the Netherlands, 642 times GDP per Capita and Austria with a fatality cost of 616 times GDP per Capita. A significant cost element in the Netherlands is for pain, grief and suffering. Norway, with a GDP per Capita of US$ 102 610, has a fatality cost rate of 262 times GDP per Capita while Iceland cost is 483 times GDP per Capita and Finland have a fatality cost rate of 460 times GDP per Capita. The orange dots in Figure 7 are African countries.

Figure 7 : Economic Cost of Road Crash Fatalities, Globally

Source WHO, 2015 page 77 to 258 using Labuschagne 2016 information for South Africa

The road crash cost for Namibia, using Formula 2, is US$ 416.9 million or 5% of GDP. Namibia GDP per capita was US$ 5 780.00 with 551 road crash fatalities (WHO, 2015, page 187).

Crash Cost in Africa based on WHO data

The estimated GDP loss, due to road traffic crashes, was recorded for 9 out of 36 African countries in the WHO data sheets. South Africa reported an 8% loss of GDP, Tanzania 3.4% of GDP and Nigeria 3% of GDP. Cote D'Ivoire had the lowest estimate of 0.5% of GDP followed by Ethiopia at 0.9% of GDP (WHO, 2015 page 77 to 258, Bezabeh, 2013, page 6).

The trend of these crash costs was determined, and are presented in a Fatality Cost Formula 3. The statistical error of this equation is R^2=0.853 implying a good fit to the data.

Fatality Cost Formula

Total Crash Cost = (0.0384 * GDP per Capita +17.256) * GDP per Capita * Number of fatalities

Formula 3

The road crash cost for Namibia, using Formula 3, is US$ 761 million or 9% of GDP.

Crash Cost of South Africa

De Beer (2004, page 20) determined the total accident cost at US$3.9 billion (R42.5 billion). Labuschange's study (2016, page 36) determined that South Africa's crash costs in 2015 amounted to US$ 10.99 billion which was 3.4% of GDP.

Fatality Cost Formula 3 used the crash cost for South Africa as 8% of GDP. The 8% of GDP for South Africa is substantially more than 3.4% calculated by Labuschagne (2016, page 36). Altering the road crash cost for South Africa to 3.4% of GDP, changes the data and linear trend to Fatality Cost Formula 4, as shown in Figure 8. The statistical reliability of Formula 4 is R^2=0.465, implying a greater variation from the trend line.

Fatality Cost Formula

Total Crash Cost = (0.0143 * GDP per Capita +46.866) * GDP per Capita * Number of fatalities

Formula 4

The road crash cost for Namibia, using Formula 4, is US$ 412.4 million or 5% of GDP.

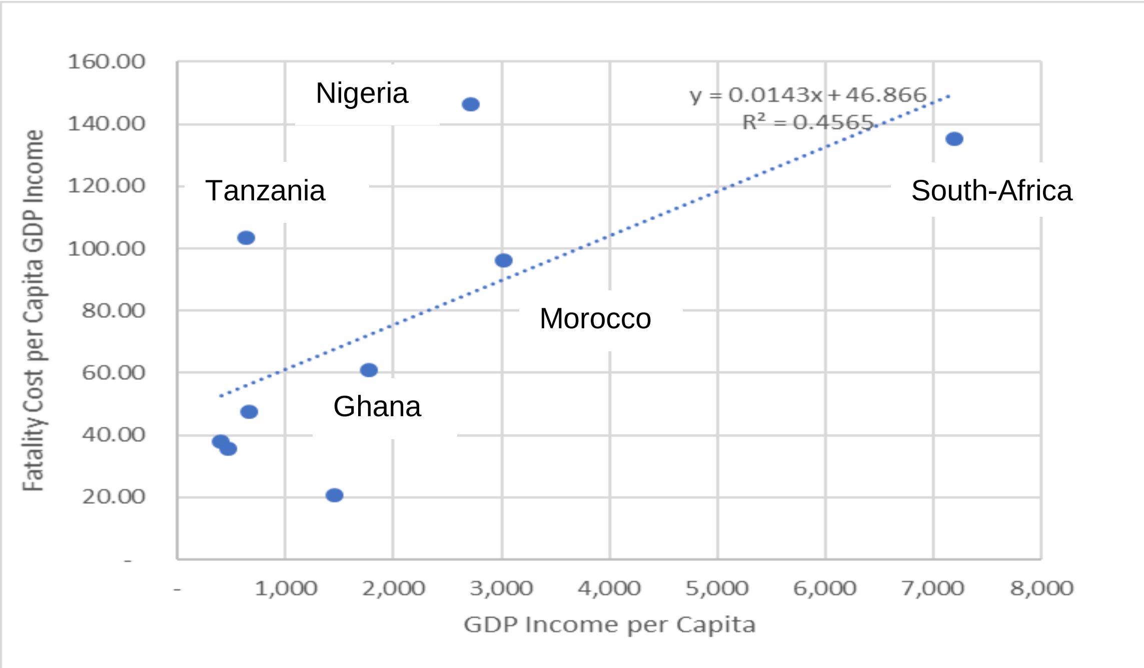

Figure 8 : *Economic Cost of Road Crash Fatalities in Africa*

Source WHO, 2015, page 77 to 258 using Labuschagne 2016 information for South Africa

Road Crash Costs in Namibia

The purpose of the Motor Vehicle Accident Fund (MVA) is “to design, promote and implement crash and injury prevention measures, provide assistances and benefits to all people injured and the dependents of people killed in road crashes” (MVA, 2016, page 5). According to the MVA Annual Report of 2016 the total MVA cost due to the crashes was US$ 23.7 million (N$ 308 million) or 0.3% of GDP. The cost consists of the following components, namely: Hospital and Medical expenses of US$ 16.5 million (N$ 214 million), loss of support undertakings at US3.9 million, general injury grants of US2.7 million, funeral expenses of US$ 0.34 million and legal settlements of US$ 0.12 million. Figure 9 shows the yearly increase of the MVA’s direct crash cost to the Namibian economy.

Labuschange’s study (2016, page 38) determined that the medical treatment cost is 5.94% of the total road crash cost. Using this relationship, the total road crash cost for Namibia in 2015 would be US$ 277.36 million or 3.3% of GDP, which is close to the average road crash cost of 3% of GDP that the WHO determined.

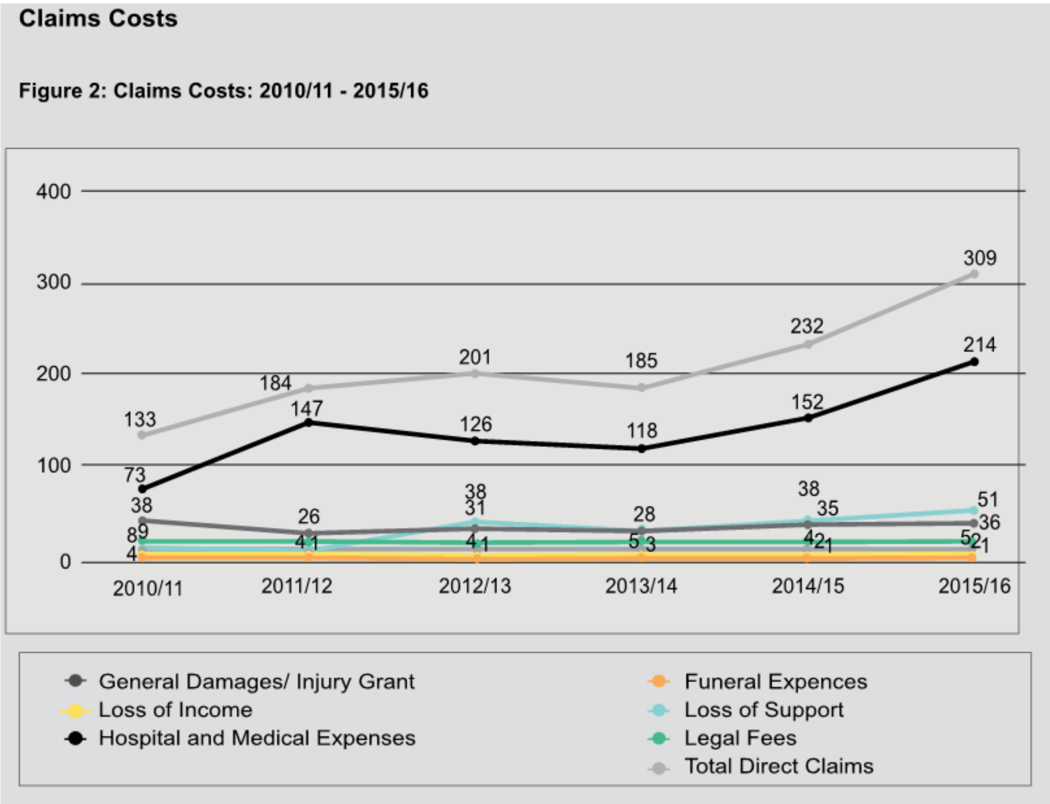

Figure 9 : MVA Cost of Crashes in Namibia

Source MVA Annual report 2016, pg21, Values in million N$

A study, by Ernst and Young (2016, page 56), an accounting company, on the cost of road crashes to the Namibian economy determined the financial cost at US$ 39.46 million (N$ 512.9 million) in 2015 and the total monetary cost of road crashes at US$103.07 million (N$1.34 billion) or 1.23% of GDP. The unit cost per crash in South Africa and Namibia differ due to the difference in severity mix of the crashes and the average income. (Ernst and Young, 2016, page 56). The financial cost appears low based on the MVA total crash cost of US$23.7 million (N$ 308 million) for 2015.

The calculation of the economic impact of road crashes is not an exact science. The lowest economic value for the road crash cost in Namibia was obtained by the Study of Ernst and Young (2016, page 56) with a value of US$103.07 million or 1.23% of GDP. The highest economic cost was derived with Formula 3, Africa Correlation, with a total economic cost of US$ 761 million or 9% of GDP. The Global Correlation, Formula 2, and Modified African Correlation, Formula 4, resulted in an estimate of US$ 412.4 million or 5% of GDP. The method to extrapolate the medical expenses of the MVA resulted in a total economic value of US$ 277 million or 3.3% of GDP. The MVA medical expenses exclude medical expenses paid directly by individuals or medical funds. The different results to the economic impact of road crashes in Namibia is presented in Table 5.

Table 5 : *Summary of Road Crash Cost in Namibia*

Method	Economic Value of Road Crashes in Namibia	% of GDP
Willingness to Pay Method	US$ 533 Million	6.4%
Crash Cost Formula 2	US$ 417 Million	5.0%
Crash Cost Formula 3	US$ 761 Million	9.0%
Crash Cost Formula 4	US$ 412 Million	5.0%
Crash Cost based on MVA Medical cost	US$ 277 Million	3.3%
Ernst and Young study	US$ 103 Million	1.3%

Source: MVA, 2016, page 5; Labuschagne, 2016, page 38; WHO, 2015, page 187; Ernst and Young, 2016, page 56

The economic impact of road crashes is a substantial amount, and a realistic estimate for Namibia is in the order of 3.5% of the GDP which amounts to around US$ 295 million (N$ 3.90 billion) per annum.

2.4 Namibian Regions

Namibia has 13 regions as shown in Figure 1. The capital city, Windhoek, is in the Khomas region. The Oshana and Ohangwena regions in the north have the highest population density. Windhoek has 97 500 registered drivers, 36.6% of all drivers in Namibia, and 163 400 registered vehicles, 45% of all Namibian vehicles. The Oshana region has 10.3% of the drivers and the second highest number of registered vehicles, 38 500 vehicles or 10.6% of all vehicles in Namibia (RA, 2016, page 45). The Okahandja to Karibib road is located in the Khomas and Erongo Regions.

The Khomas region has the highest number of crashes, at around 8 000 per annum, followed by the Erongo region with some 4 000 crashes. In the Oshana region, 1 300 crashes were recorded and the other regions have less crashes (NRSC dataset).

The fatal crashes in the Khomas region varied between 30 and 45 fatal accidents per year with 45 to 52 fatalities per year. The Khomas region had 250 serious injury crashes in 2009, which decreased to 200 for 2010 and 2011 and was below 100 from 2012 to 2015. The fatality rate for the Khomas region is 12 fatalities per 100 000 population (NRSC dataset).

The fatal crashes in the Erongo region were below 20 fatal crashes from 2009 to 2012 but recently saw an increase to 45 fatal crashes in 2014 and 2015 with 57 fatalities. The Erongo region has between 80 and 100 serious injury crashes per year. The road fatality rate for the Erongo region is 32 fatalities per 100 000 population, the highest in Namibia.

The Oshana region had 40 fatal crashes in 2008, which decreased to 25 in 2013 and 2014 but increased to 32 fatal crashes and 38 fatalities in 2015. The Oshana region had 147 serious injury crashes in 2009, 131 in 2010 and between 90 and 100 from 2011 to 2015. The road safety rate of Oshana region is 19 fatalities per 100 000 population.

The Ohangwena region had 42 fatal crashes in 2015 with 61 fatalities. There were 18 to 26 fatal crashes per year prior to 2013, but since 2014 there are 37 to 42 fatal crashes per year. There were 66 serious injury crashes per year for the period 2009 to 2016 with a high of 77 serious injury crashes in 2015 and a low of 50 serious injury crashes in 2016. The road fatality rate of the Ohangwena region was 24 fatalities per 100 000 population in 2015 and 16 fatalities per 100 000 population in 2016 (NRSC dataset).

In Namibia, there is, on average, a 50% split between urban and rural crashes as shown in Figure 10. The regions with larger urban centres, such as Khomas, have less rural crashes and the regions with smaller urban centres, such as the Kunene, have a higher percentage of rural crashes. There is no apparent relation between the rural households and the rural crashes, since the number of vehicles owned by rural households is less than urban households.

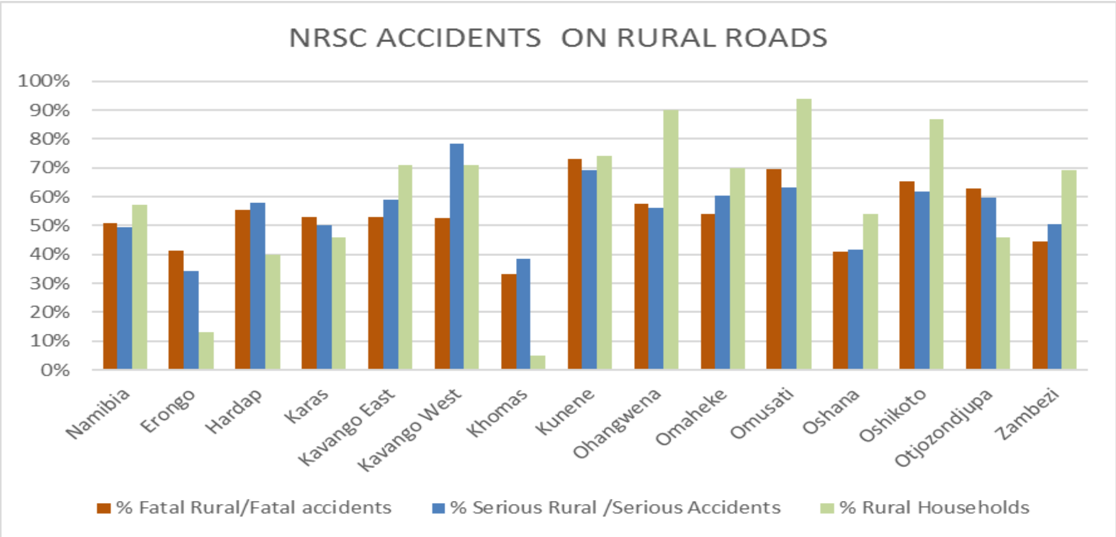

Figure 10 : Crashes on Rural Roads per Region

Source: NRSC Dataset

Namibia has 7 285km of bitumen surfaced roads, which represent 15% of the rural road network. The traffic volumes on 28.3% of the surfaced roads are between 200 to 500 vehicles per day and 26.7% of the surfaced roads have 500 to 1 000 vehicles per day. On surfaced roads 60% of all the crashes occur.

The length of gravel roads is 33 300km with nominal traffic volumes. Traffic volumes of 50 to 200 vehicles per day occur of 26% of the gravel roads and 67% of the gravel roads have less than 50 vehicles per day. The number of fatal and serious crashes on gravel roads in Namibia is around 40% of all the crashes. There are some regions where more than 50% of crashes happen on gravel roads. Unfortunately, the information on a regional level on the length of gravel roads and traffic could not be obtained.

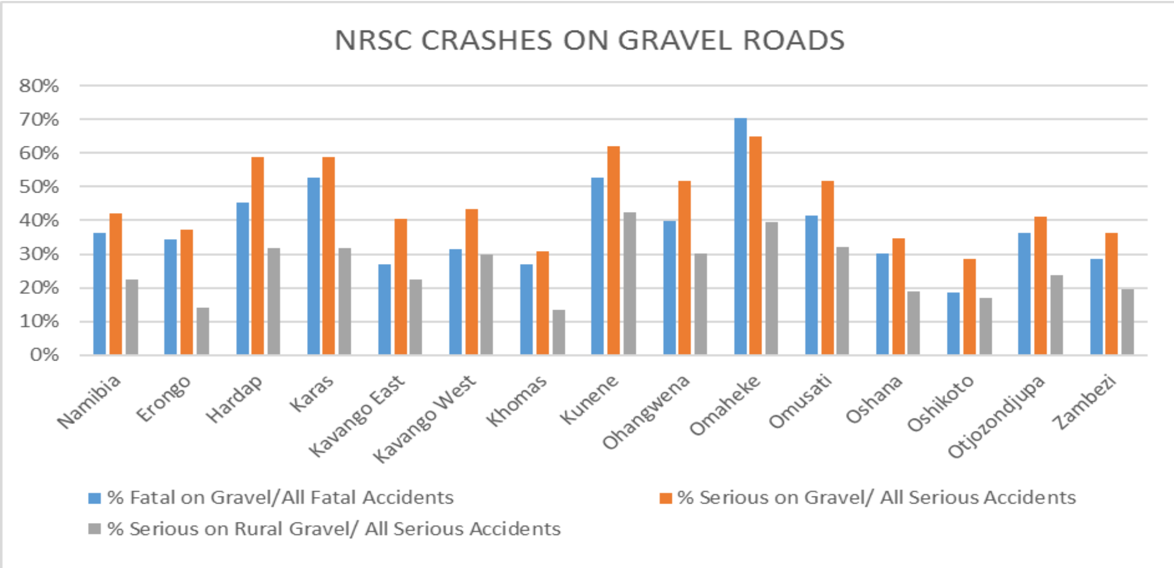

Figure 11 : Crashes on Gravel Roads per Region

Source: NRSC Dataset

2.5 Résumé

Road safety is, generally, measured as fatalities per 100 000 population when considering from a public health perspective. The WHO (2015, page 6) calculated that the average road traffic fatality in the world is 17.4 fatalities per 100 000 population with the Africa continent the region with the highest road traffic fatality of 26.6 per 100 000 population. Namibia has a small population of 2.3 million people. The WHO (2015, page 187) estimates 551 road crash fatalities, which result in a road traffic fatality rate of 23.9 fatalities per 100 000 population.

Although there is some variation in the number of the fatalities, according to various sources, the road traffic fatality rate remains high. The NRSC keep crash records based on police records and recorded 245 fatalities in 2012. The MVA record crash fatalities based on claims received. The MVA reported 542 fatalities in the 2011/2012 financial year. The WHO estimated the fatalities to be 551 based on 2012 data. The difference may be attributed to the NRSC recording only fatalities immediately with the crash, while the MVA recording fatalities within 30 days of the crash. The MVA (webpage) reported 713 fatalities in 2017 which implies a road traffic fatality rate of 31 per 100 000 population.

The relation between population, vehicles and road crash fatalities has been studied since 1949. The trend for African countries was calculated based on the 2015 WHO data. For Namibia, the African trend predicted 23.9 fatalities per 10 000 vehicles. In 2013, Namibia had 21.4 fatalities per 10 000 vehicles, which is 10% fewer fatalities than the Africa Trend.

The cost of road crashes has a significant economic impact. The cost of crashes can be determined by two methods namely the Human-Capital method or the Willingness-to-Pay method. The Willingness-to-Pay method is known to provide higher values and determined the crash cost of Namibia at US$533 million or 6.4% of GDP. The Human-Capital method estimates the crash cost at 3.5% of the GDP which amounts to US$ 295 million per annum.

Most of the crashes, 60%, occur on the surfaced road network. The road network consists of 7 285km of surfaced road or 15% of the Namibian road network. There is a 50% split of crashes between urban and rural roads. The traffic on the rural surfaced roads is between 200 and 1 000 vehicles per day. Traffic volumes on the gravel roads are generally less than 50 vehicles per day and 40% of the crashes occur on gravel roads.

3 Crash Types on Namibian Roads

The basic causes of crashes can be categorised as vehicle defects, infrastructure and environmental deficiencies, as well as road user errors. Road user errors are the major contributing factor to 75% of all road crashes (Matthews, 2011, page 221). The Decade of Action for Road Safety defined five road safety pillars, which are Road Safety Management, Safer Roads and Mobility, Safer Vehicles, Safer Road Users and Post-Crash Response (SADC, 2011, page 6). The three pillars, namely, safer roads, safer vehicles and safer road users, relate directly to the three causes of crashes.

The most reported crashes are head-rear end collisions and collisions with animals but these crashes result in a minor number of fatalities (NRSC dataset). The more serious crash types on Namibian roads are roll-overs at 29% of all crashes, and collisions between vehicles at 27% of all crashes. Crashes involving pedestrians represent 23% of all crashes, but 32% of the road crash fatalities are pedestrians. Table 6 shows that these three types of crashes combined account for 79% of all crashes. (MVA, 2016, page 13; WHO, 2015, page 187)

Table 6 : Types of Crashes in Namibia

Table 4: Types of crashes (2015 & 2016)

Types of crashes	2015		2016	
	Actuals	Percentages	Actuals	Percentage
Roll-overs	1250	29%	1210	29%
Collisions	1202	28%	1113	27%
Pedestrians	928	22%	931	23%
Hit and run	218	5%	199	5%
Cyclists	155	4%	117	3%
Fixed objects	144	3%	146	4%
Animals	142	3%	140	3%
Under investigation	119	3%	148	4%
Fell/jumped from moving vehicle	99	2%	79	2%
Tyre burst	37	1%	37	1%
Mechanical failures	8	0%	11	0%
Collision with train	7	0%	3	0%
Total	4309	100%	4134	100%

Source: MVA (2016) Crash and Claims Report page 13

Cars and light vehicles are involved with 61% of the fatal crashes with driver fatality at 31% and passengers at 30%. Pedestrians account for 32% of road crash fatalities with other road users accounting for the remaining 7% (WHO, 2015, page 187).

The NRSC data showed that 76% of fatal or serious injury crashes are single-vehicle-crashes and 22% of fatal crashes involve two vehicles. Only a small portion of fatal and serious injury crashes are caused by 3 or more vehicles.

Most of the collisions, namely 90%, occur on urban roads. The collisions on Trunk Roads are 5% of all the collision crashes, 1% on main roads and 1% on district roads and 3% are unspecified, as shown in Figure 12. Rear-end collisions are the most common collision type followed by sideswipe collisions. Most of the fatal collisions are head-on collisions.

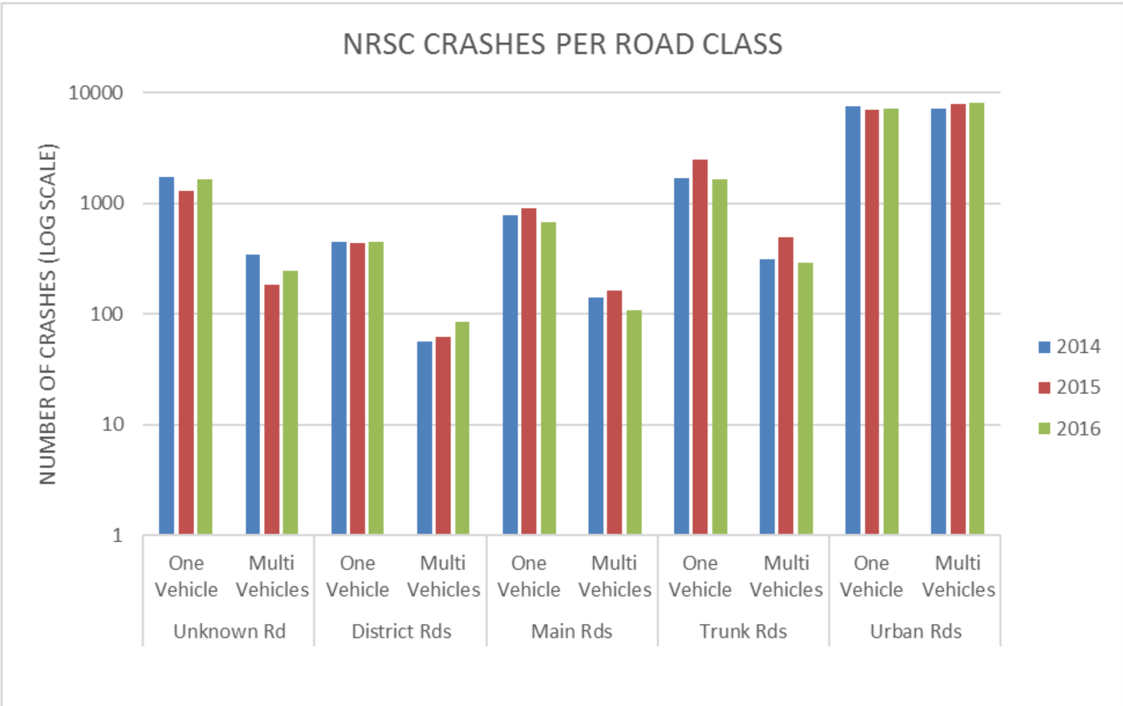

Figure 12 : Crashes per Road Category from 2014 to 2016

Source: NRSC Dataset

3.1 Literature Study on Crashes

In the United States the all crash rate of rural areas in 2001 was 1.8 per million kilometer (2.92 per million miles) driven. The study reported the fatal crash rate as 0.018 per million kilometer (2.86 per 100 million vehicle miles) (Zwerling et al., 2005, page 25). The rural fatality rate is 0.011 per million vehicle kilometer (1.81 per 100 million vehicle miles) in the USA (NHTSA, 2016, page 2).

The literature study investigated roll-over crashes, head-on collisions and pedestrian crashes

Roll-Over Crashes

International studies have been conducted into roll-over crashes, since roll-over crashes have a disproportionally high level of fatalities. In America 20% of fatal crashes are roll-over crashes, while in Australia 24% of fatalities occur with roll-over crashes. Most of these studies focussed on the vehicles and occupants of vehicles. The types of vehicles most prone to roll-over crashes are sport utility vehicles followed by pick-up vehicles (Deutermann, 2002, page 44; Grzebieta et al, 2016; Benade et al, 2016, page 2; Strashny, 2007, page 66; Keall and Newstead, 2006, page iii).

In the USA 70% of roll-over crashes occurred on straight road sections suggesting that driver distraction or drowsiness plays a roll. Speed as a contributing factor was reported with 40% of fatal roll-over crashes while some 70% of the fatalities did not use seatbelts (Deutermann, 2002, page 44).

In 2004 some 275 637 passenger vehicles with 393 545 occupants rolled over in the USA which resulted in 10 553 fatally injured occupants or 2.7%. A serious implication is the 15 312 occupants that were ejected from their vehicles. This study also found that most roll-over crashes occur while traveling on a straight, some 60% of all roll over crashes, followed by negotiation of a curve with 32% of the roll-over crashes. Roll-over crashes were associated, in 52% of the crashes, with striking an embankment and 30% of the crashes with hitting a culvert, curb or ditch. The vehicle manoeuvres before the roll-over crash with the lowest roll-over inclination is turning, changing lanes and passing another vehicle. Guardrails had a higher association with roll-over crashes for pick-up vehicles and sport-utility vehicles than for passenger cars and vans (Strashny, 2007, page 34 and 38).

In New Zealand roll-over crashes comprise 7.5% of all crashes. Medium size four-wheel-drive vehicles (4WD) had double the roll-over rate at 14% of 4WD crashes. (Keall and Newstead, 2007, page 17). Curves with a radius between 200m and 600m accounted for most run-off the road crashes on curves and the proposed treatment is a 2.5m wide surfaced shoulder on the outside of the curve. In New Zealand 40% of all run-off the road crashes occur on straight road sections (Levett, 2007, page 9).

The HSM (2010) list the contributing factors for vehicle roll-over crashes as road side design such as non-transferrable side slopes or pavement edge drop off, inadequate shoulder width, excessive speed and pavement design. Other causes of single vehicle roll-over crashes are factors such as speed, unforgiving shoulders with narrow lanes, loss of concentration, loss of control due to uneven road surfaces, tyre failures or unexpected horizontal curves.

The horizontal alignment of a road is influenced by the topographical terrain features, property boundaries and historical position of a road. The safe speed through a horizontal curve is dependent on the radii of the curve, the super-elevation of the road, as well as friction between the vehicle's tyres and road surface. An unexpected horizontal curve is where one or more of these factors substantially deviate from the preceding curves without a noticeable change in topographical features. For example, on a flat open terrain where the road had, for the preceding 5 to 10km long slow curves, the occurrence of a sharp curve will be unexpected. However, should the terrain change to mountainous conditions a sharp curve will not be unexpected. An experienced driver has developed expectancies which enable the driver to anticipate events, do forward planning and respond to common situations in a predictable and successful manner (Van Schalkwyk and Prinsloo, 1999).

Head-on Crashes

Head-on collisions occur with overtaking of slower vehicles at locations without sufficient sight distance, miss judgement by the driver or drifting over onto the oncoming lane. Speeding, drowsiness and use of alcohol are all contributing factors. Increase in traffic volumes may reduce the availability of passing opportunities resulting in increased risk-taking by drivers. The design of undivided roadways determines the driver workload (HSM, 2010: page 2-16).

The HSM (2010) names the following contributing factors for opposite sideswipe or head-on collisions, namely inadequate roadway geometry, inadequate shoulders, excessive speed, inadequate road markings and inadequate road signing. Inadequate roadway geometry can lead vehicles to encroach on opposite traffic lanes or without sufficient clearance space. The roadway geometry may limit the opportunity of safe passing zones which can lead to frustration and increase risk-taking by motorists. Inadequate shoulders do not provide safe crash evading space. Road marking and signage should guide vehicles on the correct position of the road and provide guidance on safe passing zones. Road signs should warn motorist of possible hazards ahead of the danger, to enable the motorist to adapt to a safe speed through the hazard, such as an intersection or curve. The risk reduction or increase due to geometrical features, such as lane width, shoulder width, shoulder type surface, horizontal curve properties, vertical grades, are modelled in crash reduction methods (HSM, 2010; Harword et al., 2000).

The study by Zhang and Ivan (2005, abstract) modelled head-on collisions with variables of speed, horizontal curvature and vertical curvature for Connecticut in the United States. They found that "to reduce the incidence of head-on crashes on two-lane roads, it is more effective to reduce the number and degree of horizontal and vertical curves than to widen the pavement".

A subsequent study by Deng, Ivan and Gárder (2006, abstract) investigated potential causal factors that are associated with head-on collisions. They found that pavement width and wet road surfaces relate significantly to head-on collisions in the United States. “Pavement width was found to be the most consistent factor, possibly because a wider road offers more space to avoid a direct head-on impact, thus reducing the severity of the crash. In addition, vehicle braking performance was important, as suggested by the higher probability of more severe head-on crashes on wet surfaces” (Deng et al 2006, abstract).

The most effective mitigation measure is the provision of dual carriageway roads where a physical barrier prevents vehicles from entering the opposing traffic lanes. This is however expensive and is seldom implemented due to budget constrains (Schumaker et al. 2016, abstract).

The provision of passing lanes to provide more passing opportunities has been a successful mitigation measure. A study on nine passing lane sections in Kansas showed significant safety improvement. The study found a 27% crash reduction on fatal and injury crashes and a 44% reduction in all crashes on the passing lane sections (Schumaker et al. 2016, abstract; Mutabazi et al. 1999, page 154).

Surfaced shoulders do provide more manoeuvre space for evasive action but could alter head-on collisions to side-swipe crashes. The construction of the road with sufficient passing sight distances and, where viable, reducing the no-passing zone length should be a priority with the initial design of all roads. The correction or improvement of horizontal or vertical curves is a costly exercise that requires complete reconstruction of the section of the road.

Pedestrian Crashes

The impact of the vehicle speed on the severity of the pedestrian injury has been studied. Davis (2001, abstract) analyses provided fatality risks for the three age groups, namely children up to 14 years old, adults and old age persons above 60 years. Pedestrian crashes with the vehicle speeds below 30km/h are rarely fatal. Pedestrian crashes are fatal with vehicle speed above 80km/h, but for children vehicle speed above 60km/h is fatal (Rosén at al. 2010, page 28).

The HSM (2010, page 6-8) identified some contributing factors for pedestrian crashes. They are limited sight distance, inadequate barrier between pedestrian and vehicle facilities, inadequate signs and signal phasing, inadequate pavement markings, inadequate lighting, driver has inadequate warning of mid-block crossing, lack of crossing opportunities, excessive speed, pedestrians on the roadway, long distance or nearest crosswalk and school crossing area (HSM, 2010: page 6-8).

3.2 Roll-over Crashes in Namibia

A roll-over crash is normally a single vehicle crash where control over the vehicle is lost and the vehicle overturns. There are various reasons that can cause roll-over crashes, such as sudden tire failures, potholes or uneven road surface, fatigue and unexpected obstructions in the road, in conjunction with high vehicle speeds. Driving under the influence of alcohol is also a contributing factor (MVA, 2016, page 12).

Roll-over crashes account for 29% of all crashes but result in 40% of the injuries and 36% of the fatalities. In Australia and America roll-over crashes constitute a similar portion of fatal-crashes (Deutermann, 2002, page 40; Grzebieta et al, 2016, page 1; Benade et al, 2016, page 1; Strashny, 2007, page 1; Keall and Newstead, 2006, page 17).

The roll-over crashes occur mostly on straight sections of road as recorded for 60% of fatal roll-overs and 70% of all roll-over crashes in Namibia. The trend is like the finding of Deutermann (2002, page 28) and Strachny (2007, page 24) on roll-over crashes in the USA.

More roll-over crashes occur on weekends than on week days, as shown in Figure 13 for 2015 and 2016. Saturdays have the highest occurrence of fatal roll-over crashes followed by Fridays. The Time of Day evaluation showed that the afternoon and early evening is slightly more prone for roll-over crashes. Fatal roll-over crashes occur throughout the day, with a peak from 15h00 until 17h00, especially on Saturdays and Fridays. Although there are monthly variations in the number of roll-overs, the peak hour remained between 15h00 and 17h00. December month had a slightly higher number of roll-overs which can be expected, due to the holiday season and corresponding higher traffic volumes. No other monthly trend could be observed (MVA, 2016, page 37 and 38; NRSC dataset).

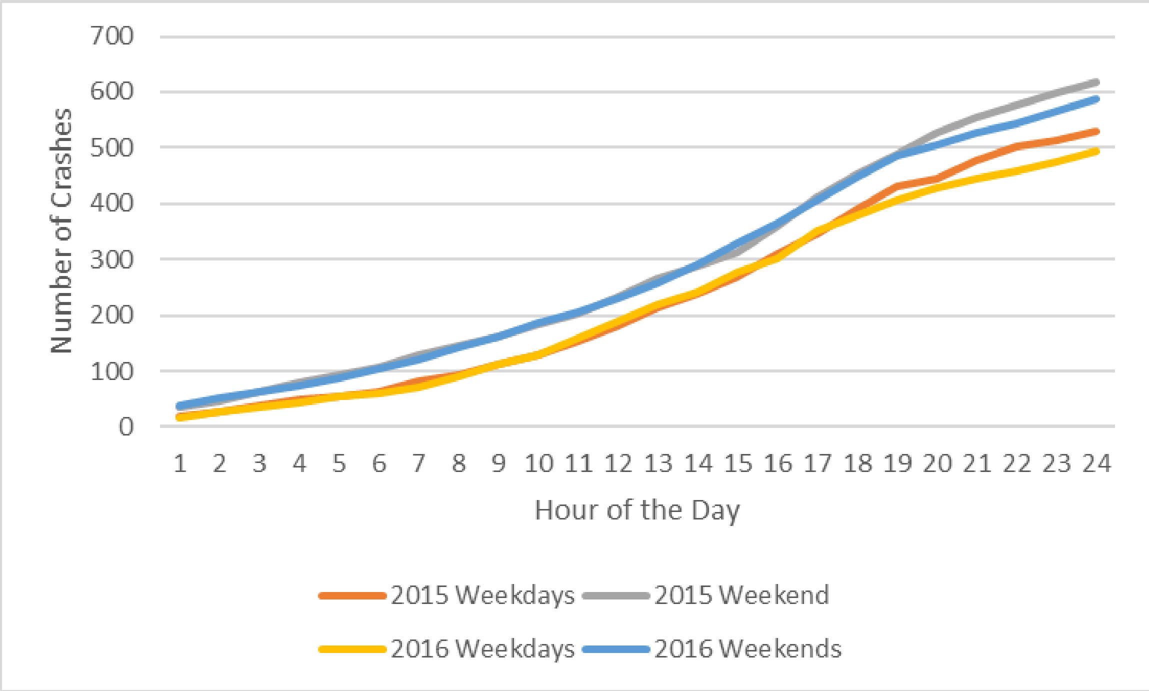

Figure 13 : Cumulative Number of Fatal Roll-over Crashes by Time of Day

Source: 2016 and 2015 NRSC dataset on fatal roll-over crashes

In Namibia there is a trend to travel on Friday afternoons and Saturdays, increasing the traffic volumes and subsequent crash risk. The roll-over peaks of 6h00 and from 15h00 to 18h00 correspond with a higher animal movement which could be a contributing factor to the crashes.

Namibia has different types of roads from freeways to gravel roads and even tracks. The improvement of the vehicles especially sport utility vehicles and pick-up vehicles, has made it possible to travel comfortably at high speed on these roads even at faster speeds than the design speed. Education of drivers, to make them aware of the risk that exponentially increases with speed and policing of speed limits, can reduce the occurrence of roll-over accidents. Warning buzzers and speed management in rental vehicles have led to substantial improvement in this regard. NAMTRACK is a company that provides such a service. Their customers fleet of 357 vehicles used to lose 40 vehicles per year, due to crashes. The implementation of the speed management has reduced the vehicle loss due to roll-over crashes substantially to only 2 per year.

Contributing factors to roll-over accidents, which can be mitigated with road maintenance, are pothole repairs and regular blading to provide an even road surface. Maintenance of the shoulders will prevent edge breaks and eroded shoulders.

Road geometrical standards provide guidance on road verge clear zones, which enables a driver to correct run-off the road incidents without resulting in fatalities. Such standards will provide suitable road shoulders and transferable side slopes. Provision of surfaced shoulders enables the driver to move back onto the correct lane or to stop safely. Surfaced shoulders also provide more manoeuvre space when two vehicles are passing one another. Road signs and furniture are off-set from the road so as not to pose a hazard. Technologies, such as collapsible poles, reduce the severity of the incidents (Van Schalkwyk and Prinsloo, 1999).

Run-off the road incidents can be mitigated by improving the delineation of the road and thereby assisting the driver to follow the road. Delineation can consist of road markings, guideposts, cat-eyes, chevron signs, as well as warning signs and speed signs. Rumble strips on the lane edges can be audible and with these vibrations warn drivers that they are leaving the lanes (Van Schalkwyk and Prinsloo, 1999).

3.3 Collision between Vehicles in Namibia

The second major type of crashes are collisions between vehicles. The MVA (2016, page 13) report did not report on the specific type of collisions. The NRSC in 2011 reported that 2% of all the reported collisions were head-on collisions but they accounted for 48% of the fatal collisions and 30% of serious injury collisions. Head-to-rear-end collisions and side swipe from opposite directions were the most frequent collision types. These two collision types accounted for 26% of the fatalities and 34% of the serious injuries.

Table 7 : *Types of Collision Crashes in Namibia*

Collision Type	Crashes	Fatal	Serious
Head-on	2%	48%	30%
Rear-end	32%	14%	21%
Sideswipe opposite directions	39%	12%	13%
Sideswipe same direction	7%	9%	11%
Turn right into oncoming traffic	10%	10%	10%
Unknown	10%	5%	15%
Sub-total	**100%**	**100%**	**100%**

Source NRSC Statistic Report 2011 Table 9

The design of undivided roadways determines the driver workload (HSM, 2010: page 2-16). On typical Namibian roads the driver's task is undemanding, which can lead to driver fatigue and sleepiness. Fatigue and sleepiness lead to run-off the road crashes or head-on collisions.

3.4 Pedestrian Crashes in Namibia

The MVA reported that 23% of crashes involve pedestrians (MVA, 2016, page 13). In Africa, 65% of all road crash fatalities are vulnerable road users (Bezabeh, 2013, page 6) and in Namibia 32% of fatalities are pedestrians (WHO, 2015, page 187). The number of pedestrians involved in road crashes peaked in 2014 with 1 164 pedestrian crashes, as shown in

Figure 14. In 2012 there were 1 030 crashes with pedestrians and in 2016 there were 1 130 pedestrian crashes.

The time of the day when pedestrian crashes occur pattern is related to the normal pedestrians activity on or along the roads. During the early morning hours from 1h00 till 5h00 there are nominal pedestrian crashes. There is also a small morning peak in the pedestrian crashes from 6h00 to 7h00. From 12h00 the occurrence of pedestrian crashes increase with the ultimate peak late afternoon and early evening as shown in Figure 15.

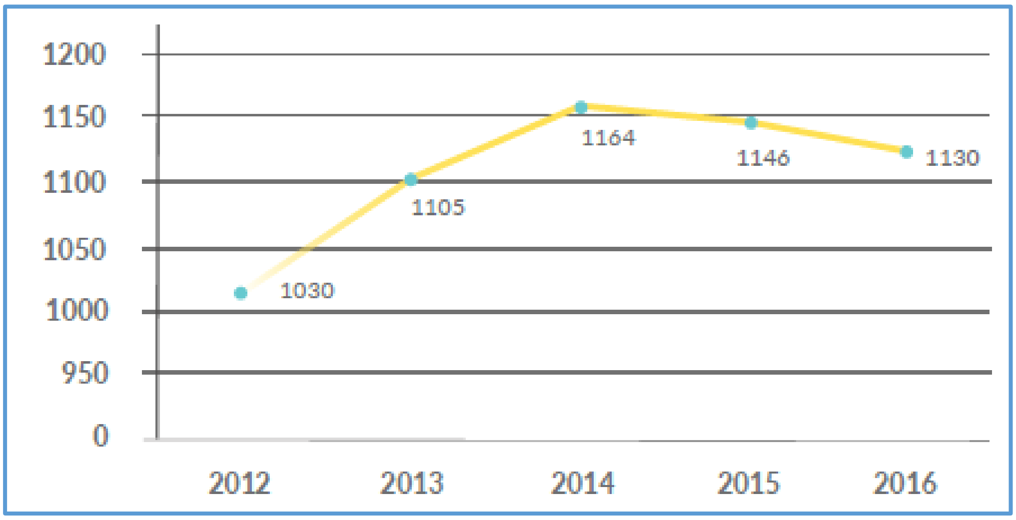

Figure 14 : Pedestrian Crashes in Namibia 2012 to 2016

Source: MVA (2016), page 32

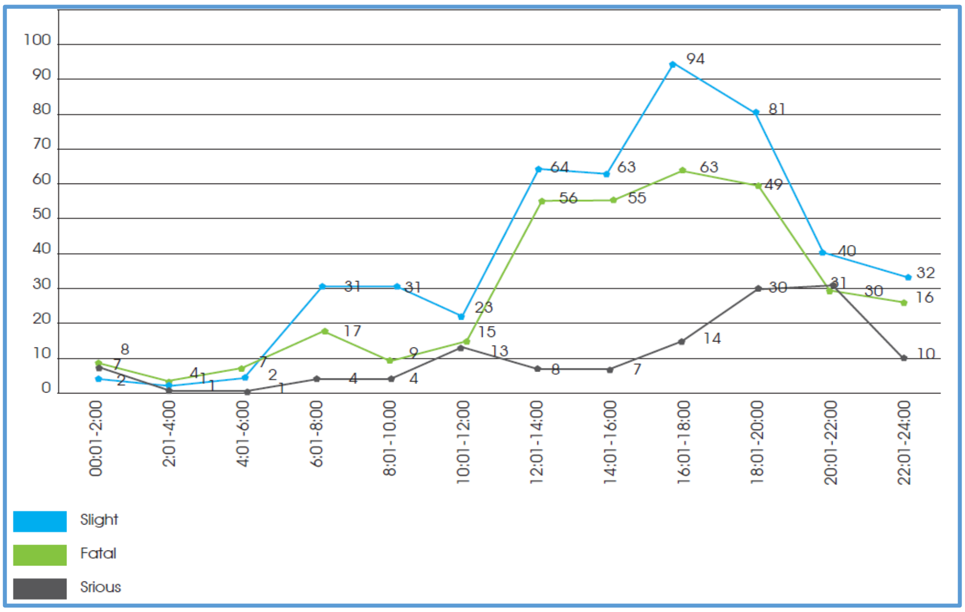

Figure 15 : Pedestrian Injuries by Time of Day

Source: NRSC (2011) page 63

The weekly crash pattern showed that on Fridays and Saturdays a higher number of pedestrian crashes occur. The daily crashes for the years 2015 and 2016 on Fridays and Saturdays reported 200 crashes per day while 100 crashes per day occur on Tuesdays or Wednesdays (MVA, 2016, page 33).

Children and young people are the most vulnerable and have the highest age-related crashes. Children in the age group 6 to 10 years were involved in 13% of the pedestrian crashes. Children from 11 to 20 years were involved in 6.5% of the pedestrian crashes. Young people within the ages of 26 to 30 years, were involved in 13% of the pedestrian crashes while the age groups 21 to 25 years and 31 to 35 years were involved in 10% of the pedestrian crashes (MVA, 2016, page 33). The information of pedestrian crashes in Botswana shows a similar pattern with a slightly higher occurances of the 21 to 25 year age group (Statistics Botswana, 2015, page 18).

Males have a higher risk than females at a 60:40 ratio (MVA, 2016, page 34).

The MVA (2016) report, unfortunately, does not distinguish, for pedestrian crashes, if the crash occurred in rural or urban areas, nor do they provide any information on the severity of the pedestrian crashes. The NRSC (2011, page 35) reported that most pedestrian crashes resulted in slight injuries, followed with 10.4% fatal crashes. Only a few crashes result in serious injuries, as shown in Figure 15. In Botswana 70.7% of the pedestrian crashes resulted in minor injuries, 20.9% in serious injuries and 8.4% of the pedestrian crashes are fatal (Statistics Botswana, 2015, page 18).

The NRSC in 2011 reported that 53% of pedestrians were walking and 39% were running at the time of the crash. Only a small portion, 8% of pedestrian crashes, happened at marked pedestrian crossings. Most of the pedestrian crashes occurred on the roadway, with 36% of the pedestrian crashes occurring on the shoulder, sidewalk or median. This indicates that there is a need to educate pedestrians and motorists on the safe use of roads.

Mitigation measures to reduce pedestrian crashes include the provision of separate pedestrian facilities along with high-speed roads. The lack of sidewalks increases the road safety risk of pedestrians, especially on high speed and high volume roads (Rahman and Kubota, 2016, page 334).

Education of pedestrians, as well as drivers on the safe crossing of roads and wearing of bright clothes to be more visible.

Traffic calming methods and particular road humps in urban environments contribute to vehicle speed reduction and gains in road safety, especially for pedestrians. The study by Bunn et al.

(2003, page 6) found that traffic calming reduces the severity of pedestrian crashes, although the number of pedestrian crashes is not reduced.

3.5 Résumé

The Decade of Action for Road Safety defined five road safety pillars, which are Road Safety Management, Safer Roads and Mobility, Safer Vehicles, Safer Road Users and Post-Crash Response (SADC, 2011, page 6) of which three pillars, namely safer roads, safer vehicles and safer road users relate directly to the three causes of crashes. The most frequent fatal crash types in Namibia are roll-over crashes, 29% of all crashes, followed by head-on collisions, 27% of all crashes and pedestrian crashes 23% of all crashes. These crash types are not unique to Namibia as they have received global attention. Various mitigation measures can be applied to reduce the occurrence or severity of these crashes.

Measures to mitigate roll-over accidents that have been discussed are correct speed for the type of road, road maintenance and road geometry standards to provide a forgiving road environment.

Measures to reduce head-on collisions include improvement of the road alignments, construction of dual carriageway roads and law enforcement. Surfaced shoulders provide more space to avoid a direct head-on impact, thus reducing the severity of the crash.

Pedestrian crashes are fatal with vehicle speeds above 80km/h. Provision of separated pedestrian facilities is the most effective measure. Provision of pedestrian crossings at convenient and safe locations also improve pedestrian safety, as well as education on the correct crossing of roads, wearing of high visibility cloth at night and street lighting. Appropriate speed calming and speed limits in urban areas can reduce vehicle speeds to limit the severity of pedestrian collisions.

4 Okahandja Karibib Road

The Okahandja to Karibib Road is part of the Namibia National Trunk Road Network, as well as the SADC Trans-Kalahari highway that links the harbour of Walvis Bay to Botswana and South Africa. The map in Figure 16 shows the Okahandja Karibib Road, which is located centrally in relation to the national road network. The road is located in the Erongo and Otjozondjupa regions.

The Okahandja Karibib Road has been upgraded with surfaced shoulders and passing lanes, from 2008 to 2012, while the adjacent trunk roads have not been upgraded. The perception is that the Okahandja Karibib Road is safer than the adjacent trunk roads.

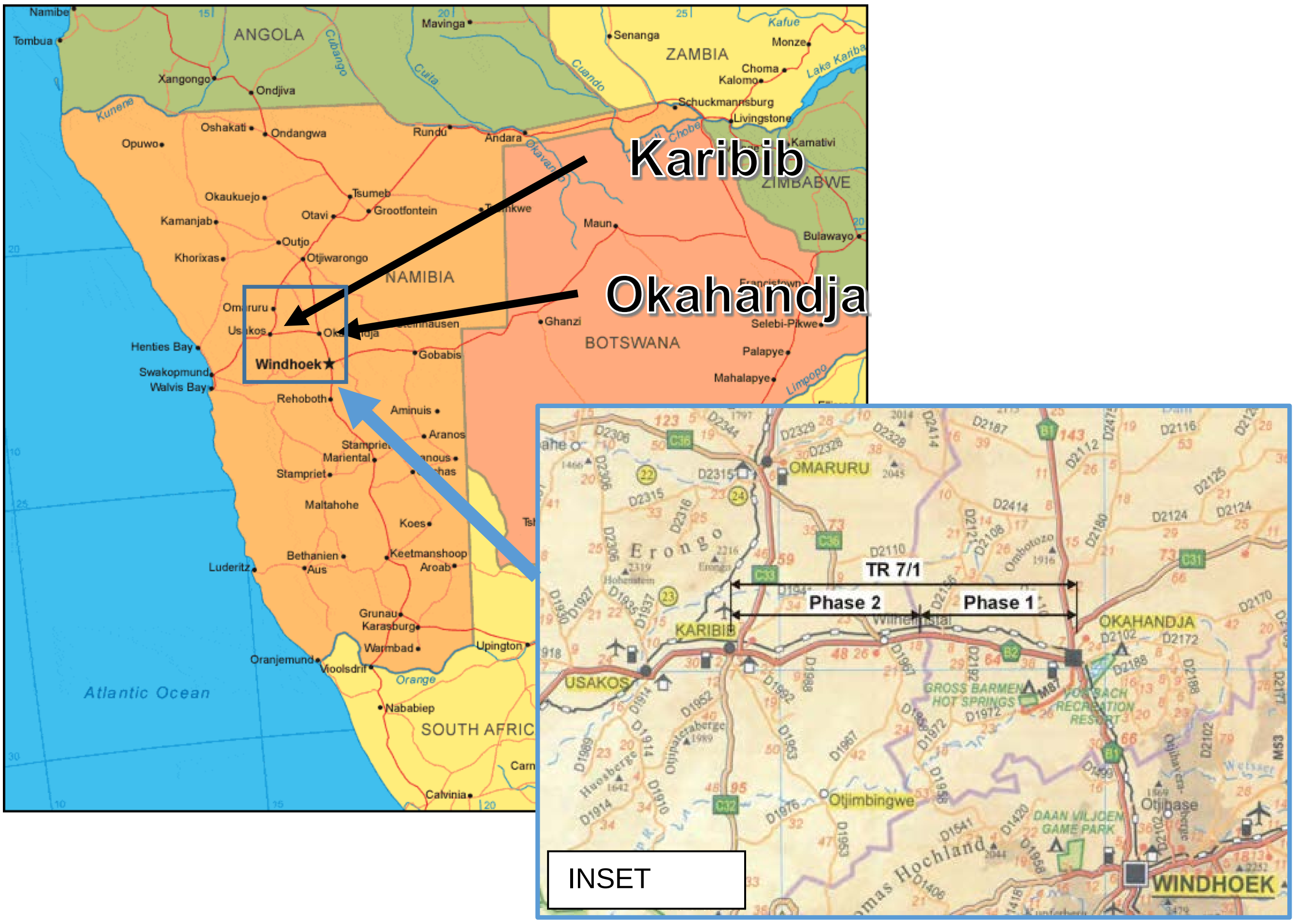

Figure 16 : Map of Namibia and Okahandja Karibib Road

Source: http://geology.com/world/namibia-satellite-image.shtml The inset from AC van der Merwe and B Alexander, 2003, Project Proposal Report, page 5

4.1 Geometrical Standards

The road from Okahandja to Karibib is 115km long and was initially constructed in the 1960's. The original road comprised of two 3.2m lanes with 1.5m gravel shoulders as can be seen in Figure 17 (AC van der Merwe and B Alexander, 2003, page 7). The first 40km from Okahandja winds through rolling terrain, which provided limited passing opportunities. Platooning of vehicles on this section was a regular occurrence prior to the road upgrading, which contributed to driver frustration and risk-taking.

Figure 17 : A) Road with pavement failure   B) Road with gravel shoulders

Source: AC.van der Merwe and B Alexander, Project Proposal, 2003

The road has been upgraded with two 3.7m wide lanes and 2.5m wide surfaced shoulders. Six passing lane sections have been added, between kilometer 8 and 45 as measured from Okahandja, which provide three lanes of 3.7m. The shortest section is 1.1km long and the longest 2.7km long. On these sections the surfaced shoulders are reduced to 1.0m width. The provision of passing lanes is generally known as a 2+1 cross-section in Namibia. The diverging tapers have a length of 100m and the merging tapers are 200m long.

The adjacent Trunk Roads to the Okahandja Karibib Road are the Karibib to Swakopmund Road, Windhoek to Okahandja Road, Okahandja to Otjiwarongo Road and the Karibib to Omaruru Road. These roads have not been upgraded and their typical cross-section consists of two 3.6m wide lanes with 2m gravel shoulders.

4.2 Traffic

The Roads Authority continuously monitor the traffic volumes on their road network. The Roads Authority provided the data from which the Average Annual Daily Traffic (AADT) could be determined.

The AADT in 1990 was 573 vehicles of which 79 (13.8%) were heavy vehicles. In 1994 the AADT increased to 774 vehicles with 91 (11.8%) heavy vehicles (AC van der Merwe et al, 2003, page 9). The AADT for the Okahandja to Karibib Road in 2000 was 1 200 vehicles with 187 (15%) heavy vehicles. The traffic volumes increased yearly by around 4% and the percentage of heavy vehicles increased from 15% in 2000 to 20% in 2015. In 2015 the AADT was 2 982 vehicles with 610 (20%) heavy vehicles. Table 8 shows that there was a decrease in traffic in 2008 and 2009 but a substantial increase in 2010. The increase from 2007 to 2010 is 7% or an average of 2.2% per year. The traffic volume increased after construction with 8% a year and the portion of heavy vehicles increased from 18% in 2011 to 20% in 2015. (RMS traffic data).

Table 8 : *Traffic on Karibib Okahandja Road*

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Light Vehicles	1,710	1,564	1,491	1,715	1,807	1,950	2,051	2,210	2,372
Heavy Vehicles	242	305	326	367	407	459	525	575	610
% Heavy Vehicles	12%	16%	18%	18%	18%	19%	20%	21%	20%
AADT	1951	1869	1817	2081	2213	2410	2575	2785	2982
Increase in AADT		-4%	-3%	15%	6%	9%	7%	8%	7%

The adjacent roads traffic volumes for 2015 are presented in Table 9. The portion of heavy vehicles on the roads vary between 19% and 28% of the AADT. The road with the highest traffic volumes is between Windhoek and Okahandja with 6 691 vehicles per day, followed by Okahandja to Karibib and then Karibib to Swakopmund with 2 774 vehicles per day. The Windhoek Okahandja Road carries 1 251 heavy vehicles per day and the Swakopmund to Karibib Road has 678 heavy vehicles per day. The road from Karibib to Okahandja carries a substantial volume of traffic in comparison with the adjacent roads.

Table 9 : *Traffic on Selected Trunk Roads in 2015*

Road	Trunk Road Number	AADT in 2015	Length in km	% Heavy Vehicles and number of HV
Swakopmund to Karibib	TR0202	2,774	180	24% (678)
Karibib to Okahandja	TR0701	2,982	115	20% (610)
Okahandja to Windhoek	TR0106	6,691	70	19% (1251)
Karibib to Omaruru	TR0203	1,157	60	28% (326)
Okahandja to Otjiwarongo	TR0107	2,501	170	27% (670)

Source : RMS traffic data

4.3 Construction

The road was upgraded and rehabilitated in two phases. Phase A consists of the first 77km from Okahandja, which was rehabilitated during the period from 2008 until September 2010. The construction work is a possible reason for the decrease in traffic volumes during 2008 and 2009.

Phase B consisted of the rehabilitation and upgrading of the remaining 35km to Karibib which commenced in November 2010 and was completed in August 2012. The project value of Phase A was US$ 22.3 million (N$ 289,7 million) and the project value of Phase B was US$ 8.9 million (N$ 116,7million).

4.4 Crashes on Okahandja to Karibib Road

There were 100 road crashes in 1999 on the Okahandja to Karabib Road, of which 49 were collisions with animals. The highest number of crashes occurred in 2007 with 122 crashes. In 2016 there were 103 crashes of which 50 collisions were with animals or birds.

Roll-over crashes were the crash type that accounted for 60% of the fatal crashes prior to construction. The crash data from 2007 to 2016 showed that there was a substantial reduction of road crashes in 2008, with 44 crashes. There were two fatal crashes in 2008 which resulted in two fatalities and another five crashes in which 15 people were seriously injured. In 2007 the number of road crashes was 122 of which two crashes resulted in three fatalities and eight crashes resulted in 15 seriously injured people. The number of crashes through the remaining construction years, until 2012, varied between 89 and 95 crashes per year. In 2012 five crashes with ten fatalities occurred and eleven road crashes resulted in 17 seriously injured people. In the previous years, 2009, 2010 and 2011, the number of fatal road crashes was zero, one and two, with four to eight serious injury crashes.

The crashes of the nine years showed that most of the crashes occurred in June followed by January and then February. The cumulative monthly crashes, as seen in Figure 17, show that there is no constant trend.

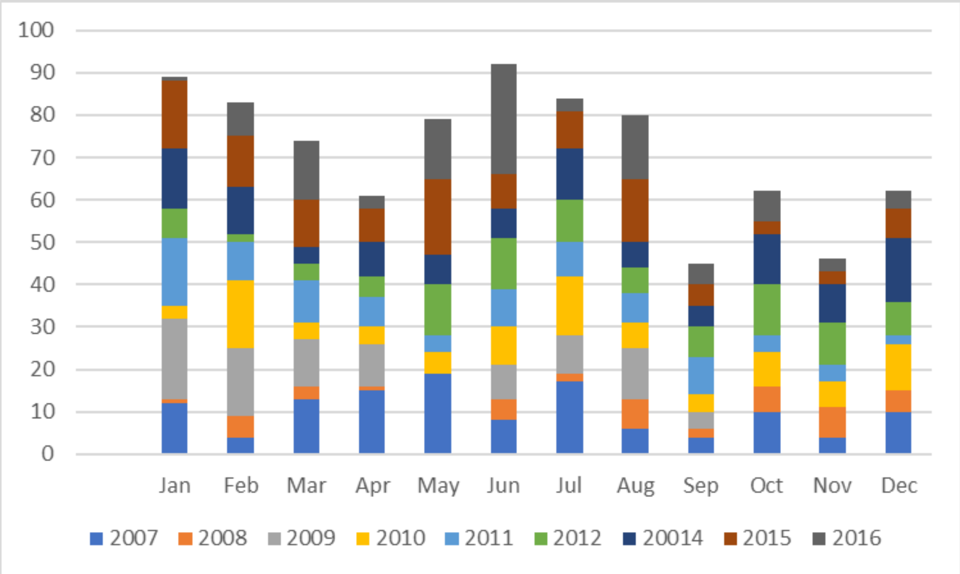

Figure 18 : Cumulative Monthly Crashes on Okahandja Karibib Road

Source: NRSC dataset

Single vehicle crashes were the most frequent, accounting for 83.6% of the crashes. Collisions between two vehicles accounted for 14.8% of the crashes, while multiple vehicles collisions only occur rarely. The crashes with multiple vehicles resulted in fatalities every time. Single vehicle crashes were fatal at 1.6% of the crashes and 4% resulted in serious injury. Crashes with two vehicles were fatal at 0.9% and 1.3% resulted in serious injury.

Crashes with an animal were the most frequent, with 35% of the crashes, followed with roll-over crashes at 15% of all crashes. The crashes with animals substantially decreased from 2008 to 2011, as shown in Figure 19. Roll-over crashes had a peak in 2011 with 26 roll-over crashes. Other single-vehicle crashes were with birds at 5.8% of all crashes and crashes with fixed objects at 4.6% of all crashes. Crashes which involved pedestrians accounted for 1.2% of all crashes and a single crash with a cyclist was recorded in 2009.

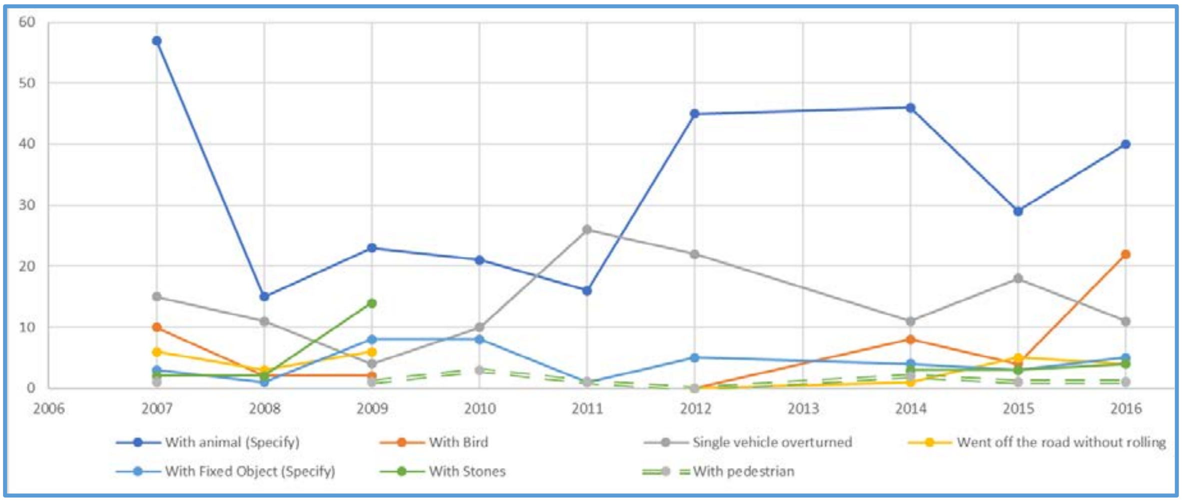

Figure 19 : Single Vehicle Crashes on Karibib Okahandja Road from 2007 to 2016

Source: NRSC dataset

Rear-end crashes accounted for 34% of collisions followed by sideswipe from opposite directions at 31% of the collisions. Sideswipe from the same direction accounted for 19% of the two-vehicle crashes, while head-on crashes accounted for 8% of the collisions. The number of sideswipe from opposite direction crashes substantially varied over time, as shown in Figure 20. Rear-end crashes had a peak of 10 crashes in 2011. Fatal head-on crashes occurred in 2012 and 2015. In 2007 and 2016 a rear-end crash resulted in one fatality for each year. Sideswipe from opposite direction crashes resulted in one fatality in 2014 and 2016 two of these crashes resulted in four fatalities.

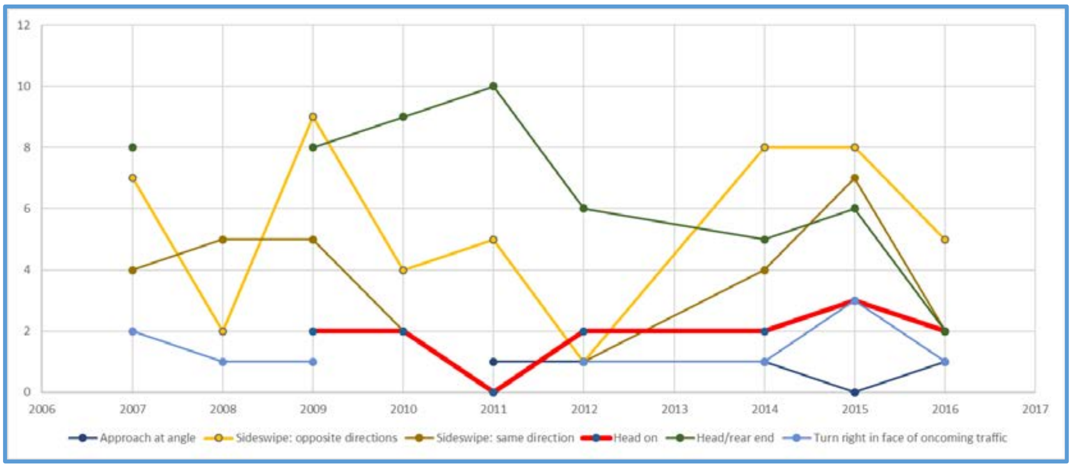

Figure 20 : Two Vehicle Crashes on Karibib Okahandja Road from 2007 to 2016

Source: NRSC dataset

The locations of 50% of the crashes were recorded but from where it was measured is not always clear and the recording police station was used as a guide in this regard. Figure 21 used Okahandja as kilometer 0 and ended at Karibib with kilometer 115. The Roads Authority has initiated the erection of kilometer markers along the Trunk Road network which will aid in capturing the crash locations more precisely in future. There was no location information for the crashes of 2008, 2009 or 2013. The road was under construction from 2008 to 2010.

The six passing lane sections commence at kilometer 8.7 and end at kilometer 43.7, their position is shown in Figure 21. The fatalities of each year are indicated with the bubble that is above the Year Serie in Figure 21. The size of the bubble is determined by the number of crashes.

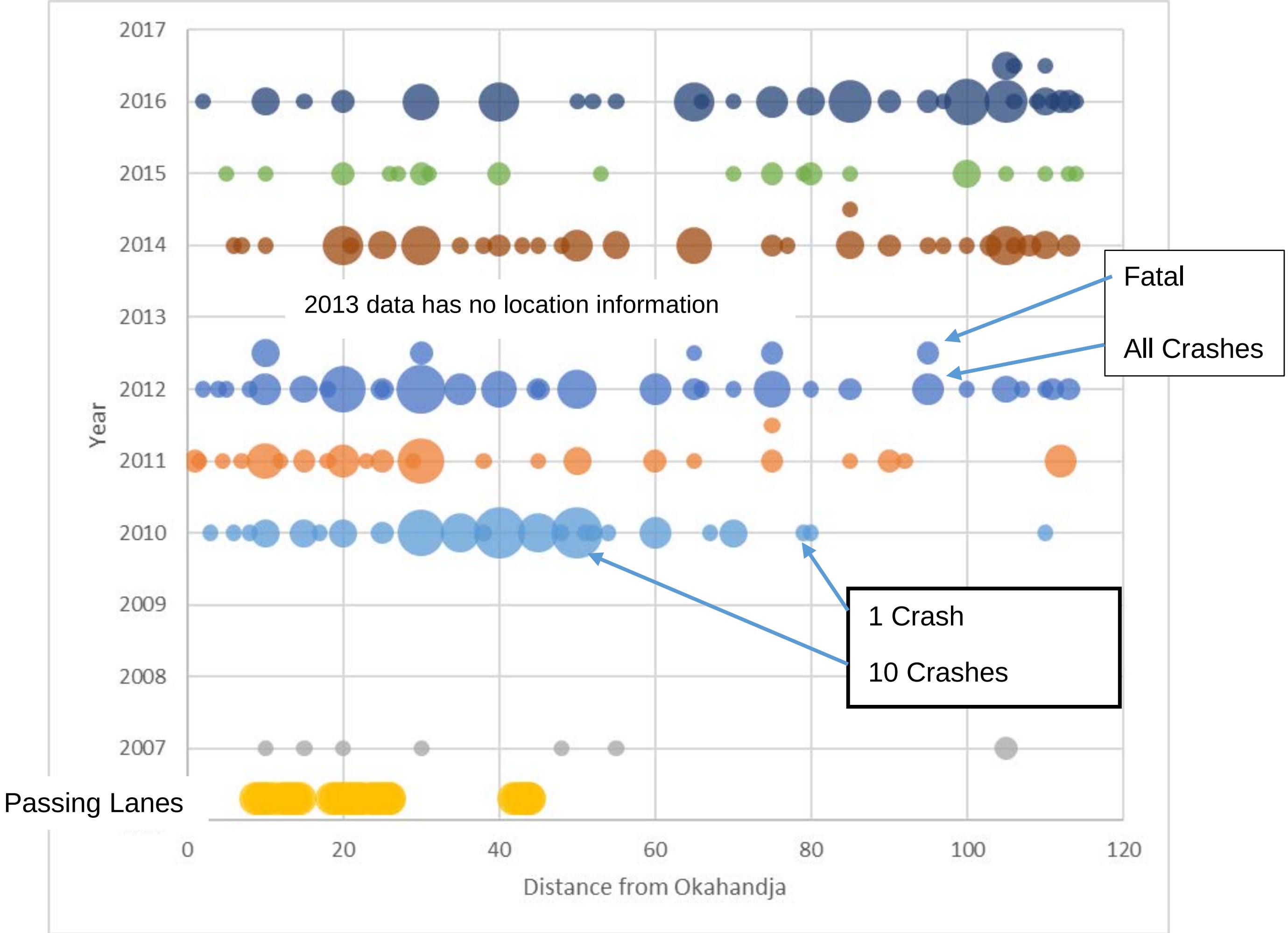

Figure 21 : Location of Crashes

Source: NRSC dataset

In 2016 most of the crashes occurred on the Karibib side and there were three fatal crashes with five fatalities at kilometer 105 to kilometer 110. Kilometer 30 shows a high number of crashes from 2010 to 2014 and in 2016. In 2011 and 2012 a fatal crash occurred in each year at kilometer 75.

Crashes with animals or birds account for 50% of the crashes at kilometer 10. The fatal crash in 2012 at kilometer 10 was a single vehicle turn-over crash with three fatalities on a Saturday afternoon at 16h10. Kilometer 10 is a straight section of road with a passing lane. The passing lane section is from kilometer 8.7 to kilometer 10.9.

Most of the crashes at kilometer 30 are with animals or birds. The fatal crash in 2012 at kilometer 30 was a single vehicle turn-over crash with two fatalities and three seriously injured people on a Friday morning at 11h25. The road cross-section at kilometer 30 consists of two lanes with shoulders that were surfaced in 2009. Two of the four crashes in 2011 at kilometer 30 were due to tyre bursts.

Two fatal crashes occurred at kilometer 75, one in 2012 and one in 2011. The fatal crash on Friday morning 5 August 2011 at 8h00, was a single vehicle, registered in Swakopmund, which overturned with one fatality. The fatal crash on Friday afternoon, the 26 May 2012 at 13h30 near km 75, was a head-on collision that resulted in two fatalities and two seriously injured persons. On 17 October 2012 at 18h00 a single vehicle overturned with one seriously injured person. There were three crashes with animals in 2012 at kilometer 75.

The fatal crash at kilometer 105 on Sunday afternoon at 17h00 on 7 August 2016, happened with a sideswipe from opposite direction collision which ended with three fatalities and four seriously injured persons. The fatal crash on Thursday night at 21h00 at kilometer 106 was a rear-end collision that resulted in one fatality. The other crashes at kilometer 105 in 2016 were three with animals or birds, a single vehicle that overturned and two collisions.

The fatal crash on Thursday night at 18h10 on 18 February 2016 at kilometer 110, happened with a sideswipe from opposite direction collision which ended with one fatality and one seriously injured person.

The crash data showed the random occurrence of the crashes and no specific location appears to have a higher crash occurrence. The estimation of the crash location has bundled crashes at the nearest 10 kilometer position. The recent provision of kilometer markers along the roads will aid in improving the location data of road crashes.

4.5 Prediction Modelling of Crashes

To evaluate the road safety benefits of different road design and road operations, a model which predicts road safety was developed by the National Cooperative Highway Research Program (NCHRP) in association with the Federal Highway Association (FHWA) (HSM, 2010).

The Predictive Method estimates the expected crash frequency, crash severity and collision types based on the known characteristics of the road. This methodology is a stepped process which estimates the average crash frequency for a specific year and site based on the crash frequency of the base model modified by the site-specific characteristics and calibrated to the local conditions. The Predictive Method is based on data of United States of America and, therefore, should be calibrated to adjust for the local driver population, local road and roadside conditions, traffic composition and traffic control measures. The Predictive Method for rural two-lane, two-way roads was used for the evaluation on the Okahandja to Karibib Road.

The base model determines the Safety Performance Function (SPF). The SPF is a regression model that predicts the average crash frequency for the road section for a year with the base conditions. The base condition is for a two-lane, two-way road with 3.6m (12 feet) wide lanes and with 1.8m (6 feet) wide surfaced shoulders. The road side hazard factor is taken as one, with a driveway density of three per kilometer (5 driveways per mile). The road is straight and flat without any street lighting.

The SPF function, (function 10-6 on page 10-15 of HSM) has two variables namely the length of the road segment in miles and the Average Annual Daily Traffic (AADT). The Okahandja Karibib Road is 115 kilometer (71.9 miles) long with an AADT in 2007 of 1 951 vehicles. The base model predicted an average crash frequency of 44.5 crashes. In 2016 the AADT was 3 180 vehicles and the predicted average crash frequency is 72.5 crashes.

The base model provides distribution of crashes based on crash severity or collision type. The base prediction for 2007 is 0.58 fatal crashes, 2.4 serious injury crashes and 30.2 damage only crashes. The base prediction for 2007 is 5.38 collision with animals, 1.11 roll-over crashes, 52 run-off the road crashes, 1.6 head-on collisions and 14 rear-end collisions.

Site-specific characteristics are those that differ from the base model. These differences are modelled with crash modification factors (CMF). The CMF's that were evaluated on the Okahandja Karibib Road are lane width, shoulder width, shoulder surface, horizontal alignment, vertical alignment and presence of passing lanes. The CMF is multiplied with the SPF to adjust the crash frequency for the site-specific characteristics.

The CMF for lane width and shoulder width is a function of the AADT. The CMF for the 3.2m lane width in 2007 is 1.29 and the CMF for the shoulder width of 1.5m in 2007 is 1.14. The CMF for the gravel shoulder in 2007 is 1.02.

The CMF for a horizontal curve is a function of the curve length and radius. The CMF is determined for each curve individually. The CMF for the 19 curves on the Okahandja Karibib

Road is between 1.01 and 1.123, with the CMF of 1.123 for a curve at kilometer 93.6 with a curve length of 200m and a radius of 1 000m.

The base vertical alignment is flat with slopes of less than 3%. Road slopes between 3% and 6% have a CMF of 1.10. On the Okahandja Karibib Road only two sections, at kilometer 24 and kilometer 29, had slopes of 3.2%. These slopes were marginally steeper and the CMF for vertical alignments was not applied.

The base model is for a two-lane road. For a conventional passing lane, a CMF of 0.75 is applicable. The model assumed that the passing lane is warranted with an appropriate length for the traffic conditions.

Crash modification factor was determined for each road section by multiplying the individual CMF factor with each other. The length of the road sections was one kilometer, which was averaged to 20 kilometer sections, shown in Table 10. The CMF was determined for 2007 prior to road upgrading as well as for 2010 on completion of the upgrading. The CMF before the road upgrading was 1.52 and after the upgrading the CMF is 0.845. A CMF value of 1.00 was used for the construction period.

Table 10 : *CMF for 20 km Road Sections*

Road Section	**Pre-construction**	**Post-Construction**
Km 0 to 20	1.516	0.781
Km 20 to 40	1.550	0.827
Km 40 to 60	1.513	0.840
Km 60 to 80	1.508	0.870
Km 80 to 100	1.523	0.879
Km 100 to 115	1.513	0.873
Average	1.520	0.845

The third step of the crash prediction methodology is to apply calibration factors. The calibration factors adjust the predictive model to local characteristics such as driver behaviour, road conditions and animals. The calibration factors need to be determined on a selection of typical road sections on a bi-annual basis (HMS, 2010). The calibration factor is the observed crashes divided by the predicted crashes. In Namibia the calibration factors have not been published and the determination of the national calibration factors is beyond the scope of this study.

The Calibration Factor was determined for each year with the available data. The Calibration Factor for the pre-construction period varied between 1.4 and 3.6 as shown in Table 11. In other words, there were 1.4 to 3.6 times more crashes than the predicted crashes. The Calibration Factor for the post-construction period was nearly a constant of 2.5. In 2010, with the finalization of the construction the factor was 2.7. In 2016 the Calibration Factor decreased to 2.0 as shown in Table 12.

Table 11 : *Pre-Construction Crash Predictions 1997 to 2007*

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2007**
AADT	892	933	976	1021	1233	1,951
SPF	16.7	17.5	18.3	19.1	23.1	36.5
CMF	1.520	1.520	1.520	1.520	1.520	1.520
Predicted Crashes	25.4	26.6	27.8	29.1	35.1	55.6
Actual Crashes	35	49	100	89	71	122.0
Calibration Factor	**1.4**	**1.8**	**3.6**	**3.1**	**2.0**	**2.2**

Table 12 : *Post-Construction Crash Predictions 2008 to 2016*

Year	**2010**	**2011**	**2012**	**2014**	**2015**	**2016**
AADT	2,081	2,213	2,410	2,785	2,982	3180
SPF	39.0	41.5	45.1	52.2	55.9	59.6
CMF	0.845	0.845	0.845	0.845	0.845	0.845
Predicted Crashes	32.9	35.0	38.1	44.1	47.2	50.3
Actual Crashes	90.0	89.0	95.0	110.0	115.0	103.0
Calibration Factor	**2.7**	**2.5**	**2.5**	**2.5**	**2.4**	**2.0**

The average crash prediction for the pre-construction period shows a good correlation with the actual number of crashes. The six-year average Calibration Factor is 2.3 which predicts 76.6 crashes per year. The actual post-construction average is 77.6 crashes per year.

The average crash prediction for the post-construction period shows a good correlation with the actual number of crashes. The six-year average Calibration Factor is 2.5 which predicts 103.2 crashes per year. The actual post-construction crashes averaged 100.3 crashes per year.

The prediction model estimated a 20% reduction in the average number of crashes, due to the upgrading of the road, from 55.6 to 44.1 crashes. The observed average crashes increased by 40%, from 78 crashes per year to 109 crashes per year. Pre-construction, two fatal crashes occurred per year. Post-construction, from 2014 to 2016, there was an average of 1.7 fatal crashes per year.

4.6 Crashes on Trunk Road Network

A review of 31 Trunk Roads for the years 2014, 2015 and 2016 showed that there is substantial variation in the number of crashes. There are ten Trunk Roads with an average of fewer than 30 crashes per year. There are eight Trunk Roads with an average of between 30 and 60 fatal crashes per year and eight Trunk Roads with an average between 60 and 120 fatal crashes per year. There are five Trunk Roads with an average of more than 120 fatal crashes per year. The Crash Frequency on the Trunk Roads is shown in Figure 22. Crash Frequency is the number of crashes per year (HSM, 2010, page 3-3).

The road from Windhoek to Okahandja, TR01/06, had the most crashes, on average 285 crashes per year with an average of 2.0 fatal crashes per year and 2.3 fatalities per year. The road from Okahandja to Otjiwarongo, TR01/07 had the second most crashes, on average 255 crashes per year with an average of 4.6 fatal crashes per year and 6.0 fatalities per year. The Oshivelo to Ondangwa Road, TR01/11, had the most fatal crashes with an average of 7.67 fatal crashes per year and 15.67 fatalities per year. The Swakopmund to Karibib Road had the second most fatal crashes with an average of 7.0 fatal crashes per year and 7.67 fatalities per year.

“Crashes are rare and random events” (HSM, 2010, page 3-5). The Crash Rate is the probability that a crash will occur, irrespective of the severity. The number of fatal and serious injury crashes was determined for the various sections of the Trunk Road network. The evaluation of the NRSC data showed that 2.4% of all crashes on Trunks Roads are fatal crashes and that 3.9% of all crashes result in serious injuries.

The crash rate is the probability that a crash may occur based on a certain exposure. Exposure is measured in the distance travelled by vehicles over a road segment, thus “per million vehicle kilometer”. The crash rate is the average crash frequency of a period divided by the exposure of the period (HSM, 2010: page 3-13).

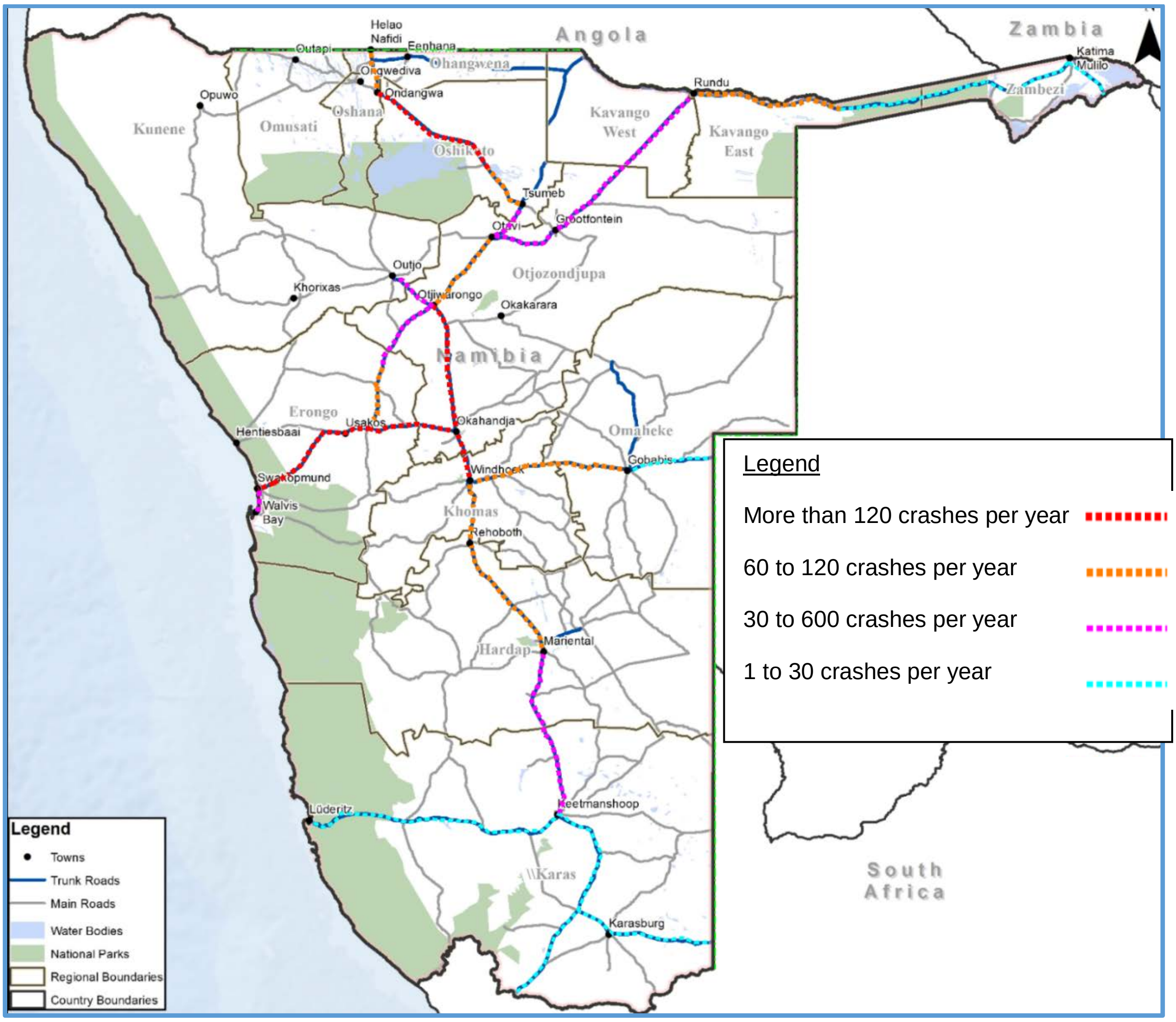

Figure 22 : Trunk Road Map with Crash Frequency from 2014 to 2016

Source: Roads Authority of Namibia

The exposure rate of the Okahandja Karibib Road as well as the surrounding Trunk Roads, were calculated and the 2015 information is presented in Table 13. The 2015 exposure rate of the Okahandja Karibib Road was 125 million vehicle kilometers (78.2 million vehicle miles), the Windhoek Okahandja Road had an exposure rate of 170 million vehicle kilometers (106.8 million vehicle miles) in 2015 and the Swakopmund to Karibib Road's exposure rate was 182 million vehicle kilometers (113.9 million vehicle miles).

The crash rate was calculated for these five Trunk Roads, as presented in Table 13. The Karibib Omaruru road has the highest crash rate of 3.15 crashes per million vehicle kilometers (5.03 crashes per million vehicle miles). The Windhoek to Okahandja Road and the Okahandja to Otjiwarongo Road had similar crash rates of 1.67 and 1.4 crashes per million vehicle kilometers (2.6 and 2.2 crashes per million vehicle miles). The road with the lowest crash rate was the Swakopmund to Karibib Road and the Karibib to Okahandja Road with 0.9 crashes per million vehicle kilometers (1.5 crashes per million vehicle miles). Prior to the road upgrading, 1997 to 2001, the Okahandja Karibib Road had an average crash rate of (2.36 crashes per million vehicle miles).

Table 13 : *Crash Exposure on Trunk Roads in Namibia*

Road	Trunk Road Number	AADT in 2015	Length in km	Exposure	Average Crash Frequency	Average Crash Rate
Swakopmund to Karibib	TR0202	2,774	180	182.3	179	0.42
Karibib to Okahandja	TR0701	2,982	115	125.2	121	0.82
Okahandja to Windhoek	TR0106	6,691	70	170.9	285	1.02
Karibib to Omaruru	TR0203	1,157	60	25.3	78	2.19
Okahandja to Otjiwarongo	TR0107	2,501	170	155.2	255	1.07

Exposure in million vehicle kilometers 2015, Average Crash Frequency 2014 to 2016, Average Crash Rate 2014 to 2016 as crashes per million vehicle kilometers

The number of fatal crashes and number of fatalities was determined for the five Trunk Roads, as presented in Table 14. The fatality ratio per fatal crash for all the Trunk Roads is 1.50 fatalities per fatal crash for the three-year period. The Karibib Omaruru Road had the worst crash record with 0.108 fatal crashes per million vehicle kilometers and 0.376 fatalities per million vehicle kilometers. The fatality ratio for the Karibib Omaruru Road is 3.5 fatalities per fatal crash.

The Karibib Okahandja Road and the Swakopmund to Karibib Road have the same crash rate of 0.9 crashes per million vehicle kilometers. The fatal crash rate for the Swakopmund Karibib Road is 0.05 fatal crashes per million vehicle kilometers and for the Karibib Okahandja Road 0.02 fatal crashes per million vehicle kilometers. Prior to the road upgrading, 1997 to 2001, the Okahandja Karibib Road had a fatal crash rate of 0.04 fatal crashes per million vehicle kilometers.

The geometrical upgrading of the Karibib Okahandja Road has reduced the severity of the crashes as well as the crash rates.

Table 14 : *Average Fatal Crashes and Fatalities 2014 to 2016*

Road	**Average Fatal Crashes**	**Fatal Crash Rate**	**Average Number Fatalities**	**Fatalities Rate**
Swakopmund to Karibib	7.0	0.058	7.7	0.064
Karibib to Okahandja	1.7	0.022	2.7	0.035
Okahandja to Windhoek	2.0	0.019	2.3	0.022
Karibib to Omaruru	2.0	0.138	7.0	0.485
Okahandja to Otjiwarongo	4.7	0.039	6.0	0.050

Fatal Crash rate per million vehicle kilometers, Fatalities Rate per million vehicle kilometers

The types of crashes were investigated to determine if there was any substantial difference on the Swakopmund Karibib Road, the Okahandja to Karibib Road or the Karibib to Omaruru Road. Firstly, the crash type of all the crashes were reviewed, after that, the crash type of the fatal crashes.

The Okahandja to Karibib Road, in 2015 had 136 crashes of which three were fatal crashes. The main collision types were sideswipe crashes at 0.12 crashes per million vehicle kilometers followed by rear-end crashes with 0.05 crashes per million vehicle kilometers. Head-on crashes had a crash rate of 0.025 head-on crashes per million vehicle kilometers.

Single vehicle crashes on the Okahandja Karibib Road was mostly with animals or birds, with a crash rate of 042 crashes per million vehicle kilometers, which is lower than the Namibian average on Trunk Roads of 0.56 crashes with animals per million vehicle kilometers. Vehicles overturning had a crash rate of 0.14 per million vehicle kilometers and run-off the road crash rate was 0.03 crashes per million vehicle kilometers.

The Swakopmund to Karibib Road, in 2015 had 199 crashes of which seven were fatal crashes. The main collision types were sideswipe crashes at 0.2 crashes per million vehicle kilometers followed by rear-end crashes with 0.15 crashes per million vehicle kilometers. Head-on crashes had a crash rate of 0.025 head-on crashes per million vehicle kilometers.

Single vehicle crashes in 2015 on the Swakopmund Karibib Road was mainly vehicles overturning, with a crash rate of 0.2 crashes per million vehicle kilometers. Due to the desert environment the crashes with animals or birds was low at 0.14 crashes per million vehicle kilometers.

The Karibib Omaruru Road, in 2015 had 64 crashes of which three were fatal crashes. The main collision types were sideswipe crashes at 0.12 crashes per million vehicle kilometers followed by approach at angle crashes with 0.08 crashes per million vehicle kilometers. Head-on crashes as well as rear-end crashes, both had a crash rate of 0.04 crashes per million vehicle kilometers.

Single vehicle crashes on the Karibib Omaruru Road were mostly with animals or birds, with a crash rate of 0.55 crashes per million vehicle kilometers. Vehicles overturning had a crash rate of 0.25 per million vehicle kilometers well above the Namibian average on Trunk Roads of 0.15 roll-over crashes per million vehicle kilometers. Run-off the road crash rate was 0.06 crashes per million vehicle kilometers, well above the Namibian average on Trunk Roads of 0.02 run-off the road crashes per million vehicle kilometers.

The fatal crash rate is expressed in million vehicle kilometers. The fatal crash rate on Namibia's Trunk Roads in 2015 was 0.037 fatal crashes per million vehicle kilometers. The fatal crash rate of the Swakopmund to Karibib Road was 0.038 fatal crashes per million vehicle kilometers. The fatal crash rate of the Okahandja to Karibib Road was 0.024 fatal crashes per million vehicle kilometers. The fatal crash rate of the Karibib to Omaruru Road was 0.118 fatal crashes per million vehicle kilometers. These fatal crash rates are substantially higher than the 0.018 fatal crashes per million vehicle kilometers (2.86 fatal crashes per 100 million vehicle miles) in the USA (Zwerling et al., 2005, page 25).

Single vehicle fatal crashes on the Swakopmund to Karibib Road were roll-over crashes with a fatal crash rate of 0.022 fatal crashes per million vehicle kilometers. Collision fatal crashes in 2015, were head-on crashes with a fatal crash rate of 0.011 fatal crashes per million vehicle kilometers and sideswipe crashes with a fatal crash rate of 0.006 fatal crashes per million vehicle kilometers.

Collision fatal crashes in 2015, on the Okahandja to Karibib Road, were head-on crashes with a fatal crash rate of 0.008 fatal crashes per million vehicle kilometers and rear-end crashes with the same fatal crash rate of 0.008 fatal crashes per million vehicle kilometers. There was no fatal single-vehicle crash in 2015 on the Okahandja Karibib Road.

Single vehicle fatal crashes on the Karibib to Omaruru Road were roll-over crashes, with a fatal crash rate of 0.08 fatal crashes per million vehicle kilometers and run-off the road crashes, with a fatal crash rate of 0.04 fatal crashes per million vehicle kilometers. There was no fatal collision crash in 2015 on the Karibib Omaruru Road.

The geometrical road upgrading of Okahandja Karibib Road provides a more forgiving road environment. The crash rate on the Okahandja Karibib Road is similar to the Swakopmund Karibib Road but the severity of the crashes has been substantially reduced. The road upgrading had no fatal single-vehicle crash for three years and the fatal head-on crashes rate has been reduced by 27% or 0.003 crashes per million vehicle kilometers.

4.7 Résumé

The Okahandja to Karibib Road is part of the Namibia National Trunk Road Network, as well as the SADC Trans-Kalahari highway that links the harbour of Walvis Bay to Botswana and South Africa. The Okahandja Karibib Road has been upgraded with surfaced shoulders and passing lanes, from 2008 to 2012. The traffic on the Okahandja to Karibib road increased from 573 vehicles per day in 1990 to 2 982 vehicles per day in 2015 of which 20% are heavy vehicles. A Case study was done on the road safety benefits.

The road has yearly around 100 to 120 crashes. Crashes with animals were the most frequent, with 35% of the crashes, followed with roll-over crashes at 15% of all crashes. Rear-end crashes are the most frequent collision type. The variations of types of crashes over time showed that the crashes with animals halved during the construction period. The other crash types vary randomly over time.

The Predictive Method estimates the expected crash frequency, crash severity and collision types based on the known characteristics of the road. This methodology is a stepped process which estimates the average crash frequency for a specific year and site based on the crash frequency of the base model modified by the site-specific characteristics and calibrated to the local conditions.

The average crash prediction for the pre-construction period shows a good correlation with the actual number of crashes. The six-year average Calibration Factor is 2.3, which predicts 76.6 crashes per year. The actual post-construction average is 77.6 crashes per year.

The average crash prediction for the post-construction period shows a good correlation with the actual number of crashes. The six-year average Calibration Factor is 2.5 which predicts 103.2 crashes per year. The actual post-construction crashes averaged 100.3 crashes per year.

The crash rate was calculated based on the traffic exposure and the actual crashes. The crash rate for the Karibib to Okahandja Road is 0.8 crashes per million vehicle kilometers, similar to, the Swakopmund Karibib road. The Karibib Omaruru road has the highest crash rate of 3.14 crashes per million vehicle kilometers. The Windhoek to Okahandja Road and the Okahandja to Otjiwarongo Road had similar crash rates of 1.6 crashes per million vehicle kilometers.

The fatal crash rate of the Okahandja to Karibib Road was 0.023 fatal crashes per million vehicle kilometers. The fatal crash rate of the Swakopmund to Karibib Road was 0.038 fatal crashes per million vehicle kilometers.

The geometrical road upgrading of Okahandja Karibib Road provides a more forgiving road environment. The crash rate on the Okahandja Karibib Road is similar to the Swakopmund Karibib Road but the severity of the crashes have been substantially reduced.

5 Conclusion

How do the road safety statistics of Namibia compare with international best practice?

Globally road fatalities have reached pandemic proportions. The Decade of Action for Road Safety of the United Nations has the aim to reduce road fatalities (UN, 2017, page 23; NDP5, 2017, page 40; SADC, 2011, page 6). Road safety is measured as fatalities per 100 000 population to compare road safety of countries and when considering public health perspective. Globally the crash fatality rate is 17.7 deaths per 100 000 population with the African continent having the highest fatality rate per continent at 25.5 deaths per 100 000 population (WHO, 2015). Namibia has a population of 2.2 million people (Census, 2011, page 74). The reported crash fatalities for Namibia for is 23.9 fatalities per 100 000 population or 551 fatalities (WHO, 2015, page 187).

The road safety statistics of Namibia had shown a substantial increase in the number of crashes from 2011 when Namibia was below the average African countries, to well above the African average road fatality rate. Compared with the international best, Namibia has significant room for improvement of road safety. There is a statistical correlation between populations, number of vehicles and fatalities. Namibia should have around 250 fatalities per year, based on the international trend, and Namibia's road fatality is well above this number. A substantial effort is required to reduce the road fatalities to meet the Decade of Action's targets, especially in the light of an increase in population and vehicle numbers.

What are the most frequent crash types on Namibian roads and which measures to mitigate them, are identified in the literature?

This dissertation reported on the three most frequent crashes in Namibia, namely roll-over crashes, at 29% of all crashes, collisions at 28% of all crashes, with head-on crashes the most fatal. Pedestrian crashes account for 22% of all crashes. These crashes are not unique to Namibia and globally they have required attention, due to the severity of these crashes. Various mitigation measures can be applied to reduce the occurrence or severity of these crashes.

Measures to mitigate roll-over accidents are correct speed for the type of road, road maintenance and road geometry standards to provide a forgiving road environment. Measures to reduce head-on collisions include improvement of the road alignments, construction of dual carriageway roads and law enforcement. Pedestrian crashes are always fatal with vehicle speeds above 80km/h. Provision of separated pedestrian facilities is the most effective measure. Provision of pedestrian crossings at convenient and safe locations improve pedestrian safety, as well as education on the correct crossing of roads, wearing of high visibility cloth at night and street lighting. Appropriate speed calming and speed limits in urban areas can reduce vehicle speeds that reduce the severity of pedestrian collisions.

Road crashes have an economic impact due to the loss of productive people to the society. The economic impact for Namibia is in the order of 3.5% of GDP which amounts to US$ 295 million (N3.90 billion) per year.

Are the fatality rates on the Okahandja Karibib Road high compared to Namibian and international practices?

The Trunk Road network of Namibia forms the major transport corridor network that connects the major cities and neighbouring countries. Trunk Roads are generally 7.0m wide bitumen surfaced roads with 2.0m gravel shoulders. The Okahandja to Karibib Road was upgraded with wider lanes, 3.7m wide and 2.5m wide surfaced shoulders and six passing lane sections.

There occur around 100 crashes per year on the Okahandja Karibib Road of which 50 collisions are with animals. The highest number of crashes occurred in 2007, 122 crashes. Prior to the upgrading, in 2008 the main type of fatal crashes were roll-over crashes. The post-construction period from 2014 to 2016, the sideswipe and head-on crash type resulted in the most number of fatal crashes. Roll-over crashes did occur in the post-construction period, but none were fatal. During the construction period, 2008 to 2012, there were five fatal roll-over crashes of which three occurred in 2012.

The fatal crash rate on Namibia's Trunk Roads in 2015 was 0.037 fatal crashes per million vehicle kilometers. The fatal crash rate of the Okahandja to Karibib Road was 0.023 fatal crashes per million vehicle kilometers. These fatal crash rates are higher than the 0.018 fatal crashes per million vehicle kilometrs in the USA (Zwerling et al., 2005). The fatal crash rates on the Okahandja Karibib Road is low compared to Namibian practice but still high compared to international practice.

Have infrastructure measures, such as road widening and the provision of passing lanes, reduced the road safety risk?

AASTHO (HSM, 2010) developed a road crash prediction model based on crash data from the United States of America. The prediction model estimated a 44% reduction in the average number of crashes, due to the road widening and the provision of passing lanes. The observed average crashes increased by 40%, from 78 crashes per year to 109 crashes per year.

The crash rate, prior to the road upgrading, was 1.48 crashes per million vehicle kilometers, which reduced to 0.94 crashes per million vehicle kilometers. The fatal crash rate, prior to the road upgrading, was 0.04 fatal crashes per million vehicle kilometers, which reduced to 0.017 fatal crashes per million vehicle kilometers. The crash rate reduced with 36% and the fatal crash rate reduced with 57%. The infrastructure measures, such as road widening and the provision of passing lanes, has reduced the road safety risk.

The study concluded that Namibia has a high road fatality rate in comparison with the global road fatalities. The road upgrading of the Karibib Okahandja Road did improve the road safety of the road since the severity of the crashes has reduced in comparison with the adjacent roads. The road upgrading reduced the crash rate and fatal crash rate of the Karibib Okahandja Road.

The Trunk road network carries the bulk of the traffic on the rural roads. The upgrading of the Trunk road network with surfaced shoulders can be recommended based on the improved road safety, which will benefit the majority of rural traffic.

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